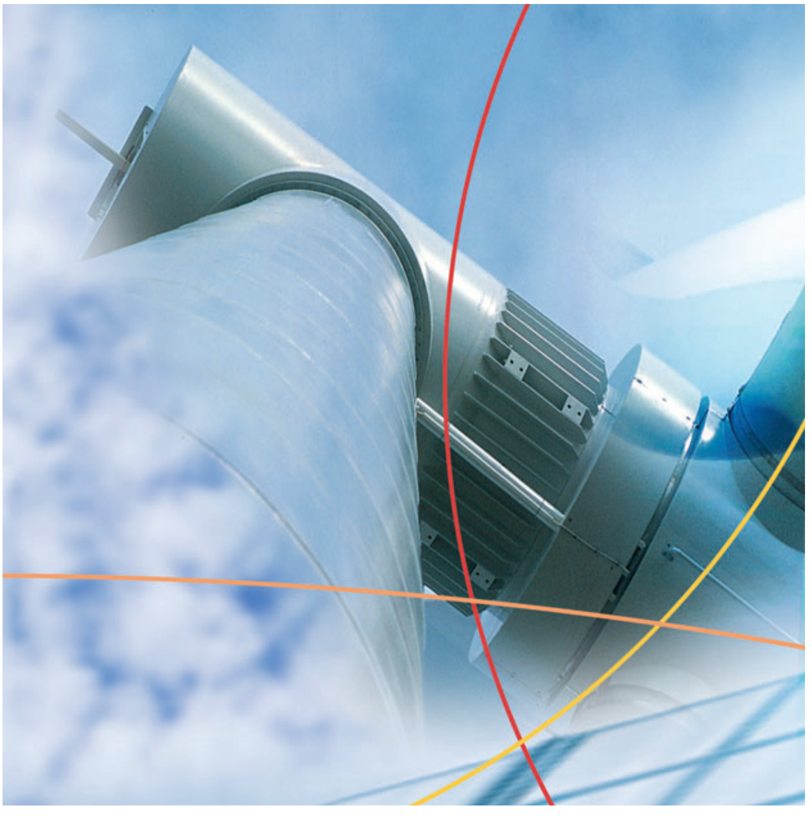
DENSY – Distributed Energy Systems 2003–2007

Technology Programme Report 11/2007

Final Report



Tekes

DENSY – Distributed Energy Systems 2003–2007

Final Report

Technology Programme Report 11/2007
Helsinki

Tekes, the Finnish Funding Agency for Technology and Innovation

Tekes is the main public funding organisation for research and development (R&D) in Finland. Tekes funds industrial projects as well as projects in research organisations, and especially promotes innovative, risk-intensive projects. Tekes offers partners from abroad a gateway to the key technology players in Finland.

Technology programmes – Tekes´ choices for the greatest impact of R&D funding

Tekes uses technology programmes to allocate its financing, networking and expert services to areas that are important for business and society. Programmes are launched in areas of application and technology that are in line with the focus areas in Tekes' strategy. Tekes allocates about half the financing granted to companies, universities and research institutes through technology programmes. Tekes technology programmes have been contributing to changes in the Finnish innovation environment for twenty years.

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Prologue

Tekes launched the five-year Densy Programme on distributed energy systems at the beginning of 2003. The main goals of the programme were to create new knowledge and understanding in the area of distributed energy technology and to enable new business and export possibilities for Finnish enterprises.

At the starting phase of the programme, extensive studies on future business potential and markets of distributed energy technologies showed remarkable growth and good business opportunities for Finnish enterprises in international markets.

There was a common understanding that the business will grow remarkably in the coming years, especially in Central and East European countries. On the other hand, a large number of Finnish companies were already active in this business area, some of them as technology leaders in their area. Based on this as well as on the studies made by consultants, the programme launching decision was made. The goals set by Tekes were highly focused on business and exports. Numerical goals were set for the year 2010.

At the starting point, the industrial basis in the field was strong, but comprised of only a few big enterprises. The participation of small companies was considered very important with regard to the development of this field in the future. The participation of industrial enterprises was very intensive from the beginning.

The work in the programme was divided into six areas: new business models and concepts, system solutions, integration, industrial manufacturing, use of information technology and model systems.

In total, over one hundred projects (exactly 123) were carried out during this five year programme, 57 being research institute projects and 66 enterprise projects. Many of the research projects were on-going, continuing over several years. This explains the high number of projects.

The total programme budget amounted to € 56,7 million, the share of enterprise projects being € 38,0 million and that of research institute projects € 18,6 million. Tekes funded the programme in total by € 31,7 million, the rest being financing from enterprises and public institutes.

In this final report, research projects and their main results are presented. In addition, there is an extensive number of enterprise cases presented in the report highlighting the success of the programme. For more detailed information on the results and programme's impact on markets and business, Tekes has ordered a separate evaluation of the programme which will be ready and presented in public in the spring of 2008. Hence more detailed analysis on the impact of Densy programme will be given in the evaluation report.

Generally speaking, the programme has significantly improved collaboration and networking of distributed energy system research, both between research institutes and enterprises.

Simultaneously, the level of research has risen, the research institutions have reached the international level and they are increasingly participating in international projects especially within EU. One success factor here is Densy's close co-operation with other EU countries in the framework of the IRED Coordinated Action (Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid).

The infrastructure of research in the field has been improved by significant investments in the equipment e. g. in building the pilot electricity grid ("Multipower") to enable testing of new distributed technologies in simulated real life conditions. This will be highly valuable and useful for Finnish researchers and enterprises in the future.

With regard to the main target of the programme, creating business and export opportunities, there are no exact values available at the time of writing. However, if we look at the figures of the whole energy technology and the export, the growth has been remarkable since the 1990's, reaching a new record value last year with almost four billion euros. Even though this doesn't account totally for the Densy programme, but a large share of it consists of the exports by the companies with a notable role in the programme.

Finally, Tekes wishes to thank all the participants in the programme: enterprises, research institutes and other interest groups and individuals for their constructive and fruitful attitude and co-operation. Special thanks are due to Mr. Jonas Wolff, programme coordinator, and the steering group of the programme for the successful realisation of the programme.

October 2007

Finnish Funding Agency for Technology and Innovation

Conclusions and Recommendations

Distributed energy systems today

It was noted in the steering committee that during the time span of the project, distributed energy has not reach break through in Finland. This is perhaps not even foreseeable or even advisable in a research and development programme, although it aims at fast lead times to market. However, it was felt that some significant advancement should be seen also on a short term, if the very ambitious targets on medium terms should be met.

Further, it was noted that only a few companies have been able to reach for global business and significantly improve their position, although there are also some success stories to be noted. A significant problem for small companies looking for international markets is that the domestic market does not prove enough support in adequately demonstrating their products and stabilizing their product development. This is especially true for system providers and consequently Finnish companies tend to look for a role as component or add-on service providers. "Born Global" –concepts are difficult to carry out in heavy industries.

Some recent changes in legislation, most notably the law on grid access for local small-scale production, putting a cap on costs for grid connection and transmission of production upwards in the distribution network, will provide some ease. Further, the goals set by the European Union related to the climate strategies also express an interest in especially renewable energy production. There is also a general understanding that energy prices will continue to rise, whereas developing technology and markets will make distributed generation cheaper. Therefore general feeling that there is a business case for small-scale environmentally friendly production is maintained.

The market estimates presented in 2003 have not been evaluated but although domestic markets have not significantly advanced global markets have indeed grown. I.e. the market for wind turbines has double from 2003 to 2006 and will repeat that manoeuvre in the coming four years, indicating that also everyone in the supply chain has to more than double capacity to increase market shares. The market opportunities can also be seen on the NordEl market, were most of the new capacity in the past ten years are either wind energy or CHP.

Recommendations

The steering group noted that the big challenges for the future is to commercialize new products on an international market, in a situation where the domestic market is as well small as slowly developing. It would be important to identify instruments that enable the industry to test their products and get real customer response in a close market so that correcting measures can be taken. Too little emphasis has been put on getting real customer demands from new market areas and especially to get that information down to product development. Albeit that the markets for renewable energy still are largely policy-driven.

There has been an interest to see more large-scale testing and demonstration of new technology, especially regarding system aspects. I.e. in ICT, much of the technology needed is available or will be, if there is a demand. Therefore there are nut much effort on R&D but the impact of a good and visible demonstration, showing what can be achieved with new ICT, would be significant. As more effort is put on developing new business models and business development is as big a challenge as technology development, there is need to be able to test and prove the feasibility of business models, as new technology is proven and tested. There would be clear benefits from testing business models by piloting them in companies. Therefore, there is reason focus on how business models in general are implemented in practical "piloting" cases– the steps, tasks, gates and milestones, and develop methodologies and instruments that could be implemented in technology programmes in general.

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1 DENSY in brief

The technology programme for *Distributed Energy Systems* (DENSY) started back in 2003 with the ambition to strengthen the Finnish energy technology industry in a bid to take it global. The programme has focused on developing new technologies and business solutions by accelerating academic research projects and private research and development. The programme has exceeded its original funding target of 46 million euros and will reach 57 million euros, supporting in total 123 individual development projects. Tekes covers about half of the total funding with the other half covered by participating companies and other organisations.

In the DENSY-programme distributed energy systems have been defined as ”*Local, small sized systems for energy conversion, production and storage as well as related services*”. This has been an inclusive definition covering any energy production unit located in the distribution network as well as production of power, heat or cold and especially renewable energy sources. Independent or grid-connected and even mobile solutions have been accepted.

Motivation

The motivation for starting the programme was the general understanding that global markets for distributed generation were growing, and growing faster than other energy markets. This transition was not seen as a revolutionary system change, but more as a gradual introduction of new technology operating aside or within a traditional or existing energy system.

In addition, it was recognised that there already was a lot of know-how of the field in Finland, including system technology and automation, distributed generation, information systems, substations and remote control, generators and gears, CHP and power from bioenergy. It was seen that the domestic energy technology industry had its core strengths in intelligent and integrated solutions, smalll-scale applications and renewable energy technology and that the sector would benefit from a global market growth. In new services like remote-controlling and condition monitoring of power plants, the follow-up of energy technology and communication in electricity trading ICT has a central role. Plus many successful Finnish products can be found in energy production, transmission, and distribution, as well as in end-use technologies. The product range covers advanced automation and ICT to large diesel engines, fluidised-bed combustion and more generally in combustion technology, components and generators of wind turbines as well as frequency converters.

There are a number of global trends that favour distributed generation. Most notably, the opening of energy markets and the importance of energy security and environmental values have led to a growing demand for renewable energy sources and combined heat and power (CHP). Distributed energy systems have low investment costs and the growing markets for energy trading give new options to run independent power plants. Independency from power and/or heating networks brings better security of supply and reduces the customers' costs of transmission. There are further commercial opportunities in developing modular systems and mass-production techniques giving the benefits of real industrial production.

Prior to launching the program, Tekes ordered a market study that was carried out by Frost& Sullivan (Frost&Sullivan 2003).The market volume in countries close to Finland was estimated to reach 11 billion euros in 2007 and the total global market volume even 53 billion euros in 2010.

Objectives and focal areas

The main objectives of the programme have been to assist this niche Finnish industry, especially SMEs in developing products and services for global markets, to increase global awareness of Finnish technology, to build a world-class innovative environment, and to produce commercial products for several niche markets by 2010.

Given the inclusive definition of the programme, and the broad scope, the programme's focal areas were chosen to be broad cross-cutting issues, as illustrated in the figure below. However, there was a motivation to establish topical research networks of and the research projects were accordingly grouped into: Electric systems, Heating systems, CHP, Business models, Industrial manufacturing and ICT. In addition, Fuel cell research targeted at energy production and energy system integration was included in the programme from 2004 until eventually in 2007 a new Fuel cell technology programme was launched. The results from the 57 research projects are reported here under these headlines.

Information and communication technology is increasingly being used in the energy sector and is still instrumental in enabling cost-effective distributed energy generation. The list of new products developed includes remote control and operation; and optimisation and energy management of dispersed CHP-units. Improvements in manufacturing are still needed in order to get the cost-efficiencies and economy-of-scale effects for small production facilities right. And lean manufacturing and modular design, especially in the bioenergy sector, is the key to drive this development. Likewise, dedicated business models, e.g. combining the earning logics of the various product streams polygeneration or biogas solutions are being developed. Although the programme has been heavy on technological development, well-timed testing and successful demonstrations are needed for commercialisation. Several new products are emerging from the programme and will find their way directly to customers or to a demonstration market within a few years.

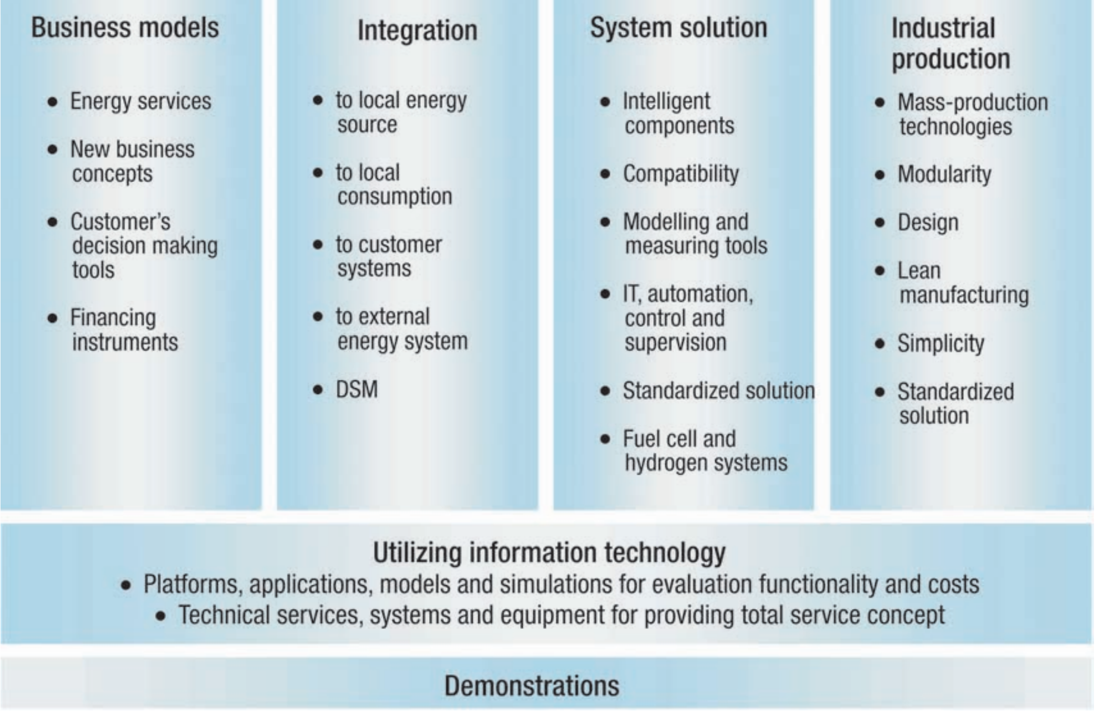

Figure 1.1. Programme focal areas.

Research co-operation

Eleven research institutes have accounted for 57 of the programme's projects totally an investment of 19 million euros. More than 140 different companies are co-funding this research. Industrial development, comprising of product development, improving production capabilities, knowledge development and business development, is carried out through the other 66 projects in the programme with a total investment of over38 million euros. This work is either carried out by the industry themselves or subcontracted to a research organisation.

Electrical systems

At the very core of the DENSY programme has been the development of products and solutions for the integration of distributed energy generation to various energy systems; i.e. integration to the electrical grid, to the district heating networks and to the endusers on-site systems. Grid integration research has been pooled in a joint project, where the leading institutes have assessed the issue both from the producers' and the network operators' point of view, building planning tools and models accordingly. Research of electric systems of distributed generation has covered two principal areas. Firstly, the influence of distributed generation on the electricity network and on the network operation has been studied in more than ten projects. Secondly, the devices and systems used in the distributed generation have been developed in less than ten research projects. In addition to public research, more than ten projects of companies were followed through to develop new devices and systems.

"Flexible interconnection" is a new idea for connection of intermittent distributed generation into distribution network thet utilizes the "free" capability of network by controlling production based on network conditions. The theoretical maximum for a local unit is the maximum transfer capability of the network in the connection point. The flexibility of a production unit is realized with local voltage control of distributed generation or with production curtailment in order to limit voltage rise in weak networks. The flexibility of distribution network is for example co-ordinated voltage control of DG units and networks.

The ring operation mode presents new possibilities in connecting distributed generation to the network. This is especially possible in weak rural networks. The ring operation of the distribution network will divide power flows to the feeders more evenly than radial operation, losses will be minimized and voltage rise due to distributed generation can be limited. The voltage profile of ring operated feeders is also more flat than profile of radial feeders. These properties will result to better utilization of distribution system than radial operation using the ring operation mode may, however, complicate the protection issues.

The network connection from the point of view of power plant technology was studied focusing on were the use of frequency converters for network interfacing, and the design of the permanent magnet generators either used with frequency converters or directly connected to electricity network. A the frequency converter driven generating hydro electric plant concept was designed and piloted. As a result of research, the possibilities and restrictions of such concept were shown. The first hydro plants using the concept are already in production use.

The system aspect of introducing large wind energy in the grid have been studied in three project related to the IEA Implementing Agreement on Wind Energy. Wind energy is one of the fastest growing energy technologies and the findings of network studies will be used as examples for integrating renewable energy and distributed generation in general.

Energy storage has bee studied in a number of projects including various techno-economical studies, simulations and demonstrations of energy storage technology and its solution in different power distribution tasks. The main research areas have covered energy storages for the network management with wind power systems and UPS, with power quality systems/stations, in DC distribution systems and microgrids; one of the research areas has also been the control and improvement of the operation and maintenance reliability of a weak electrical network.

Commercially available supercapacitors have been tested electrically using Arbin supercapacitor test station. Also long-term and low-temperature test have been performed. This device was applied also for measuring self-made components. The commercially available supercapacitors and those made in the project have been compared. The comparison shows that the specific capacitance of the commercial components has been surpassed and internal resistance is of the right level but leakage current should still be decreased.

Heating, cooling and cogeneration

Finland has one of the most extensive networks for district heating in the world and a high share of combined heat and power production. Here the promise for distributed generation is illustrated. All or most of the "easy" load, i.e. big municipalities and industrial plants already have CHP and or district heating. Thus growth or added production can only come from smaller and smaller loads. As the new installations become smaller, there is a need to find new solutions to how to ensure cost-efficiency as most technology is developed for a larger scale.

One line has been to build on further integration to either cooling (in addition to heating and power) or integration to the waste management system. Integration to cooling opens new opportunities for technical and product development and the concept has been tested in sports-halls e.g. Further integration is also challenging in that it combines different business logics in a challenging way.

Further, there has been an interest to develop biopower-solutions. With also other Tekes activities going on in the field, the programme has mainly focused on small scale bio-CHP solutions. The studied µCHP's produce electricity directly from solid biomass and the price of the produced electricity should be competitive to the wind turbines and/or the traditional biomass-fired power plants.

Liquid fuel fired aggregates have been widely used in micro-scale electricity production. These units (< 1 MW_e) are of the same magnitude with the solid biomass fired units studied.. Although the aggregates have been so far fired with fossil-based gasoline and diesel, bio-diesel is possible to be used as well leading to CO_2 free energy production. The aggregates have traditionally been used during short periods, for example in farm houses during the shut downs of the grid and in cases outside the grid with low base consumption and occasional peaking. The base load has been covered for example with solar cells and the peaks which and aggregate. The development of the aggregate technology has led, however, to larger units (with 10–100 kW_e) which can be in continuously use with additional production of district heat. The trend has also been from gasoline-fired aggregates to diesel-fired aggregates to minimise the fuel costs

Fuel cell activities

Fuel cell research was quite modest until the beginning of the 21th century when Wärtsilä Corporation started its SOFC development. This gave a strong boost the fuel cell activity in Finland. Tekes accepted its role as funding organization for this activity and the budget of Tekes funded fuel cell projects increased from > 1 M€ in 2000 to 5 M€ in 2005. There was a clear interest in Tekes to coordinate this activity, and therefore the fuel cell and hydrogen activity was incorporated into the Densy technology program from the beginning of 2004. These projects ended in the end of 2006. The Densy technology program has reached its end in 2007, but the Fuel Cell and Hydrogen research funded by Tekes is continuing in a new Technology program "Fuel Cells", which will continue over the whole period 2007–2013, corresponding to the EU FP7.

ICT

It is apparent that technical development ICT and automation has brought new opportunities for local power production. On the other hand, while small plants are usually low cost in building, the added cost of including expensive data communication systems or remote operation systems can be too much. The combination of new hardware, communication, and software technologies creates opportunities to achieve two-way interaction with all kinds of power network nodes, customers and customer equipment and to more autonomous, flexible self-managing (self-configuring and self-healing) system of networks. These novel ICT-enabled solutions will be key contributors in realizing reliable and efficient power distribution systems with high degrees of distributed power production.

Manufacturing

One of the promises of small-scale generation lies in being able to utilise developed industrial manufacturing to move from economy of scale (i.e. large power plants) towards economy of numbers (i.e. large number of power plants) and thus significantly reducing costs. At the same time, it needs to be understood that the advanced manufacturing solutions need big markets to pay back the investments.

Although industrial manufacturing was one of the most active areas of the programme, only two research projects were financed. Also, these were not pure research projects but to a large extent project pre-feasibility activities, where eventual ideas for development projects were pre-assessed. However, the ideas and concepts presented in these projects have to some extent been carried forward in the various industrial development projects.

Business concepts

In the business concept research of the Programme, several research projects have been conducted to create new knowledge of future business opportunities, to form optimal business concepts, and to make demonstrations for business use.

The overall *scope* of the research projects:

- Define value chain, business opportunities, and customer benefit.

The main *Objectives* of the research projects:

- Commercialization of new technologies and services
- Formation of business networks
- Benefiting from the changing business environment.

According to the following research projects, the business development of the DG is mainly related to the investments in existing systems and the intervention of the authorities. The future business development depends on the saturation point of the returns of the present investment. In other words, the business will increase when the returns of investments in new DG technology will be more profitable than the past and present investments.

This inflection point can also be affected by the authorities. According to the research projects, the most potential and strongest way in generating new business is to force companies utilize new technology through the legislation. This concerns only the areas with the well-developed infrastructure. At the same time, there are areas where such dilemma does not exist, e.g. Africa, South-America, and Far East. Due to that they are able to pass obsolete technology and can directly utilize advanced Distributed energy generation technology.

Although, there within the program has been significant research into the area of business models only one of the research projects have gone so far as to piloting the business model. In research and development work piloting is an important step. In the natural and technological sciences piloting, i.e. the practical testing of one's theories, models and assertions is common practice – proof of which is not only all the new solutions that are brought forward but also the numerous ideas that have been disproved. Unfortunately, the tradition of testing ideas and theories is not nearly as usual in business studies – i.e. the field of how business is done in a certain industry.

Demonstration

The MULTIPOWER platform can nationally and internationally be used for example as a testing site for the components and generation units of a DG system, as a platform for the validation of the control and management system of a DG distribution system, for the production optimisation in the multi production systems, as well as it acts as a platform for the component and system integration tests.The testing environment has also been introduced also for the European Network of DER Laboratories and Pre-Standardisation for possible membership.

Also an extensive computer-based simulation environment was created. This environment can be applied in studies related to the analysis and design of grid interconnection of various types of distributed generation. The primary aim was to create a collection of simulation models representing various types of networks and generators. The network models serve as a basis for the simulation environment, and the user will have a free choice to include a desired selection of various distributed generators into the network model. In addition to these the aim was also a have library of models representing the protection relays and control systems. The primary tool applied in the projects was PSCAD, which is a well-known power system transient simulation tool.

In addition the testing and demonstration of technical concepts there would be clear benefits from testing business models by piloting them in companies. First, by testing the models it is possible identify weaknesses in the underlying theories and assumptions thereby contributing to business studies and the study of the particular field. Second, testing and piloting the business model is also the best way to ensure that the companies concerned are able to take concept into practice and thereby benefit from the basic research being carried out at universities. Third, even if the model were to prove unworkable that would in itself contribute to overall knowledge and function as a basis for further theories and models.

Technology for global markets

The DENSY programme actively cooperates with partner institutions on programmes and at project level by sharing information and participating in joint projects. Tekes is especially interested in activities that can demonstrate the capability of new technologies. International cooperation focuses on the field of basic research, however enterprises are also encouraged to collaborate with their foreign counterparts in greater depth as technology programmes can provide an ideal framework for business development. Tekes is involved in several of International Energy Agency's implementing agreements and DENSY activities are reported or included in the areas of bioenergy, hydrogen, fuel cells, DSM, energy storage, wind power and solar heating.

Through IRED, 'Co-ordinated action on Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid', the programme has established European-wide networks. IRED started the conference series on the Integration of Renewable Energy Sources and Distributed Energy Resources and has further been instrumental in the inauguration of the EU Technology platform 'Smart Grids', where Tekes is represented in the Mirror Group for national authorities.

Several market studies and partnership building activities target the North American markets. In particular the North America Access Program (NAAP) aims at establishing cooperation between Finnish and overseas companies to enable market access. Tekes, Finpro, Helsinki School of Economics (HSE), Motiva and nine Finnish companies operating with distributed energy systems have examined the best operating models for exports and are looking for local partners in the UK. The companies in the project have approached the promising UK energy markets with new operating methods. The project examines small and medium sized companies' internationalisation both in practice and in theory.

2 Electric systems

2.1 Introduction

Distributed energy resources cover biomass, solar energy, wind energy, geothermal energy, hydro energy etc. Electric systems are involved in majority of the energy conversions of these resources. In addition, the distribution and storage of electric energy is a part of most systems. Electrical energy produced in a stand-alone plant is used locally, and in order to match the time-varying production and consumption, the energy must be stored. If, on the other hand, the plant is operated parallel to the electricity network, the electric systems connect the plant to the electricity network, and in that case, safe and economical network operation has to be guaranteed.

In the DENSY program, the public research of electric systems of distributed generation covers two principal areas. Firstly, the influence of distributed generation on the electricity network and on the network operation has been studied in more than ten projects. Secondly, the devices and systems used in the distributed generation have been developed in less than ten research projects. In addition to public research, more than ten R&D projects of companies were followed through to develop new devices and systems.

2.2 List of projects

VTT, **System impacts of wind power**
Date of funding decision: 7.2.2006
Research project, ongoing

VTT, **Energy storage for managing distributed generation**
Date of funding decision: 7.2.2006
Research project, ongoing

VTT, **Development of a supercondensator, stage 2**
Date of funding decision: 7.2.2006
Research project, finished

Lappeenranta University of Technology
Power distribution and distributed generation
Date of funding decision: 27.4.2005
Research project, ongoing

VTT Processes
Integration of wind and hydropower
Date of funding decision: 17.2.2005
Research project, finished

VTT **Developing a super-capacitor, step ½**
Date of funding decision: 20.1.2005
Research project, finished

VTT Processes
International co-operation in wind energy, IEA R&D WIND
Date of funding decision: 20.1.2005
Research project, finished

VTT Processes
Mid-sized energy storage in decentralised power distribution applications
Date of funding decision: 22.4.2004
Research project, finished

Tampere University of Technology
Grid integration of distributed generation 2/2
Date of funding decision: 18.3.2004
Research project, finished

Savonia Polytechnic
A local system for power distribution and application in rural areas
Date of funding decision: 30.10.2003
Research project, finished

VTT Processes
A simulation environment for grid connection of distributed generation
Date of funding decision: 26.6.2003
Research project, finished

Lappeenranta University of Technology
Distributed generation devices and grid connection
Date of funding decision: 26.6.2003
Research project, finished

VTT Processes
Wind power models in grid studies
Date of funding decision: 18.6.2003
Research project, finished

VTT Processes
Energy storage technologies in Finnish wind power plants
Date of funding decision: 18.6.2003
Research project, finished

Tampere University of Technology
Grid connection of distributed generation ½
Date of funding decision: 5.6.2003
Research project, finished

2.3 Funding and co-operation

The companies participating in Active network management in electricity distribution have been ABB Oy Sähkönjakeluautomaatio, Fingrid Oyj, Fortum Sähkönsiirto Oy, Nokian Capacitors Oy, Oittisen tila and Wärtsilä Oyj.

The companies participating in ENVATUULI have been ABB Oy, Fortum Power and Heat Oy Generation and Merinova Oy Ab.

The companies participating in ENVADE have been ABB Oy, Evox Rifa Group Oyj, Oy Finnish Electric Vehicle Technologies Ltd, Fortum Power and Heat Oy Generation, Merinova Oy Ab, Nokian Capacitors Oy, Powerware Oy, Powest Oy, Winwind Oy and Wärtsilä Finland.

The companies participating in ENVADE+ have been ABB Oy, Evox Rifa Group Oyj, Fortum Power and Heat Oy Generation, Merinova Oy Ab, Nokian Capacitors Oy, Eaton Power Quality Oy and Helen Sähköverkko Oy.

The Switch

The Switch was established in 2006 when Rotatek Finland, Verteco and Youtility joined forces to become The Switch. As a part of the DENSY programme, the company has developed a product family of permanent magnet machines (PM) for a range of motor and generator applications.

The integrated design of The Switch PM machines is developed for both efficiency and adaptability in various applications. In the case of outer rotor motors - which are used in conveyers - the entire motor is assembled inside a driving roll. In pump and blower applications, the motor may be directly integrated onto the equipment shaft, a solution which completely eliminates the need for mechanical couplings and axle alignments. High, smoothly controllable motor torque is guaranteed throughout the drive speed range - even at the lowest speeds. The permanent magnet machine power range extends to 5 MW and the speed range to 6000 rpm.

The future looks bright: the company expects to double its sales every year until 2011. The Switch's customers are mainly in the wind power branch and located all around the world. In five years, the company has grown from four employees to 15, almost all of whom all are involved in the product development.

The companies participating SUPER3 have been Evox Rifa Group Oyj, Kone Corporation, Konecranes Plc, Panipol Ltd and MSc Electronics Oy.

The companies participating in VELKO, part 1 have been ABB Oy, Drives, Verteco Oy, MSc Electronics Oy, Vaasa Engineering Oy, Waterpumps WP Oy, Power Factor Ay, Konetuote Piispanen Oy and Kylmätec Ky.

The companies participating in ELDIG have been ABB Oy, Drives, Verteco Oy, Vaasa Engineering Oy, Rotatek Oy, Waterpumps WP Oy, Axco Motors Oy, Power Factor Ay, Fortum Sähkönsiirto Oy, Vattenfall Verkko Oy, Kemijoki Oy, ABB Oy, Sähkönjakeluautomaatio, Wärtsilä Oyj, Vamp Oy, Rovakaira Oy.

The companies participating in MULTIPOWER have been Wärtsilä Oyj, Merinova Oy, E.ON Finland Oyj, Gasum Oy, Finnish Natural Gas Association, VaPo Oy and ABB.

The companies participating in DIGIN 1 and 2 have been ABB Oy Sähköasema-automaatio, Cybersoft Oy, Finergy, Fortum Sähkönsiirto Oy, Kemijoki Oy, Koillis-Satakunnan Sähkö Oy, MX Electrix Oy, Nokian Capacitors Oy, Tampereen Sähkölaitos, Vattenfall Verkko Oy.

International co-operation: IEA co-operation:

NREL (USA); UWIG (USA); Northern Arizona University (USA); DG&SEE (UK); UMIST (UK); UCD (Irl); Eirgrid (Irl); KTH (Swe); Chalmers (Swe); Sintef (Nor); Statkraft (Nor); Risö (Den); Energinet.dk (Den); ISET (Ger); RWE (Ger); E.On Netz (Ger); INETI (Portugal); EWEA (European Wind Energy Association, Bryssel); ECN (NL); University Castilla la Mancha (Spain); REN (Por); Hydro Quebec (Can); Manitoba Hydro (Can); Hydro Tasmania (Australia); Swiss Federal Office of Energy (Switzerland); Natural Resources Canada (Can).

2.4 Energy network analyses and management

ELDIG, 2004–2007, Power distribution and distributed generation, 1170 k€, Lappeenranta University of Technology, Tampere University of Technology, VTT Technical Research Centre of Finland and University of Vaasa.

2.4.1 Active network management

Statistical network planning method

The starting point for a study of statistical planning methods for electricity distribution network were the existing network information systems (NIS) applied in Finnish network companies today. The aim of the study was to develop methods which could take into consideration the influence of distributed generation (DG) at analysis and planning functions. NIS tools in Finland have a long tradition to utilize statistical load curves (time series for a customer type) in network analysis. A similar method was developed for production units (wind power, combined heat and power units and hydro power) to model time variation of power production based on statistical properties like monthly average wind speed, outdoor temperature and inflow. (Repo, 2005a).

The statistical planning method and production curves were verified with measurements made in Hailuoto distribution network and wind power units. The measurements showed that the dimensioning of distribution network should be based on the worst case planning principle when the network includes only wind power. Wind power production correlated well with load demand, when monthly average production and load are considered. However individual hours may behave differently depending on wind conditions. The probability of voltage rise above a planning limit during a minimum load condition is somewhat smaller what is considered today at network planning. (Bastman, 2007)

The statistical network planning method creates several production curves for use in the network analysis. These calculations will produce a distribution function for each hour, network node and variable. For example the voltage distribution of DG connection point during the hour of minimum load demand describes the probability of exceeding the maximum voltage limit or the amount of network transfer capability with chosen probability level. Calculation examples have shown the benefits of statistical planning method at distribution network planning when a network includes wind power units (Laaksonen, 2004), (Repo, 2004a), (Repo, 2005a), (Repo, 2005c), (Repo, 2005d), (Mäki, 2006b). The same method has also applied to estimate variable costs of electricity distribution company due to DG (Repo, 2005a), (Repo, 2006a).

"Flexible interconnection" is a new idea for connection of intermittent DG into distribution network (Repo, 2006b). The worst case planning principle will lead to strong enough distribution network from technical point of view, but from economical point of view that will lead to deterioration of utilization rate of distribution network facilities. The worst case planning principle allows addition of DG capacity according to minimum of network transfer capability which occurs once a year and the capability is higher than that rest of the time. The flexible interconnection of DG utilize the "free" capability of network by controlling DG unit based on network conditions. The theoretical maximum for a DG unit is the maximum transfer capability of network in the connection point. The flexibility of DG unit is realized with local voltage control of DG unit or with production curtailment in order to limit voltage rise in weak networks. The flexibility of distribution network is for example co-ordinated voltage control of DG units and network. (Repo, 2005a).

Interconnection of small-scale hydroelectric power plant to weak network

The interconnection of small-scale hydroelectric power plant to a 20 kV electricity distribution system was studied by modelling a case network and DG units in PSCAD. Developing the model and verifying it constituted the central part of this project. In order to verify the simulation results comparative disturbance recorder measurements were arranged in the real MV network with the startups of the appropriate power plants. The comparison of the measured and simulated quantities indicated that applying the dynamic model of the system the magnitude and waveform of the starting current and voltage dips due to it can be reliably simulated.

One aim of the study was to utilize the simulated results of connecting the asynchronous generator to the medium voltage (MV) distribution system to find solutions to power quality problems caused to customers by the starting and operation of these generators. According to simulations the starting current may cause significant voltage dips to other customers. The depth of the voltage dip depends on the electrical distance of the customer from the appropriate generator. The loading condition of the feeder also has a clear effect on the voltage dip, being deepest when the loading of the feeder is at its maximum. Because of the extent of the disadvantage caused by a voltage dip it is necessary to limit the starting current in many cases.

An induction generator of a few megawatts considerably increases the transmission of the reactive power via the MV feeder. To improve the power factor, increase the active power transmission capacity and decrease the power losses it is appropriate in many cases to fit local power factor correction capacitors at the terminals of the generator. The main benefit will be achieved if the local parallel compensation is adjustable. If only all or part of the no-load reactive power demand is compensated the part of the reactive power in the total power remains relatively high when the generator operates with rated power. By applying series compensation the part of the series impedance of the line can be compensated which increases the power transmission capacity of the feeder. The wide variation of the ratio of the productive and load capacity along the MV feeder makes it difficult to locate the compensation unit at the optimal point. (Nikander, 2005), (Nikander, 2007a) and (Nikander, 2007b)

Testing of PSS in small gas power plant

The behaviour of a power system stabilizer (PSS) at synchronous machine voltage controller applied in a small gas power plant was examined with PSCAD and RTDS simulations. Testing a real automatic voltage regulator (AVR) and especially the power system stabilizer was an important part of the subproject. Therefore, time domain simulations are used instead of modal analysis. The closed-loop testing of the physical device is conducted using the Real Time Digital

Simulator (RTDS). Simulations are also carried out using PSCAD simulation software. In these simulations the whole study system, including the AVR, is represented by a model.

The low inertia of the gas power plant presented some problems in the application of the power system stabiliser. Because of the low inertia, the frequency of local oscillations was high (>3 Hz), and it was difficult to tune the power system stabiliser for the whole frequency range covering both inter-area and local modes of oscillation. In the study system, the power system stabiliser improved the damping of inter-area oscillations in almost all cases studied. The modeled PSS enhanced also the damping of local oscillations in almost all simulations, whereas the real stabiliser deteriorated it nearly each time. In steady state, the power system stabiliser introduced significant noise to the AVR output because the oscillations of mechanical power were visible also in electrical power. This is also due to the low inertia of the power plant. The noise in steady state could be decreased by adding filtering to the PSS or using a different type of stabiliser. (Partanen, 2006a), (Partanen, 2006b) and (Kulmala, 2007a)

Active voltage control of DG units and OLTC

A method for active voltage control has been developed and its functioning has been tested with PSCAD-simulations at MV network feeding the Högsåra wind park. The method is based on co-ordinated control of on-line tap changer (OLTC) of primary transformer and local voltage and power factor controls of DG units. The basic idea of the method is to adjust the voltage setting value of OLTC within acceptable limits which are checked based on distribution system state estimate. The benefit of the active voltage control method is better utilization of distribution assets by allowing connection of larger production capacity into existing network than with traditional voltage control method. The control method operates as expected in the simulations. It is capable of restoring voltages within acceptable limits after disturbances like production changes, when that is possible by controlling the voltage of primary substation. The method includes also properties which prevent OLTC hunting and continuous operation of network with exceptional high or low voltages. A planning method for selection of controllers' setting values has been proposed when a network includes one DG unit. (Kulmala, 2007b) and (Kulmala, 2007c)

2.4.2 Protection co-ordination

Protection impacts of DG and protection planning

The main objective of the studies conducted was to determine the problems related to the traditional network protection due to the propagation of DG. The phenomena related have been studied with different simulations and calculations. A further objective was to ideate methods for including the observations in network planning methods. As most of the typical distribution network planning is performed in steady-state NIS systems and the impacts of DG have, on the other hand, strongly dynamic nature, this objective is very challenging. However, according to the feedback from network utilities, the impacts of DG should be integrated to the planning systems. Utilities are not eager to use dynamical simulation tools for their planning purposes. The studies have been performed strictly from the distribution network's point of view; thereby the focus has been on coordinating the operation of protection devices.

The study has not aimed for any new protection techniques or for protection device development. Instead, methodological development and practical guidelines have been the desired output. Some methods have been developed for achieving these objectives. The protection planning procedure seeks to present the studies needed for connecting new DG unit with the public power system. (Mäki, 2006c) The sequence of the studies is of great importance. Other methods such as graphical protection requirement graph (Mäki, 2007b) and NIS fault calculation extension method (Mäki, 2006d) have been designed to assist the procedure. More general development ideas and requirements for NIS to better support the DG planning process have also been ideated. (Mäki, 2006e) Together, these methods and ideas form a protection planning entity that might be used as a functionality of NIS.

The typical feeder protection problems related to DG can be divided in sensitivity and selectivity problems. The sensitivity of feeder protection may be harmed due to blinding effect caused by the presence of DG. When located between the feeder relay and the fault, DG can significantly decrease the fault current measured by the feeder relay. This is due to normal fault current distribution in the network. (Mäki, 2005a) Operation of relay can be delayed or totally blocked. As the DG is also likely to increase fault levels in the network, the situation can be problematic. Selectivity problems relate usually to faults occurring outside the feeder the DG unit is connected to. In these cases it is possible, that the upstream fault current contribution of DG trips the feeder relay although there is no need for this. The direction of fault current is not sensed in many cases, thus enabling this sympathetic tripping. Selectivity of the power system is also harmed when the DG unit itself becomes tripped due to faults on adjacent feeder. So far, this is not considered a great problem for the network, but as the contribution of DG becomes more important system-wide, these trippings can be problematic. One of the most important observations made in the studies is the contradiction of the actions required by blinding and sympathetic tripping. (Mäki, 2004a), (Mäki, 2005a), (Mäki, 2005b), (Mäki, 2005c) Other potential problems relate to operation of DG protection during reclosings and islandings. The DG unit must become disconnected during these events. A failing reclosing results in evident power quality impacts as a longer interruption is needed. Islanding results also in quality problems but especially in safety hazards and should thereby become always tripped. Unfortunately there is no detection technique available for the worst-case islanding. (Mäki, 2007c) However, developments in detection techniques have made sustained islandings far more exceptional situations. (Mäki, 2006f)

DG and earth faults

The problematic impact of distributed generation on system earth fault protection is caused by its ability to sustain voltage momentarily in an isolated feeder after the tripping of the feeder breaker. If the generator is connected directly to the network its ability to sustain the voltage during isolated operation remains short because the supply of the reactive power to the generator will be prevented but the increase of the duration of earth fault current must be taken into account when the touch voltage regulations are considered. The directional earth fault protection of MV feeders is normally based on measurements of zero sequence voltage and zero sequence current. Due to the vector groups of the unit generator transformer the zero sequence quantities, voltage or current generated by an earth fault of the MV system cannot be indicated on the low voltage side of a transformer (generator side). The earth fault protection of the distributed generator is often based only on loss-of-mains protection. With larger hydro power generators a separate neutral voltage measurement on the high voltage side can be used to indicate an earth fault. Applying the autoreclosings with MV feeder including distributed generators increases from before the need for rapid and reliable operation of loss-of-mains protection so that production unit can be reliably disconnected before the autoreclosing and the out of phase connection can be avoided. (Nikander, 2007a), (Mäki, 2007d)

Ring operation of distribution network

The ring operation mode presents new possibilities in connecting DG to the network. This is especially possible in weak rural networks. The ring operation of the distribution network will divide power flows to the feeders more evenly than radial operation, losses will be minimized and voltage rise due to DG can be limited. The voltage profile of ring operated feeders is also more flat than profile of radial feeders. These properties will result to better utilization of distribution system than radial operation (Repo, 2004b). Using the ring operation mode may, however, complicate the protection issues. There may be some problems concerning the operation of protection. Thermal limits of network components may also become inadequate as the fault levels in the network increase when applying the ring operation mode.

Typical case of using the ring operation mode in the distribution network is closing the open connection between two feeders with a remote controlled recloser. A ring is thus formed. Normally it is reasonable to feed the ring from one substation only. When the fault occurs it is possible to open the ring connection at first. After this, the fault is located on one feeder only and the protection can function as in radial use. The thermal limits of components may become a barrier for using this kind of protection as the opening of the ring takes some time and hence prolongs the duration of fault. The opening can be done by using a recloser placed in the network between the feeders. If one of the feeders is equipped with sectionalizing reclosers, they can be used to open the ring as well.

The opening of the ring is simply based on the magnitude of the fault current flowing through the recloser. The direction of the current is normally not recognized by the recloser. Thus the tripping limit must be set low enough to be able to detect all possible faults also far from the recloser. On the other hand, during a fault the current is typically big enough to easily be differentiated from the maximum current of a normal use situation. It is worth noting that an unnecessary momentary opening of ring connection usually does not cause problems in the network. The changes in voltage of the network may, however, cause some problems with certain generation-consumption combinations. Some switching transients may appear, too. DG itself complicates the implementation of protection. Together DG and ring operation could lead to relatively difficult protection systems. With small-scale production suitable protection settings can usually be found, but the problems will multiply as the installed power or amount of plants is increased. (Mäki, 2004b)

2.4.3 Island operation of DG units

The penetration of DG and the consideration of distribution network reliability have increased the interest for intended island operation of distribution system. The most important challenge of island operation is probably the control of voltage and frequency in island system i.e. management of active and reactive power balance. The controllability and control systems of DG units have great influence on stability of island. Another challenge is the co-ordination of protection system in the network and production units so that safety will be guaranteed and island operation and smooth transition to it will be possible when normal variation range of voltage and frequency are relatively wide in island operation. There is also needed a clear classification of intended and unintended island operations from protection point of view, because unintended island operation must be avoided in all situations.

The electricity distribution system of Hailuoto-island has been used as a case system which includes four wind turbines equipped with directly connected asynchronous generators and standby diesel engines capable of feeding the maximum load demand alone. Normally wind turbines are disconnected in case of island operation. The study was performed to find out if wind turbines may contribute island operation and thus minimize the use and cost of diesel engines. According to PSCAD-simulations the island operation is stable in maximum loading situation when all wind turbines are connected. However during the minimum loading condition none of wind turbines may be connected due to over-frequency of system. Frequency limits of wind turbines are relatively tight from island operation point of view. Sudden disconnection of wind turbine due to exceeding the over-frequency limit does not endanger the operation of island system because over-frequency will be avoided and the frequency control of diesel engines will contribute for possible under-frequency situation. (Mäki, 2007d).

Literature survey of island operation possibilities at electricity distribution network clarifies requirements of stable island operation (Repo, 2005b). The study describes existing requirements and properties of island operation in Finland. These islands are traditionally created at sub-transmission level and they are based on synchronous machines which have been equipped with suitable controllers. The report brings also into attention new distribution network related challenges which are: utilization of DG and load control in island operation, formation and braking of island, and network protection in island operation.

2.4.4 Measurement services

Measurement services were demonstrated by measuring, collecting and analysing power quality data of Hailuoto electricity distribution system including wind power units. Measurements were arranged vertically along the radial network. Measurements were done with remotely readable power quality guards of MX Electrix Oy and PQNet measurement collection and storing system of PowerQ Oy. Recorded 10 min average measurements were active and reactive power, voltage level, current, voltage harmonics, voltage unbalances and flicker indices. Also voltage dip events were recorded. According to measurements and analysis results the effect of wind power units to distribution system power quality is not such remarkable that there would be needed separate measurement system for that purpose alone. The monitoring of distribution system power quality should be developed more like one integrated measurement system which should take into consideration among other measurement tasks the effects of DG units on distribution system power quality. (Antila, 2003)

The effect of DG units on power quality is dependent on unit type and network characteristics itself and thus the effect on power quality may be positive or negative depending on a case. The most important power quality issues in DG unit interconnection are: voltage level should be within acceptable planning limits, voltage changes due to connection and disconnection of DG unit into network should not be too large in proposition to frequency of occurrence, and fast voltage changes (flicker) may not appear too large extend. These quantities are also the most important quantities in the power quality monitoring from the DG units point of view. Small DG units connected into low voltage network would probable be considered widely enough if power quality monitoring is included in advanced AMR-meters and temporary measurements are done at distribution transformer stations. Large units might require more extensive measurement system due to system wide effects of these units. (Bastman, 2007)

Another measurement case was realized in wind park of Olos fjeld. These measurements were realized in order to collect disturbance data from distribution substation and from wind park connection point for the verification of simulation models and the development of fault indication and location algorithms. (Hänninen, 2005), (Uski, 2006)

One detail of the research of power quality measurement was the development of calculation tool for flicker indices. The tool is based on standard IEC 61000-4-15 and it is fast in order to be able to implement it in power quality guards having limited computation capability. (Koponen, 2003)

2.5 Network connection

The network connection from the point of view of power plant technology was studied in the research projects of Lappeenranta University of Technology. The main focuses were the use of frequency converters for network interfacing, and the design of the permanent magnet generators either used with frequency converters or directly connected to electricity network. In the VELKO, part 1 project, the frequency converter driven generating hydro electric plant concept was designed and it was piloted in Tirva. The results were collected to final report (Lindh, 2005). As a result of research, the possibilities and restrictions of such concept were shown. The first hydro plants using the concept are already in production use.

2.5.1 Permanent magnet generators directly connected to grid

The research concentrated in the definition of proper machine parameters that are required for the direct network connection of permanent magnet synchronous generators (motors) and, on the other hand, the definition of the parameters that are required when these machines are used as a part of a power plant.

Permanent magnet synchronous generators (PMSG) are often connected to the grid via frequency converters, such as voltage source line converters. All the power produced by the generator is fed through the converter. The price of the converter can constitute a large part of the costs of a generating set. Some of the permanent magnet synchronous generators with converters and traditional separately excited synchronous generators could be replaced by direct-on-line (DOL) non-controlled permanent magnet synchronous generators. Small directly network-connected generators are likely to have large markets especially in the area of distributed electric energy generation. Typical prime movers could be, for example, wind turbines and water turbines. The benefits would be a lower price of the generating set and the robustness and easy use of the system.

The basic concept is simple and competitive. There is neither a need for an excitation system nor for a frequency converter, only coarse synchronization equipment is needed for the phase angle difference and the frequency. Despite the constant excitation, the generator is capable of producing enough asynchronous accelerating torque by the damper winding and pull-in torque to synchronize by itself.

The hydroelectric plant drives are low speed applications. At low speeds in direct network applications lots of poles are needed. The magnetising inductance L_m of a rotational field machine is inversely proportional to the square of the pole pair number p.

$$L_m \cong \frac{1}{p^2} \tag{1}$$

In induction generators, this causes a low power factor for low speed machines. In synchronous machines, a low synchronous inductance, however, is a benefit because the peak torque of the machine is inversely proportional to the synchronous inductance L_s which consists of the magnetising inductance and the stator leakage $L_{s\sigma}$

$$T_{max} \cong \frac{1}{L_s}, L_s = L_m + L_{s\sigma} \tag{2}$$

We see that a synchronous machine is more suitable for low-speed applications than an asynchronous machine. In particular, it is easy to construct low-rotational-speed permanent magnet synchronous generators having excellent electromagnetic properties, especially compared to induction generators. In many cases, the prices of such machines are lower than those of separately excited synchronous generators, especially when generators are submerged. Often, the PM generators are controlled by four-quadrant frequency converters. In these applications, the network side inverter can feed the network with any power factor in the limits of its current handling capacity. On the other hand, when a variable rotational speed of the turbine is not required, the frequency converter is not needed if a PM generator is capable to a direct electrical network connection. PM generators cannot, however, be used if the generator plant is so large that the network stability has to be supported for example with a power system stabilizer (PSS). This limits the size of a generator to less than 50 MW class in many countries. The main requirement of the PM generator with a direct network connection is the adequate damping property so that stabile operation is guaranteed. The PM generator design and damping properties have been studied recently e.g. by Kinnunen et al. (Kinnunen, 2006a, 2006b, 2006c).

PM machines can be designed so that they produce power with a near to unity power factor within their whole operating range. In this project, A) the possibility to construct such a generator was discussed, and guidelines for the design of the main parameters of this kind of a machine were proposed (Lindh, 2007), (Kinnunen, 2006a) and B) prototype generators for direct network connection were designed.

The following rules and restrictions are affecting the design:

a. If the generator is synchronized with no phase error, the starting current is affected by the subtransient inductance of the machine and the induced back EMF.
b. The voltage-level fluctuation during synchronization is restricted in the EU primarily by the EN 50160 and secondarily by the standards and engineering recommendations that normally restrict the voltage fluctuation at the connection point during synchronization to 3–5 %. Also the synchronization terms can determine the voltage error between the net and generator poles for example to less than 10 % according to the VDN guidelines. This restricts the maximum induced back-EMF of a permanent magnet generator e_{PM} to 1.1.

c. Magnetization of the machine cannot be changed at different loads. The stator voltage of a generator is connected to the electrical network voltage and thereby the stator voltage should be u_s = 1 p.u. If the e_{PM} is designed to the value of 1.p.u., the minimum starting current is obtained and a light load power factor of about unity is achieved. However, the power factor of the loaded generator then decreases with the load. Therefore, e_{PM} may be designed to greater values than 1 p.u. to achieve a high power factor also with a full-loaded generator. Thus the power factor can remain high enough to meet the recommendations and network connection rules of network companies (usually the power factor should exceed the value of 0.95–0.97). In this case, a capacitor bank parallel to an induction generator can be avoided.
d. The minimum continuous short circuit current is required usually when the generator is used islanded. This is due to the fact that generator must give an adequate current for the over-current and possibly touch-voltage protection. Therefore, twice or three times the nominal current may be required during a sustained short circuit. However, when used parallel to a distribution network, no special short circuit current capacity is required.
e. The pull-out torque of the generator has to be above the nominal torque to guarantee the synchronous operation during the short time variation of the torque of the prime mover or turbulence of primary energy source. For the hydro power generator, the pull-out torque requirement is often 1.2–1.3 times the nominal torque.
f. Customer requirements. The network codes of distribution companies may set requirements that affect the design principles and sizing of the generator. For example thermal limits in design are not the key issue if large overload capacity is required during voltage sags etc. The customer often requires very high efficiency. These factors usually lead to slight oversizing of the machine. The p.u. value for impedance is given

$$Z_B = \frac{U_N}{I_N} \tag{3}$$

Hence, if the nominal current I_N is reduced because of the oversizing of the generator, the p.u. values are scaled, and this should be considered always when using the p.u. equations that are the basis for the design.

Both the voltages as well as the synchronous inductance L_d have an influence on the power available. The designer may select the pole number (in a small scale, because for example in the case of the hydro power plant, the hydraulic properties such as flow and the head height set limits to the rotational speed range) and other machine dimensions to gain a desired inductance. Ignoring the effects of the stator resistance and possible saliency, the torque developed by a synchronous machine without saliency can be solved using the load angle equation

$$T = \frac{mp}{\omega_s^2} \frac{E_{PM} U}{L_d} \sin(\delta_a) \tag{4}$$

where m is the number of phases, U is the supply phase voltage, E_{PM} is the induced back-EMF, δ_a the load angle, ω_s the synchronous electrical angular velocity and p the pole pair number. If connected to the network, the supply phase voltage is u_s equal to 1 p.u. The rated speed would be 1 p.u., and the maximum achievable power can be written as

$$P_{\max} = \frac{m}{\omega_s} \frac{E_{PM} U}{L_d} \infty \frac{e_{PM}}{l_d} \quad \text{(p.u.)}. \tag{5}$$

The equations above and the equations describing the transient phenomena of generators the parameters were varied and their effect on the rules listed above were analysed and compared to the FEM calculations made by Flux2D® software. The following results were presented in a paper by Lindh (2007). In a hydro-power application, where a turbine with adjustable blades is used for power control, the useful adjustment range varies from 30–100 %. It was concluded that the power factor remains over 0.95 for quite wide a range so that if e_{PM} is 1, the d-axis synchronous inductance must be less than approx. 0.3 and if e_{pm} is 1.05 the l_d should be 0.3–0.75. If e_{PM} is 1.1, the l_d should be in the range of 0.5–0.9. If the short-circuit current feeding capacity is not required, then in order to limit the starting current l_d should be as large as possible and the pull-out torque requirement should set the upper limit for l_d. Setting the required pull-out torque to 1.3, the l_d should be less than 0.77–0.92 (e_{pm}=1–1.1). If the generator is oversized, to increase the efficiency, the suitable inductance values (p.u.) are increased.

2.5.2 Parameter design and prototype generators

Axial flux permanent magnet generator prototype for direct network connection

The general guidelines and recommendations presented above were applied in the analysis. By analyzing the results produced by the simulation model for the permanent magnet machine, the guidelines for efficient damper winding parameters for directly network-connected permanent magnet generators were determined. The simulation model was used to simulate grid connections and load transients. The effects of the electrical parameters, especially the damper winding parameters, on the generator performance were simulated. The damper winding parameters were calculated by the finite element method (FEM). Both two-dimensional and three-dimensional modelling were carried out. Analytic equations governing the phenomena are very complex because of the 3-dimensional behaviour of the eddy currents. Therefore the three-dimensional finite element analysis (3D FEA) is preferred in the analysis of the damper winding constructions.

The results from the simulation model and the finite element analysis were compared with practical measurements.

The dimensioning of the damper winding parameters is case specific. The damper winding should be dimensioned based on the moment of inertia of the generating set. It is shown that the damper

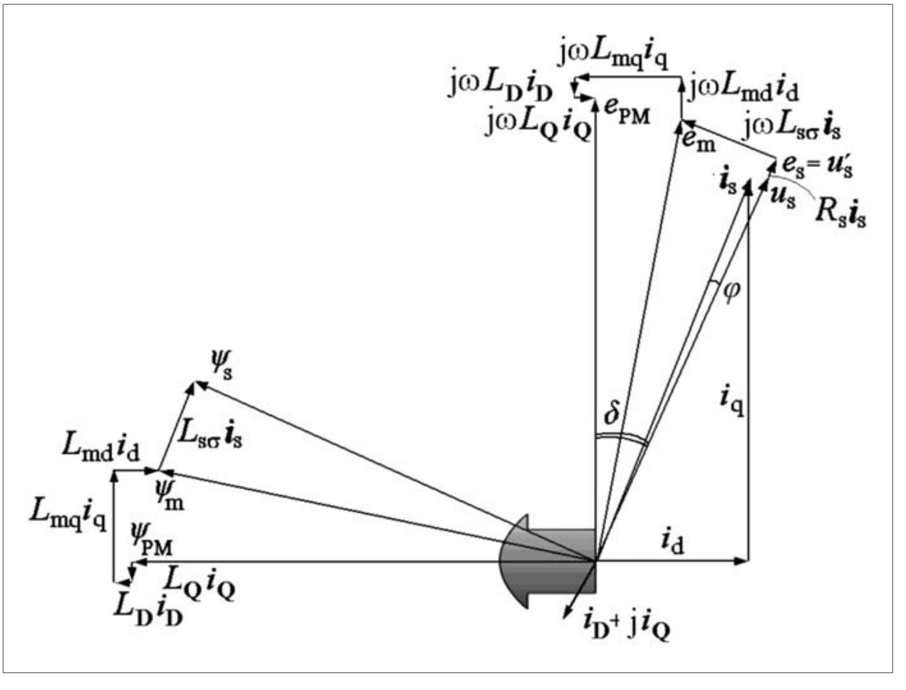

Figure 2.1. Permanent magnet synchronous generator phasor diagram in a transient state. In the transient state, the rotor speed or load angle are not correct and the generator tries to reach equilibrium. The change in the flux flowing through the damper windings induces damper winding currents that try to keep the flux constant. The rotor is rotating counter-clockwise.

winding has optimal values to reach synchronous operation at the shortest period of time after transient operation. With optimal dimensioning, the interferences in the grid are minimized.

Permanent magnet synchronous generators have two main requirements in directly network-connected operation. First, the generator must be capable of synchronization after grid connection and second, the generator has to maintain synchronous running during electric load variation and other transients. The generator characteristics vary depending on the strength of the electric network. Therefore, both infinite bus network and isolated microgrid operations were processed in the analysis.

In a DOL PMSG, careful design of the damper winding is needed. The price of the machine must also remain competitive with traditional generators. This may limit the practical applications of some damper winding structures with expensive materials. Modern Neo magnets have a relatively low resistivity, in the range of 150–250×10^{-8} Ωm, and hence the eddy currents in the permanent magnets produce losses and increase the temperature of the permanent magnets. This must be taken into account particularly in rotor constructions with a poor or average thermal conductivity. If the cooling of the rotor is not sufficient, permanent demagnetization of the magnets can take place. The demagnetization is far easier if the temperature of the magnets rises.

The prototype AFPMSG1 is a one-rotor-two stator construction with an aluminium-frame rotor, while the AFPMSG2 is a single-sided construction with a cast-iron rotor yoke. Both the machines have short-pitched stator windings with W/τ_p = 5/6 and q = 2.

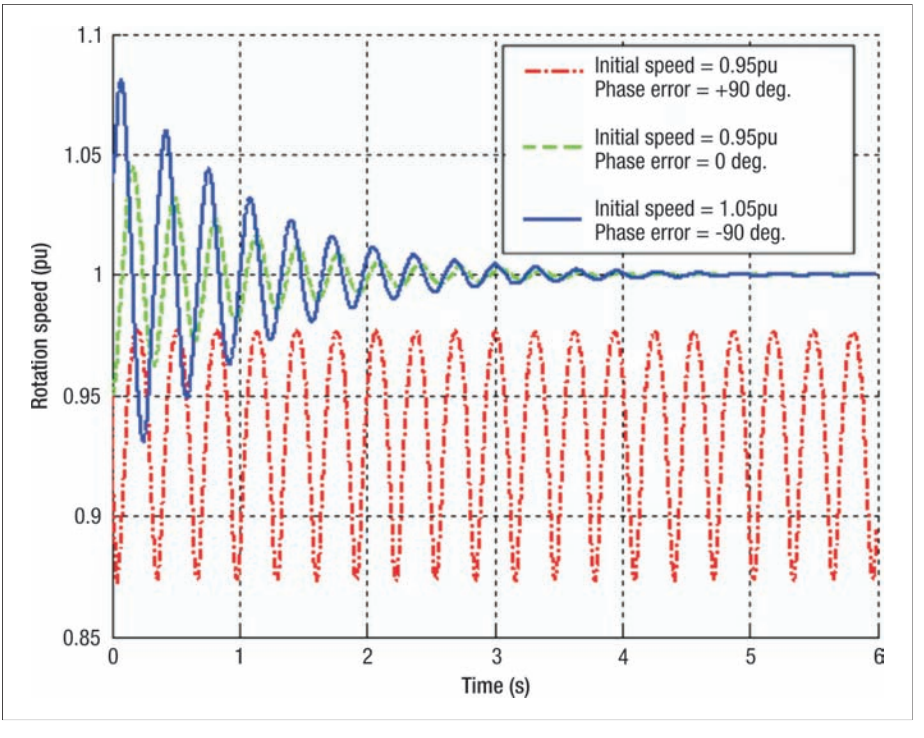

Figure 2.2. DOL PMSG at grid connection. The successfulness of the synchronization depends on the speed error and the phase shift error.

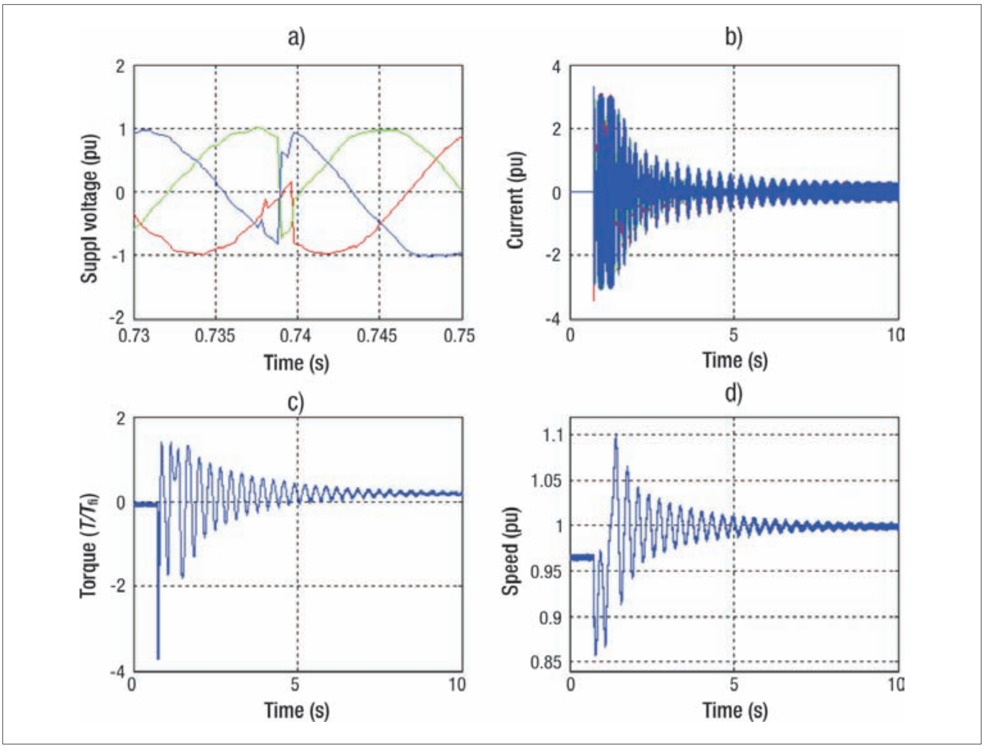

Figure 2.3. Grid connection of the AFPMSG1. The generator is connected to the grid with a large phase difference $\Delta\varphi = +137°$ at time $t = 0.739$. The initial speed before the grid connection is 0.96 pu. a) The phase difference between the grid and the back-EMF of the generator. b) Transient phase current in the grid connection. c) The shaft torque during synchronization. d) The speed of the generator. The generator is still able to synchronize.

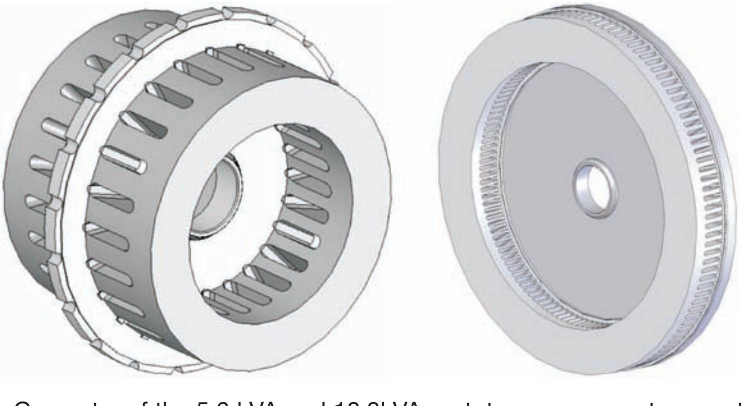

Figure 2.4. Geometry of the 5.6 kVA and 18.3kVA prototype permanent magnet synchronous generators. a) The generator AFPMSG1 has four magnetic poles. It consists of two stators and one rotor between the stators. The body of the rotor is made of aluminium. The generator is an axial flux machine. The permanent magnets are surrounded by installing jig and surface plate, both made of aluminium. b) The geometry of the prototype permanent magnet synchronous generator AFPMSG2. The generator has 16 magnetic poles. It consists of one stator and one rotor. The body of the rotor is made of cast iron. The generator is an axial flux machine. The rotor has the installation jig and the surface plate made of aluminium.

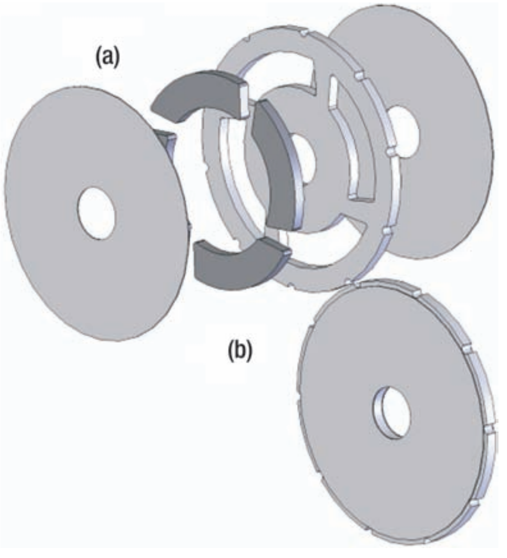

Figure 2.5. Construction of the damper winding.

Radial flux permanent magnet generator prototype for direct network connection

The aim was to design and manufacture 55 kW 8 pole permanent magnet synchronous generators capable for a direct network connection. The two different types of rotor constructions with different damping properties were investigated (Figure 2.6).

In this research, the possibility to simulate the traditional no-load and short-circuit tests using FEM-calculations was tested. The dynamic state d- and q-axis parameters were evaluated by FEM calculations and measurements. The results of the short-circuit calculation are shown in Figure 2.7. The FEM-calculated and the measured results have quite a good correspondence.

The prototype machines were tested in motor laboratory of LUT. According to the test results, the machines are suitable for the direct network con-

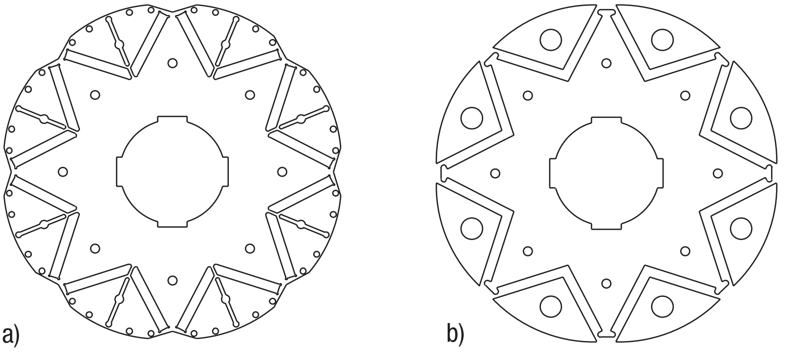

Figure 2.6. Rotor constructions of the permanent magnet generator made of a) 0.5 mm thick electrical steel and b) 10 mm iron sheets.

Table 2.1. The advantages and disadvantages of these rotors are presented below.

Rotor type	Advantages	Disadvantages
Electrical 0.5 mm steel	Better efficiency because the iron losses are lower in laminated steel.	Damper windings required.
Iron sheet 10 mm	Cheap, robust and simple to manufacture.	Lower efficiency because of the higher iron losses. Weaker and inexact Damping properties

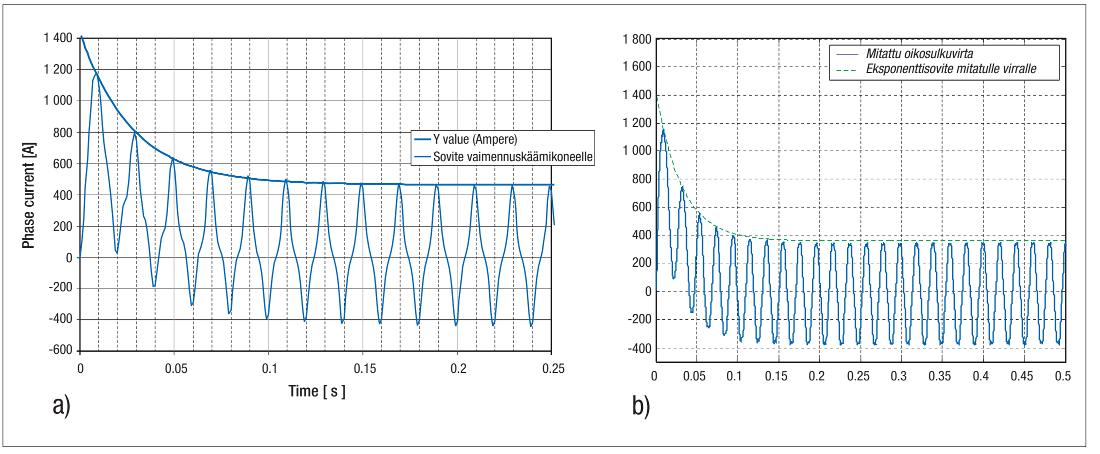

Figure 2.7. a) FEM-calculated and b) measured phase current during a 3-phase short-circuit test.

nection. This gives one a possibility to use such PM-machines as generators. The concept has the advantage of the good performance of traditional externally excited synchronous machines and at the same time benefits of a very simple construction. The know-how of such machines has remarkably increased giving the industry the possibility to utilize new information in a large variety of applications.

2.6 Inverters and converters in network connection

Traditionally, distributed generation plants have been relatively large (typically at least hundreds of kilowatts), and generators have been connected directly to the electricity network. The connection codes of authorities and distribution companies are fit to these conditions. Now, however, two ongoing changes affect the area: More and more power plants use frequency converters between the generator and the electricity network, and secondly, more and more micro power plants will be installed parallel to the network. Micro generation mainly aims to reduce the amount of purchased energy of the electricity end-user, not to feed the distribution network.

Frequency converters, when used in electricity network connection, set several issues under consideration: for example, how is the quality of electricity affected, how should the connection and disconnection be done, how are the anti-islanding protection and network fault protection affected, and how the quality measures of electricity should be defined, what would be the appropriate levels and how they should be measured in the commissioning phase.

In addition to the questions set by a frequency converter connection, the micro generator set new challenges to the network connection. From the economic point of view, the construction should be simple when the value of produced energy is low, or even negative for an electricity company. The situation at present is such that the connection rules and the power plants are treated equally in the commissioning phase regardless of the size of the plant. When the electricity network operation and safety issues are concerned, this is rational. On the other hand, however, some of the electricity quality measures can become questionable. The international standardization (EN 50438) aims to facilitate the connection procedures by the standardization of the power quality parameters and the interface protection and by the use of type testing of these, so that the commissioning would be as simple as possible. This is important for two reasons: The installers of micro generation plants have often little or no expertise on network connection, and if there are a large number of micro generation plants, it is a burden to a network company to have individual concern of each plant. In addition, the installers of micro generating units should be treated equally at least at the national level.

In this project, the technical aspects of frequency converter network connection have been studied, yet the conclusions and proposals for acts to be taken have been left to future projects. Details of the subjects will be given in final report of VELKO, part 2 project.

2.6.1 Frequency converter in the control of a small-scale hydropower plant

Frequency converters can be utilized in a hydropower plant as a control method alternative to using a variable blade angle turbine or a bank of fixed blade angle turbines that can be utilized in different combinations to have the head change as little as possible (two-point control). The overall economical feasibility of each of the options is determined by their investment and operating (maintenance) costs, and efficiency. The feasibility of each of the control methods (variable blade angle, two-point control, frequency converter) was studied. The usage of the two-point control and the frequency converter in keeping the head constant are illustrated in Fig. 2.8 and Fig. 2.9. Furthermore, the torque characteristics of a fixed-blade propeller turbine as a function of rotation speed were measured.

The frequency converter can be used to flexibly control the output power and thus the head of the power plant. The produced energy is metered hourly, and the producer is often credited based on an hourly-changing price. The price can be, for example, the hourly Nordpool spot price (or some fraction of it). This information is publicly available on the Nordpool WWW site. Typically, in a small-scale hydroelectric plant, the power production has a significant impact on the head of the pool (pool volume is small) and vice versa. Therefore, it is possible to optimize the power production so that, as a basic principle, the water is stored in the reservoir when the price is low, and released through the turbines when the price

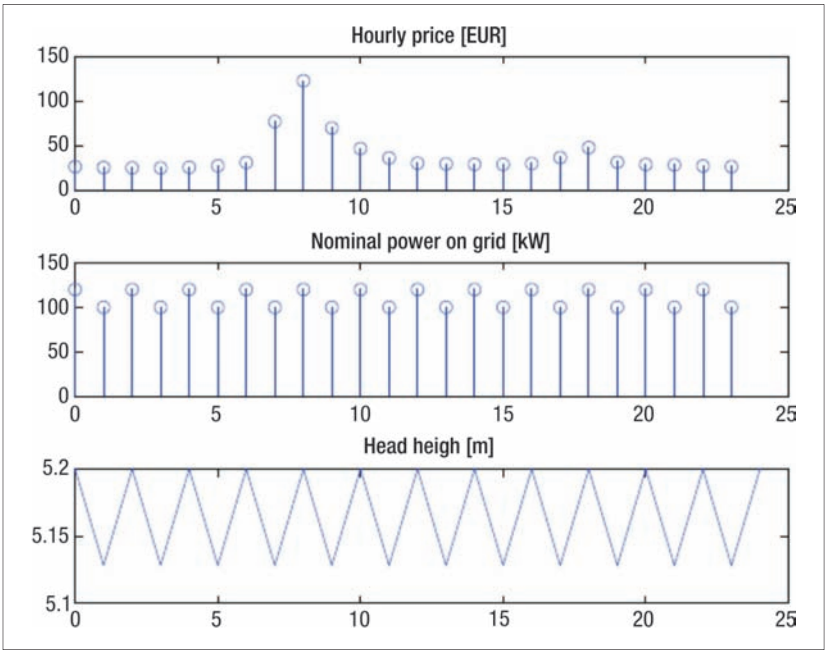

Figure 2.8. Two-point control. The head is kept as constant as possible by the use of two generator combinations providing 100 kW and 120 kW.

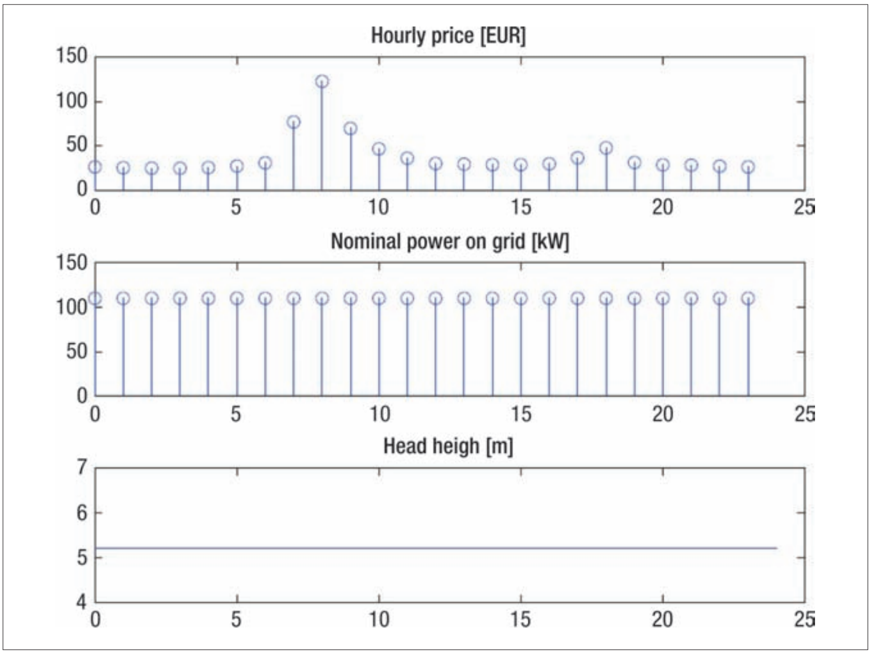

Figure 2.9. Head control using a frequency converter. The power can be kept at constant 110 kW. Compared to the two-point control (Fig. 2.8), switching of generator circuit breakers is eliminated, and the head is not fluctuating.

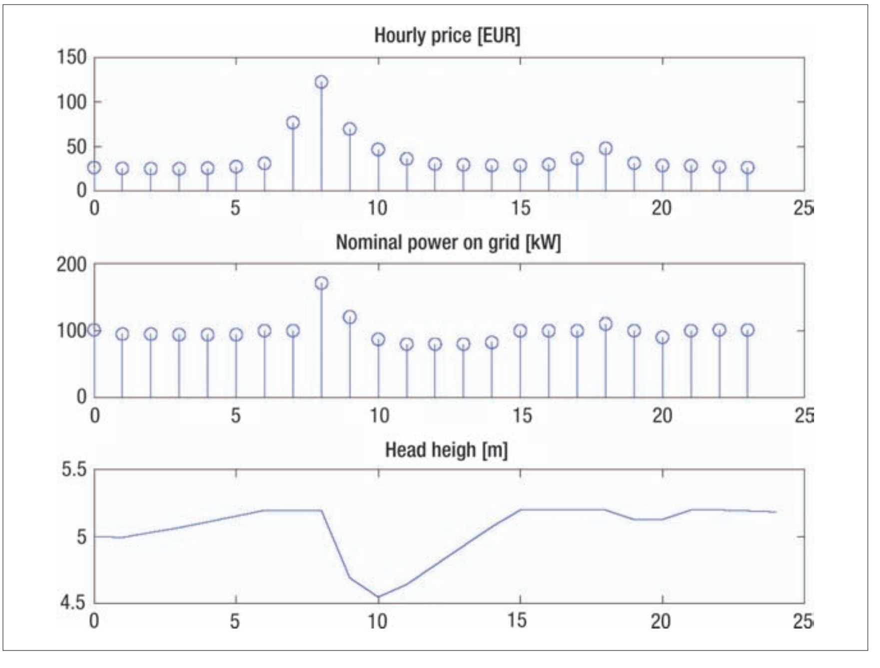

Figure 2.10. Generator utilization with optimization based on the hourly price, an example.

is higher. In the project, a simulation model of the behavior of the pool was created, and the effects of different optimization methods were compared. An example of an optimizer-generated power production sequence during a 24 hours time is presented in Fig. 2.10. In the example, the inflow was set to 50 % of the maximum combined flow of the generators. The income using the optimized combination was increased with 4 % compared to income using constant-head control. The difference is remarkable for the power plant owner and thus encourages to produce more energy when the demand is high.

2.7 Power system impacts of wind power – IEA collaboration

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Bettina Lemström, VTT

International collaboration has been active in IEA WIND (International Energy Agency, Implementing Agreement on Wind energy). VTT has participated in the Executive Committee of the IEA WIND, as well as several research tasks related to power system impacts of wind power: Task 21 (Dynamic Models of Wind Farms for Power System Studies), Task 24 (Integration of Wind and Hydro power systems) and Task 25 (Design and operation of power systems with large amounts of wind power, VTT as coordinator).

The Executive Committee of IEA R&D WIND meets twice a year with a follow-up of wind energy development and R&D in all participating countries (20). VTT has gathered and reported the information of Finland and disseminated the information from abroad in Finland.

Wind power will introduce more uncertainty in operating a power system; it is variable and partly unpredictable. To meet this challenge, there will be need for more flexibility in the power system. How much extra flexibility is needed depends on the one hand on how much wind power there is and on the other hand how much flexibility exists in the power system. The existing targets for wind power anticipate a quite high penetration of wind power in many countries. It is technically possible to integrate very large amounts of wind capacity in power systems, the limits arising from how much can be integrated at socially and economically acceptable costs.

2.7.1 Task 21 Dynamic models of wind farms for power system studies

Large wind power installations may have a significant impact on power system stability that must be assessed prior to installation. Such assessment is commonly conducted using commercially available software packages for simulation and analysis of power systems. These packages normally facilitate a set of well-developed models of conventional components such as fossil-fuel-fired power stations and transmission network components. However, models of wind turbines or wind farms represent new features with, in many cases, unknown accuracy. This at best leads to uncertainty in the market, and at worst it leads to an erroneous design jeopardising the power system stability. The challenge is twofold. First, the technology in modern wind farms is fairly complex, and the dynamic behaviour of these wind farms may differ significantly depending on the wind turbine type and manufacturer-specific technical solutions. Second, model validation must be transparent and adequate for providing confidence. Task 21 under the IEA Wind Agreement was formed for a coordinated effort aiming to enhance progress in 2002 with SINTEF Energy Research of Norway as the Operating Agent.

The overall objective of Task 21 is to assist the planning and design of wind farms by facilitating a coordinated effort to develop wind farm models suitable for use in combination with software packages for simulation and analysis of power system stability. The Task established an international forum for exchanging knowledge and experience within the field of wind farm modelling for power system studies. Wind farm models were developed by the individual participants of the task, and description and validation of the models were coordinated by the task, which helped provide state-of-the-art models and pinpoint key issues for further development. A common database was set-up for benchmark testing of wind turbine and wind farm models as an aid for securing good-quality models.

Task 21 had participants from nine countries (Denmark, Finland, Ireland, the Netherlands, Norway, Portugal, Sweden, the United Kingdom, and the United States). In these countries, research institutes and universities carrying out work to develop and test wind farm models. They also perform grid studies in cooperation with wind turbine manufacturers and electric utilities. In total, participants of the task are expected to contribute more than 20 person-years of work effort. Cooperation within the task comes from sharing measurement data, model descriptions, and discussions at meetings. A total of eight task meetings were arranged. The task was the first to present a systematic comparison of wind generation models against measurements. The test results give a clear indication of accuracy and usability of the models tested, and pin-point the need for both model development and testing.

Model developments are still ongoing among participants. They include both fixed- and variable-speed technologies and use various software tools (Matlab/ Simulink, PSS/E, SIMPOW, DIgSILENT and EMTDC). The database contains measurements mainly from fixedspeed wind turbines, but also a small collection of measurements from variable speed wind turbines is included. A method for benchmark testing of models has been established by the task, and selected models developed by the task participants have been tested. The tests include both validation against measurements and model-to- model comparisons. They consider dynamic operation during normal, fault-free conditions and response to voltage dips. In total, more than 10 models have been tested, including models of both fixed-speed and variable-speed wind turbines. A topic of high interest is the ability of wind turbines to ride through temporary grid faults. If they can ride through faults they will contribute to grid stability. Detailed numerical models may be used to assess such abilities, but these models must be validated against measurements to provide confidence. A proposal emerging as a spin-off from Task 21 is to update IEC 61400-21 (Measurements and assessment of power quality characteristics of grid connected wind turbines, ed. 1, 2001) to specify requirements for such testing. This work will continue in 2007.

National project

Participation in the Nordic Energy Research project: *Large scale integration of wind energy into the Nordic Grid.* 2003–2006.

Additional information about Task 21 can be found on the Internet at http://www.energy.sintef.no/wind/IEA.asp.

2.7.2 Task 24 Integrating wind and hydro power systems

Hydro generators typically have very quick start-up and response times and may have flexibility in water-release timing. Therefore, hydro generators could be ideal for balancing wind energy fluctuations or for energy storage and redelivery. Studying grid integration of wind energy, particularly on grids with hydropower resources, will help system operators understand the potential for integrating wind and hydropower resources. Task 24 under the IEA Wind Agreement was formed for a coordinated effort aiming to enhance progress in 2004 with NREL, US as the Operating Agent (2004–2008).

The task has established an international forum for exchange of knowledge, ideas, and experiences related to the integration of wind and hydropower technologies within electricity supply systems. In addition, the IEA Wind Task 24 works in cooperation with the IEA Hydropower Implementing Agreement, which is investigating integration of hydropower and wind through a complementary set of investigations. The goal is to identify technically and economically feasible system configurations for integrating wind and hydropower, including the effects of market structure on wind-hydro system economics with the intention of identifying the most effective market structures. The outcome will be a consistent method of studying the technical and economic feasibility of integrating wind and hydropower systems, the ancillary services required by wind energy, as well as an understanding of the costs and benefits of and the barriers and opportunities to integrating wind and hydropower systems.

Participants of the task are contributing a wide variety of case studies, with some representing small systems (<1,000 MW peak load), such as Grant County Public Utility in Washington State, USA, to large systems (>35,000 MW peak load) such as Hydro Quebec. There is also a wide variety of hydropower facilities, with some being essentially run-of-the-river with little storage capacity (a day or two), to very large hydro plants with multi-year storage capability. This diversity should allow for a comprehensive look at the grid integration scenarios (Australia, Canada, Finland, Norway, Sweden, Switzerland and United States).

The case studies are divided in four categories: 1) grid integration, 2) hydrologic impact, 3) market and economics, and 4) simplified modelling of wind-hydro integration potential. The wide variety of hydropower installations, reservoirs, operating constraints, and hydrologic conditions combined with the diverse characteristics of the numerous electrical grids (balancing areas) provide many possible solutions to issues that arise. Depending on the relative capacities of the wind and hydropower facilities, integration may necessitate changes in the way hydropower facilities operate in order to provide balancing or energy storage. These changes may affect operation, maintenance, revenue, water storage, and the ability of the hydro facility to meet its primary purposes. Beyond these potential changes, integration with wind may provide benefits to the hydro system related to water storage or compliance with environmental regulations (e.g., fish passage) and create new economic opportunities. Economic feasibility of wind and hydro integration project will depend on the type of electricity market considered. Addressing economic feasibility in the electricity market will provide insight into which market types are practical for wind-hydro integration, as well as identify the key factors driving the economics. Simplified methods for approximating the amount of wind power that can be physically or economically integrated with existing hydropower generation should be devised based on the characteristics of the local transmission control area loads, hydropower facilities, and the wind power resource. The analysis methods should include only the most influential operational constraints for hydro and electric reliability concerns. The goal is to develop a technique to approximate the potential for integrating wind and hydropower without the need to conduct an in-depth study.

The Finnish national project in DENSY programme has studied two case studies. Simulations with model WILMAR with hourly time steps has been used to study the Nordic electricity market with large amounts of wind power (Kiviluoma and Holttinen, 2006). Analyses of a single producer with limited amount of hydro power show that adding wind power as distributed wind farms along the West coast of Finland can be handled cost effectively either by the spot and regulation market or by the hydro and thermal production units, up to same capacity of wind power as the capacity of hydro power (Holttinen et al, 2007).

By the end of 2007, five meetings of the Task participants had been held, reporting progress on all case studies. Final report is due in late 2008. Additional information about Task 24 can be found on the Internet at http://www.ieawind.org.

2.7.3 Task 25 Design and operation of power systems with large amounts of wind power

In recent years, several reports have been published in many countries investigating the power system impacts of wind power. However, the results on the costs of integration differ substantially and comparisons are difficult to make due to using different methodology, data and tools, as well as terminology and metrics in representing the results. Estimating the cost of impacts can be too conservative for example due to lack of sufficient data. An in-depth review of the studies is needed to draw any conclusions on the range of integration costs for wind power. This requires international collaboration. Task 25 under the IEA Wind Agreement was formed for a coordinated effort in 2005 with VTT Finland as the Operating Agent, for years 2006–2008. There are 11 participating countries (Denmark, Finland, Germany, Ireland, Norway, Netherlands, Portugal, Spain, Sweden, UK and USA) and EWEA.

The ultimate objective is to provide information to facilitate the highest economically feasible wind energy penetration within electricity power systems worldwide. Task 25 supports this goal by analysing and further developing the methodology to assess the impact of wind power on power systems. The Task has established an international forum for exchange of knowledge and experiences related to power system operation with large amounts of wind power. The participants collect and share information on the experience gained and the studies made up to and during the task. The case studies will address different aspects of power system operation and design: reserve requirements, balancing and generation efficiency, capacity credit of wind power, efficient use of existing transmission capacity and requirements for new network investments, bottlenecks, cross-border trade and system stability issues. The main emphasis is on the technical operation. Costs will be assessed when necessary as a basis for comparison. Also technology that supports enhanced penetration will be addressed: wind farm controls and operating procedures; dynamic line ratings; storage; demand side management DSM etc.

The task work started with a state-of-the-art report collecting the knowledge and results so far. The task will end with developing guidelines on the recommended methodologies when estimating the system impacts and the costs of wind power integration. Also best practice recommendations will be formulated on system operation practices and planning methodologies for high wind penetration.

By the end of 2007, five meetings have been organised, mapping the on-going wind integration projects and the main results obtained so far.

National project of Finland has case studies on the Nordic electricity market and the transmission and stability analyses for Finland.

Additional information about Task 25 can be found on the Internet at http://www.ieawind.org

2.8 Energy storage applications in distributed power system management

Environmental questions, open electricity market and the need for more reliable and efficient electricity distribution are among the driving forces for distributed energy generation and systems. Energy storage is seen as a key technology for promoting the wider implementation of distributed energy systems. The use of energy storages would provide a proper energy management, power quality and improve energy efficiency.

Distributed power generation is defined as a small scale generation near the customers including renewable energy, solar and wind generation. Especially solar and wind energy productions have been rapidly increasing. A typical feature of the renewable energy generation is an irregular output with stochastic power variations and breaks. These variations are not usually detectable above normal variations in supply and demand, but when the amount of irregularly varied power generation exceeds the performance limits of the local network, it can have an influence on the power quality and system reliability. The output power smoothing and limitation may be needed in a weak, low-voltage electrical grid especially when uncontrollable wind power generation is very high. Output power management is also needed if the distribution grid can have an autonomous microgrid operation mode.

Output power smoothing during different types of power variations and breaks is a typical example of the application of energy storages. Energy storages can also be a solution for different network management problems and can also improve the efficiency, flexibility and convenience of the overall use of electrical and thermal energy, and they can also support the existing qualifying standards, regulations and recommendations for network power quality and control (Table 2.2).

Generally, customers' demands for higher power distribution reliability and power quality are increasing. Among the other power quality and reliability improving devices and systems, a power quality station with energy storages is a solution for different power quality demands of customers. Direct current distribution is an old solution, but it is nowadays considered again as a power distribution solution that could provide more overall energy-efficient and techno-economically improved systems. Energy storages can be seen also an important technology to support peak load management and the efficiency of overall demand size management.

In the DENSY program, VTT has had research projects ENVATUULI, ENVADE and ENVADE+, which have included various techno-economical studies, simulations and demonstrations of energy storage technology and its solution in different power distribution tasks. The main research areas have covered energy storages for the network management with wind power systems and UPS, with power quality systems/stations, in DC distribution systems and microgrids; one of the research areas has also been the control and improvement of the operation and maintenance reliability of a weak electrical network. The research has been made in co-operation between universities (Helsinki University of Technology and the University of Vaasa). The projects have been funded mainly by Tekes but also by a number of companies (see attached list) and VTT.

2.8.1 Energy Storages to support wind power and weak networks management

Energy storages can be used to improve wind power management especially when uncontrollable wind power is interconnected to a weak network or into islanding capable microgrid.

Stochastic power variations are typical for the wind power and PV production. Both the real and reactive power output can include a large amount

Table 2.2. Energy storages in power distribution applications.

Time scale	Target	Driving force examples	Storage requirements	Energy storage type
Very fast (ms)	Power quality control, smoothing	Power quality standards, regulations, recommendations	Very fast, very high cycle life, power demand varies	Electrostatic/ electro-chemical (super) capacitors, SMES, flywheels
Fast (s)	Power quality control, smoothing	Power quality standards, regulations, recommendations	Very fast, very high cycle life, power demand varies	Electro-chemical (super) capacitors, SMES, flywheels
Medium fast (min)	Power quality control, smoothing	Power quality standards, regulations, recommendations	Fast, high cycle life, power demand varies	Super-capacitors, flywheels, batteries
Slow (h)	Power smoothing, management of peak power, breaks etc.	Power production reliability, economical aspects	High power, high energy, proper cycle life	Batteries, flow batteries, fuel cell+ electrolysator, CAES, pumped hydro
Very slow (d, m)	Energy management	Power production reliability, economical aspects	High energy and power	Batteries, flow batteries, fuel cell+ electrolysator, CAES, pumped hydro

CAES (Compressed Air Energy Storage), SMES (Superconducting Magnetic Energy Storage)

Table 2.3. Types of power variations or breaks in wind power production.

Time scale Caused by	Very fast f> 0.1Hz	Fast f< 0.1Hz	Medium fast Minutes	Slow Hours	Very slow Days (months)
Tower shadow effect	X				
Wind gusts		X			
Local variations of wind speed			X	X	
Long period wind speed variations, time of day, weather, season, maintenance					X

of variations at different frequencies and amplitudes and numerous interruptions of different lengths mainly because of wind variations (Table 2.3).

Variations and especially breaks at the network connection point decrease remarkably when turbines are connected as a wind park. Also the wind turbine system design and control strategy impacts on the amount of output power variations. Wind turbine output power variations are normally insignificant, but they can be harmful in weak networks and in microgrids capable of islanding. Fast variations are usually only seen as the flickering of lights, but breaks can be harmful and costly even if power companies are obligated in certain cases to compensate the costs. The cost of power outages varies according to the consumer type (Table 2.4).

Table 2.4. Cost of power outages according to a consumer type.

Consumer type	Break time	
	2 min	1 h
Private	0.7 €/kW	6.5 €/kW
Service	1.8 €/kW	24.9 €/kW
Public	4 €/kW	30 €/kW

Requirements for energy storages described in Table II are relevant also in wind power management. Combination of a fast power storage technology with a slower high energy storage will provide an ability to smooth fast energy peaks to ensure power quality, and, on the other hand, to smooth slower energy variations and manage power production interruptions. A currently commercially available, applicable solution is a combination of electrochemical (super/ultra) capacitors and batteries. There are two basic concepts to connect a dual storage system (DC sources) to a wind turbine concept. In the following picture (Figure 2.11), there is a dual energy storage system connected A) to the directly grid coupled asynchronous generator output before a network transformer, where the storage system works as a power quality station and B) into the DC link of the wind turbine network converter.

A dual storage system can be controlled with respect to various aspects:

- Limit maximum output power (Figure 2.12, A)
- Sustain minimum output power
- Smooth output power (Figure 2.12, B)
- Maximize profit from electricity trade
- Support load management e.g. peak shaving

Financial benefits can be reached with dual storage system using advanced multifunctional (system performance, cost, time etc.) wind turbine output power control if the electricity price follows the power demand and/or is sufficiently high and the storage system has the same subsidies as the wind turbine.

Energy storages can be exploited in the control of electrical network and especially in the support of a weak network operation and maintenance reliability and in the forming of microgrids. In con-

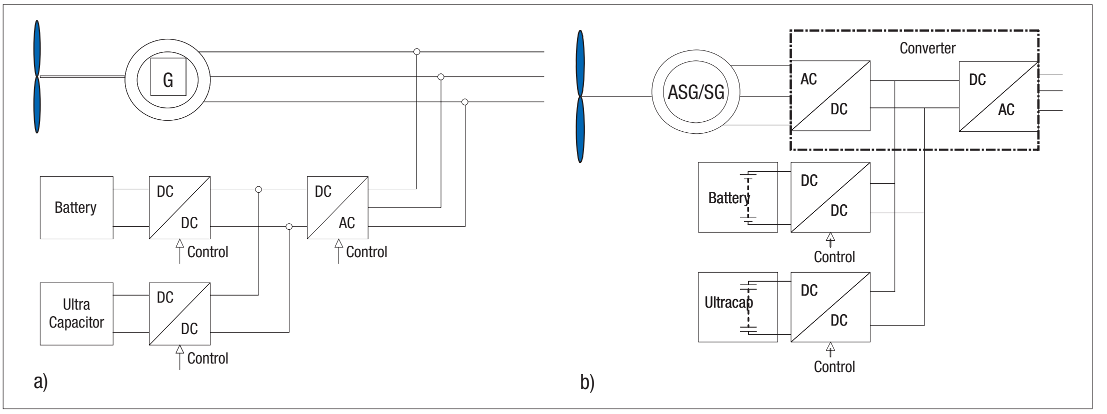

Figure 2.11. Schematic diagram of a dual energy storage system and A) a directly grid coupled wind power generator, B) a variable speed wind power generator.

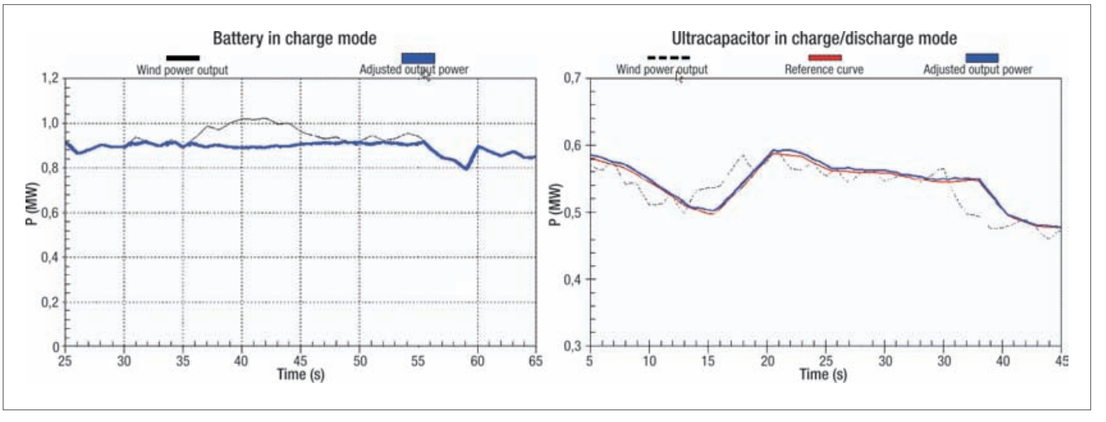

Figure 2.12. Dual storage system in wind turbine output power management A) battery bank limits output power and B) supercapacitors smooth fast variations.

trolling of the maintenance reliability, the energy of the storage has to be adequate. Depending on the target, a relatively high power is also often needed, and therefore there is also a need for the combination of high energy capacity and high power. When a microgrid is formed due to a fault, there is a requirement for fast control and accuracy of the network linkage unit of the energy storage.

The studies show that in the case of a main feeder fault, it is technically possible to shift smoothly to the island mode with the help of energy storages. However, the most serious problem is often the high cost of the energy storages. When the load is increasing in a weak electrical network, the typical solution is often to reinforce the grid, which is very expensive. In that kind of a situation it might be economically reasonable to substitute or shift reinforcements and use energy storages rather than for example to be able to run network with average power instead of the peak power.

2.8.2 Energy storages and power quality station

Power quality management has become a more interesting issue because the demand for power quality, the amount of distributed energy and the amount of electrical components has been growing. Power quality control includes for example the control functions for harmonics, reactive power and voltage unbalance.

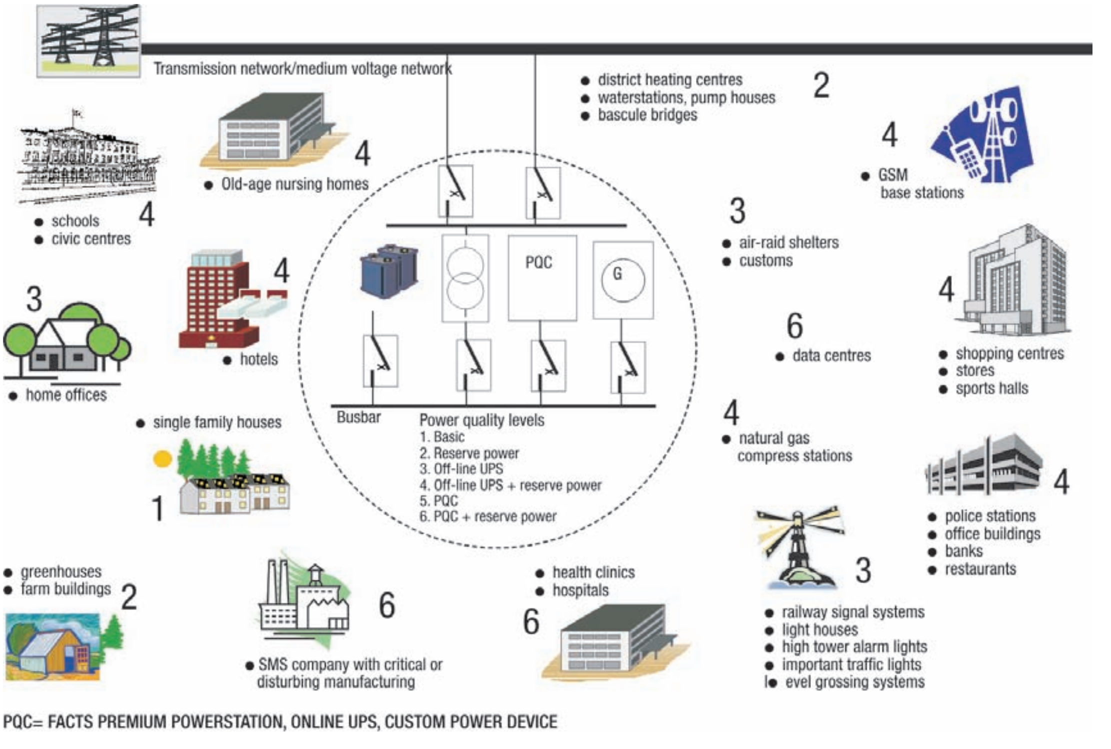

Figure 2.13. Example of the centralized power quality station, power quality levels and potential customers.

Various devices, systems and concepts have been developed to control power quality. Flexible AC Transmission Systems (FACTS) include devices such as static synchronous compensators (STATCOM), static Var compensator (SVC) and power factor correction capacitors (PFCC). Energy storages used with FACTS devices can improve the system performance. FACTS are mainly used in high and medium voltage grids.

A new idea for the power quality management of a low voltage distribution is a centralized power quality station that is capable to produce different power quality for the groups of end-customers with different demands. A concept of power quality station includes reserve power and UPS (uninterruptible power) systems and energy storages. Power quality levels can vary from the basic quality that is sufficient for ordinary single family houses to the uninterrupted high premium quality power for hospitals and other similar demanding customers (Figure 2.13).

The main functions of the concept include power quality, distribution reliability and energy management (Figure 2.14). The balance of the functions can be modified according to the demands. The concept can be placed with consumption or production systems. The power quality station can also be placed in the distribution network, which allows electrical companies to sell e.g. reliability and power quality services.

Energy storages used with a power quality station can be e.g. different kinds of batteries, flywheels and supercapacitors depending on the required functions. The capacity needed varies according to the functions (Figure 2.14).

The power quality station can be also seen as a main part of the microgrid that has autonomous function mode. The following illustrations present different modes of the power quality station that consists of a series and shunt converter and energy storages interconnected to the DC link of the converters.

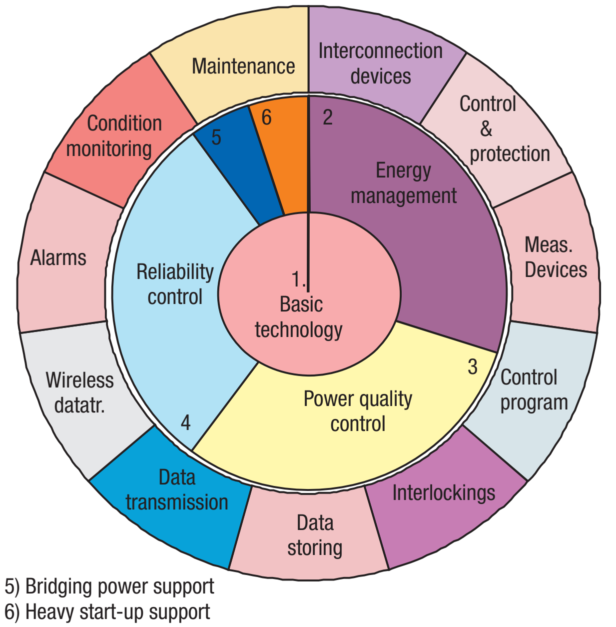

Figure 2.14. Basic functions of a power quality station.

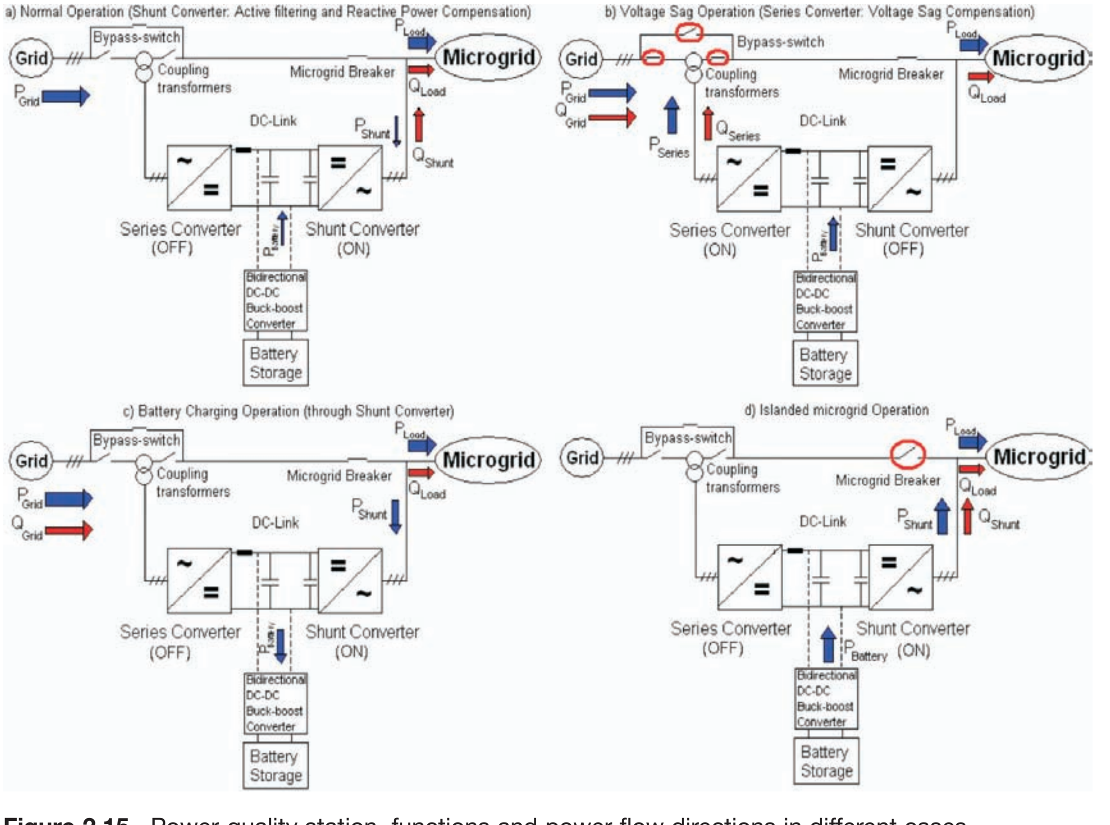

Figure 2.15. Power-quality station, functions and power flow directions in different cases.

Table 2.5. Estimated energy storage capacity in different functions.

Function	Energy storage power	Discharge time	Energy storage
Power quality control	0.01 x Pload	0–1s	Supercapacitors, batteries
Distribution reliability control	1 x Pload	1s –15min	Batteries, flywheels etc.
Energy management	0.1 x Pload	15min–24h	Batteries

According to the results of the PSCAD simulations the above-presented power quality station system with energy storages can solve many of the power quality problems: 1) The shunt converter of PQC can compensate the microgrid current harmonics and reactive power, 2) The series converter of PQC can eliminate utility grid voltage sags and utility grid voltage imbalance and 3) Islanding and island operation is possible unintentionally or intentionally by the developed adaptive configuration and control system of PQC shunt converter, and with that the instantaneous voltage control and power balance management in islanded microgrid with low harmonic distortion is possible.

Both the customers and the power companies gain from the benefits of power quality station, such as the good power quality and high reliability. The system can also improve energy efficiency, and it eliminates the need of separate reserve power systems of customers. The benefits of power quality systems are observed worldwide, and for example similar types of power quality stations as described above are already implemented in Japan.

2.8.3 Energy storages in direct current distribution systems

Direct current (DC) was earlier used in industrial and general power distribution, and for example in Helsinki it was partly used in the power distribution even until the 1950s. Nowadays DC is commonly used in long undersea high-voltage power connections because of smaller power losses and costs and better power management. Medium-voltage DC links are used e.g. in offshore wind plant connections, and both medium- and low-voltage DC distribution systems are common in the connections of large industrial drives and in railway and ship electrification systems. Lately, DC has been considered also for general medium- and low-voltage power distribution even for residential low-voltage power distribution, where it could bring more benefits for example because of the overall increase of DC components and devices such as information technology equipment and PV systems. Especially DC is seen a viable solution with the distributed energy system, where the DC network interconnection would be more convenient and efficient.

Direct current distribution could be implemented in many voltage levels having different topologies (Figure 2.16). Ring networks, distributed power generation and energy storage systems support distribution reliability and power quality and make possible to build microgrids that have an islanding capability.

A DC distribution described above (Figure 2.16) could be implemented with currently existing devices (transformers, circuit breakers, converters, cables, protection relays) but the device selection is very limited, and therefore further device and system development is needed. Specific standards and implementation guidelines, especially standards and rules for voltage levels, protection and network interconnections would improve the system implementation and expedite the product development.

Considerable benefits on power quality can be seen to be achieved with DC systems compared with AC systems especially when systems are provided with energy storages. However, protection, fault management and distributed DC network control systems would need further studies

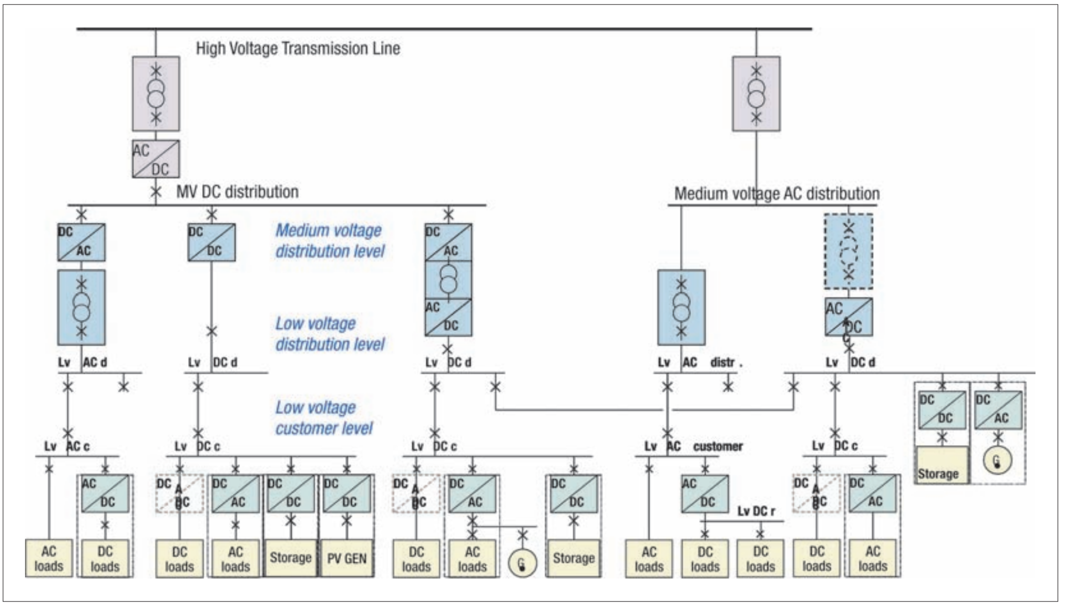

Figure 2.16. An example of direct current supply options in power distribution.

and development. Advanced devices such as fault-limiting circuit-breakers and converters with a bi-directional current control switch or an anti-parallel ETO (emitter turn-off) thyristor would limit the short-circuit current and the fault time and thus provide a proper fault management system. The control system of a distributed DC network with several parallel DC converters has an important role in the load and fault management. Control method can be centralized (Figure 2.17) or de-centralized. Suitable control methods for DC distribution can be e.g. voltage droop, average current, master-slave and central limit methods.

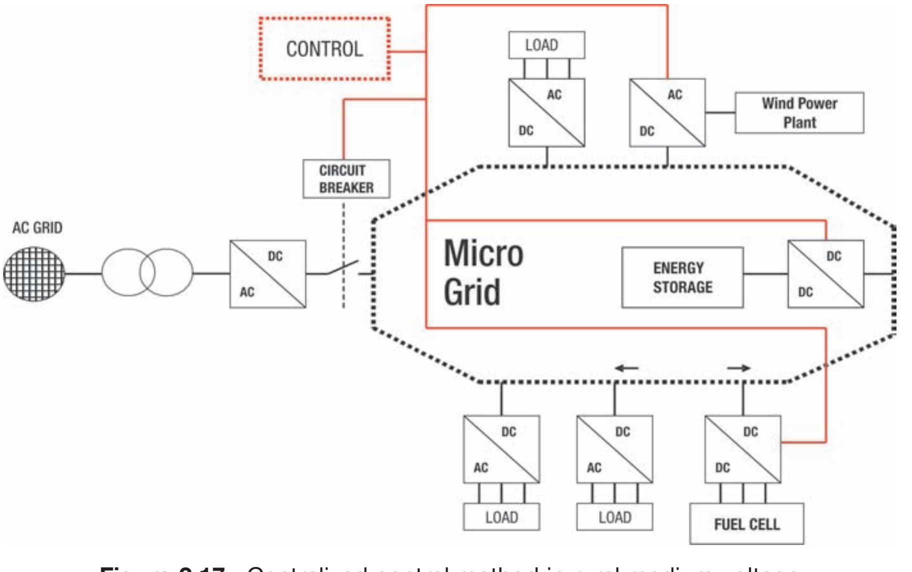

Figure 2.17. Centralized control method in rural medium voltage power distribution.

Distributed power generation and storage systems can improve the DC network energy management and customer-level power quality. DC microgrids capable of islanding can be implemented at different levels of the distributed DC network. Local power production and energy storages can be placed at the local power distribution level and/or they can be placed on the customer's side. Energy storages play an important role in power and voltage management and in power production optimization also in DC distribution (Figure 2.18). Own power production and energy storages bring new opportunities also for small power producers for electricity trade.

Cost comparison between AC and DC distribution systems has shown that low-voltage DC distribution can be more cost efficient than AC distribution. Cost comparison of medium voltage AC and DC systems and the customer-level systems is difficult because of the limited device availability. Investment costs of medium- voltage level implementation can be higher with the DC system, yet clear benefits can be seen in the cost of losses (about 1/3 of the AC system losses). The positive price development of converters (about -5 %/a during next 10 years) would remarkably improve the DC system cost efficiency and competitiveness compared to AC systems.

In the near future, MVDC and LVDC distribution can be seen to be used in the power distribution of data centers, in-feed to city centers and in power supply of small islands or offshore wind systems. Potential areas are also in-feeds of other urban areas, such as shopping centers and large office building centers, but DC might be also seen in limited areas of a consumer-level electricity distribution.

2.8.4 Supercapacitors, SUPER

At VTT there have been four research teams involved. These teams have developed carbon electrodes, conductive polymer electrodes, solid ion conducting electrolytes and liquid electrolytes. At Åbo Akademi the work has been done at Process chemistry group. This work has included electrochemical characterization, especially voltammetric measurements. At Helsinki University of Technology the work done in the Power Electronics Laboratory has included a study for measuring the impedance characteristics of a supercapacitor, a literature study of circuit topologies and a Master's Thesis. Circuits for balancing supercapacitor systems have been implemented.

The work has included the following topics:

- Carbon electrodes having very high specific surface area (carbon powder/carbon cloth)
  - Improvement of electrical conductivity to minimize losses
  - Advanced electrolytes
- Completely polymeric dry supercapacitor
  - Economic manufacturing method for thermally stable polymer electrolyte

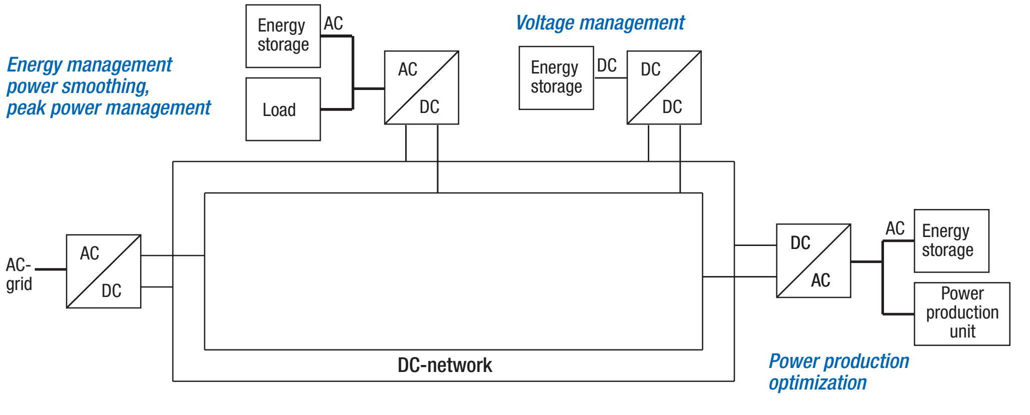

Figure 2.18. Energy storage placement and energy management functions in DC distribution network.

– Optimization of chemical or electrochemical synthesis for the production of polyaniline or other conductive polymer
- Power electronics for supercapacitors
  – Voltage balancing in series connection
  – Voltage stabilization during charge and discharge
  – Dc-dc converter

Different activated carbon powders have been used for processing supercapacitor electrodes. Some tests have also been done using a cloth made of activated carbon. Mechanically relatively strong electrodes have been made with polymer binder. Both PVDF and PTFE have binders have been applied. The performances obtained for propylene carbonate and acetonitrile organic electrolytes have been compared. With organic electrolyte the measured specific capacitance values have been of the order of 20–40 Farads per 1 gram of carbon. Beside capacitance also series resistance, leakage current and energy efficiency have been defined.

The normal test structures having plate-like structure have been prepared from almost all material combinations developed during the project. Selected materials have been applied in manufacturing cylindrical supercapacitors. This geometry would be the choice also for commercial components.

Polyaniline and polyortotoluidiinin electrodes have been synthesized electrochemically onto carbon cloths and powders. Tests show that specific capacitance can be appreciably improved with these materials. Specific capacitance of about 100 F/g has been achieved.

The synthesis process for sulfonated polyetheretherketone (SPEEK) electrolyte film has been developed. The film presents good mechanical stability when dry. According to thermal tests the SPEEK film is more stable at high temperatures than PTFE based Nafion. Capacitors having Nafion electrolytes have been constructed. In these capacitors carbon cloth was used as electrodes. The capacitance values measured have been 34 F/g which is slightly better than the ones reported in the literature. A stack of four Nafion capacitors has been done.

Electrochemical characterization procedures for supercapacitors using voltammetric measurement and impedance spectroscopy have been developed. Commercially available supercapacitors were measured and the results showed the methods were reliable. A voltammetric measurement method was tailored for characterizing the active surface area of carbon powder and electrodes.

The charging of the double layer has been studied with chronoamperometric techniques, using a model carbon powder and a model organic electrolyte. A charge separation within the diffuse layer has been identified and measured, as well as its relaxation. Total charges associated with the charging of the double layer has been identified and quantified.

Commercially available supercapacitors have been tested electrically using Arbin supercapacitor test station. Also long-term and low-temperature test have been performed. This device was applied also for measuring self-made components. The commercially available supercapacitors and those made in the project have been compared. The comparison shows that the specific capacitance of the commercial components has been surpassed and internal resistance is of the right level but leakage current should still be decreased.

A survey has been made of balancing circuits and dc-dc converter topology. The balancing can be done using either passive or active solution. Passive balancing is preferred since it is cost effective compared to an active balancing circuit. Improvement in manufacturing tolerances of supercapacitors is making balancing circuits obsolete. Characteristics of balancing circuits have been researched with a special instrument designed for the purpose. According to the literature survey the best topology for the dc-dc converter seems to be a solution based on a half- bridge, although the most suitable implementation for each application must be evaluated separately.

An approach of utilizing power electronics with supercapacitors for energy storage was presented in an MSc thesis. In this thesis charging characteristics of one Maxwell PC10 supercapacitor have been studied. The bigger supercapacitor is the larger current for the measurement is needed. If an estimate for the capacitance is needed it should be measured with an electrical load sinking constant current according to the operating conditions. Charging studies showed that supercapacitor should be regarded as a DC-component and the frequency response doesn't have much significance when considering practical applications. Supercapacitor serves as a bypass for high frequency ripple component and this ripple should be taken into consideration if calculations for maximal operating temperature are needed. Power Electronics Laboratory has purchased a prototype for charging and discharging a supercapacitor bank and studies with a microcontroller have been made in order to replace the voltage control with digital one, which is now implemented analogically.

Two patent surveys of supercapacitor structures have been done, one in the beginning of the project and one in 2007.

The results will be utilized by the companies that participate the management group. The technology that is developed during the project can be used in industrial manufacturing of supercapacitors or their raw material. The experience of supercapacitors and power electronics obtained from the project is essential when supercapacitors are applied in energy storage systems.

2.9 Simulation and laboratory facilities

2.9.1 Development environment for distributed generation. Research platform MULTIPOWER

During the last years several different independent energy production and operational testing environment have been realised in different research projects at VTT, Espoo. In Multipower project the existing separate testing systems were integrated for a complex DG testing environment so that in the future different technical solutions for distributed energy systems can be tested in a multioperational environment. In the environment, which was build in the project, different parallel testing circuits can be created. for simultaneous tests. Moreover, in the project validation

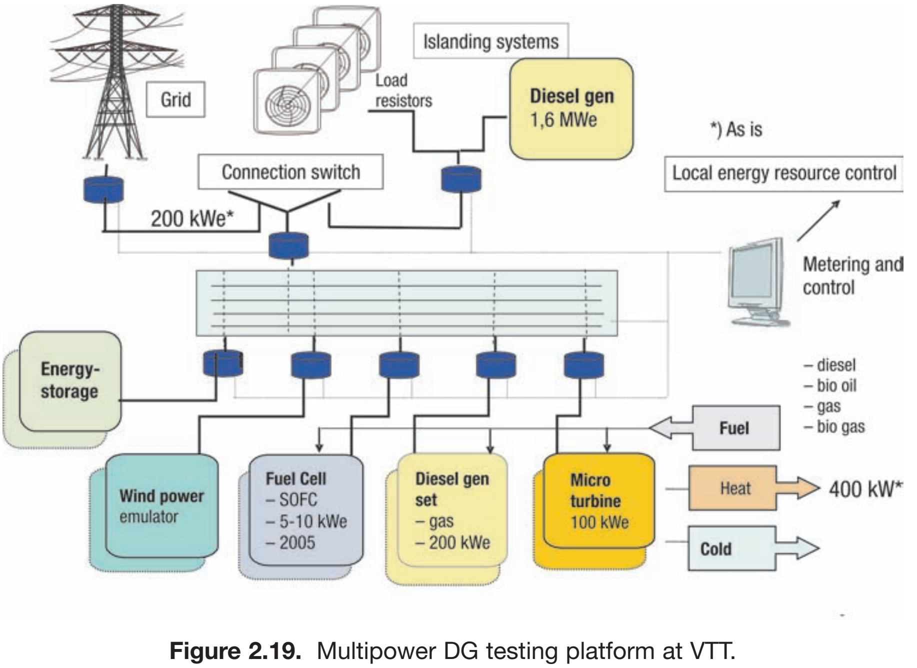

Figure 2.19. Multipower DG testing platform at VTT.

of the control- and simulation tools with the platform characteristics were performed to the limited extend. During the project also a service concept for the component and system development utilization with the DENSY program projects was created.

Environment today consists of diesel generator units (1.6 MVA, 60 kVA), microturbine (100 kVA), rotating and static loads, and optional wind power generator emulator (< 500 kVA), storage (30 kVar) and fuel cell power unit (5 kW).

Platform will be used for domestic and international needs into the product and system development as well as approval test by the Finnish research parties. It forms one essential element in the product development process.

MULTIPOWER platform can nationally and internationally be used for example as a testing site for the components and generation units of a DG system, as a platform for the validation of the control and management system of a DG distribution system, for the production optimisation in the multi production systems, as well as it acts as a platform for the component and system integration tests.

MULTIPOWER testing environment has also been introduced also for the European Network of DER Laboratories and Pre-Standardisation for its possible membership.

2.9.2 Simulation environment

An extensive computer-based simulation environment was created by VTT and the University of Vaasa. This environment can be applied in studies related to the analysis and design of grid interconnection of various types of distributed generation. The primary aim was to create a collection of simulation models representing various types of networks and generators. The network models serve as a basis for the simulation environment, and the user will have a free choice to include a desired selection of various distributed generators into the network model. In addition to these the aim was also a have library of models representing the protection relays and control systems. The primary tool applied in the projects was PSCAD, which is a well-known power system transient simulation tool.

Both medium- and low-voltage network models were developed representing typical Finnish networks. Also several network models representing

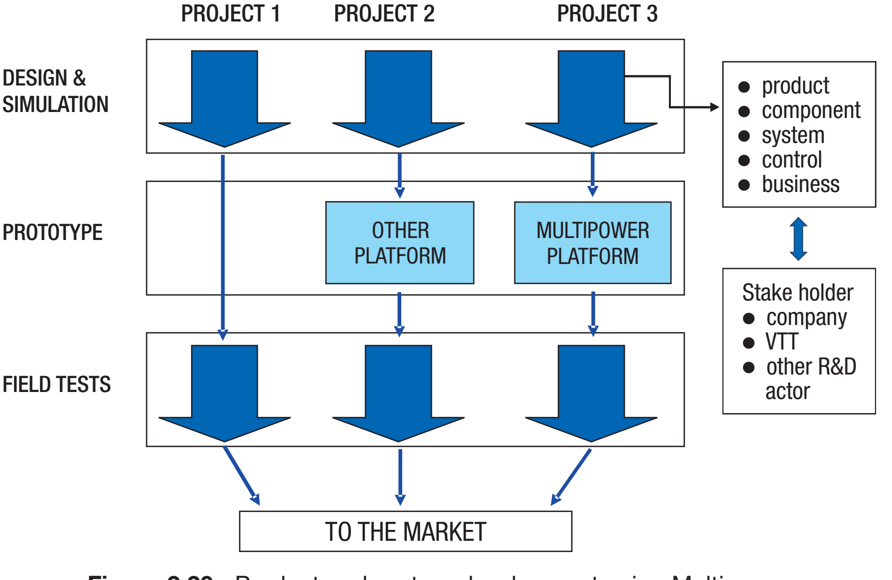

Figure 2.20. Product and system development using Multipower DG testing platform at VTT.

typical networks found in foreign countries were developed. The number of alternative system arrangements around the world is large, and thus it was possible to model only some key alternatives.

Also the models for the common protection relays applied in various types of networks were developed. To be exact, these models do not exactly represent protection relays that are nowadays more or less multifunctional, but merely the various protection functions included in the relay software. Also models for the relays applied especially with the distributed generation were included in the model library. For the low voltage networks models representing standard fuses were developed.

In the power plant models the main aim was to have electrical parts modeled as exactly as possible, while the representation of the primary energy source was kept less detailed. In practice this means that for modeling a solar power plant, a simple inverter model was created, where the energy source (i.e. solar cells) is represented by a constant voltage source. The same model can actually represent quite well any power plant that has an inverter-based interface on the network side. However, in practice there are certain differences in the inverter control principles. For this reason, basic models applying several alternative control arrangements were developed.

For the rotating-machine-based generators, the approach was to use constant torque applied to the shaft. An exception of this was the diesel generator, which also includes a model for the engine and its control system. One of the highlights of the project was the development of a model for the doubly fed induction-generator-based wind power plant. The model includes accurate representation of the converters at the rotor circuit and the advanced control and protection systems required.

In addition to generator models, simple models representing energy storages, a battery and ultracapacitor, have been developed.

To verify the modeling technique applied, it was necessary also to model some real systems. For instance, a model representing the Olos wind farm was created. This wind farm is located on top of the Olos fjeld in Northern Finland, in Lapland. In this system, also disturbance measurements were made so that it was possible to compare the model behavior with the behavior of the real system in various fault situations.

At Lappeenranta University of Technology (LUT) the primary goal was to model the small-scale hydropower production chain from the water reservoir to the grid. The modeling was carried out for the analysis and verification purposes. The models were created using PSCAD and Matlab Simulink software packages. The modeled system consists of grid, back-to-back converter, permanent magnet synchronous generator (PMSG) and fixed blade propeller turbine. The turbine is the part of the hydropower plant. The plant model includes the models of the reservoir, the penstock and the turbine. The PMSG is rotational speed controlled by the generator inverter. The interface to the network was realized using pulse width modulated (PWM) rectifier. This kind of interface could also be applied when modeling other distributed generation systems, for example, renewable energy sources such as wind turbines and solar power plants.

The models used to describe the hydropower generation include the transfer function models from the position of the gate to the electric power generated by the generator. More applicable model was developed at LUT to describe the dynamics of the low-head hydropower plant. Still, the idealization had to be made concerning the fluid dynamics of the penstock in order to model the water flow using the constant coefficient nonlinear differential equations. However, with the model the impact of the inertia of the water to the generator power production could be examined. That is essential when the different failures on the grid side are studied. Also influence of the speed control of the PMSG to the water flow in the penstock could be studied, which was impossible when using the transfer function models.

In addition to active interface hydropower plant model the directly network connected PMSG hydropower plant was developed. Because the

PMSG was directly connected to the network, the PMSG was modeled with the damper windings. The purpose of the model was to compare the results with the directly network connected PMSG manufactured at LUT when used at small-scale hydropower production. Moreover, several different models were created in order to examine the benefits that could be achieved when using the active front-end. The active filtering and reactive power compensation features of the PWM rectifier were tested (Peltoniemi, 2006). Especially, the reactive power compensation was studied when used in parallel with the directly network connected PMSG.

2.9.3 Integration of real-time simulation environments RTDS and dSPACE

The power electronic and power system related studies are yet performed more or less separately. It can be seen that novel combined simulation environments could be useful. RTDS is a real-time simulation tool for power system studies and dSPACE is a similar tool for computer-aided control systems. Combining these tools could offer a suitable environment for studying the interactions between the power system and power electronic sides. Although the aggregate impact is studied, both power system and power electronic sides can still be modeled with familiar tools and models, which is one of the main benefits of integrating the systems. In Tampere University of Technology, the combined environment has been tested for studying active power filtering (Parkatti, 2006), (Mäki, 2006a) and wind power units (Tuominen, 2006), (Tuominen, 2007), (Mäki, 2007a).

From the power system's viewpoint, the integrated research platform enables more realistic studies in the cases in which power electronic devices are connected to the network. Determining the adequate level of modeling the more complex devices has always been a problematic issue. Using the dSPACE for power electronic modeling saves the calculation resources of the RTDS. The dSPACE could also be used to run Matlab models as a part of the simulations without converting them to RTDS. However, the capacity of the data transmission as well as possible delays between the systems must be taken into account when utilizing the dSPACE for sharing the calculation loading.

From the power electronics viewpoint, it is very useful to see how the whole power system affects the converter performance. It is also beneficial to observe how the converter actually changes voltages of the power system interface when the converter is running. Normally these experiments are completed by making a prototype and testing it in a real power system. Integrated simulation environment is needed when we want to advance from offline-simulation and see how power electronic affects the power system without building a prototype. Also, the real-time simulation can help to simulate the operation of converters and the power system in different fault situations without damaging the real prototype or disturbing the power system.

Publications

Final reports

Alanen, R., Hätönen, H., Kallunki, J., Ikäheimo, J., Knuuttila, O., Holma, J., Kauhaniemi, K., Saari, P., Rinne, T. "Keskikoon energiavarastot hajautetun sähkönjakelun sovelluksissa". Projektiraportti. VTT-R-03856-06.

Alanen, R., Holttinen, H. & Saari, P. 2004. "Energian varastoinnin teknologiat Suomen tuulivoimalaitoksissa". Projektiraportti PRO2/P5 120/04. Espoo: VTT Prosessit. 148 s. + liitt. 3 s.

(Kauhaniemi, 2005) Kimmo Kauhaniemi, Ilari Ristolainen, Pekka Saari, Henry Lågland, Heikki J. Salminen, Martti Hokkanen, Bertil Brännbacka. Simulointiympäristö, loppuraportti. VTT ja VY, 2005.

(Lindh, 2005) Tuomo Lindh, Markku Niemelä, Jorma Haataja, Juha Pyrhönen, Anna-Lena Rautiainen, Petr Spatenka, Antti Tarkiainen, Risto Tiainen, Jero Ahola, Asko Parviainen, Timo Torttila, Tomi Tirronen, Hajautetun voimantuotannon verkkoliityntä ja koneet, tutkimusraportti SÄTE 19, Lappeenrannan teknillinen yliopisto, 2005. Lappeenranta. ISBN 952-214-073-2 (paperback) ISBN 952-214-074-0 (PDF).

(Repo, 2005) Hajautetun sähköntuotannon vaikutukset keskijänniteverkossa, Repo S., Laaksonen H., Mäki K., Mäkinen A., Järventausta P., Raportti 3-2005, TTY / Sähkövoimatekniikka

John Olav G Tande, Jarle Eek, Eduard Muljadi, Ola Carlson, Jan Pierik, Johan Morren, Ana Estanqueiro, Poul Sørensen, Mark O'Malley, Alan Mullane, Olimpo Anaya-Lara, Bettina Lemstrom, Sanna Uski. Dynamic models of wind farms for power system studies. IEA RD&D WIND Annex XXI, 83 p.

Other reports

Alanen, R. & Hätönen, H. 2006. ”Sähkön laadun ja jakelun luotettavuuden hallinta –State of the art selvitys”, VTT, VTT Working Papers 42.

(Antikainen, 2007), Antikainen J., “Distributed generation and reliability of distribution network”, (Hajautettu sähköntuotanto ja sähkönjakeluverkon käyttövarmuus), TUT, M.Sc. thesis, 2007, in Finnish

(Bastman, 2007), Bastman J., Mäkinen A., Repo S., “Modelling of distributed generation in network calculation and verification of calculation results with measure-ments”, (Hajautetun sähköntuotannon mallinnus verkostolaskennassa ja tulosten verifiointi mittauksilla), TUT, Institute of Power Engineering, re-search report, 2007, in Finnish

(Hänninen, 2005), Hajautettua tuotantoa sisältävän jakeluverkon muutosilmiöiden mittaaminen, Hänninen, S., Uski, S., Projektiraportti PRO3/P3009/05, 2005, VTT Prosessit

Hajautetun tuotannon tilastollisuuden ja keskijänniteverkon aktiivisen jännitteensäädön huomioiminen verkostolaskennassa, Laaksonen H., diplomityö, 2004, TTY

Hokkanen, M., Kauhaniemi, K., Modelling of Doubly-Fed Induction Generator – Crowbar Protection System Simulation, Vaasan yliopisto, 2006, Vaasa

Holma, J., ”Energy Storage System to the Medium Circuit of a Frequency Converter“. MSc Thesis. in Finnish. “Taajuusmuuttajan välipiiriin liitettävä energianvarastointijärjestelmä”, diplomityö, TKK, 2005.

Hätönen, H. 2005. ” Energy Storage Connected to Distribution Network in Controlling Power Quality, Distribution Reliability and Energy “. MSc thesis. in Finnish. ”Jakeluverkkoon liitettävä energiavarasto sähkön laadun, jakelun luotettavuuden ja energian hallinnassa. Diplomityö. Teknillinen Korkeakoulu / VTT, Espoo. Work done at VTT.

Esa-Martti Isola: Power electronics for supercapacitor based energy storage, MSc thesis, Helsinki University of Technology, 2006.

(Kulmala, 2007b) Kulmala A., “The application of active voltage control in Högsåra distribution network”, (Aktiivisen jännitteensäädön soveltaminen Högsåran verkossa), TUT, Institute of Power Engineering, research report, 2007, in Finnish

Teemu Kontkanen, IEA Wind Energy Annual Reports 2004, 2005 and 2006 (available at www.ieawind.org). Diplomityö, 2006, TKK.

Tiia-Maaria Ketola: Performance of supercapacitor structures, MSc thesis, Tampere University of Technology, 2007. Work done at VTT.

Komulainen, R.” Multipower, hajautetun energiajärjestelmän kokeellinen tutkimusympäristö”. Tutkimusraportti VTT-R-04053-07, 2007, VTT, in Finnish

(Koponen, 2003) Koponen P.,Välkynnän häiritsevyysindeksien laskentaohjelma, Tutkimusraportti, 2003, VTT

(Kulmala, 2007b) Kulmala A., “The application of active voltage control in Högsåra distribu-tion network”, (Aktiivisen jännitteensäädön soveltaminen Högsåran verkossa), TUT, Institute of Power Engineering, research report, 2007, in Finnish

Kylkisalo, T, Alanen, R. ”Tasajännite taajaman sähkönjakelussa ja mikroverkoissa”. (DC in Urban Areas Distribution Power Systems and Micro-grids). VTT Working papers 6698. Espoo 2007.

Kylkisalo, T. 2007.” The Utilization of DC Distribution Power Systems and Energy Storages in Urban Areas”. MSc thesis. in Finnish. ”Tasajännitteen ja energiavarastoinnin hyödyntäminen taajaman sähkönjakelussa”. Diplomityö. Teknillinen korkeakoulu. Sähkö- ja tietoliikennetekniikan osasto. Work done at VTT.

Laaksonen H., Kauhaniemi K., “Energiavarastolla varustettu sähkönlaatuasema microgrid-verkkokonseptin osana”, Vaasan yliopisto, 29.01.2007 .

(Laaksonen, 2004) Laaksonen H., ” Statistical production curve for distributed generation and active voltage control in calculation and network planning of MV distribution networks”, (Hajautetun tuotannon tilastollisuuden ja keskijänniteverkon aktiivisen jännitteensäädön huomioiminen verkostolaskennassa), TUT, M.Sc. thesis, 2004, in Finnish

Lågland, H., Keskijänniteverkkojen analyysi mallintamista varten. Diplomityö, Vaasan yliopisto, 2004, Vaasa

Olli-Pekka Laitinen, Mikrotuulivoimageneraattorin tehonohjaus forward-hakkurilla. Diplomityö, Lappeenrannan teknillinen yliopisto, 2006.

(Mäki, 2007d) Mäki K., Kulmala A., Repo S., Järventausta P., "Distributed generation and island operation of distribution network", (Hajautettu tuotanto ja jakeluverkon käyttö saarekkeessa), TUT, Institute of Power Engineering, research report, 2007, in Finnish

Mäki, K., "Novel methods for assessing the protection impacts of DG in distribution network planning", Dr.Tech. dissertation, TUT, in process

(Mäki, 2004c) Mäki, K., "Effect of distributed generation connected in medium voltage network on feeder overcurrent protection", (Keskijänniteverkkoon liitetyn hajautetun tuotannon vaikutus johtolähtöjen oikosulkusuojaukseen), TUT, Institute of Power Engineering, research report, 1-2004, in Finnish

(Nikander, 2007a) Nikander A., "Aspects of connecting a small-scale hydroelectric power plant in a medium voltage distribution network - a simulation study", (Pienvesivoiman liittäminen keskijännitteiseen sähkön-jakeluverkkoon - simulointitarkastelu), TUT, Institute of Power Engineering, research report, 2007, in Finnish

(Partanen, 2006a)Partanen A., "Application of power system stabilisers in distributed gene-rating units", (PSS–lisästabilointipiiri hajautettua tuotantoa sisältävässä alueverkossa), TUT, M.Sc. thesis, 2006, in Finnish

(Partanen, 2006b) Partanen A., "Investigating the operation of a power system stabiliser ap-plied in a small gas power plant using real time digital simulator (RTDS)", TUT, Institute of Power Engineering, research report, (not public), 2006

Parviainen A., "Tuulivoimaa Lappeenrannan teknillisellä yliopistolla", Tuulensilmä, nro. 4/2003, pp.11

Peltonen, Lasse. 2007. "Energy storages as a support for control and maintenance reliability of a weak electrical network". MSc thesis. in Finnish. "Energiavarastot heikon sähköverkon hallinnan ja huoltovarmuuden tukena". Diplomityö. Tampereen Teknillinen Yliopisto. Sähkötekniikan koulutusohjelma. Work done at VTT.

Pykälä, M-L.,"MULTIPOWER tutkimusympäristön sähkötyöturvallisuusohje".

Tutkimusseloste VTT-S-09482-06, 2006, VTT, in Finnish

Rautiainen A.L., Sähkökoneiden kunnonvalvonta-antureiden kehitys vaativiin ympäristöolosuhteisiin. Diplomityö, Lappeenrannan teknillinen yliopisto, 2004. Lappeenranta.

(Repo, 2005b) Repo S., Koponen P., "Island operation possibilities of electricity distribution network", (Sähkönjakeluverkon saarekekäytön mahdollisuudet), TUT, Institute of Power Engineering, research report, 2005, in Finnish

Rinne, T. "Simulation research of the network influences of the energy storage systems", MSc thesis. in Finnish. "Simulointitutkimus energiavarastojärjestelmien vaikutuksista sähköverkkoon", diplomityö. VY. 2007.

Tirronen T., Flyback-hakkuriteholähteen suunnittelu pientuulivoimageneraattorikäyttöä varten. Diplomityö, Lappeenrannan teknillinen yliopisto, 2005. Lappeenranta.

Torttila T., Pienoistuulivoimalan kuormitusanalyysi. Diplomityön käsikirjoitus, Lappeenrannan teknillinen yliopisto, 2005. Lappeenranta.

(Tuominen, 2006) Tuominen O., "Modelling and simulation of wind power drives", (Tuuli-voimakäytön mallintaminen ja simulointi), TUT, M.Sc. thesis, 2006, in Finnish.

(Tuominen, 2007) Tuominen O., "Simulation of a matrix converter in the wind power drive", (Matriisikonvertterin simulointi tuulivoimakäytössä), TUT, Institute of Power Electronics, research report 2007:1, in Finnish.

(Uski, 2006) Uski, S., Hänninen S., "Muutosilmiöiden mittaaminen ja analysointi hajautettua tuotantoa sisältävässä verkossa", VTT Tutkimusraportti, VTT-R-08322-06, VTT.

International publications

J. Ahola, T. Lindh, V. Särkimäki, R. Tiainen, "Modeling the High Frequency Characteristics of Industrial Low Voltage Distribution Network", Norpie 2004, 12-14 June 2004, Trondheim, Norway.

Alanen, R., Saari, P., Kauhaniemi, K. "Feasibilities of Dual Energy Storage on Wind Power Systems". 2005 WSEAS International Conferences EEESD '05: Energy, Environment, Ecosystems, Sustainable Development 2005, Vouliagmeni, Athens, Greece, July 2005.

Alanen, R., Saari, P. "Ultracapacitors and Batteries in Wind Power Systems Control and Operation". Electrical Energy Storage Applications and Technologies, EESAT 2005, San Francisco, USA.

(Antila, 2003) Antila S., Kivikko K., Trygg P., Mäkinen A., Järventausta P., Power Quality Monitoring of Distributed Generation Units Using a Web-based Application, AUPEC, Uusi-Seelanti, 2003

EWEC´06 Session: Dynamic models of wind farms for power system studies - IEA Wind R&D Annex 21. Chair(s): John Olav Tande, SINTEF Energy Research, Norway, Mark O'Malley, University College Dublin, Ireland. 28.2.2006 Session Code: BW1, Athens, Greece. 9 papers and presentations including Finnish contribution: Electric network faults seen by a wind farm – analysis of measurement data. Sanna Uski, Seppo Hänninen and Bettina Lemström.

EWEC´07 Session: Integration Studies (IEA WIND Task 25) Chairs: Hannele Holttinen, VTT, Finland, Ana Estanqueiro, INETI, Portugal. 8.5. 2007 Session Code: BW2, Milan, Italy. 10 presentations including Finnish contribution: Imbalance Costs of Wind Power for a Hydro Power Producer in Finland. Hannele Holttinen, Göran Koreneff; and Summary: State-of-the-art of Design and Operation of Power Systems with Large Amounts of Wind Power, Summary of IEA Wind collaboration by Hannele Holttinen et al.

Hokkanen, M., Salminen, H.J., Vekara, V., "A short review of models for grid-connected doubly-fed variable speed wind turbines", 2004 NORPIE conference, Trondheim

Holttinen, Hannele et al. Design and operation of power systems with large amounts of wind power production, IEA collaboration. EWEC 2006 – European Wind Energy Conference & Exhibition. Athens, Greece, 27 February - 2 March 2006.

Hannele Holttinen, Pirkko Saarikivi, Sami Repo, Jussi Ikäheimo and Göran Koreneff. Prediction Errors and Balancing Costs for Wind Power Production in Finland. Global Wind Power Conference September 18-21, 2006, Adelaide, Australia.

Hannele Holttinen. Estimating the impacts of wind power on power systems - first results of IEA collaboration. EWEA Grid Conference, 7-8th November, Brussels, Belgium. available at http://www.ewea.org/index.php?id=233

Models of Supercapacitors and their charging behaviour, Esa-Martti Isola, Jorma Kyyrä, Mikael Bergelin, Jari Keskinen, 2nd European Symposium on Supercapacitors and Applications, Lausanne 2.-3.11.2006, Paper ES06-26.

Kauhaniemi, K., Rinne, T., Alanen, R. "Network simulations of variable speed wind power system with dual energy storage": Nordic Wind Power Conference – NWPC´2006 Grid Integration and Electrical Systems of Wind Turbines and Wind Farms 22-23 May 2006, Hanasaari, Espoo, Finland.

Jari Keskinen, Pertti Kauranen, Mikael Bergelin, Max Johansson. Supercapacitors with activated carbon power and cloth electrodes, 2nd European Symposium on Supercapacitors and Applications, Lausanne 2.-3.11.2006, Paper ES06-07.

(Kinnunen, 2006a) Kinnunen J., Pyrhönen J., Liukkonen O., Kurronen P., "Parameter analysis of directly network connected non-salient pole permanent magnet synchronous generator", Nordic workshop on Power and Industrial Electronics, NORPIE 2006, 12-14.June.2006, Lund, Sweden.

(Kinnunen, 2006b) Kinnunen J., Pyrhönen J., Liukkonen O., Kurronen P., "Analysis of directly network connected non-salient pole permanent magnet synchronous machines", Proceedings of the International Symposium on Industrial Electronics, ISIE 2006, Montéal, Canada, July 2006

(Kinnunen, 2006c) Kinnunen J., Pyrhönen J., Liukkonen O., Kurronen P., "Design parameters for directly network connected non-salient permanent magnet synchronous generator", International Conference on Electrical Machines, ICEM 2006, Chania, Greece, 2-5.September 2006.

Kiviluoma, Juha; Meibom, Peter; Holttinen, Hannele. The operation of a regulation power market with large wind power penetration. Nordic Wind Power Conference – NWPC'2006. Grid Integration and Electrical Systems of Wind Turbines and Wind Farms. Hanasaari, Espoo, Finland, 22 - 23 May 2006 (2006).

Kiviluoma, Juha; Holttinen, Hannele. Impacts of wind power on energy balance of a hydro dominated power system. EWEC 2006 – European Wind Energy Conference & Exhibition. Athens, Greece, 27 February - 2 March 2006.

(Kulmala, 2007a) Kulmala A., Repo S., Järventausta P., "RTDS/PSCAD study on the opera-tion of a power system stabilizer in a small gas power plant", 19th Interna-tional Conference on Electricity Distribution, Cired2007, May, 2007, Vienna, Austria.

(Kulmala, 2007c) Kulmala A., Mäki K., Repo S., Järventausta P., "Active voltage level management of distribution networks with distributed generation using on load tap changing transformers", International conference of IEEE PowerTech, 1-5 July, 2007, Lausanne, Switzerland.

Laaksonen H., Kauhaniemi K., “Fault Type and Location Detection in Islanded Microgrid with Different Control Methods Based Converters”. CIRED 2007.

Laaksonen H., Kauhaniemi K., “Sensitivity Analysis of Frequency and Voltage Stability in Islanded Microgrid”. CIRED 2007.

Laitinen, Olli-Pekka, Lindh, Tuomo, Ahola, Jero. ”Requirements and Implementation of an AC-to-DC Power Converter for Micro Wind Turbine”, 2006, 5, CD julkaisu, XVII International Conference on Electrical Machines. September 2-5, 2006, Chania, Crete Island, Greece.

T. Lindh, J.Ahola, P.Spatenka, A-L Rautiainen, “Automatic bearing fault classification combining statistical classification and fuzzy logic”, Norpie 2004, 12-14 June 2004, Trondheim, Norway.

(Lindh, 2007) Tuomo Lindh, Pia Salminen, Juha Pyrhönen, Markku Niemelä, Janne Kinnunen, Jorma Haataja. ”Permanent Magnet Generator Designing Guidelines”, International Conference on Power Engineering, Energy and Electrical Drives, POWERENG 2007. Setubal, Portugal, 12 - 14 April, 2007

(Mäki, 2004a) Mäki K., Repo S., Järventausta P., Effect of wind power based distributed generation on protection of distribution network, Eighth International Conference on Developments in Power System Protection, Amsterdam, Hollanti, 2004

(Mäki, 2004b) Mäki K., Repo S., Järventausta P., Protection Issues Related to Distributed Generation in a Distribution Network Using Ring Operation Mode, Nordic Wind Power Conference, Göteborg, Ruotsi, 2004

(Mäki, 2005a) Mäki K., Repo S., Järventausta P., “Protection coordination to meet the re-quirements of blinding problems caused by distributed generation”, WSEAS Transactions on Circuits and Systems, Issue 7, Volume 4, July, 2005.

(Mäki, 2005b) Mäki K., Järventausta P., Repo S., “Protection issues in planning of distribution network including distributed generation”, CIGRE Symposium: Power Systems with Dispersed Generation, April, 2005, Athens, Greece.

(Mäki, 2005c) Mäki K., Repo S., Järventausta P., “Blinding of feeder protection caused by distributed generation in distribution network”, 5th WSEAS International Conference on Power Sys-tems and Electromagnetic Compatibility, August, 2005, Corfu, Greece.

(Mäki, 2006a) Mäki K., Partanen A., Rauhala T., Repo S., Järventausta P., Parkatti P., Tuusa H., “Real-time simulation environment for power system studies using RTDS and dSPACE simulators”, Nordic Workshop on Power and Industrial Electronics, NORPIE2006, 12-14 June, 2006, Lund, Sweden.

(Mäki, 2006b) Mäki K., Repo S., Järventausta P., “Impacts of distributed generation as a part of distribution network planning”, Nordic Distribution Automation and Asset Management Conference, Nordac2006, 21-22 August, 2006, Stockholm, Sweden.

(Mäki, 2006c) Mäki K., Repo S., Järventausta P., “General procedure of protection plan-ning for installation of distributed generation in distribution network”, International Journal of Distributed Energy Resources, ISSN 1614-7138, Volume 2, Number 1, January-March 2006, pp. 1-23.

(Mäki, 2006d) Mäki K., Repo S., Järventausta P., “New Methods for Studying the Protection Impacts of Distributed Generation in Network Planning Systems”, 15th International Conference on Power System Protection, PSP2006, 5-8 September, 2006, Bled, Slovenia.

(Mäki, 2006e) Mäki K., Repo S., Järventausta P., “Studying the protection impacts of distributed generation using network planning systems”, Nordic Workshop on Power and Industrial Electronics, Norpie2006, 12-14 June, Lund, Sweden.

(Mäki, 2006f) Mäki K., Repo S., Järventausta P., “Network Protection Impacts of Distributed Generation – A Case Study on Wind Power Integration”, Nordic Wind Power Conference, NWPC2006, 22-23 May, 2006, Espoo, Finland.

(Mäki, 2007a) Mäki K., Kulmala A., Repo S., Järventausta P., “Studies on grid impacts of distributed generation in a combined real-time simulation environment”, 7th International Conference on Power Systems Transients, IPST 2007, 4-7 June, 2007, Lyon, France.

(Mäki, 2007b) Mäki K., Repo S., Järventausta P., “Protection requirement graph for inter-connection of distributed generation on distribution level”, The IJGEI International Journal of Global Energy Issues, vol. 28, pp. 47-64, 2007.

(Mäki, 2007c) Mäki K., Kulmala A., Repo S., Järventausta P., ” Problems related to islanding protection of distributed generation in distribution network”, International conference of IEEE PowerTech, 1-5 July, 2007, Lausanne, Switzerland.

(Mäki, 2007d) Mäki K., Repo S., Järventausta P., “Impacts of distributed generation on earth fault protection in distribution systems with isolated neutral”, 19th International Conference on Electricity Distribution, Cired2007, May, 2007, Vienna, Austria.

(Nikander, 2005) Nikander A., Ala J., "Connecting induction generators in parallel with main synchronous generators of a hydroelectric power plant in electrical network-simulation study", 18th International Confenrence on Electricity Distribution, Cired2005, 6-9 June, 2005, Turin, Italy.

(Nikander, 2007b) Nikander A., "Aspects of connecting small-scale hydroelectric power plant in MV distribution network – a simulation study", 19th International Conference on Electricity Distribution, Cired2007, May, 2007, Vienna, Austria.

Parviainen A., "Axial Flux Permanent Magnet Generator for Wind Power Applications," Julkaistaan: Flux magazine, nro. 45.

Parviainen A., M. Niemelä, J. Pyrhönen, "Analytical approach to performance prediction of a double-sided AFPM machine with internal rotor and slotted stators", Toimitettu julkaistavaksi: IEEE Transactions on Industry Applications

(Peltoniemi, 2006) P. Peltoniemi, R. Pöllänen, M. Niemelä, J. Pyrhönen, "Comparison of the effect of output filters on the total harmonic distortion of line current in voltage source line converter - simulation study", In Proceedings of the International Conference on Renewable Energies and Power Quality ICREPQ'06, Palma de Mallorca, Spain, April 5-7, 2006.

A-L. Rautiainen, R. Tiainen, J. Ahola, T. Lindh, "A Low-Cost Measurement and Data Collection System for Electric Motor Condition Monitoring", Norpie 2004, 12-14 June 2004, Trondheim, Norway.

(Repo, 2004a) Repo S., Laaksonen H., Järventausta P., New methods and requirements for planning of medium voltage network due to distributed generation, Nordic distribution and asset management conference, Espoo, Suomi, 2004

(Repo, 2004b) Repo S., Laaksonen H., Mäki K., Ring Operation of Distribution System in Case of Distributed Generation - Voltage Control, Nordic Wind Power Conference, Göteborg, Ruotsi, 2004

(Repo, 2005c) Repo S., Laaksonen H., Järventausta P., "Statistical models of distributed generation for distribution network planning", 18th International Confer-ence on Electricity Distribution, Cired2005, 6-9 June, 2005, Turin, Italy.

(Repo, 2005d) Repo S., Laaksonen H., Järventausta P., "Statistical short-team network planning of distribution system and distributed generation", 15th Power System Computation Conference, PSCC2005, 22-26 August, 2005, Liege, Belgium.

(Repo, 2006a) Repo S., Mäkinen A., Järventausta P., "Estimation of Variable Costs of Electricity Distribution Company due to Distributed Generation", 9th In-ternational conference of Probabilistic Methods Applied to Power Sys-tems, PMAPS2006, 12-15 June, 2006, Stockholm, Sweden.

(Repo, 2006b) Repo S., "Flexible Interconnection of Wind Power to Distribution Net-work", Nordic wind power conference, NWPC2006, 22-23 May, 2006, Espoo, Finland.

Salminen P., Pyrhönen J., Jussila H., Niemelä M. and Mantere J. "Concentrated Wound 45 kW, 420 rpm Permanent Magnet Machine with Embedded Magnets". The 3rd IEE International Conference on Power Electronics Machines and Drives, PEMD 2006, 4 – 6 April 2006, The Clontarf Castle, Dublin, Ireland, Organised by the IEE Power Conversion & Applications Professional Network.

Salminen P., Parviainen A., and Pyrhönen J.. Maximum torque and inductances of surface mounted PM machines. XVII International Conference on Electrical Machines ICEM 2006, Greece, Chania, 2 – 5. September 2006.

P. Spatenka, T. Lindh, J. Ahola, J. Partanen, "Requirements for embedded analysis concept of bearing condition monitoring," in Proc. of Nordic Workshop on Power and Industrial Electronics NORPIE/2004, June 2004.

Särkimäki, Ville, Tiainen, Risto, Lindh, Tuomo, Ahola, Jero. "Applicability of ZigBee Technology to Electric Motor Rotor Measurements", 2006, 5 s., Automation, and Motion (SPEEDAM 2006), Taormina, Italy, May 2006.

Söder, L.; Hofmann, L.; Orths, A.; Holttinen, Hannele; Wan, Y.-H.; Tuohy, A. Experience from wind integration in some high penetration areas. IEEE Transactions on Energy Conversion. Vol. 22 (2007) No: 2, 4 – 12.

Söder, Lennart; Hofmann, Lutz; Nielsen, Claus Stefan; Holttinen, Hannele. A comparison of wind integration experiences in some high penetration areas. Nordic Wind Power Conference – NWPC '2006. Grid Integration and Electrical Systems of Wind Turbines and Wind Farms. Hanasaari, Espoo, Finland, 22 - 23 May 2006 (2006).

J.O.G. Tande, E. Muljadi, O. Carlson, J. Pierik, A. Estanqueiro, P. Sørensen, M. O'Malley, A. Mullane, O. Anaya-Lara, B. Lemström, "Dynamic models of wind farms for power system studies – status by IEA Wind R&D Annex 21",. EWEC'04, 22-25 November, London, UK.

J.O.G. Tande, I. Norheim, O. Carlson, A. Perdana, J. Pierik, J.Morren, A. Estanqueiro, J. Lameira, P. Sørensen, M. O'Malley, A. Mullane, O. Anaya-Lara, B.Lemström, S. Uski, E. Muljadi, "Benchmark test of dynamic wind generation models for power system stability studies" submitted to Wind Energy Journal.

Tarkiainen A., Pöllänen R., Niemelä M., Pyrhönen J., "Current Controlled Line Converter Using Direct Torque Control Method", to be published in European Transactions on Electrical Power.

Tarkiainen A., Pöllänen R., Niemelä M., Pyrhönen J, "Identification of Grid Impedance for Purposes of Voltage Feedback Active Filtering", to be published in IEEE Power Electronics Letters.

Tarkiainen A., Pöllänen R., Niemelä M., Pyrhönen J, "Compensating the Island Network Voltage Unsymmetricity with DTC-Modulation Based Power Conditioning System", in Proc. IEEE IEMDC'03, Recommended for publication in IEEE Transactions on Industry Applications.

Uski, S., Hänninen, S., Lemström, B., "Electric network faults seen by a wind farm – analysis of measurement data", European Wind Energy Conference, EWEC 2006, Athens, Greece, 27th February – 2nd March, 2006.

3 Heating, cooling and cogeneration systems

3.1 List of projects

Lappeenranta University of Technology
Optimal design of a biofuel power plant
Date of funding decision: 10.2.2005
Research project, finished

Helsinki University of Technology
Power 10 kW and heat from wood pellets / HUT
Date of funding decision: 10.1.2005
Research project, finished

University of Jyväskylä
Power 10 kW and heat from wood pellets / JYU
Date of funding decision: 15.12.2004
Research project, finished

VTT Processes
Power 10 kW and heat from wood pellets / VTT
Date of funding decision: 15.12.2004
Research project, finished

Lappeenranta University of Technology
Displacement engine processes in distributed energy supply
Date of funding decision: 19.5.2004
Research project, finished

Helsinki University of Technology
Indirect feeding of biofuels in microturbine processes
Date of funding decision: 22.4.2004
Research project, finished

Wärtsilä Biopower

A world leading manufacturer of small power plants, Wärtsilä BioPower looked for support from DENSY four years ago to extend their subcontractor chain and to develop new, environment friendly products. The company target was to intensify the realization of customer projects and strengthen the expertise in selected product sectors. To achieve these targets, Wärtsilä participated in DENSY both as a sponsor company and as an applicant for the R&D financing.

Wärtsilä carried out two product development projects as part of the DENSY program. The first focused on research of technology for purifying the smoke gas emissions of the BioPower plants. Wärtsilä BioPower expanded fuel selection from boreal wood to agricultural biomass and tropical wood, and minimized fine particle emissions of the plant.

Wärtsilä's other project concentrated on industrial production of the biopower plants. The company developed a modular biopower plant that can be quickly designed and built.

According to Wärtsilä, the biopower market has undergone a remarkable change in the past few years. The limits on emission rates accelerate the sales of low emission power plants, especially in Europe. Furthermore, the modular power plant structure turned out to be the right decision, because it facilitates the overall responsibility for the delivery, makes building faster and thus enables realization of larger power plant series.

Savonia Power Oy

Savonia Power Oy developed the use of CHP in the production of power and heat. The project target was to make the power production cost-efficient in smaller units than previously. The research was conducted in cooperation with Lappeenranta University of Technology. The key technology of Savonia Power is CHP, which combines a steam turbine, a power generator and a feed water pump. The combination enables a good allround efficiency of 80-85 percent, also when operating in the power category below 10 megawatts or with partial capacity. Power production module can replace a traditional steam turbine or it can be connected to steam boiler environments.

”Our asset is the small volume of power production, lightness and short repayment period. In the Nordic countries, our solution is particularly suitable for use in saw mills, forest industry and municipal heat plants. It uses local bio fuels efficiently and with exceptionally low emissions in its volume category”, says Hannu Nissinen, the CEO of Savonia Power.

The small volume power production is based on utilising the inverter technology. Due to this technology, the power plants do not need a gear box or lubrication. Consequently, the steam is clean of oils and there is no need to invest in a lubrication system.

Condens Ltd

Condens Ltd based in Pori has developed a efficient gasification power plant in the DENSY-programme. The low emission gasification plant uses biomass fuel.

The 7 MW Novel gasification plant with the new method of gasification developed by Condens Ltd and VTT Processes was introduced in Kokemäki in early 2005. The demonstration plant turns wood fuel into gas and burns it in three gas motors to produce electricity and district heat. The new plant type produces 50 percent more electricity from bio fuel in comparison with traditional steam operated small plants.

The gasification technique used by Condens is based on forced fuel feeding. Biomass and waste are used more efficiently than before without expensive handling. The technique also improves the cost-efficiency of combined power and heat production. Furthermore, the target of the development work is to map out the emissions of the gasification plant and optimal cleaning process. Novel gasification plant uses catalytic cleaning, a bag filter and a wet scrubber.

According to Ilkka Haavisto, the Managing Director of Condens Ltd, the main market for the gasification plants is outside Finland.

”The Nordic view on biomass is radically different from that of the rest of Europe. In Finland, wood is seen as fuel and there is an organised market for it. We open windows for new ways of thinking, and the interest in using biomass is increasing especially in Southern Europe.

Åbo Akademi University
Integration of heating and cooling in regional and building systems
Date of funding decision: 15.4.2004
Research project, finished

University of Jyväskylä
Power 10 kW and heat from wood pellets
Date of funding decision: 26.2.2004
Research project, finished

Mikkeli Polytechnic
Technical and economical constraints delivery of heat energy
Date of funding decision: 27.11.2003
Research project, finished

VTT Processes
Technical requirements for heat trade in the district heating network
Date of funding decision: 4.9.2003
Research project, finished

Greenvironment

Originated in Lahti, Finland, Greenvironment has grown in the past five years from a local mircoturbine developer to a leading company in the area of combined heat power using biogas to fuel microturbines operating now in Germany. The growth is due to combining a long-term product development to a needy market and creating a unique operating concept.

Greenvironment started its product development with the aid of the Tekes's technology programmes DENSY and Climbus. After years with microturbine technology Greenvironment discovered an appealing market in Germany that has taken into use feed-in-tariffs for renewable energy and advanced technology. Greenvironment created an unique concept to sell bioenergy: fuelVALUE.

FuelVALUE means that the agriculturalist or the operator of the biogas plant establishes and runs a biogas plant and sells the generated biogas to Greenvironment. Greenvironment establishes and runs a block heat-and-power-plant using the microturbine technology; the power plant will be used to generate electricity and heat. Greenvironment binds itself by contract to buy a previously established amount of biogas and thanks to the feed-in-tariff, Greenvironment is also able to sell the gas with a fixed price.

"As Greenvironment operates the plant, farmers' only task is to produce the biogas. Greenvironment also invests the power plant, which lowers the farmer's initial investment and no investments to maintenance are needed. In short, the concept brings the farmer same money with significantly less work. Environmentally our technology means lower emissions and energy effectiveness through producing both electricity and heat", says Matti Malkamäki, Director Technical Development, Greenvironment.

The company's German subsidiary Greenvironment GmbH in Berlin currently has 18 employees has been present in Germany since early 2006. Since entering the German market Greenvironment has quickly made a name for itself on the market for green technologies and has become one of the leaders in biogas-fuelled microturbines. Greenvironment now has 25 million euros financing to build power plants and proof that the concept works.

Lappeenranta University of Technology
Utilizing local by-product streams in distributed energy systems
Date of funding decision: 26.6.2003
Research project, finished

Helsinki University of Technology
Development and testing of a bio-CHP concept
Date of funding decision: 18.6.2003
Research project, finished

Lappeenranta University of Technology
ORC in distributed energy supply: basic research
Date of funding decision: 18.6.2003
Research project, finished

Åbo Akademi University
Design of Optimal Distributed Energy Systems
Date of funding decision: 12.6.2003
Research project, finished

3.2 Integrated heating and cooling systems for sport halls

VTT, Energy and Pulp&Paper/Energy Systems
Funding decision day: 29.11.2006
Research project; open
Person in charge: Kari Sipilä

District cooling means centralised production and distribution of cooling energy. Compared to building-specific cooling, district cooling is more energy efficient, reliable and cost-effective during life-cycle. With district cooling, very little equipment is necessary in buildings and any possible noise or vibration problems due to cooling equipment are removed. Also space needed for the equipment is freed and can be used for other purposes. However, a distribution network is always needed, which limits the availability of district cooling to densely populated areas where the network investment can be cost-effective.

Sport halls need often heating and/or cooling. Integration of heating and cooling systems in such situations means substantial cost savings. For instance a swimming hall that need heating and an ice hockey hall that needs cooling can well be integrated. For distribution of heat or cooling pipeline networks are needed, similar to urban district heating (DH) and district cooling (DC) pipelines. Compressor-driven heat pump is one option to cool the circulating DC water and at the same time heat the circulating DH water.

The project will be carried out in collaboration between VTT Energy and Pulp&Paper/Energy Systems, Åbo Akademi University, Heat Engineering Laboratory and Tampere University of Technology, Institute of Energy and Process Engineering.

3.2.1 Objectives

Measurement data from skiing pipe in Uusikaupunki is collected and developed simulation models for energy balances in sport centers. Energy systems in Ideapark (Lempäälä) will also be studied and different types of systems will be compared. Ideapark is also intention of collection data from the energy systems.

The second object is to develop the CO_2 pipeline model for skiing pipe. The aim is to study how carbon dioxide could be utilized as a heat transfer medium for cooling the skiing pipe. During the project a network model was constructed, which enables networks of both glycol water and carbon dioxide to be calculated and analyzed. Carbon dioxide cooling process takes advantage of the phase change energy by evaporating carbon dioxide to achieve the cooling effect. Liquid carbon dioxide is pumped to the cooling pipes under the snow track where it evaporates. The evaporation is not complete in order to avoid the need for larger heat exchanger area (pipelines) due to low heat transfer coefficient in high qualities. The return flow is in two phases. Also the potential of swimming halls and ice hockey halls as well as skiing pipes and swimming halls located close enough to each other ware investigated.

The third object is to improve the compressor-driven heat pump process. The key feature is to lower the pressure difference over the compressor and thus reduce the compressor power demand. By this way the cold factor (COP), defined as the ratio between the created cooling effect and the compressor effect, can be improved. The savings in the electricity cost of the cooling task is the result of the improvement. An effect enhancement can be obtained at the same time also on DH water heating. The process is called PDC process. It has been presented in Ref. [1].

3.2.2 Model for skiing pipe sport centre

Collecting of data in Uusikaupunki has started with two different measurement systems. Another one collects data from skiing pipe, temperatures, moisture etc. Another system is connected to compressors which produce cooling energy for skiing pipe. Focus of measurements is to analyze operation of CO_2 pipes in skiing pipe. Also function of compressors and relation between outside air conditions and skiing pipe. Possible function problems in CO_2 is aim to find out.

Simulation model of energy systems in sport centers has also started. Model will be created with EES (Engineering equation solver). Software is not designed for simulation but specific systems can be simulated with it. Program consist large library of fluid properties which is important in modeling. Figure 1 shows screen capture of EES. Model consists of heat pump and ice hall.

3.2.3 Model for snow pipeline system in skiing pipe

The model is used to simulate the carbon dioxide cooling network in a skiing facility in the city of Uusikaupunki. The system consists of a network, air heat exchangers and cooling pipes under the track. The structure of the network is defined by nodes and pipes. Pipes have connections to nodes, lengths and pipe size specific conductance. Nodes can represent simple connecting nodes or have tasks such as consumer or pro-

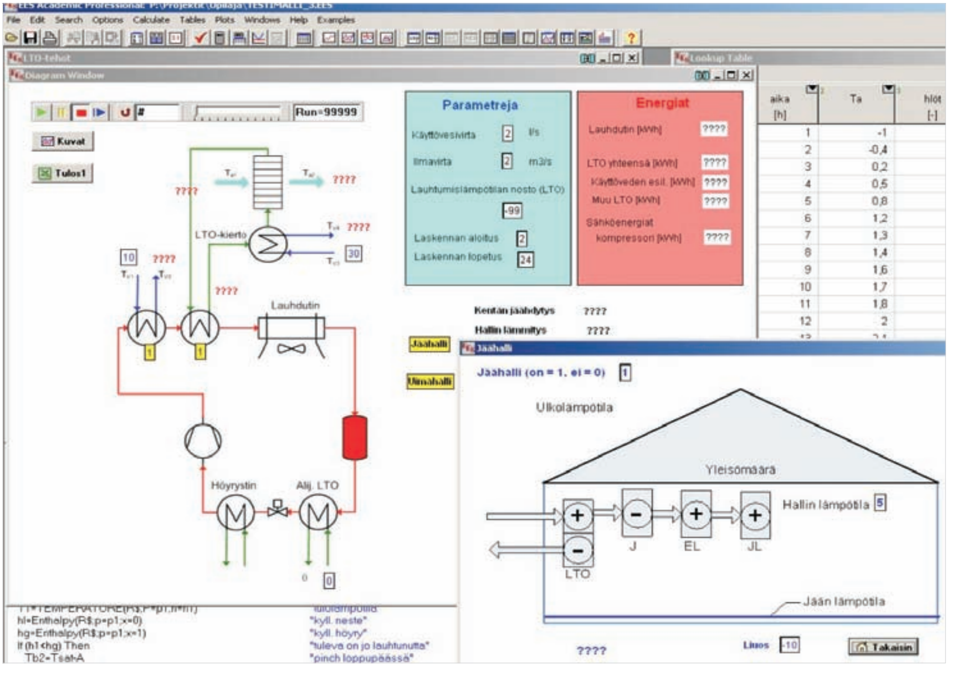

Figure 3.1. Simulation model in EES.

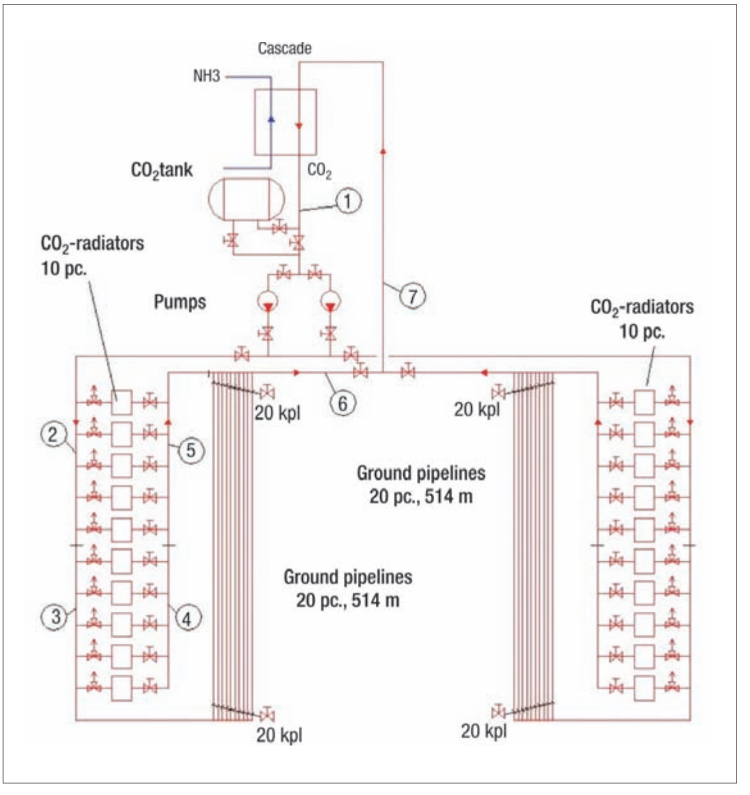

Figure 3.2. Cooling system in the skiing pipe

ducer. Carbon dioxide is presumed liquid in feed pipes, but in return pipes the 2-phase change flow is taken in account. The correctness of the assumption concerning the feed pipes is confirmed by monitoring pipe temperatures. The heat exchangers and the compressor are not modelled in detail. Only amount of evaporation and cooling power are defined for heat exchangers, while compressor has a set maximum capacity and a level of super cooling (in ºC).

Model calculates flows, temperatures, pressures, heat losses and the pumping power. The pipeline construction and diameters are supposed to known.

The cooling pipes under the skiing track can be calculated more accurately with a separate tool that solves the state of carbon dioxide flow in smaller steps. At this time, the tool is not integrated into the network model.

3.2.4 Integration of DC and DH

The PDC process is studied in the project with simulations and laboratory tests, where the actual heating and cooling effects are measured in different running conditions. A heat pump with 7.5 kW nominal heating effect, 2.5 kW compressor effect and 5 kW cooling effect has been installed and connected to three 50 l tanks with water distribution pipelines on both DH and DC sides. The system is equipped with comprehensive flow, pressure and temperature measurements. The required volumes of the tanks are dependent of the dynamic behavior of the heat pump in varying capacities. The volume demand is one of the key questions to the economy of the process.

First results are obtained with the test series that will be accomplished till the end of this year. The PDC process gives a possibility to increase the energy efficiency by increasing the heating effect to DH and the cooling effect to DC water. The

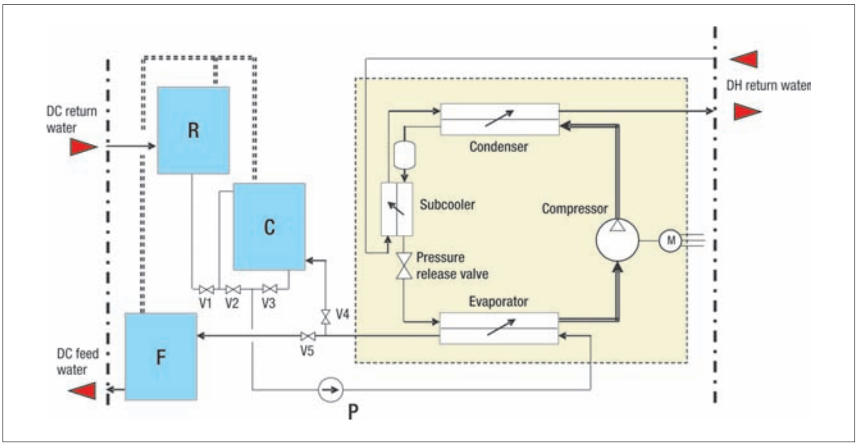

Figure 3.3. Continuous Compressor-driven PDC Process with condensation heat recovery into DH water. DH water side tank arrangement is not shown in the figure.

PDC water tank system means an additional cost that could be reduced when the sport hall need buffer tanks for DH and/or DC water in any case. Water tanks in the PDC process can be atmospheric, so the tank costs can be kept low. The annual operation hours of the heat pump is to be considered as it has a strong influence in the economy.

Publications, conference papers

1. Jarmo Söderman, Göran Öhman and Henrik Saxén, A periodic process for enhanced district cooling generation, 10th Symposium District Heating and Cooling, 3.–5.9.2006, Hannover.

3.3 Design and operation of integrated cooling and heating systems in regions and buildings

Åbo Akademi
Funding decision day: 15.4.2004,
Research project; closed
Person in charge: Jarmo Söderman

3.3.1 Introduction

Cooling has become a natural part of good working and residential environment. For hospitals and health institutions cooling is of utmost importance. In urban areas district cooling (DC) has increased in recent years, replacing separate cooling machines in each room or building with central cooling generation plants and cold media distribution networks. Cold water is distributed to the customers in similar pipelines as hot water in the district heating (DH) networks. By combining a central cooling plant with cold media storages the daily variations in the cooling demand can be handled with smaller machine capacities. Integration of heating and cooling in regions and buildings can further improve the energy efficiency and economy of the future systems.

The project was carried out in collaboration between Åbo Akademi University, Heat Engineering Laboratory, Tampere University of Technology, Institute of Energy and Process Engineering and VTT Processes.

3.3.2 Objectives

The objectives of the project was to study and develop integrated cooling and heating systems in regions and buildings with the focus in energy efficiency and economy and in overall optimisation of the cooling systems. The transport and storage technologies applicable in district cooling were studied in this frame together with the suitability of different media for cooling effect distribution.

3.3.3 Implemented research work

In the project seasonal and daily variations of the cooling demand in an urban region were studied. Data were collected from an institutional building block comprising a number of buildings. The block is connected both to the district heating and cooling networks of the region.

Further it was studied how absorption cooling process can be applied at a process industry site, where large amount of excess heat is available. The absorption cooling process was designed using data of cooling demands and brackish water temperature variations at the site.

For enhanced operation of a compressor-driven cooling machine a periodic cooling process with condensation heat recovery was studied. In the process the pressure difference between the evaporator and the condenser is periodically lowered so that the needed compressor power is reduced, compared to a conventional process. The improvement can be obtained by a stepwise lowering of the temperature of the cold water that is circulated into the evaporator and similarly by a stepwise increase of the temperature of the hot water into which the condensation heat is recovered.

A Mixed Integer Linear Programming (MILP) model for the optimisation of district cooling networks was developed and applied in an urban region both with the present day data and with predicted data for the year 2020.

The economic viability of integrated heating and cooling systems in large buildings was studied in three real cases with energy balances and investment estimates. Further the different influencing aspects of integration of a heat pump in cooling systems were studied and test runs at a sports institute were carried out.

The suitability of different media in transport and storage of cold was studied. The distribution network was designed for different transport media: water and CO_2. Additionally, a comparison study with ice-water media was accomplished. In a regional cold distribution system it was studied on how a two-phase system of CO_2 is built and what are the influences of the system on the DC network pipeline sizes.

3.3.4 Results

In the project report [1] the results of the project tasks are described in more detail. The main results are given below.

The measurements at the premises of a district cooling/heating consumer showed that in most summer days high cooling capacity is needed only in a relatively short time frame, usually from 14 to 20 o´clock. The increase/decrease of the cooling demand is very sharp with the peak demand at approx. 18 o´clock.

The absorption cooling process with circulating sea water in absorber and condenser was simulated with the plant's condition using data of cooling demands and sea water temperature variations at the mill site and compared with existing compressor-driven cooling units The running costs of the absorption cooling is much lower that in the compressor units. There is a trade-off between the decreased operational costs and the investment costs of additional pipelines and heat exchangers.

Simulation calculations for the developed periodic cooling process showed that cooling effect can be generated by the process with 12 % less electricity consumption compared with a conventional cooling process. For an existing cooling machine an increase of 6 % of the cooling capacity can be obtained together with a reduction of 6 % of compressor power demand.

Using cooling demand predictions for future years and the developed optimisation model a conceptual design was obtained, of how the DC network should be expanded, where should new cooling generation capacity be built, what capacity should the new plants have and where and what size should the cold media storages be built.

The results of the studies of integrated heating and cooling systems showed that the pay-back time of an integrated heat pump system can be short and the system economically viable.

The comparison of different cooling transfer media showed that phase change materials like ice and vaxes can decrease the needed storage volume compared with cold water storages. Additionally it was shown that district cooling networks with ice slurry or CO_2 require 50–70 % of the pipe dimension compared to water-based systems.

3.3.5 Use of results

The project gave valuable guidelines of how future cooling systems should be designed. The results can be used in decision making of the future cooling system investments at urban regions and industries. The developed periodic cooling process opens up opportunities for new or existing district cooling plants to save electricity and enhance the cooling generation process. The developed optimisation model can be used to produce good starting points in developing a DC network for a new region or in expanding or retrofitting existing district cooling networks. The cooling system simulations can be utilized by the HVAC designers when selecting the design and lay-out for separate cooling systems and integrated heating and cooling systems. The results of the studies with CO_2 as distribution medium can be used in planning of the future district cooling networks and cold storages.

Publications, conference papers

1. Jarmo Söderman, Göran Öhman, Antero Aittomäki, Ali Mäkinen, Kari Sipilä and Miika Rämä, KYLMÄ+ – Design and operation of integrated cooling and heating systems in regions and buildings, 2006, Report 2006-3, Åbo Akademi University, Department of Chemical Engineering, Heat Engineering Laboratory. ISBN 952-12-1821-5.
2. Jarmo Söderman, Göran Öhman and Henrik Saxén, A periodic process for enhanced district cooling generation, 10th Symposium District Heating and Cooling, 3.–5.9.2006, Hannover.
3. Jarmo Söderman, Structural and Operational Optimisation of District Cooling Networks, 17th Intern. Congress of Chemical and Process Engineering, 27.–31.8.2006, Prague.
4. Jarmo Söderman, Optimisation of structure and operation of district cooling networks in urban regions, in press, Applied Thermal Engineering 2007.

Theses

1. Jesper Broo, Measurements of consumption and regional production of district cooling, Master’s thesis, 2005, (in Swedish). Åbo Akademi University.
2. Kim Fagerudd, Production of district cooling at a steel mill with absorption cooling machine, Master’s thesis, 2005, (in Swedish). Åbo Akademi University.
3. Anssi Pesonen, Utilisation of heat pump for heating and cooling of buildings, Master’s thesis, 2005, (in Finnish). Tampere University of Technology.
4. Ali Mäkinen, Heat pump in heating and cooling, Simulation of energy balances, Master’s thesis, 2006, (in Finnish). Tampere University of Technology.
5. Miika Rämä, Carbon dioxide in district cooling, Master’s thesis, 2006. VTT Processes.

3.4 Technical and economical conditions for the DH heat supply at the delivery boundary

Mikkeli University of Applied Sciences,
the Business Development Centre
Funding decision day: 27.11.2003
Research project; closed
Person in charge: Veli-Matti Mäkelä

3.4.1 Objectives

The intention of the research was to find out how the competitiveness of combined heat and power (CHP) production could be improved by developing the client interface of district heating. Also new solutions to append small and earlier unprofitable targets to district heating were considered. One of the aims was to find out what kind of preconditions there is for heat producer to handle the whole delivery chain from production to the client. This would include procurement, installation, service and maintenance of the nowadays client-owned heat distribution centre. Use of small-scale CHP-plants outside district heating network was examined as well. Preconditions for the new products and services and the need for product development were also figured out in the research.

The research was carried out by the Business Development Centre of Mikkeli University of Applied Sciences. Researcher in charge is executive Veli-Matti Mäkelä. The project was supported by management team and participating organisations brought much needed knowledge, know-how and aid in determination of demand.

3.4.2 Methods

Client interface of district heating was approached from aspects of both the client and the heat producer. The aim was to find out what kind of deficiencies and needs for improvement present interface comprise. Based on those was researched what kind of new products, connection solutions and business models can be used to improve the interface. Also ownership solution related legislative issues were plotted.

Connections and presence of present client interface and CHP-plants was investigated from literature and internet in the beginning to be the basis of the research. Then the information was gathered by interviewing heat producers and carrying out a client survey. Based on the results was researched what functional and principle solutions the new interface needs and furthermore possibilities relating to business activity and new products was outlined.

3.4.3 Results

It came out that, although there is interest in development of client interface of district heating, no large scale public research was made before. The clients still need new services and are willing to accept new solutions and working. The importance of expenses and benefits was emphasized. There is a call for new products and services, but extensive market analysis or product development is yet to be made.

Clients' need for various services will increase. It is possible that there will be whole new doers that are faster, more flexible and more able to serve the client regarding those needs. Considering the results it can be presumed that district heating client interface will steadily develop. The development will be controlled by approach of different technical systems and improvement and regrouping of already existing solutions. In the future it is presumable that heat sale is a part of a larger service concept. There is a call for further study relating the subject. This research especially offers significant support when deciding the trend of company specific development projects.

Publication

Executive summary + 7 appendixes, 278 p.

Examination

Engineering theses, Heikki Nousiainen

3.5 Technical features for heat trade in distributed energy generation

Technical Research Centre of Finland
VTT Energy and Pulp&Paper,
Energy Systems (earlier Processes)
Funding decision day: 4.9.2003
Research project; closed
Person in charge: Kari Sipilä

3.5.1 Introduction

Liberated heat market works mainly like a liberated electric market in Nordic countries with the exception that the heat market works within a local district heating network There are producers, customers, network operator and system operator as there exist in the electric market. Physical actors in the liberated heat trade market are the traditional large scale producers that sell heat to customers connected to the district heating network, and the end users, that would also be small-scale producers using a micro-CHP or a boiler. They would buy heat from other producers or sell heat to customers through the network. The liberated heat energy market will also need the transmission-network-company that takes care of the temperatures, pressures and hydraulic balance of the heating network. Network-company is also responsible for services and enlarging the network when necessary. A balance-sheet-operator is also needed to coordinate the heat contracts between producers and customers as well as to take care of reserve capacity, spot and future markets and billing.

3.5.2 Objectives

The main objective for the liberated heat trade market is to produce heat in more economical ways and to use more effective production units. However, the quality of the heat and minimum environmental impacts must be ensured. This means that combined electricity and heat production (CHP) must be furthered and new more effective techniques of utilisation should be ensured.

The district heating network operation should be separated from the production like in the electricity side. Then the network operator works more transparently.

The market may consist of basic contracts continuing until further notice, from one month to one year short contracts and some kind of spot markets 24 hours ahead like in the Nordic electric market. Future contract can be bought for the next heating season. The heat balance sheet operator is responsible for heat trade. The heat capacities and contracts must be in balance including the reserve capacity. A coming heat boiler capacity in next heating season can be sold as futures to consumers.

3.5.3 Results

Heat trade simulations were done for a limited population of buildings connected to the district heating network in a small town Kaskinen in western Finland. Simulations were designed to answer the question whether the town could be self-sufficient in terms of heat or electricity production, could the community sell out some heat or electricity or did it need to buy from the centralised energy production. Analysis showed that when the degree of decentralisation was lower, the system naturally needed more heat from the centralised production. An optimum solution was found regarding the amount and placement of the micro-CHP plants in different types of buildings. Our limited simulations showed that heat trading theoretically could be a functional way to develop decentralised energy systems. There is a potential advantage to be utilised when buildings with consumption profiles different in shape and/or timing are connected through a district heating network.

The hydraulic performance of the district heating network was checked to make sure that there are no network based restrictions for the heat trade. Typically the network places two different types of constraints: (1) pressure constraints and (2) temperature change constraints. The pressure constraint refers to the fact that the maximum pressure that the feed pipes can withstand is finite. New producers can change the geographical distribution of production so that distribution is no longer possible without exceeding the maximum pressure. It is also possible that the pressure in some return pipe becomes so low that evaporation takes place on the suction side of a pump. Whatever situation may occur depends on the average pressure of the network and the producer's location and current running mode (purchase or sell). The temperature change constraint refers to the fact that the time derivative of temperature in a certain pipe should not exceed a given limit

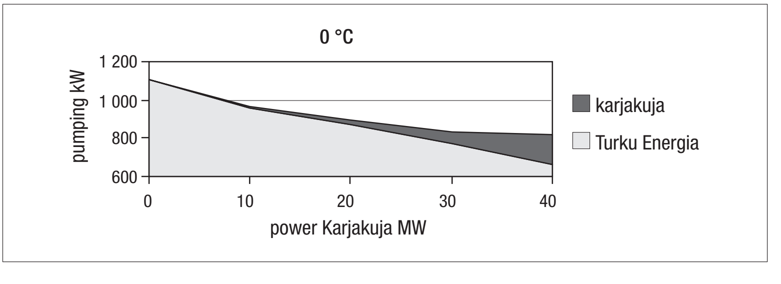

Figure 3.4. Pumping power in the district heating system as a function of new heat supplier (Karjakuja).

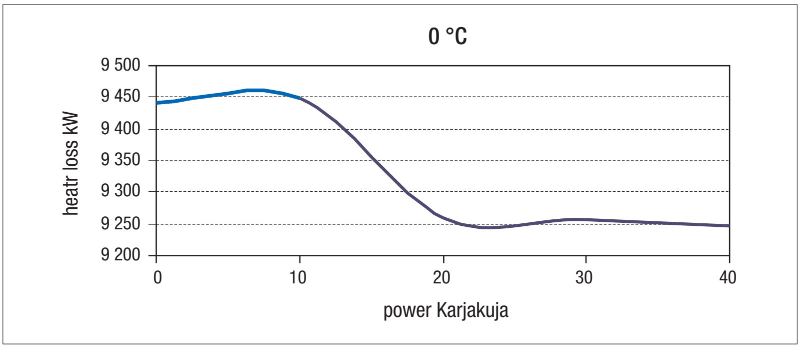

Figure 3.5. Heat losses of the network as function of new heat supplier (Karjakuja).

value. This value is usually taken as ten degrees per hour. The reason behind this is that the heat expansion places a stress on pipes and joints. From the technical point of view, selling of the heat to the network did not cause a problem. Only the temperature changes were larger compared with the traditional centralised system when the heat trade was on. Small producers brought more time-varying factors into the system. They can create additional changing low-flow connections in their vicinity. It was seen that small producers have quite little effect on network pressures.

The recommended physical connection (fig. 3.6) is the version, in which the small scale producer is connected to the DH-network via a heat exchanger. This connection does not bring any changes to the standard modular substation unit in buildings, it is safe solution to the user (no water leaks) and to the DH network (no gas leak problems), it is easy to control, it is suitable for new installations and renovations, and maintenance of the CHP unit does not cause any problems to the DH operation. In general, we found out that the physical connection will need standardized rules, in which the quality and the performance of the connection unit are unambiguous defined, in the same way as the current Finnish District Heating Associations' guidelines do for the district heating substations.

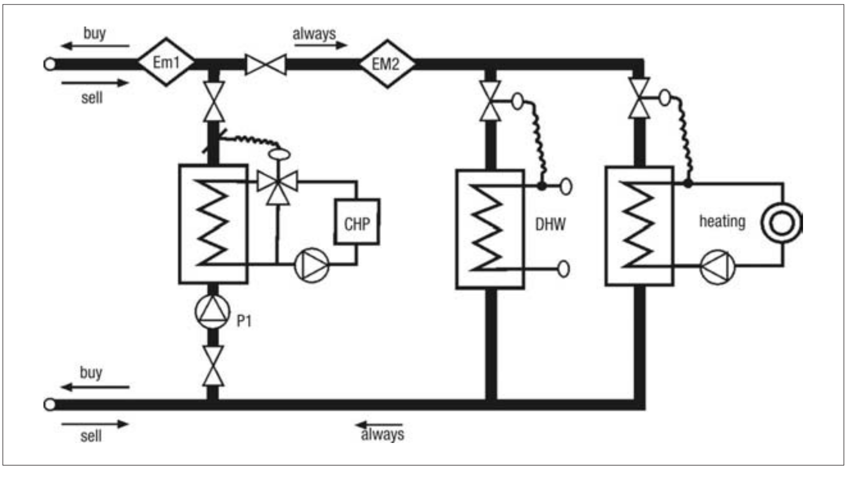

Figure 3.6. Indirect connection of the heat supplier to the DH-network with a heat exchanger.

Published reports and papers

1. Kari Sipilä, Jussi Ikäheimo, Juha Forsström, Jari Shemeikka, Krzysztof Klobut, Åsa Nystedt & Jenni Jahn, 2005, Technical Features for Heat Trade in Distributed Energy Generation, VTT Processes; VTT Building and Transport. VTT Research Notes 2305, 111 p. ISBN 951-38-6731-5; 951-38-6732-3, http://www.vtt.fi/inf/pdf/ tiedotteet/ 2005/ T2305.pdf
2. Kari Sipilä, Jussi Ikäheimo, 2005, Open Heat Trade Markets, Euro Heat & Power, English Edition IV/2005, pp. 22-25.
3. Nystedt, Åsa; Shemeikka, Jari; Klobut, Krzysztof; Ikäheimo, Jussi; Sipilä, Kari. 2005. Analysis of heat trade potential in a group of buildings connected by district heating network. Proceedings of the 8th REHVA World Congress. (Clima 2005). Lausanne, 9 - 12 Oct. 2005. Paper 102.

3.6 Energy Logistics

Tampere University of Technology
Institute of Energy and Process Engineering
Funding decision day: 18.6.2003
Start date: 1.9.2003
Project end date: 31.12.2004
Research project; closed
Person in charge: Antero Aittomäki

Participants

- Institute of Energy and Process Engineering, Tampere University of Technology
- University of Vaasa
- University of Jyväskylä
- Helsinki Univ. of Technology
- City of Vaasa

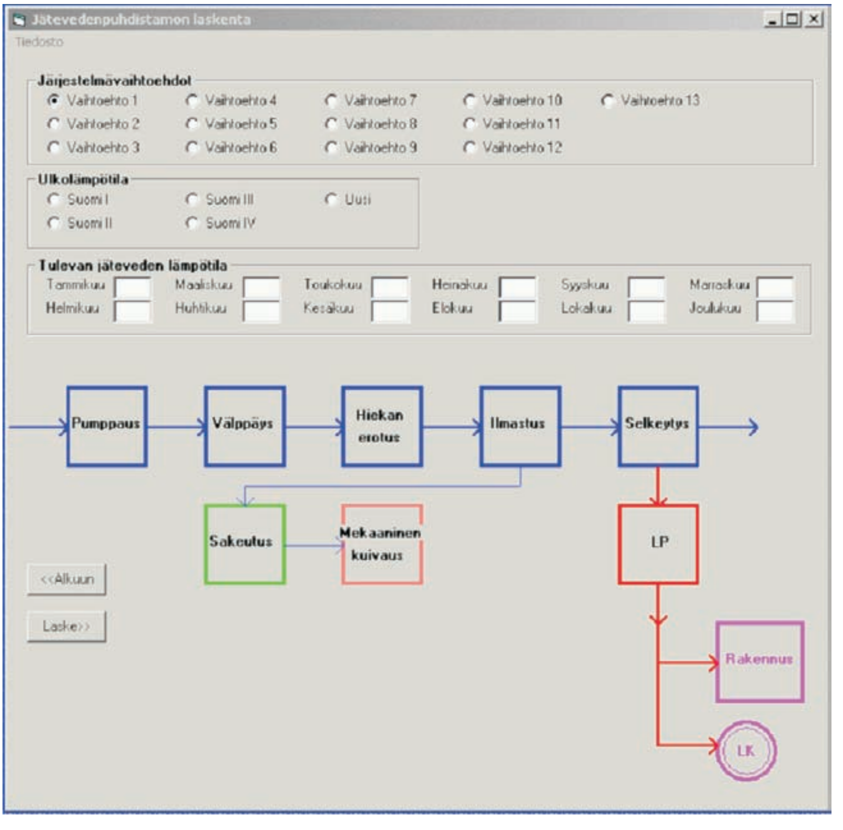

Figure 3.7. The starting window of the program for sewage cleaning plant.

3.6.1 Introduction

Objectives in Energy Logistics project were to develop methods and models for general selection and optimization of energy utilizing systems. Work was divided in two mains parts.

1. Developing a tool for analyzing the energy flows in different energy using systems
2. Developing a general methodology for investment decisions

3.6.2 Focus

A PC-tool was developed Microsoft Visual Basic as the platform. The tool is modular allowing setting up the system using different modules. The tool was applied for three case-systems:

1. The base center of mobile phone network
2. The sewage cleaning plant
3 The production system of plastic pipes

3.6.3 Methods

The tools developed were supplied for the use of the participating actors. Using the model, the influence of the lay-out and dimensioning of the system components ca be studied. The tool was utilized to find measures to degrease energy demand of the system. The program can be modified for modeling other types of systems, as well. Picture SS shows starting window of sewage cleaning model.

Published reports and papers

Aittomäki, A., Kianta, J., Savolainen, K., DENSY. Energialogistiikka. Energiamallinnus. Tampere 2005. Tampereen teknillinen korkeakoulu, Energia- ja prosessitekniikan laitos. Raportti 179.

References

1. Visual Basic –programs (CD) and manuals. Tampereen teknillinen korkeakoulu, Energia- ja prosessitekniikan laitos.
2. Keskinen, S., Energialogistiikka-projektin loppuraportti. Vaasa 2004. 5.8.

3.7 DO^{2}DES – Design of Optimal Distributed Energy Systems

Åbo Akademi
Funding decision day: 12.6.2003
Research project; closed
Person in charge: Jarmo Söderman

3.7.1 Introduction

Conventionally both electric power and district heat have been produced in large central units. When energy consumers often are quite scattered in a region, it has been questioned whether the suppliers could be smaller and closer to the consumer sites than the large units far away. A better overall economy and important environmental benefits could eventually be achieved with distributed energy systems (DES).

The project was accomplished in collaboration between Åbo Akademi University, Heat Engineering Laboratory, Helsinki University of Technology, Laboratory for Energy and Power Production and VTT Processes.

3.7.2 Objectives

The goal of the project was to develop an approach for the following optimisation task: in a specific region find the optimal design and the optimal locations for production plants of both heat and electric power, the optimal routing for the district heating network pipelines and the optimal locations and design of heat storages, all in accordance with the locations of the heat and power consumers and their heat and power demands in different periods of the year.

3.7.3 Modelling DES

In the developed optimisation model for DES a number of optional sites for heat and power production, heat storage sites and a number of energy consumers with given heat and power demands in different time periods in the region are given as input data. The coordinates of the consumer sites and the optional energy supplier and/or storage sites are also needed.

Different types of heat or power production units and combinations of these can be applied. Combined Heat and Power plant (CHP), boiler plant that produces district heat, wind power, heat pumps and small hydro power were included in this study.

The region was considered as self-content in respect of heating demand. The electric power demand could be satisfied both with power produced within the region and/or from the grid. The power from the grid was considered to be purchased with different prices for day and night and for different seasons.

Consumers could produce their own heat in competition with the district heat. If a heat pump were installed at a consumer site, additional electricity consumption at that site was needed.

The costs of district heating comprised the network investment and running costs and the costs for heat storage tanks. The distances between supplier and consumer sites were calculated separately prior to the optimisation and used as input data.

Two formulations for solving the optimisation problem were developed and tested: a deterministic Mixed Integer Linear Programming (MILP) formulation and a hybrid stochastic-deterministic formulation with Genetic Algorithm (GA) combined with Linear programming (LP). With the MILP approach global optimum solutions are obtained, but the approach cannot be applied in large problems due to a combinatorial expansion that causes impractical calculation times. With GA-LP approach even large problems can be solved but no guarantee on the optimality of the solutions can be given.

3.7.4 Results

In the project report [1] a simulated case is presented to show the applicability of the developed optimisation approach. The case comprised 5 optional power and heat production sites and 12 consumer sites with defined heat and power demands in different seasons of the year. Heat could also be stored during day time and used the next

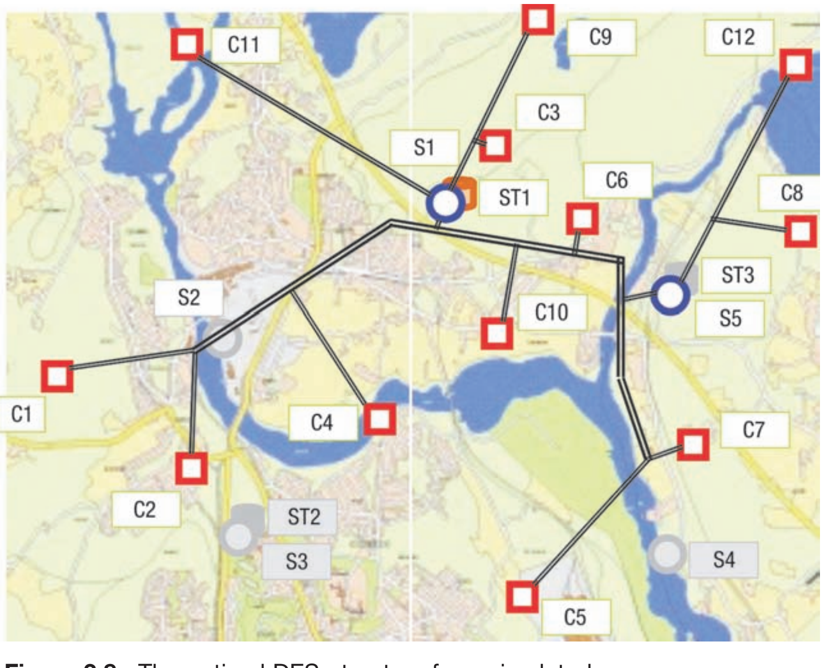

Figure 3.8. The optimal DES-structure for a simulated case.

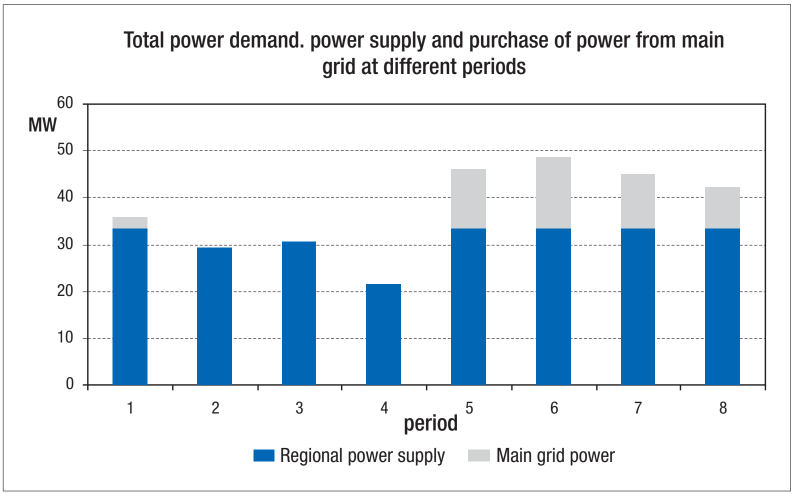

Figure 3.9. Regional power supplies and purchased power from the grid for the case.

night in 3 optional sites. The obtained optimal solution comprised two CHP plants, a heat storage tank and a district heating network, as shown in Fig. 3.8.

In Fig. 3.9 the power generation in the region is shown together with the purchased power from the grid outside the region. The optimal solution is that the CHP plants to be built need not to cover the whole power demand in the region.

The optimisation of the simulated case was based on the survey of the investment and running costs of the applied heat and power production plants, together with heat pump, heat storage and district heating network costs.

3.7.5 Use of results

The work in the project showed that a distributed energy system can be optimised with the developed approach. The optimisation approach serves as the first step in the design process and the basis for more accurate calculations. The approach can also be used for answering what-if type questions and sensitivities of different parameters of a suggested design.

With the developed approach the involved parties, like energy producing companies, plant equipment suppliers, designers and consultants as well as the authorities and energy consumers are able to handle the investment proposals on equal basis. The approach gives better understanding of the impacts of the different system parameters and leads parties to make better decisions.

Publications and conference reports

1. Jarmo Söderman, Frank Pettersson, Pekka Ahtila, Ilkka Keppo, Arto Nuorkivi, Kari Sipilä and Jussi Ikäheimo, DO^2DES – Design of Optimal Distributed Energy Systems, 2005, Report 2005-1, Åbo Akademi University, Department of Chemical Engineering, Heat Engineering Laboratory. ISBN 952-12-1587-9.
2. J. Söderman, F. Pettersson, Structural and Operational Optimisation of Distributed Energy Systems, Applied Thermal Engineering, 26, 2006, 1400-1408.
3. Jarmo Söderman and Frank Pettersson, 2004, Structural Optimisation of Distributed Energy Systems, CHISA 2004 Conference, PRES 04, Prague, Czech Republic. Proceedings CD.

Theses

Fredrik Rönnlund, Distributed energy systems - optimisation with Genetic Algorithms, 2004, (in Swedish). Master's thesis at Åbo Akademi, Heat Engineering Laboratory.

3.8 Development of biomass-based micro-CHP concepts

3.8.1 Introduction

Distributed energy production with small units may complete well the traditional energy production, where the energy is produced to the grid with relatively large power plants (usually > 10 MWe per unit). In some EU countries like in Germany, Denmark and Spain the growing wind power capacity has already increased the importance of rather small energy production units (0.5-2 MWe per unit) to the grid. With wind power a problem may originate from the need of fast shut downs of the local networks with a high number of wind turbines for example when the wind velocity exceeds the critical limit. Independently, the grid should maintain its stability. Instead, a shut down of a single micro-scale CHP plant (μCHP) does not make instability to the grid. The sufficient quality of the electricity from a μCHP can be guaranteed, and the energy flow to the μCHP owner is guaranteed independently to the possible shut downs of the main grid.

The biomass-based μCHP concepts studied in DENSY are clearly smaller (< 1 MW) than the typical wind power plants. Correspondingly, the number of bio μCHP- units would be much higher than the number of wind turbines in a particular country. The studied μCHP's produce electricity directly from solid biomass. The price of the produced electricity should be competitive to the wind turbines and/or the traditional biomass-fired power plants.

Liquid fuel fired aggregates have been widely used in micro-scale electricity production. These units (< 1 MW_e) are of the same magnitude with the solid biomass fired units studied in the DENSY programme. Although the aggregates have been so far fired with fossil-based gasoline and diesel, bio-diesel is possible to be used as well leading to CO_2 free energy production. The aggregates have traditionally been used during short periods, for example in farm houses during the shut downs of the grid and in cases outside the grid with low base consumption and occasional peaking. The base load has been covered for example with solar cells and the peaks which and aggregate. The development of the aggregate technology has led, however, to larger units (with 10-100 kW_e) which can be in continuously use with additional production of district heat. The trend has also been from gasoline-fired aggregates to diesel-fired aggregates to minimise the fuel costs.

Figure 3.10 compares potential technologies to μCHP for different use and figure 3.11 gives a rough estimate of the hardware costs per kW_e

Options to micro scale heat and power production (CHP) for the future

single house combined houses big building hotels etc. greenhouse small scale industry		Gas or diesel engine	Micro turbine	Stirling engine	Fuel cell
Kohde	kWe	Kaasu- ja dieselmoottori	Mikroturbiinit	Stirling-moottori	Polttokenno
Pientalo	< 5	-	--	++	++
Rivi- ja pienkerrost.	< 30	+	-	++	++
Suuri kerrostalo	< 100	+	-	+	+
Hotelli, kylpylä	< 300	++	+	-	+
Kasvihuone	<50*	++	+	--	+
PK teollisuus	<300	++	++	--	+

* Painottu voimakkaasti lämpöön * =Need of heat dominates over electricity

Source: Valkiainen et al 2001

Figure 3.10. Users and optional techniques to μCHP.

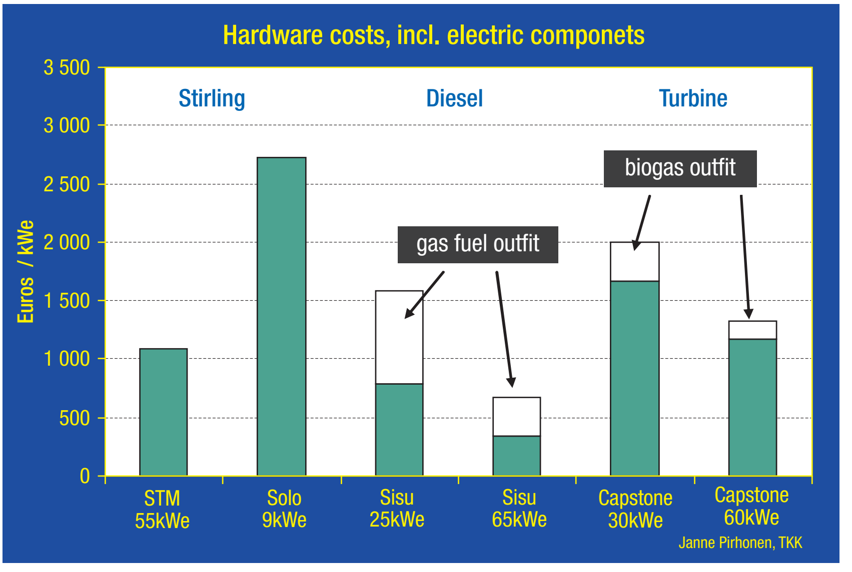

Figure 3.11. Rough estimate of the price of electricity with optional μCHP technologies. Source: Helsinki University of Technology (HUT), 2005

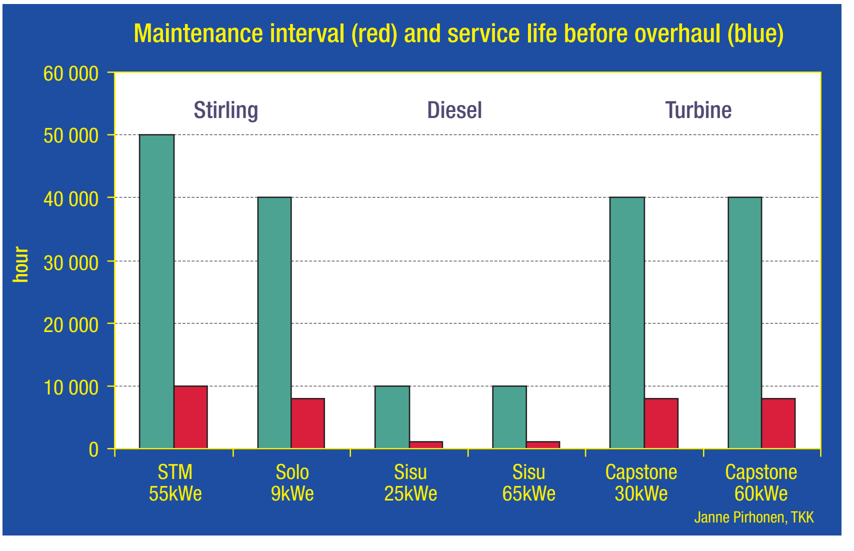

Figure 3.12. Rough estimate of the need of maintenance: Comparison of optional μCHP technologies. Source: HUT 2005

with optional μCHP's fired with bio-fuels. Diesel concepts are probably cheaper than Stirling- and micro-turbine-based concepts. There are clear differences, however, in the need of maintenance between the listed technologies (Fig. 3.12). The diesel engine based concepts need maintenance more frequently than the other optional concepts included to figure 3.11. The higher hardware costs of the solid biomass-based concepts are partly compensated by their lower need of maintenance. However, it is essential to know that the information in figures 3.11 and 3.12 are a rough estimate: No commercial μCHP's for solid biomass exist in the markets.

3.8.2 Description of the µCHP research projects in DENSY

Stirling-engine-based µCHP concepts

Project network description

The projects in this research were the following:

- Electricity (10 kW) and heat from wood pellets, co-ordinated by the University of Jyväskylä (JYU)
- The projects of technical Research Centre of Finland (VTT) and Helsinki University of Technology (HUT) with the same title

These three projects formed an operational network co-ordinated by JYU. The main funding source was Tekes through DENSY programme. Figure 3.13 describes co-operation and industrial support. In addition to direct funding, industry gave technical support. Some EU funding was directed to the research through Jyväskylä Science Park (JSP) and after the DENSY period through Tekes.

The goal for the project network was to plan and manufacture a Stirling-engine based and wood pellet-fired µCHP concept and conduct the first testing with this plant.

JYU co-ordinated administrative and technical part of the research. VTT assisted JYU in calculating the furnace of the µCHP with computerized fluid dynamics (CFD), in making detailed planning and selection of some key components of the µCHP, in conducting overall process calculations and in supporting the instrumentation work. HUT assisted JYU in planning the heat transfer from the furnace to the Stirling-engine and in transferring the overall information on Stirling technology and comparable technologies to the project network.

3.8.3 Main results

An estimate of the efficiency of electricity production with Stirling- based and optional µCHP concepts is given in Figure 3.14 when fired with natural gas, which is an optimal fuel to these concepts.

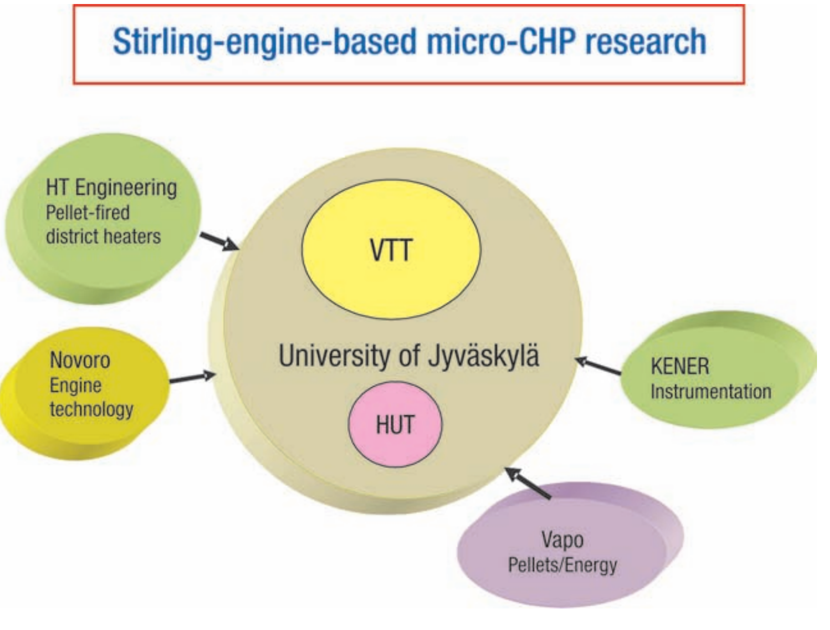

Figure 3.13. Organisation of the research of Stirling-based µCHP concepts in DENSY.

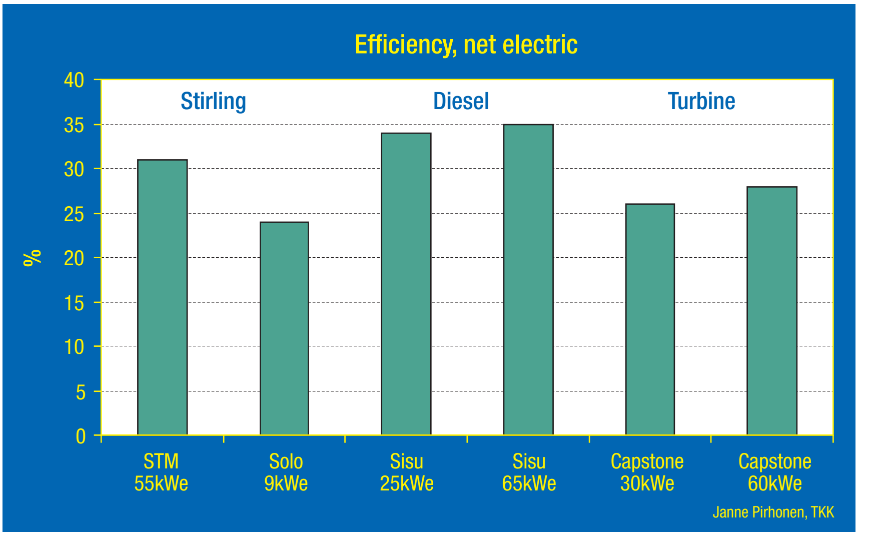

Figure 3.14. Estimated net efficiencies of optional µCHP concepts during natural gas firing. Source: HUT

According to Fig. 3.14 it is possible to produce electricity with the efficiency of 25–30% from fuel energy with Stirling-based µCHP concepts fired with natural gas. When changing the fuel to solid biomass, the ash makes problems to the concept for two reasons:

a. The fly ash from even the best quality biomass (like wood pellets) start to soften at about 1300 °C. Softening starts when the portion of melt in the fly ash becomes significant. The molten fraction makes the fly ash sticky when passing through the heat exchanger between the furnace and the engine. As a result such fly ash will damage the heat exchanger already during short time operation.
b. Due to the mechanical plugging effect of the fly ash (even without detected softening) the heat exchanger cannot be as effective during biomass firing as during gas firing. Natural gas allows clearly higher number of fins with narrower spaces than biomass because no fly ash is formed during natural gas firing. Mechanical plugging problem with biomass cannot be solved with a large-volume heat exchanger because the inner volume of the heat exchanger cannot exceed the inner volume of the Stirling engine.

Figure 3.15 lists means to increase the net efficiency during biomass firing from poor values to acceptable values. The drop of the net efficiency during biomass firing from the natural gas values presented in Fig 5 due to the two drawbacks listed above can also be clearly seen.

It is necessary to design a new furnace with an unique construction to meet the goal in electricity production (net efficiency about 15%). Both combustion air preheating and flue gas re-circulation are necessary (see fig. 3.15). And it is essential to control carefully the conditions in the furnace of the µCHP plant to find an effective compromise between the following things:

a. Ash softening must be avoided
b. The ratio between the energy flow through the heat exchanger and the fuel energy must be maximised

These requirements lead to the need of CFD calculations to know the details of the furnace geometry, stoichiometry, combustion air preheating and flue gas re-circulation. Wood pellet is supposed to be the fuel. It is the best solid biomass with minimum ash content. Its high production enables extensive use in the µCHP plants.

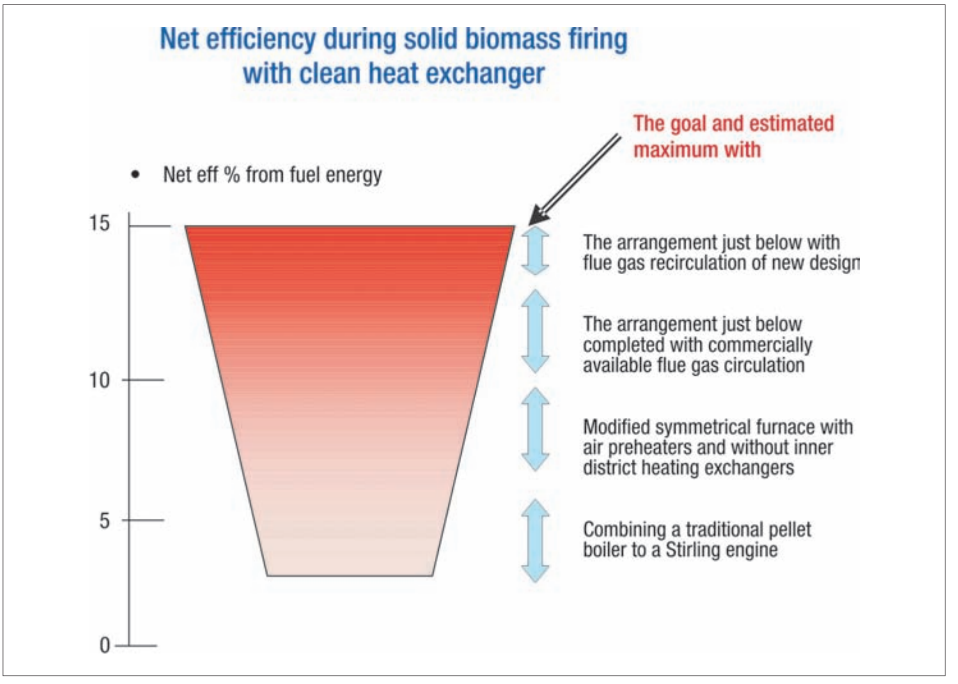

Figure 3.15. Calculated net efficiency (% electricity from fuel energy) for different µCHP constructions in Stirling-assisted power production from solid biomass.

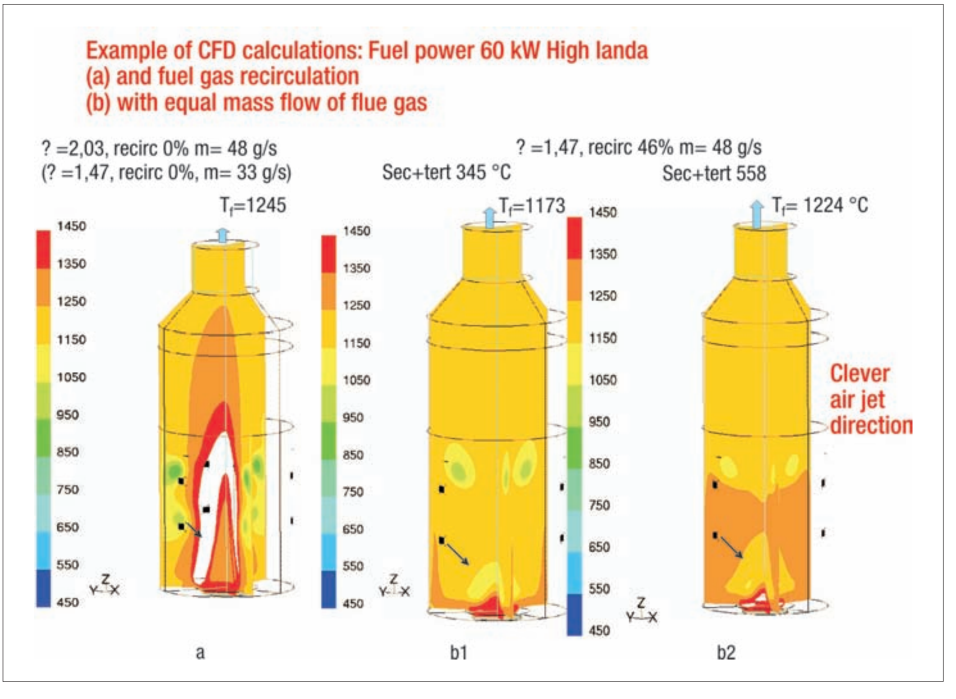

Figure 3.16. The influence of stoichiometry, combustion air preheating and flue gas recirculation to the temperature distribution in the furnace of a wood pellet fired µCHP plant.

Results of the CFD calculations carried out at VTT are illustrated in Figure 3.16. The energy flow out from the furnace top (see the arrow) to the heat exchanger in cases a and b2 is roughly similar (temperature and mass flow in the out coming gas are roughly similar). However, very high furnace temperatures (> 1500 ^{o}C) were calculated in case a, whereas the furnace temperatures remain in all zones below the softening point of typical wood pellet ash in case b2. According to the results, the above mentioned design parameters are critical.

3.8.4 State of the µCHP plant

The CHP plant is almost completed, but instrumentation, control system, air pre-heater, burner and the experimental hall have still some details to be completed. The construction work has been more time taking than estimated but the costs have not exceeded as much as the time schedule. However, there is a gap between the funding and the costs which may become a problem. Additional public funding through Tekes is not available.

3.8.5 Future aspects of Stirling-engine-based biomass fired µCHP plants

The costs of Stirling engine are in the key position when determining the price of electricity produced with a wood pellet fired µCHP plant if the process development and the further simplification of the plant to mass production prove to be successful. Probably the traditional construction of a Stirling engine would not allow a µCHP plant with moderate electricity prise (Figure 3.11) because of the long pay-back time of the investment. Instead, a new innovation was made in 1976 to simplify the construction of the Stirling engine which can give a solution. In the novel construction called as free piston engine, there is no connection between the power piston and displacer piston. This arrangement enables much simpler construction which can reduce the production costs even by 70–90%. The information of Figs. 3.14 and 3.15 prevails with this new engine because similar heat exchanger has to be used. The necessary furnace construction described above can also be realised with rather simple solutions in a mass product. In consequence, there are technical and economic possibilities to develop an economic wood pellet fired µCHP plant. Such development work needs, however, funding and time.

3.9 Waste-to-energy – a modular CHP plant utilizing municipal waste streams in distributed energy generation

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Lappeenranta Innovation Oy, Lappeenranta
Laitex Oy, Lappeenranta
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Master's thesis produced
Techno-Economic Analysis of the Treatment Flows and Incineration of Municipal Sewage Sludge and Biofuels

The Treatment of Municipal Sewage Sludge before Thermal Drying and Incineration

3.9.1 Introduction

This brief presentation will outline the preliminary results and future of the Waste-to-Energy (WtE) Project which focuses on the technical and economic studies and analyzing the commercial opportunities of a modular small-scale power plant utilizing biofuels and fuels from waste material in its electricity and heat production. This report summarizes the current state of the project. The final results will be provided in the final report by May 2008.

3.9.2 Objectives and scope of the study

The objective of this university project, funded by Tekes, the Finnish Funding Agency for Technology and Innovation, under the Densy (Distributed Energy Systems) Technology Programme, is to improve the technical and economic prospects of a modular small-scale power plant, which utilizes industrial and municipal sludge, other biofuels and fuels from waste material in its electricity and heat production, in the future energy market. The modular small-scale power plant concept is based on studies on sludge treatment methods and bio CHP (combined heat and power production) combustion technology at Lappeenranta University of Technology, and on the technology used in industrial and municipal sludge drying and combustion plants (SDC plants) and their electricity generation. By integrating these we can create a modular small-scale CHP plant.

This research project includes both the technical analysis and the study on the concept's commercial opportunities. The technology analysis focuses on examining fuel alternatives, the recovery potential of their combinations and transportation processes, and the recovery of residual ashes, and on techno-economic process calculations, the choice and planning of optimal electrical drives technology and automation, and on devising the plant's remote system management. Moreover, we shall define the plant's power generation potential and evaluate the entire plant's techno-economic capacity, namely determine the intangible and tangible resources required in the construction and operation of the plant and analyze their cost structure on both the component and system level. The objective of the business prospects analysis is to provide a commercially exploitable business concept by combining a macro level study on the competition environment with a micro level resource analysis. The all-encompassing theme in the project is the creation of new business opportunities and development of the *WtE* technology. Along with the creation of the new business, the better understanding of conditions for the social acceptance of the plant may widen.

In the following, all the parts of the research project, their preliminary results and future concerns will be discussed separately. The terms *WtE concept* and *WtE process* refer to the technology used in the dewatering and incineration of industrial and municipal sludge and other fuels and the combined process of electricity and heat production which can be applied in distributed energy generation.

Technical and economic modeling of a thermal sludge treatment plant

Technical performance of the thermal sludge treatment plant forms a basis for further consideration of its viability in a given business environment. In this study, both technical and economic models are developed for the plant. The focus area is first on using sludge as the only fuel, but it is later expanded to include multi-fuel operation where biofuels and recycled fuels can be burned together with sludge. The developed models are utilized for analyzing the effect of operating parameters on the plant performance as well as for determining the prerequisites for the profitability of the investment. Furthermore, consideration is given to the optimal integration of the plant into the sewage sludge treatment process.

The developed thermal sludge treatment plant applies steam power (Rankine) cycle and is equipped with a drum-type boiler and a back-pressure turbine. Circulating fluidized bed (CFB) technique is used both for drying the sludge thermally in a commercial indirect CFB dryer and incinerating the dried sludge and odorous vapor in a constant temperature combustion (CTC) reactor.

In the boiler, feed water is first pre-heated in the economizer and taken into the drum. The saturated water is evaporated in two consecutive stages by leading it through the evaporator in the CTC reactor and additional evaporator in the exhaust gas duct. The saturated steam is superheated into live steam conditions in the superheater and led through the turbine to get mechanical power. The plant has one open feed water pre-heater (feed water tank) which uses saturated water from the drum as a heat source. Therefore, no bleeds are required in the turbine. The heat from the turbine exhaust steam is utilized in the dryer to reduce the moisture content of the sludge before combustion. This increases the electric power and efficiency of the plant. The returning condensate from the dryer is pumped into the feed water tank and again into the boiler. At design conditions, the dry solids content of the sludge entering the dryer is selected so that all heat from the plant is consumed in the drying process. This value is designated as the minimum dry solids content. Nevertheless, the plant is equipped with a supplementary heat exchanger for cases when additional cooling is required.

Simulation models have been developed and programmed for the dryer and reactor using an IPSEpro process simulator. The developed component models have been combined with the standard models from the software to set up a process model for the plant. The specifications for the components have been selected to reflect the typical values of the small-scale plants while the composition and heating value for the sludge are characteristic of municipal sewage. When the mass flow of the dry solids corresponds to a population of 200 000 inhabitants, the net electric power of the plant becomes about 500 kW. Sensitivity studies show that increasing the dry solids content from its minimum value increases additional thermal power significantly while the increase in electric power is only mild. The plant parameters have a minor effect on the minimum dry solids content. From the parameters, live steam pressure, back pressure and isentropic efficiency of the turbine have a strong effect on both electric and thermal power. Compared to these, steam temperature has only a minor effect.

The economic analysis is based on determining the present value of investing in the thermal sludge treatment plant. Aside from the investment costs, the following costs are taken into account in the model: the avoided costs of generating electric and thermal power, the income from selling energy (if any), the income from receiving sludge, the processing costs for the ash as well as operation and maintenance costs for the plant. Support systems for the investment and taxation are excluded from the study.

The economic model can be used for determining the maximum investment cost for the plant to be economically feasible. With given input parameters the major share of the revenue comes from the sludge acceptance fee while the contribution of avoided costs remains lower. Compared to these, the costs from processing ash have only a minor role in the economy. It must be noted that the results depend on the technical and economic input values and are valid when sludge is used as the only fuel. In case biofuels – for instance reed canary grass or forest residue chips – and recycled fuels are utilized in parallel with sludge, the cost structure of the plant changes significantly.

Further studies include the analysis and comparison of variations for the developed process as well as alternatives for sludge combustion. Surplus heat that is not required for drying sludge can be used for district heating or drying the raw material for wood pellets, for instance. One option to utilize surplus heat is to introduce a condensing turbine in the process to maximize the electric power yield. The thermal sludge treatment plant can be replaced by a boiler plant where the heat for drying sludge is produced using a low-pressure steam boiler and surplus heat is utilized. In this option the revenue from electricity is lost but the plant configuration is essentially simpler. Aside from using sludge as the only fuel, multi-fuel operation with biofuels and recycled fuels will be considered. The overall optimization of the sewage sludge treatment process will also be studied.

Optimal steam turbo generator technology – a techno-economical analysis

The steam power plant process seems to be the most suitable technology for converting thermal energy to electricity in a thermal sludge treatment plant. Depending on the moisture content of the sludge before combustion, some or all of the rejected heat after the turbine can be utilized for drying the sludge further. Instead of using sludge as the only fuel, the steam power plant process enables multifuel operation where biofuels or recycled fuels can be burned together with sludge. This multifuel plant operates in a CHP mode producing heat for local use and delivering notable amounts of electric energy to the grid.

The following results were found during the first half of the project: It is most suitable to have a back-pressure turbine when using sludge as the only fuel, because the process steam after the turbine is needed for drying sludge. For the turbo generator, the energy efficient multi-stage turbine without any gearbox is traditionally considered to be economical only beyond the multi-megawatt size. With sludge as the only fuel, the power output from the turbo generator varies from only 500 kW to 2000 kW. On this very small scale, the generator's prime mover is most often constructed as a single-stage turbine coupled with a reduction gearbox. This economically optimized construction makes small-scale turbo generators suffer from low isentropic efficiency. Poor performance is a major lack among the existing commercially available equipments.

In the future studies, two state of the art technologies will be investigated to improve the performance of small-scale turbo generators. The first way is to eliminate the gearbox and use a directly coupled high-frequency generator (HSG) instead of a grid-frequency generator. The second way is to use a direct on-line permanent magnet synchronous generator (DOL PMSG) instead of a traditional induction generator or synchronous generator. Moreover, a techno-economical analysis of the HSG and DOL PMSG in a turbo generator drive will be performed. The challenging high speed technology will be further investigated after the process model for the multi-fuel plant has been developed. Then, the technical and economic performance of a novel hermetical turbo generator with a condensing turbine in this multi-fuel plant will be analyzed. Several challenging research features are included in finding the technically and economically best turbo generator technology for the purpose.

Automation of CHP power plant

The research approach goal is to design the connection of a CHP power plant to electricity network. The CHP power plant consists of the Einco Oy CFB dryer (circulating fluidized bed), the Einco Oy CTC reactor and a turbo generator.

The electric systems and control equipment of the power plant must be designed for stable operation with the network, and electricity quality must satisfy the requirements of the network provider. At the beginning of the project, today's network providers' requirements, recommendations and electricity quality demands have been analyzed and are used in the design process.

Two types of network interfaces have been designed. One connects a turbo generator running at a constant speed to the network directly; another connects a variable speed turbo generator by using a frequency converter. The generator types used were the synchronous generator and the asynchronous generator. Every design option includes main circuits, electric wiring, drawings, primary and secondary protection, automation equipment and operation instruction.

The study continues with the design of automation hardware, controlling software, data transfer between field level and process control level devices, and the evaluation of both the HMI design and the requirements of unmanned use.

The treatment of municipal sewage sludge before thermal drying and incineration

The aim of the study is to examine the treatment of municipal sewage sludge from the view of the sludge incineration plant, to find treatment methods and transport options for sludge and to track down the costs of these units. The aim is also to clarify the characteristics of municipal sewage sludge and the problems with sludge treatment. In addition, the study includes examination of sludge handling in the south-eastern parts of Finland. The objective is to accomplish an appropriate model of sludge treatment for each case.

In the beginning of the study, sludge is examined from the point of view of both fuel and waste. The review contains facts of characteristics and volumes of municipal sewage sludge, legal limitations and the general process of wastewater treatment. The study deals with pretreatment, mechanical dewatering, thermal drying and incineration of sludge. The machines of the dewatering process are also specified and compared. The study revealed that the centrifuge and belt filter press are ideal especially for municipal sewage sludge.

The final part of the study consists of a more detailed inspection of the parts of sludge treatment. Attention is paid to storage of sludge, feeding and discharge systems, conveyance and transportation. Local opportunities of sludge treatment in Kymenlaakso and South Carelia regions are considered. In these regions 6 000 and 15 000 tonnes of mechanically dewatered sludge respectively is treated every year. In both cases it seems that electric and heat power depend strongly on the dry solids content of sludge, and not so much on other sludge properties. The costs of sludge treatment, from thickening to feeding for thermal drying, range between 12 and 20 euros per tonne. The cost depends on the number of treatment parts. Mechanical dewatering and storage induce most of the costs. All of these results are useful for planning a sludge incineration plant.

Co-incineration of sewage sludge and biofuels

The aim of this study is to examine how the Waste- to-Energy system of sewage sludge changes if biofuels or recovered fuel are admixed into sewage sludge. Another objective is to find out about the possibilities and benefits, but also the challenges and limitations that integrating these fuels produce technically and economically. This analysis will be done paying attention to the limitations of legislation. The study considers the material flow chain, the process of the combustion plant and energy that the plant produces. The analysis is conducted by using three cases: a waste management company Etelä-Karjalan Jätehuolto Oy, the Kymenlaakso Region and City of Lappeenranta.

The benefit of burning several fuels instead of burning only sewage sludge is increased volume of range. The quantity of sewage sludge is often quite small, so sheer burning of sewage sludge is often not cost-effective. As well heat that co-incineration produces can be used in several purpose. The investment profitability of a small-scale CHP plant could increase when the plant is processing sewage sludge and integrated handling of waste. In addition to the benefit of waste treatment the economic efficiency could be improved by power production

Co-incineration also has its limitations. The heat that arises in the combustion process has to be utilized nearby the combustion plant. Moreover, the plant is a waste combustion plant, which increases investment and operation expenses, when compared to a biofuel plant. Also, the fuel cost-benefit is lost when the share of fuels that cost increases. When several fuels are used, there will be challenges for the fuel taken in, handling, storage and feeding systems.

The co-incineration analysis is conducted by using a model developed in the project. The financial analysis is based on the results that the model produces. The starting point is the combustion of sewage sludge. Along with sludge the co-incineration process will use either recovered fuel, chip, peat or reed canary grass. Furthermore, the several ways of heat creation in the production of electricity and how profitable these ways are will also be studied. There are a few options for the use of heat, such as to supply heat to the municipal heating grid or utilize it for example in drying raw material for wood pellets.

Utilization and treatment of ashes from the WtE process

The possibilities of utilizing ashes from the waste-to-energy process will be studied during the project. Although ashes from the process are residues that have to be dealt with rather than a product which has value in itself, handling of ashes is an important and necessary phase of the process. The WtE process which will be introduced to the public must include the whole process including all the inputs (energy, fuels etc.) and the outputs (energy, residues).

The aim of the ash study is to find the most feasible handling methods for WtE ash. Ash utilization will be emphasized, but also the final disposal methods will be studied. The study will include discussion on the following issues:

- Ash contents from different sludges
- Present level of suitable treatment methods for WtE ash
- Review of novel ash treatment methods

Research will be carried out mainly as a literature study. The results of the ash study will be available later in the autumn of 2007.

Business research

When determining the WtE concept's business opportunities, the competitive environment was first defined on a macro level in a PESTEL analysis to find the political, environmental, social, technical, economic and legislative factors influencing the major trends in the development of business operations. These macro level factors are briefly presented below:

- *Political factors* – On both the international and national level, global and EU policies on energy, environment and climate to reduce greenhouse gas emissions have an impact on the planning and application of new technology. Increasing renewable energy generation and decreasing land filling of biodegrable waste has been seen as one of the most central tools to reduce these emissions.
- *Environmental factors* – The greatest environmental factor affecting power generation and waste management globally is the marked increase in greenhouse gas emissions and their negative impact on the atmosphere. At the moment, fossil fuels are most widely used and one of the biggest causes for greenhouse gases which creates pressure for developing new methods for electricity generation and waste recovery.
- *Social factors* – One of the most important social factors, the rapidly increasing population and the resulting pressure on the development of new waste recovery and power generation methods have an influence on the appeal of new technology in the market. Attitudes and values in the business environment, furthermore, influence the acceptance of the technology and ultimately the refusal or approval to implement the new plant concept.
- *Technical factors* – Renewable methods are still only a fragment of power generation when compared to fossil fuels, and there is no quick solution to satisfy the increasing energy demand in the short term. Alternative generation methods replacing fossil fuels are, however, being developed continually. These methods are based on renewable sources of energy, such as biomass, waste, hydropower, tide and wave energy, wind power and geothermic and solar energy which create an interesting investment and diversify competition in the international energy market. Furthermore, the increased official standards in waste management as well as reforms of waste legislations push public institutions and private companies to invest in

more efficient waste management technologies. Pressure is above all directed at minimizing the quantity of qualitatively diverse waste in a dumping ground, the control over unpleasant odour, the elimination of the causes of diseases, and more efficient exploitation of waste material and energy reserves. Existing technologies on the market do not fully meet the above mentioned requirements.

- *Economic factors* – Strong global economic growth in recent years has increased purchasing power and the interest to invest in new technologies. Flux in the prices in the energy market and several countries' dependence upon the international market also enhance the opportunities of technology based on renewables. As mentioned in the above paragraph, the increased standards in waste management push public institutions and private companies to develop more efficient technologies to minimize the quantity of waste in a dumping ground i.e. to prevent the upsurge of cost in waste disposal.
- *Legislative factors* – In Finland in particular economic control mechanisms, such as the fiscal policy or the obligatory waste tax and charges, influence the planning of a WtE plant. The planning and implementation of the concept is also affected by various legislation concerning wastes. Our national legislation complies with global policies, and some of the most important of these laws and regulations are the *Waste Act,* which places the recovery and disposal of household waste and waste of comparable nature from public activities in the responsibility of municipalities, whereas industrial and commercial waste fall within the responsibility of the waste producer; the *Waste Incineration Decree,* which aims at preventing polluting emissions into the air and water from waste incineration; the *Decree on Landfills*, which proposes to increase waste recovery and to set criteria for the quality requirements of landfills; and the *Act on Fertilizer Products,* which sets strict criteria for the recovery of ashes resulting from the incineration of sludge and other fuels.

In the next phase of the project, (1) the business research and commercial potentiality analysis will define the general competitive factors and the most significant future markets for the sludge incineration plant and the customers and their needs in the emerging market for distributed generation. Moreover, (2) the suppliers of SDC plant core technology and (3) the energy sources will be defined. The results will reveal the central success factors in the sector that will have to be taken into account as minimum requirements when planning business operations. Finally, we will provide a business concept in co-operation with the companies participating in the project to implement a modular pilot plant. The business plan (part B in figure 3.17) will be done by combining research results (part A in the following picture) as shown in the figure 3.17.

In addition and along with the business research, the preconditions for approving the plant in a community (end users) will be examined, i.e. associations with waste matter that is at the end of its life cycle and how these associations influence the acceptance of a new technology among the end users and other stakeholders.

During the first phase of the project, some social themes that have an impact on the acceptance of new WtE technology have already been identified.

The acceptance analysis will be continued and the themes examined along with the development of the business plan. By analyzing how cultural issues, i.e. pre-knowledge/attitudes, affects the diffusion of new technology among the end users, it may be possible to create wider understanding of the acceptance of the WtE plant and support business operations related to it. Such an analysis has a central role when generating new business, especially in still emerging market.

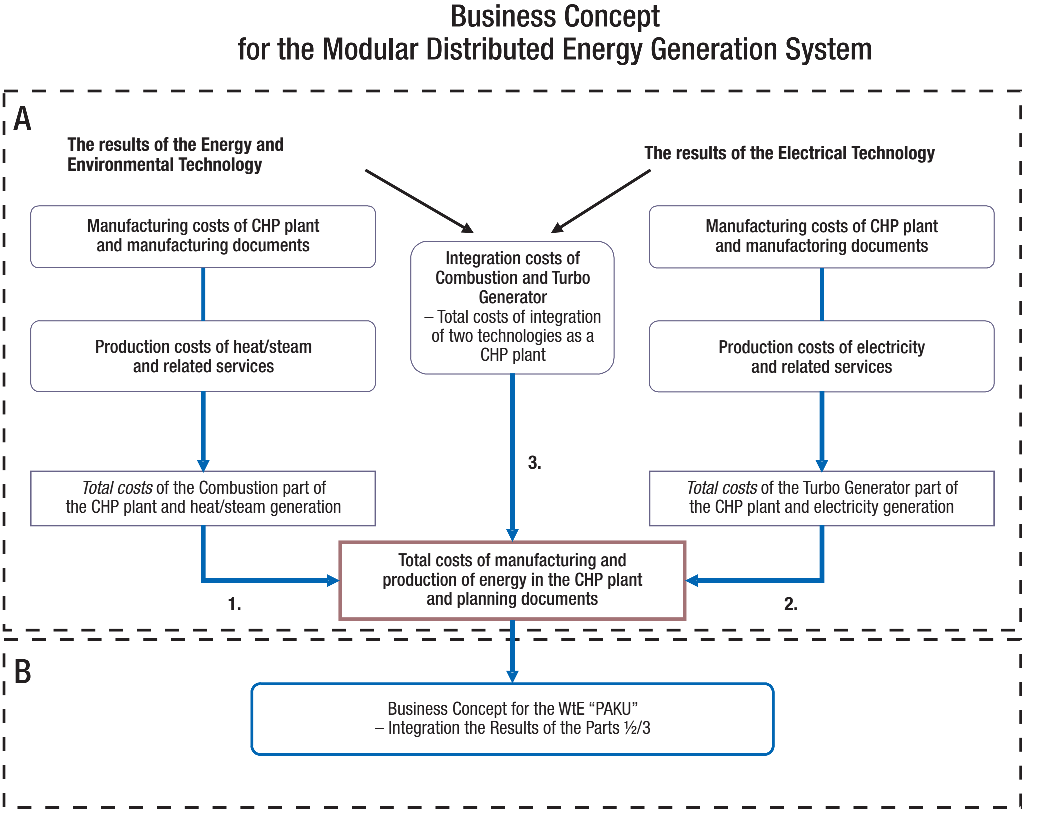

Figure 3.17. Creation of the Business concept for the new WtE Concept.

4 Fuel cell and hydrogen systems

4.1 Introduction

Fuel Cell and Hydrogen research work in universities in Finland started in the early 1990s. Industrial activity started also in the early 1990s with the test run of the Onsi 250 kW phosphoric acid fuel cell (PAFC) and the establishment of Hydrocell Oy and Labgas Oy companies. However, the level of funding for fuel cell research was quite modest until the beginning of the 21th century when Wärtsilä Corporation started its SOFC development. This gave a strong boost the fuel cell activity in Finland. Tekes accepted its role as funding organization for this activity and the budget of Tekes funded fuel cell projects increased from > 1 M€ in 2000 to 5 M€ in 2005. There was a clear interest in Tekes to coordinate this activity, and therefore the fuel cell and hydrogen activity was incorporated into the Densy technology program from the beginning of 2004. These projects ended in the end of 2006. The Densy technology program has reached its end in 2007, but the Fuel Cell and Hydrogen research funded by Tekes is continuing in a new Technology program "Fuel Cells", which will continue over the whole period 2007–2013, corresponding to the EU FP7.

Parallel with these developments the Finnish research organizations and industry started to participate in EU-projects dealing with fuel cells. At present Finnish universities, VTT and industry are participating in nine EU projects related to fuel cells.

In the Densy program Helsinki University of Technology (TKK) coordinated two projects and VTT Technical Research Centre of Finland (VTT) coordinated also two projects. The TKK projects were both executed by individual research groups in cooperation with industry. The projects were "Distributed modular hydrogen systems" (THETA) and "Analysis and optimisation of heat exchangers for fuel cells". Focussed research areas of THETA were advanced hydrogen storage (IEA HIA Task 17), hydrogen generation and machine-free compression, electrical power generation, waste heat/cold recovery, modular system total design, simulation and optimisation, applied safety issues and system operations. Fuel cell heat exchangers were focused on analysis of heat balance and heat exchangers of fuel cells.

VTT coordinated projects were PowerPEM and FINNSOFC. The PowerPEM deals with the development of technology and concepts for class 1 kW power units for different applications. Those could be small vehicles, back up power or power for telecommunication, houses and so on. PowerPEM was executed in cooperation with TKK and industry.

In the FINSOFC project technology was developed for SOFC based power sources using natural gas or diesel as fuel. In this case possible applications are CHP from 1 kW to MW sizes and APU for ships and vehicles to mention the most important ones. Although coordinated by VTT, the projects were executed in cooperation with the universities TKK and Åbo Akademi as well as industry, as described in connection with the individual project descriptions.

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4.2 List of projects

VTT, **Development of a PEM-fuel cell, stage 3**

Date of funding decision: 2.1.2006
Research project, finished

VTT Processes **FINSOFC 2006**

Date of funding decision: 21.11.2005
Research project, finished

VTT Processes
Development of fuel cell technology and business in Finland

Date of funding decision: 22.9.2005
Research project, finished

VTT Processes
Development of a PEM Fuel Cell, stage 2

Date of funding decision: 3.2.2005
Research project, finished

VTT Processes
FINSOFC – Business for Finnish industry

Date of funding decision: 31.1.2005
Research project, finished

Helsinki University of Technology
Distributed modular hydrogen systems

Date of funding decision: 25.3.2004
Research project, finished

VTT Processes
Development of a PEM fuel cell 1/3

Date of funding decision: 12.2.2004
Research project, finished

Helsinki University of Technology
Analysis and optimisation of heat exchangers for fuel cells

Date of funding decision: 12.2.2004
Research project, finished

VTT Processes
FINSOFC – Business for Finnish industry

Date of funding decision: 26.1.2004
Research project, finished

Wärtsilä

Technical Research Centre of Finland (VTT) and **Wärtsilä** together developed an internationally unique fuel-cell system. Research groups from both organizations are developing solid oxide fuel cell (SOFC) technology in the same place and at the same time. The systems are based on the same principles, but differ from one another with respect to components and the reforming of fuel.

In their plate-shaped fuel cells, both SOFC systems use natural gas supplied by the network. Electricity produced by the fuel cell array, which has an efficiency of about 50 percent, is fed into VTT's electric power grid. Heat produced by the systems can also be stored easily.

The research covered the processing of fuel, the operation of the cells and cell matrices, connections to the electric power grid and natural gas network, and the control of the entire system. In addition, the projects have developed the power station's monitoring and automation systems and dynamic system-modelling tools.

The research also had a strong focus on the modelling of the fuel-cell system. The operation of the system was simulated using computer models which are verified using the experimental equipment in use. The aim was total understanding of the functioning of a fuel cell power plant.

The research co-operation between VTT and Wärtsilä helped to solve countless technical problems in the development of the SOFC system. In addition to Wärtsilä, the FINSOFC research project included the participation of over ten companies interested in the development of fuel-cell technology and components, as well as the Helsinki University of Technology and Tampere University of Technology.

4.3 Distributed modular hydrogen systems, "THETA"

The Distributed modular hydrogen systems" (**THETA**) project focussed research areas were advanced hydrogen storage (PH, MH, HFP)[1] hydrogen generation (electrolysis, HFP) and machine-free compression (EHC)[2], electrical power generation (AFC), waste heat/cold recovery (thermal management), modular system total design, simulation and optimisation (power conditioning), applied safety issues (leak tests) and system operations (H2/DC/heat supply, blackouts activations, infrastructure).

Analysis and optimisation of heat exchangers for fuel cells. There were three work packages in the project. In the first work package the thermodynamical analysis (i.e. exergy analysis, entropy analysis, thermodynamic equilibrium calculations, thermal and mass transfer calculations etc.) of different system possibilities were carried out. During the analysis the thermodynamic role of the different components was clarified and after that the optimal process parameters and coupling of the whole system was defined. In the second work package a feasibility of different heat exchanger possibilities for the fuel cell systems were more precisely worked out. The fuel cells and fuel cell systems have specific features which may set new kind of limitations or demands for heat exchangers compared to more conventional CHP systems. The third work package contained an analysis of demonstrations or simulations of the fuel cell system in a CHP application in co-operation with VTT.

The project **POWERPEMFC** was performed in co-operation with VTT and Helsinki University of Technology (TKK). The project includes development of PEMFC bipolar plate design and validating the modelled results in a segmented cell. Construction of a 1 kW power source including stack and BoP has been done and control strategies have been developed. Also bipolar plate materials have been developed, both conductive composites and metals. This project is continuation of the research done at PEMFCTEHO (Power-pack solutions of PEMFC), which was a sub-project of "Development and productization of fuel cell materials" 2002–2003.

The general objective of **FINSOFC** was to create possibilities for SOFC-related business to the companies involved in the program. It also offers good facilities for research and education to the Finnish universities. However, the concrete target of the project was to construct a natural gas fuelled 5 kW_e SOFC (planar type) power plant demonstration connected to heat and electricity grids and run it for a long period of time to gain valuable operational experience. The plant did run for 7000 h. Other accomplishments of the project are construction of a prereformer natural gas. This has been operated for 10 000 h. A prereformer for diesel oil has also been developed. The reformer is performing well and has been tested for more than 1000 h. Cell and short stack test riggs have been developed and constructed. A number of cells and short stacks have been tested for periods up to 3000 h using natural gas reformate both with sulphur and without sulphur. A dynamic system model of the SOFC power plant demonstration has been composed and it comprises all main components of the real system: the SOFC stack situated in a furnace, autothermal reforming (ATR) unit, catalytic afterburner and anode and cathode side heat exchangers.

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1 PH =pressured hydrogen tank, MH=metal hydride, HFP=hydrogen flash power

2 ECH=Electrochemical Hydrogen Compressor

4.3.1 Introduction

"Distributed Modular Hydrogen System" research project was lead by Helsinki University of Technology (TKK), Laboratory of Materials processing and powder metallurgy (MVT), in Espoo (FIN). The main partners were HIAT oGmbH (DE), Hydrocell Oy (FIN), Japan Steel Works (J), Kompozit-Praha (CZ), Labgas Oy (FIN), MG Innovaatiot Oy (FIN), Rollerco Oy (FIN) and Woikoski Oy (FIN). The project was carried out during 01.06.2004–31.12.2006 period and it was a part of the Tekes' Distributed Energy Systems (DENSY) technology program and IEA HIA Task 17.

Focussed research areas were advanced hydrogen storage (PH, MH, HFP)[3] hydrogen generation (electrolysis, HFP) and machine-free compression (EHC)[4], electrical power generation (AFC), waste heat/cold recovery (thermal management), modular system total design, simulation and optimisation (power conditioning), applied safety issues (leak tests) and system operations (H2/DC/ heat supply, blackouts activations, infrastructure). The layout of potential distributed modular hydrogen system (DHS) is presented in Fig. 4.1.

Part of the project, "Combined Metal Hydride and Composite Tanks Hydrogen Storage", was linked to in IEA's Hydrogen Implementation Agreement (HIA) Task 17 (Solid and Liquid State Hydrogen Storage Materials). Within this framework it was possible to participate in Task 17 scientific seminars (Charleston, USA, February 2005, Utsira, Norway, May 2005 and Tateshima, Japan, October 2005). Researchers have highly appreciated information gain from informal discussions e.g. from safety issues. TKK representatives have separately attended IEA HIA ExCo meetings as alternate members and reported about the co-operation.

The results related to Task 17 are shown below together with other project specific results (a sepa-

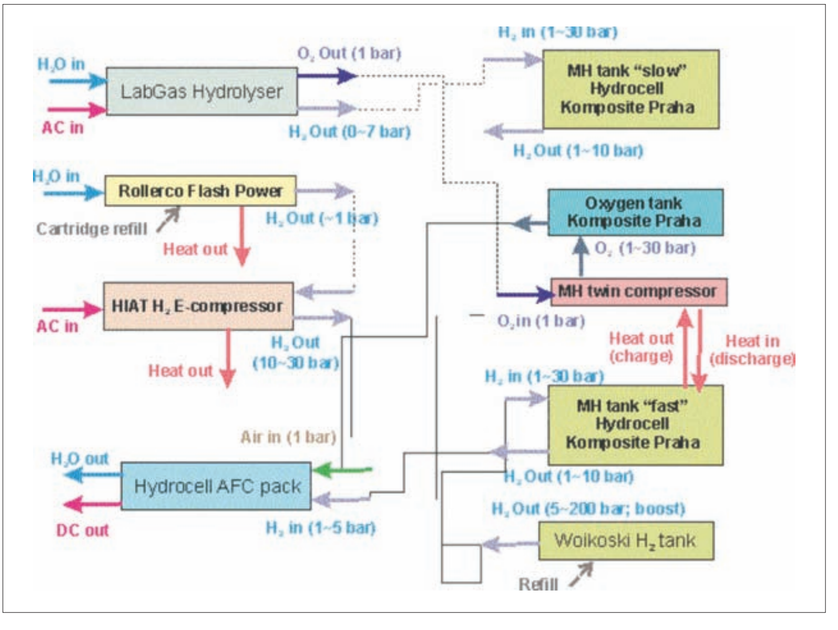

Figure 4.1. The layout if the distributed modular hydrogen system. Waste heat recovery unit (MG Innovaatiot Oy) is not shown here.

3 PH = pressured hydrogen tank, MH=metal hydride, HFP=hydrogen flash power

4 EHC = Electrochemical Hydrogen Compressor

rate report on Task 17 has been submitted in August 2006 to IEA and it is available from the site www.ieahia.org).

4.3.2 Project results

All major components (Fig. 4.1) were tested as received from suppliers taking part in the project and their operating properties were integrated to new model of virtual hydrogen station. Some experimental testing on focused research areas was also needed to e.g. find out safety issues (leak tests).

Hydrogen Flash Power (HFP) is innovative system concept, design needs to be developed in future projects. Target is to provide high-density storage of H2 (>7% wt.) for either mobile applications or for the case of UPS-function or in the case of systems' blackouts. Hydrogen and some heat would be released by adding dosing water "on demand" in the case of a blackout or unavailability of DC/AC power. The HFP will be based of NaBH4 (sodium borohydride, SBH). After screening of potential combinations of mixtures of SBH with some additions, a suitable compromise was chosen with has more than three times lower exothermic effects (0.28 kWhth/kg), relatively high net hydrogen storage (8.6 wt. %, equivalent to ~950 NL H_2/kg of mix), does not increase pH with time, does not emit fuel cells poisons like NH_3, CO or CO_2, results in only neutral, harmless and fully disposable substances. This solution is believed to be cost-effective vs. pure SBH or any other combination. Since SBH and the other component are solid powders, they won't react until water is added to the mix. Nearly neutral pH should be helpful to prevent corrosion issues. To implement the system with SBH, water-dosing system should be integrated with the MH storage tank (of whatever design).

TKK started studies of novel composite shell integration with MH storage. In 2004, typical AB_5 ($La_{0.85}Ce_{0.15}Ni_5$ and $La_{0.7}Ce_{0.3}Ni_5$ commercial powders, also those alloys with additional aluminium) were analysed as a benchmarking material. Basic PCT curves were measured for 40–550 NL H_2/h (120-1650 W LHV) charge/discharge rates and with different heat management routines, Fig. 4.2.

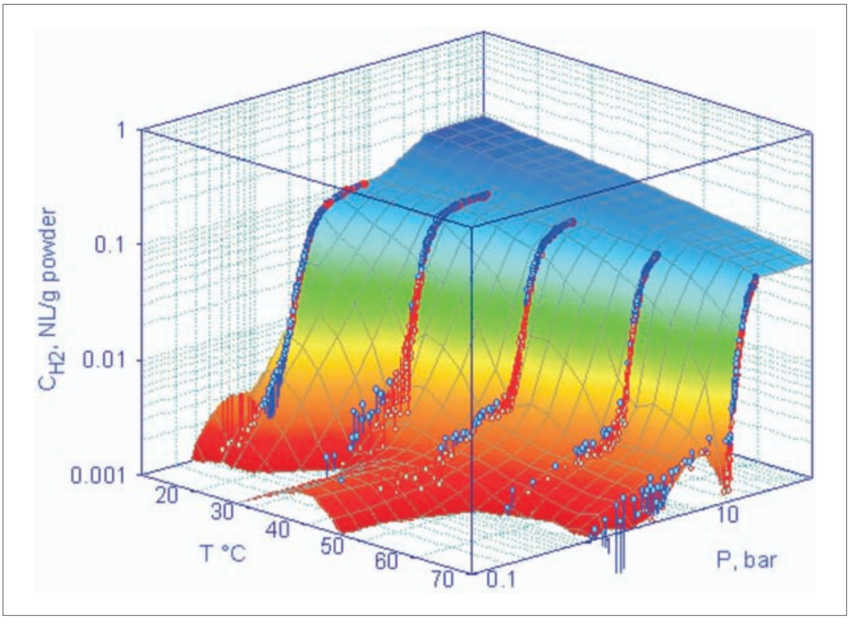

Figure 4.2. Example of the PCT surface of the $La_{0.7}Ce_{0.3}Ni_5$ powder (rate 40 NL/h). Points are experimental measurements.

Figure 4.3. Commercial MH storage tank (AB_5) using novel heat exchanger, implemented with an alkaline fuel cell (left) and the fuel cell electric scooter (right), Hydrocell Oy.

Such approximation has allowed using of a special correlative equation to be implemented into simulation algorithms to optimise different storage design versions. These solutions were used in a commercial product development, Fig. 4.3.

Chosen Electrochemical Hydrogen Compressor (ECH) was product of HIAT (Germany). It designed for productions of 200–1000 NL/h H2 via PEM conversion for a pressure gains ~16:1 (<30:1). ECH ideal cell potential is only 0.045V for 30:1. The cell potential is depending only on pressure ratio.

Hydrogen pressure tank has been designed to be a "smart". Tank has a logic control for multiply inputs and users. It is completed with overpressure protection and interactive monitors for own state. Tank will command hydrolyser and EHC when needs to be refilled. Hydrogen tank is used as a buffer for fast car charge (day) and refilling (day/night) with e.g. solar or wind power.

Hydrocell provided alkaline fuel cell (AFC) stack. Stack is based on one unit cell (may be combined in 6-unit packs and also connected in parallel). System was optimised by varying hydrogen supply (in other words current was limited) assuming that airflow supply was enough. The AFC stack gives power of 90W at 12V DC with electric efficiency ~60% (the ratio of real power generated to the LHV value of fuel supplied) and performance ~74% (the ratio of real power generated to theoretically possible electric power at fixed fuel supply), with heat recovered ~23% and maximal running time (UPS) 9.8 hours (for full tank of 12 g H2).

A proper automatic system to control AFC stack's power conditioning is desirable: variable active load result in efficiency losses. With proper control efficiencies up to 65% (DC) and performance up to 85% are achievable. Internal heat recovery 20–60% is possible when purging MH storage.

The principle of the enthalpy recovery device used in the project is based on the reversibility of the gas flow (air, hydrogen, etc.) through the chamber, which has heat/cold accumulator. The rationale for the tests was that AFC and MH output air contains significant amount of water vapour and thus presents a high energy value vs. input air. By properly condensing water inside the device, this humidity variation may be converted into heat to transfer it to input air and thus equalise thermal balance of AFC stack, EHC and MH cooling/heating etc. Based on temperature measurements, the effective energy recovery was calculated and for the steady case it takes about

6–10 kJ/m^3 air passed. The tests has demonstrated the 40–60% temperature recovery efficiency (humidity effect was not measured, it will add other 20–30% more) and possibility of energy recovery not only for the DHS alone but also when it will connected to the whole energy management chain of the building where DHS is located (e.g. ventilation).

Major components were tested and their operating properties were integrated to new model of virtual hydrogen station. Modular units simulations of hydrolyser, EHC composite tank and fuel cell module clarifies their logics, basic relationships and interfaces were made. The simulation was implemented into a software, where basic correlation equations, internal and connecting logic between different components, which resemble realistic automation of the system in life-size.

The whole system simulation was made for a small house assuming the set of a typical (fixed) parameters, for instance stationary tank of 20 m^3 with maximum 700 bar compressed hydrogen storage, 56 AFC in a serial stack, sleep DC power demand of 150W and maximal DC power demand of 2000W at peak load (by-heat production was counted). For different scenarios additional hydrogen generation was imposed on demand as 350 NL/h (based on hydrolyser) if SOC of the storage tank went too low (this automatically sets AFC stack off, as shown above so no DC power generated and consumed at the same time). The power demand was composed of the above limits adjusted by daily load and harmonic variation over the year (lower demand for summertime). Power demand needed by hydrolyser and EHC was counted as negative power (consumed) in the whole balance:

Energy delivered by AFC stack	+7660 kWh_{el}
Energy by-heat from EHC and hydrolyser	+28 kWh_{th}
Energy delivered to hydrolyser	-4989 kWh_{el}
Energy delivered to EHC	-41 kWh_{th}

Hydrogen
consumed -711.2 kg, generated +51.6 kg

4.3.3 Conclusions

The simulation algorithm has been demonstrated to produce adequate evaluation of the power and energy balances (DC, hydrogen, heat). Final design also requires a proper heat management module, but it was found to be dwelling-dependent, so in a real application these modules should be connected to e.g. fresh air supply, local heating etc. to ensure the proper balance of temperature and ventilation. Additional interface for car tanking has been also developed and can be connected into the whole system.

Even with this simple model it is possible to find the operational windows for the simple distributed energy system like size of the storage tank and AFC stacks vs. power demand. To build up a real hydrogen station means larger financial investments. Thermal management using advanced ERV (enthalpy recovery ventilator) concept, heat recovery from air (annual), oxygen storage (by-product from hydrolyser), and heat recovery circuit still must be designed to close the complete polygeneration system. HFP can be used as back-up solution to start the system after shutdown or a blackout and it is not very dependent for the DHS internal structure. For large-scale module design proper integration with off-grid power (solar, wind) is needed (e.g. Utsira's experience).

The experience acquired during this project allows now extending R&D towards practical novel tanks design, where new MH materials might be employed besides AB_5 and SBH. Both reversible and non-reversible materials were demonstrated to be feasible with this system (tank, heat management, balance of plant). In future safety issues need to re-considered (e.g. if alanates or the like advanced materials will be used).

Future studies will also include advanced heat management to improve heat recovery (either from charge/discharge or adjacent fuel cells or BoP components), control system and integration of the MH storage with practical applications. The work is being continued under framework of new national and international projects.

4.4 Analysis and optimization of heat exchangers for fuel cells

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4.4.1 Introduction

A CHP system based on fuel cell technology includes several gas recycling, heat exchanger and transfer equipments and solutions. However, the linking of these systems is not well understood or analysed, although the quality of the linking may in practise be the decisive issue, that defines the efficiency of the system. In this study fuel cell based CHP-systems were analysed and optimized by thermodynamical methods and tools.

The main objectives of the project were to find out the critical internal linkages of the different components in fuel cell system based CHP-applications and to analyse and optimise these mutual interactions in a sense of the total system optimum. The study included both the low (PEM) and high (SOFC) temperature fuel cell systems but the emphasis was in SOFC systems. The focus of the study was in whole fuel cell system and its components (heat exchangers, reformer, etc.) whereas there was no technical development of the fuel cell unit itself.

4.4.2 Work undertaken

There were three work packages in the project. In the first work package the thermodynamical analysis (i.e. exergy analysis, entropy analysis, thermodynamic equilibrium calculations, thermal and mass transfer calculations etc.) of different system possibilities were carried out. During the analysis the thermodynamic role of the different components was clarified and after that the optimal process parameters and coupling of the whole system was defined.

In the second work package a feasibility of different heat exchanger possibilities for the fuel cell systems were more precisely worked out. The fuel cells and fuel cell systems have specific features which may set new kind of limitations or demands for heat exchangers compared to more conventional CHP systems.

The third work package contained an analysis of demonstrations or simulations of the fuel cell system in a CHP application in co-operation with VTT.

4.4.3 Methods

A new optimization procedure was developed. All the processes are assumed to be adiabatic and no pressure losses were considered. The evaluation of the system's quality consisted in the exergy losses in different components. One example of systems is presented in figure 4.4. For all the components energy fluxes were defined and calculated taken in account temperature levels determined by earlier components:

$$P + \sum_{out} \dot{n}_i h_i - \sum_{in} \dot{n}_i h_i = 0 \qquad (1)$$

where P i the power of the component and sum terms the enthalpies of outgoing and incoming fluxes of the component, respectively. The compositions of gas fluxes from reformer, fuel cell and burner were defined by equilibrium assumption, i.e thermodynamically by minimizing the Gibbs energy:

$$dG = \left(\frac{\delta G}{\delta T}\right)_{p,n} dT + \left(\frac{\delta G}{\delta p}\right)_{T,n} dp = \left(\frac{\delta G}{\delta n_i}\right)_{T,p,n_j}^{dn_i} \qquad (2)$$

where Gibbs energy G is defined as

$$G = G(T, p, n_1,...n_i) \equiv H(T, p, n_1,...n_i) - TS(T, p, n_1,...n_i) \qquad (3)$$

The conventional expression of exergy is presented in an inequality form and with not well defined magnitude called ambient temperature. In this project a new presentation for the real working power was formulated by combining the first and second law of thermodynamics and by separating the system into heat-absorbing and heat-emitting parts:

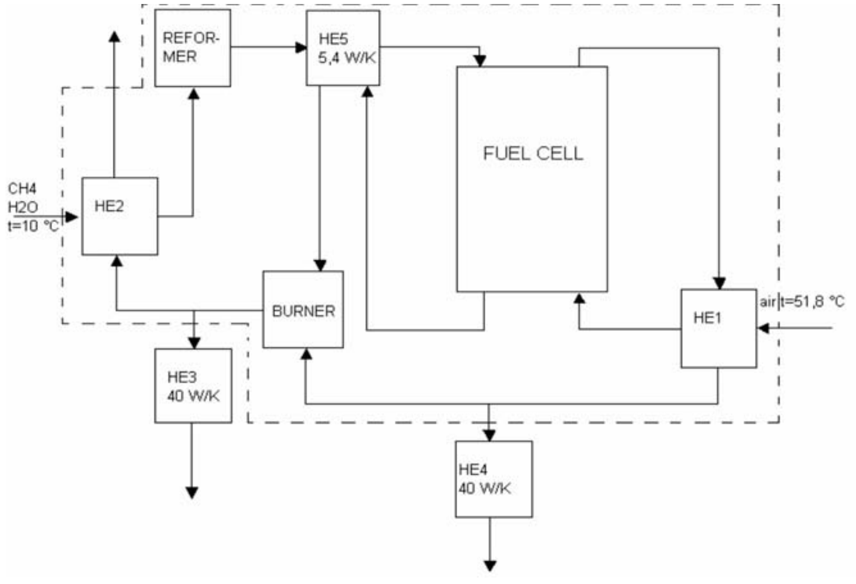

Figure 4.4. An example of CHP-systems analysed in the project (HE = heat exchanger).

$$P = \dot{m}\left[\left(\left(h_{in} - T\_s_{in}\right) + \frac{1}{2}w_{in}^2 + gH_{in}\right) - \left(\left(h_{out} - T\_s_{out}\right) + \frac{1}{2}w_{out}^2 + gH_{out}\right)\right] \quad (4)$$
$$+\phi_+\left[1 - \frac{T_-}{T_+}\right] - T\_\sigma$$

With this new formula a new, system depending, definition for ambient temperature can be found and a real comparing of different system alternatives is possible.

4.4.4 Results

During the project it had become clear that the conventional definition of exergy (loss) is not convenient to analyse and optimise the system, because the mutual interactions of different components stay unclear. By using the new expression defined in the project the effect of these interaction can be taken into account.

With the optimization procedure developed in the project fuel cell systems, like in figure 4.4, with several different input parameters were analysed and optimized. As an example in figure 4.5 is presented how the incoming mass flow of air affects to the exergy losses (ie. lost power) in different components.

In the analysis proved that there is an operation area, where the system is extremely sensitive to any change in input parameters. On the other hand the operation parameters can be defined also so, that the system behaves very stably. A detailed analysis of the limits of unstable and stable situations was made in the project.

From the system components, reformer and heat exchangers were analysed more precisely. Reformer study consists of equilibrium state calculations, temperature, pressure and mole fractions as parameters. From the reforming technics steam, autothermal and partial oxidation were included in the study and from the fuels methane and (bio)ethanol.

Heat exchangers were studied both thermodynamically and experimentally. The main result of theoretical consideration was that the exergy losses due to heat losses may easily be 90% of the total losses and that heat insulation has to be

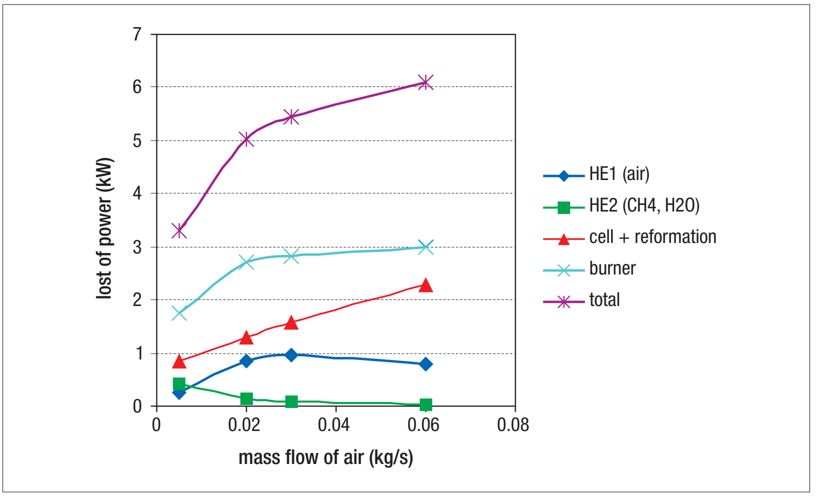

Figure 4.5. The effect of incoming mass flow of air on the exergy losses of components and system.

taken seriously. Heat exchangers were also studied in laboratory tests. In the fuel cell based CHP-systemseffective gas-to-gas heat exchangers are needed. On the other hand commercial heat exchangers are most often gas-to-liquid based. In tests it was found out that the commercial heat exchangers can be used in these systems, but they need to be modified. In figure 4.6 is presented a modified gas-to-liquid heat exchanger developed and tested in the project.

Figure 4.6. Modified gas-to-liquid heat exchanger tested as a gas-to-gas heat exchanger.

Published reports and papers

Articles

Markku Lampinen, Ralf Wikstén: Theory of effective heat absorbing and emitting temperatures in entropy and exergy analysis of combined flow systems, Accepted to be published in J. Non-Equilibrium Thermodynamics

Master's Theses

Xavier Linares Coderch, Literature survey with chemical equilibrium calculations of bioethanol processing for fuel cells, Master's thesis, 6.7.2005, 65 s.

Paula Tynjälä, Exergy analysis of solid oxide fuel cell system.

Student exercises

Paula Tynjälä: Thermodynamic analysis of pre-reforming methane in SOFC system, Course Ene-39.044 Individual Assignment in Thermal Engineering, large, 2.1.2005.

Outi Engman: Thermodynamic analysis of SOFC-system, Course Ene-39.018 Theoretical Assignment in Applied Thermodynamics, 26.8.2005.

Paula Tynjälä: Literature survey with theoretical study of reaction kinetics and the equilibrium state calculations of ethanol steam reforming. Course Ene-39.018 Theoretical Assignment in Applied Thermodynamics 26.1.2006.

Ursula Lirchgässner: Thermal performance of Vahterus Plate&Shell heat exchanger for gas-to-gas heat exchange, Special Assignment in Applied Thermodynamics, 8.6.2006.

Kaisu Malinen, Thermal performance of modified Vahterus Plate&Shell heat exchanger, Special Assignment in Applied Thermodynamics, 13.6. 2006.

4.5 Development of a 1 KW power pack concept (POWERPEMFC) 2004–2006

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Electrochemical energy conversion will play a key role in the hydrogen economy for the efficiency of the devices is not limited by the Carnot efficiency limiting thermal devices. Thus fuel cell markets are expected to grow substantially in the near future. Typical early application areas are portable electronics, telecommunication and computers, emergency supply especially to computer centres and link plus measurement stations in remote locations: applications, where fuel cells are competing with primary and secondary batteries. Polymer electrolyte membrane (PEM) based fuel cells and hydrogen generators are considered candidates for hydrogen production from water and conversion back to electricity. PEM fuel cells are being developed for portable power sources, distibuted power generation and automotive power. The main R&D issues are to increase the operational life and to reduce the cost of the components and systems.

When fuel cells are competing with conventional combustion engines the early markets can be found in areas where reduced pollution or other features add value for fuel cells. Those early markets are military applications and mining vehicles. When technology matures it will expand to other traffic solutions, both as Auxiliary Power Units (APU) and the main power supplies. Another major market segment is residential and distributed combined heat and power. As to industry, this means possibilities to create new production and growing turnover. Already today the essential components of PEMFC: proton conducting membrane in contact to catalytic surface and gas diffusion layer (GDL) are available on industrial scale, which enables the markets to expand to mass markets.

The key cost factors of PEM fuel cells are the electrolyte membranes, the catalysts and the bipolar plates used to interconnect individual electrochemical cells in series. The long-term objective is to reduce the system cost from 1000–10000 €/kW today to 300 €/kW for distributed power and working machines and to 50 €/kW for automotive.

Perfluorosulfonated Nafion® membranes by DuPont are commonly used as the electrolyte in PEM fuel cells and hydrogen generators. Different alternatives are being developed all over the world.

In the fuel cell projects VTT's approach is networks build up including universities and industry. VTT is also actively involved in international co-operation, both with EU and other countries. In this report also some results achieved amongst the consortium co operation are mentioned.

The project POWERPEMFC has been performed in co-operation with VTT and Helsinki University of Technology (TKK). The project included development of PEMFC bipolar plate design and validating the modelled results in a segmented cell. Construction of a 1 kW power source including stack and BoP was done and control strategies were developed. Also bipolar plate materials were developed, both conductive composites and metals.

4.5.1 Objectives

It is growing interest amongst Finnish industry to apply PEM fuel cells in various targets. The ability to design and construct a FC stack and a power pack will profit the application by facilitating already the demonstration and prototype version with appropriate fuel cell engine. This project supports the application phase of fuel cell power by deepening the expertise in the essential areas of fuel cell operation. Industry will benefit of that, when it chooses to apply PEM fuel cells in its applications. The participating companies include those, which are interested in different phases in the value chain.

The POWERPEMFC-project aimed to the development of a PEM fuel cell based power pack. The first phase was the power level 1–2 kW, but upgrading to the level of 10 kW was in the program during the last year. The construction was designed series production in mind.

This project was started in 2004 with one year funding the work plan being for three years (2004–2006). The continuation in 2007 is under the name WorkingPEM.

The optimisation of the channel structure of the fuel cell is based on modelling that has been constructed by TKK Advanced Energy Systems. The validation of the model can be based on segmented cell together with the measuring electronics realized at VTT. The optimization of the MEA-GDL-structure has been in the program and reported. The work has included also a study of the effect of airborne impurities on the FC cathode. This work was made in LANL, USA by Mikko Mikkola (TKK Advanced Energy Systems).

A very important component in the stack is the bipolar plate being also that cost wise. This work has included the design of the bipolar plate. The development of compression moulding of the bipolar plate is includes in the program. Compression moulded epoxy resin/graphite powder materials have shown excellent conductivity values. Materials for composite bipolar plates have been well defined. Very high graphite powder fill rate is possible to obtain with specially designed fully reactive epoxy resin system. The responsible organisation is VTT.

Metallic bipolar plate materials possess useful properties from the point of serial production. The durability of stainless steel materials were under study. The pre-selection of durable formulas was done before characterisation in the fuel cell environment. The expert organization in metal properties in this project has been TKK Laboratory of Materials processing and powder metallurgy. The test includes analysis of condensate collected from the gas outgoing from the cell. Also conducting composite material has been tested identically.

The development of the application has been done by first acquiring the main auxiliary components of the cell: humidifiers pump for air and the control system together the measuring instrumentation and constructing a power generating FC system based on the stack developed in the previous project PEMFCTEHO.

The second phase has included the design of a minimized instrumentation for the BoP. That means omitting of any components not directly necessary and minimizing the amount and costs of the components left. All the necessary components including current conditioning were contained in a compartment and all the instruments were equipped with the necessary converters to be connected to the control system. The responsible organisation was HUT Automation Technology Laboratory.

The initial idea of the project was based on the fact that the essential component of the fuel cell: MEA production exists in volumes basis and the customer can order the MEAs shaped according to the stack design. It is thus possible to begin system development based on MEA and own know how. In this paragraph a short summary and conclusions are made.

4.5.2 Results

Cells and stacks

The initial design of the cell was done in co-operation between TKK Laboratory of Advanced Energy Systems and VTT (Figure 4.7). Different MEA/GDL constructions were going to be tested in the project in order to know which combination is most suitable for the aimed stack. Because of limited availability, the tests were performed with two combinations. MEA was PRIMEA Series 56 from W.L. Gore and GDLs were SGK

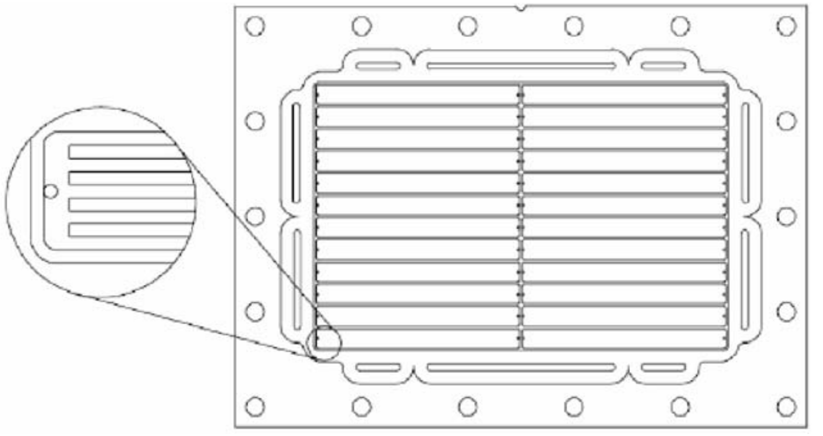

Figure 4.**7.** The channel structure of the flow field plate.

10-BB from SGL Carbon Group and Carbel from W.L. Gore. Based on the results, the recommended GDL is SGL 10-BB if the cell temperature is relatively low (60 °C), because it was not affected by possible too low or high humidification at that temperature. This also requires that the stack cooling system is efficient enough in order not to increase temperature of some parts of the cell too high. If the cell temperature is higher, the recommended GDL is Carbel.

The MEAs for the cell had been already ordered to be PRIMEA® Series 57 and the gas diffusion layer Carbel® from the same company. The MEA Series 57 is designed for reduced balance of plant requirements. It can be concluded that the results can be applied also to Series 57 MEA, which is more tolerant to low humidification than Series 56.

The effect of impurities

This work was made in LANL, USA by Mikko Mikkola (TKK Advanced Energy Systems). Air contaminants may affect fuel cell performance by many different mechanisms. The effect of NaCl on PEM fuel cell performance was studied. Sodium is known to replace protons in Nafion® polymer, thus increasing cell resistance, and chlorine ions adsorb to the catalyst surface, decreasing the number of available reaction sites. In this study NaCl was injected in an operating single cell and degradation of performance observed.

The results showed that the performance loss could be attributed to changes in proton conductivity due to the displacement of protons from the membrane by sodium ions. The effects of chloride ion on catalysis were not evident, although they could be important under longer and higher potential operation. The change in proton conductivity was not accurately reflected by HFR as sodium ion conductivity and ionic conductivity in the electrodes could not be separated.

The amount of NaCl used in the experiments presented here was very large. While the exposure time was relatively short, the total salt exposure would be more than most fuel cells could expect to see even under the harshest conditions (marine applications or stationary devices in coastal regions).

Optimization based on modelling

Flow field distribution and end plate structure have been modelled and a 2-D fuel cell model that takes into account the inhomogeneous compression of GDL in order to optimize the rib/ channel -structure of the flow field plate have been made.

The flow field properties of the POWERPEMFC -project cell were studied with a finite element method based model that was implemented with commercial finite element software Comsol Multiphysics (previously called Femlab). The results showed that for a parallel flow field design, which typically has an uneven flow distribution in the channels, the channel configuration was relatively good. In order to make the flow velocity distribution more even, the distributor channel geometry was modified. The flow velocity distributions in the original and modified distributor channel geometries were also studied experimentally and the results were in agreement with the modelling data.

The main function of the end plates is to offer mechanical support for the stack. The pressure distribution in the stack resulting from the end plates was studied with finite element modelling. The original stack end plates of the POWER-PEMFC-project cell were two centimetres thick steel plates with a combined weight of approximately 14.2 kg. The results show clearly that despite its bulkiness, the current end plate structure could not provide sufficiently even pressure distributions on the gas diffusion layers of the cell. Different rib structures were tested to improve the gas diffusion layer compression and simultaneously decrease the end plate mass. When aluminium was used as the end plate material, significant improvements on both accounts were reached.

In order to be able to optimize the rib/channel –structure of the flow field plate, the effects caused by the inhomogeneous compression of GDL must be known. The GDL intrusion into the channel was measured with several channel widths and compression values. The evaluation of parameters was done with SGL 10-BA. The gas permeability as a function of thickness was measured with a purpose-build measurement apparatus. A model that can be used in the rib/channel –structure optimization was constructed.

Segmented cell

Anode flow field was divided into 60 segments to study current distribution in the flow field area. The measurement technique used in this work to sense the current from each segment is based on the Hall Effect. The most important result of the measurements has been validation of the calculated result of the shape of the distributor channel. Figure 4.8 shows the measurement device.

Characterisation of a commercial stacks from SGL Carbon and Nedstack

A 5-cell stack from commercial components from leading suppliers has been assembled. MEAs and GDLs were purchased from W.L. Gore. Bipolar plates, end plates, current collectors and other stack hardware were bought from SGL Carbon. It was observed that the groove

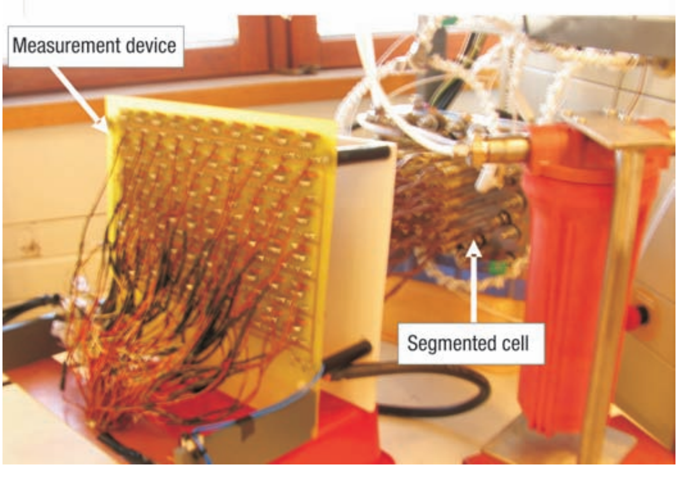

Figure 4.8. Measurement device attached to the segmented cell.

depths had deviations causing uneven pressure distribution. After replaced by acceptable plates the 5-cell stack was characterised at 50 C. Tests showed that flooding of gas channels is a performance limiting factor, but it can also be reduced by proper flow management. During the assembling of the 20 cell stack a mistake was conducted. One of the gaskets in one of the end plates was misplaced, so the stack was disassembled and assembled again. The misplaced gasket had a permanent effect on the performance on the cells 18, 19 and 20. Even if the performance was limited by the behaviour of the cells 18–20 the performance was sufficient that a power of 1000 W could be reached. 1 kW 8-cell pemfc stack from Nedstack was studied as a part of PowerPEMFC project. Overall performance of the studied stack seems good and no significant problems were found during tests.

Design of third generation stack with graphite composite bipolar plates

In 2006 the stack development was redirected so that the initial cell has been replaced by the one that allows cost effective manufacturing and assembling. Due to requirement of low pressure drop on the cathode straight channels were chosen. On the anode and cooling side conventional serpentine channels are used. It was possible to get the stack gas-tight and the performance was acceptable. The cell voltage was 20-30 mV lower than in small single cell with the same operational parameters. This is an excellent result. Pressure drops were as planned for the gas channels but for the cooling channels the values were higher than planned. Figure 4.9 shows the cathode design.

On the anode side and on the water side the chosen geometry was multiple serpentine. The designs are shown in Figures 4.10 and 4.11.

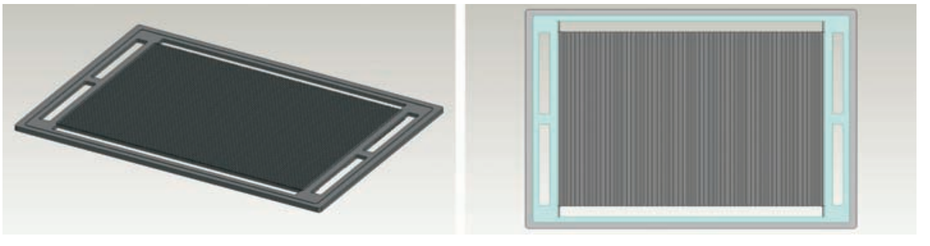

Figure 4.9. Cathode design and gasket.

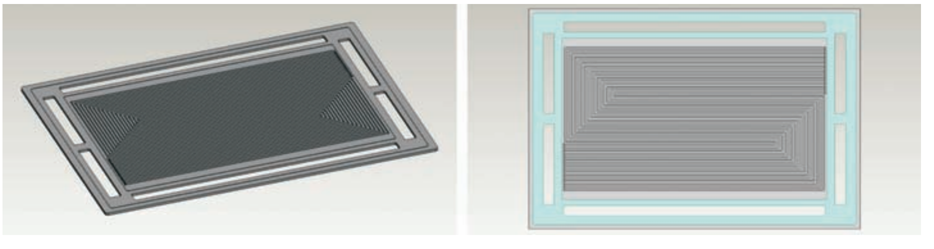

Figure 4.10. Anode side

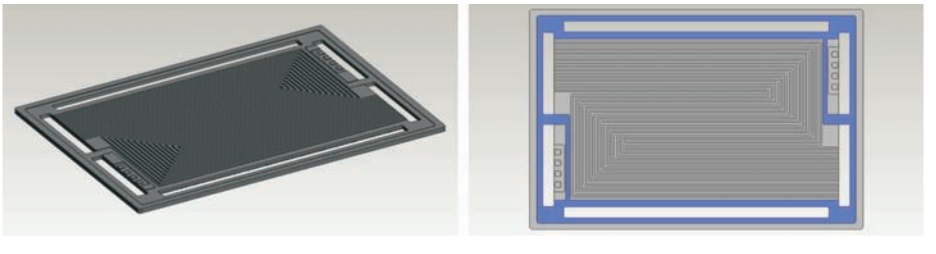

Figure 4.11. Cooling cell

On the water side is possible to use thicket gasket and place a Grafoil layer on top of the water channel. This possibility was used in the project.

Composite bipolar plates

Research at VTT Advanced materials has produced competitive properties for PEM fuel cell bipolar plates. A series of tryouts was made to learn and define details of manufacturing practices.

Steel bipolar plates

A channel structure was formed on the steel samples by electro discharge machining in order to use the samples in single cell test arrangement. Voltage drop during constant current operation and corrosion metal ions in the exhaust gas condensate were observed. It was found that the concentration of corrosion products is more pronounced on the anode side. The voltage drop versus time data is from a short period of time (Table 4.1).

Table 4.1. Voltage drop rate during the bipolar material test. The composite material is made in March 2005.

Sample material	Voltage drop rate mV/h	
	Anode	Cathode
316 L	1.08	0.18
904 L	0.7	0.4
309 S	0.3	0.4
Composite	0.25	0.13
Reference	0.11	

Development of Instrumentation and BoP for the Power Pack

The first version of the control and measurement system has been built around the "old" 18-cell PEM stack developed in the previous project. The second version of the BoP and control system is a pre-commercial prototype built inside a cabinet. The BoP and the control system have been set up successfully and tested during operation. Figure 4.12 shows the air and hydrogen circuit and instrumentation.

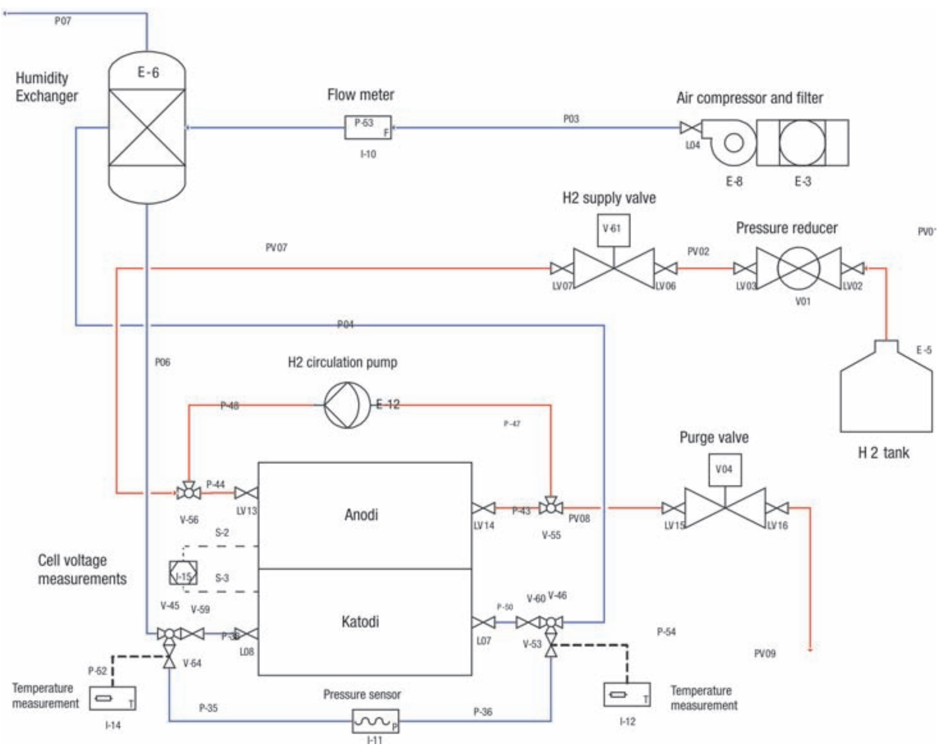

Figure 4.12. Air and hydrogen circuit instrumentation

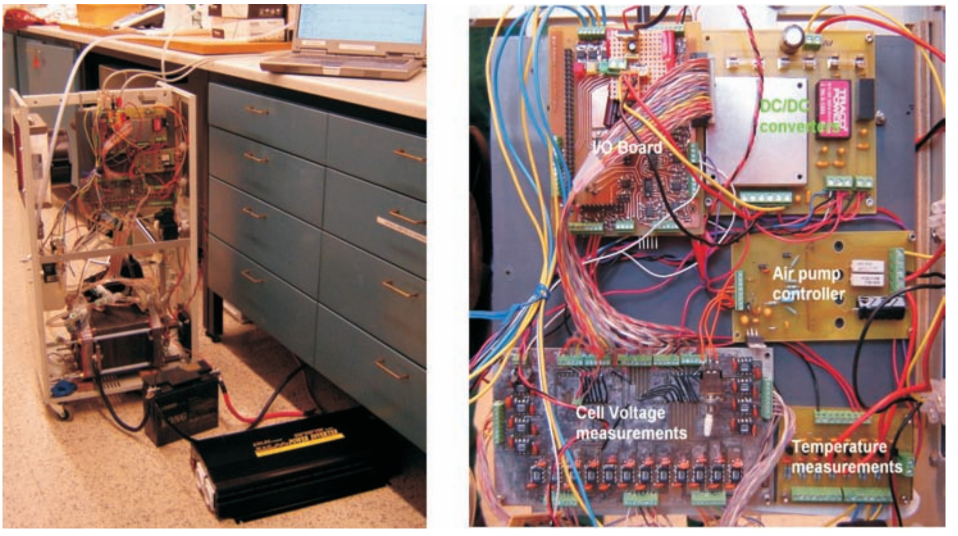

Figure 4.13. a) The 1 kW Power Pack under test drive b) The controller centre

The one kilowatt system was build around the 20 cell SGL stack, Figure 4.13. The nominal gross power of 1100 W was easily obtained by using air pulses to drive the excess water out from the cathode channels. The hydrogen stoichiometry has been varying between 1.1 and 1.2 during the tests.

Net power of the system remains at 900–950W because of the air pump not very economical: ~2.4 W consumed at a rate of one litre per minute. This leads to the system net efficiency ~31–33%.

The prototype BoP could be developed to a series product after some modifications and additions: especially less energy consuming pump would be necessary. The current inverter needs to be applied depending on the application.

4.5.3 Networking

Participants of POWERPEM were VTT, TKK, Tekes, Labgas, FY-composites, Outokumpu, Wärtsilä, MSC-electronics. International cooperation included participation in the EU project FCTestNet during 2003–2005 and the IEA Advanced Fuel Cells annexes IEA-Annex XVI Polymer FC, IEA annex XXI Portable fuel cells and organisation of CEA/VTT workshops.

Reports and published papers

1. M. Mikkola et al. “The Effect of NaCl in Cathode Air Stream on PEMFC Performance”, Abstracts of the 205th Electrochemical Society Meeting (9.–13.5.2004, San Antonio, Texas, USA), The Electrochemical Society 2004.
2. M. Mikkola, T. Rockward, B. Pivovar, F. Uribe, ‘The Effect of NaCl in Cathode Air Stream on PEMFC Performance’, Fuel Cells 2007, 7(2), pp. 153-158.
3. S. Karvonen, T. Hottinen, J. Saarinen, O. Himanen, ”Modeling of Flow Field in Polymer Electrolyte Membrane Fuel Cell”, J. of Power Sources 161, 2006.
4. T. Hottinen, M. Mikkola, O. Himanen, I. Nitta, ‘Inhomogeneous Compression of Gas Diffusion Backing under Flow-Field Plates’, Abstract, In: Conference Proceedings of The First European Fuel Cell Technology and Applications Conference, p. 106, 14. –16.12.2005, Rome, Italy.
5. Giuseppe Pepe , Jussi Suomela, Matti Valkiainen, Jorma Selkäinaho, Steady state optimization of a PEM fuel cell system operational parameters, Poster in First European Fuel Cell Technology and Applications Conference, 14.–16.12. 2005, Rome, Italy.
6. Nitta, T. Hottinen, O. Himanen, M. Mikkola, ”Inhomogeneous compression of PEMFC gas diffusion layer, Part I:Experimental”, accepted for publication in Journal of Power Sources.
7. T. Hottinen, O. Himanen, S. Karvonen, I. Nitta, M. Mikkola, “Inhomogeneous compression of

PEMFC gas diffusion layer, Part II:Modeling the effect, accepted for publication in Journal of Power Sources.

8. Modeling and Optimization of PEMFC Stack End Plates, Suvi Karvonen, Tero Hottinen, Jari Ihonen, Heidi Uusalo, submitted to Journal of Fuel Cell Science and Technology (2006).

Theses

1. Giuseppe Pepe, Measuring and Control System for an Experimental PEM Fuel Cell, Helsinki University of Technology, Master's Thesis 142 p. 2004.
2. Heidi Uusalo, Vesijäähdytteisen polymeeripolttokennon rakenteiden optimointi ja suorituskyvyn määrittäminen (Optimization of the structure and determination of efficiency of water cooled polymer electrolyte fuel cell), Tampere University of Technology, Master of Science thesis, 70 p. 2005.
3. Suvi Karvonen, 3D Modeling of Flow Field in Polymer Electrolyte Membrane Fuel Cell, Helsinki University of Technology, Master's Thesis 49 p. 2005.
4. Timo Keränen, Development of a precommercial 1 kw PEM fuel cell power pack, Helsinki University of Technology, Master's thesis 86p, 2007.
5. Mikko Mikkola, Studies on Limiting Factors of Polymer Electrolyte Membrane Fuel Cell Cathode Performance, Helsinki University of Technology, Doctoral Thesis (Dissertation 4.5.2007), ISBN 978-951-22-8589-1, ISBN 978-951-22-8590-7 (PDF), ISSN 1456-3320, ISSN 1459-7268 (PDF).

4.6 The national SOFC project FINSOFC

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4.6.1 Introduction

The aim of the Finnish publicly-funded solid oxide fuel cell program (FINSOFC) is to develop technology for a SOFC power plant demonstration and to provide a development platform for industrial enterprises in order to support their development work. The program was originally proposed by Wärtsilä Corporation, which is interested in the large fuel cell applications in a power range of 50 kW to 5 MW to be used in various CHP and marine applications. The program is also supported by several other companies with interest in different business areas related to the SOFC technology such as production of balance of plant (BOP) components or utilising SOFC systems in a wide range of possible applications, e.g. as distributed combined heat and power systems and auxiliary power units (APU). This platform development program is managed by Fuel Cell Group at VTT Technical Research Centre of Finland.

4.6.2 Objectives

The general objective of FINSOFC is to create possibilities for SOFC-related business to the companies involved in the program. We also offer good facilities for research and education to the Finnish universities. However, the concrete target of the project is to construct a natural gas fuelled 5 kW_e SOFC (planar type) power plant demonstration connected to heat and electricity grids and run it for a long period of time to gain valuable operational experience.

Description of experimental work

In practise, the program is divided into four subprojects with own targets, but the targets are linked to the construction work of the grid connected natural gas fuelled SOFC based 5 kW_e power plant demonstration (SOPOP). The subprojects are 1) Fuel processing, 2) Characterisation of fuel cells and short stacks in real operation conditions 3) System and BOP-component development and 4) System modelling.

Fuel Processing

In fuel processing the main fuel choices are natural gas and commercial low sulphur diesel (5 ppm) but also bio-based fuels like methanol will be processed. Autothermal reforming (ATR) was chosen for fuel processing due to the flexibility of the technology i.e. the process can be operated in steam reforming (SR) and catalytic partial oxidation (CPOX) modes. In Finland, natural gas comes from Russia and contains mainly methane (97.7 mol-%) and minor amounts of ethane (0.8 mol-%), propane (0.3 mol-%), nitrogen (0.9 mol-%) and trace amounts of other component (0,3 mol-%) such as higher hydrocarbons and sulphur odorants.

Characterisation of fuel cells and short stacks in real operation conditions

The characterisation of unit cells and short stacks is mainly done in collaboration with EU IP Real-SOFC project. Cells and stacks are delivered by European developers such as Research Centre Jülich (FZJ), HTceramix (HTc) and Energy research Centre of the Netherlands (ECN). The purpose of the cell and short stack characterisation is to deliver information for system controlling purposes; e.g. how the system should be controlled during load changes and under different gas compositions. In addition, benchmarking for unit cells from different manufacturers has been conducted.

Unit cell test stations (Figure 4.14) have been acquired from ECN and they have been modified and fully automated for our own purpose by VTT. Humidified (3%) hydrogen, synthetic reformate (H_2, CH_4, CO, CO_2, N_2 and H_2O), single reformate component and real natural gas reformate are used as fuels for unit cell testing. Short stack testing facilities (Figure 4.15) are designed and constructed at VTT and hydrogen, synthetic reformate and real natural gas and diesel reformates can be used as a fuel.

Figure 4.14. Unit cell test station.

Cell and short stack testing includes for example conventional reverse IV-curves, and studies of the load following capability, thermo cycling, degradation behaviour up to 4000 hours, fuel utilization, fuel contaminants, fuel composition variation, impedance spectroscopy and microscopy.

System and BOP-component development

The purpose of system development work is to demonstrate a small-scale combined heat and power plant (CHP) that includes all main BOP components needed in real power plant operation (Figure 4.16). The system operates at atmospheric pressure using autothermally reformed natural gas as fuel. Alternatively, hydrogen can be use as fuel as well during operation or in system stand-by situations. The system is designed for a planar anode-supported stack. The first 5 kW_e stack was delivered by Research Centre Jülich.

Figure 4.15. Short stack test station.

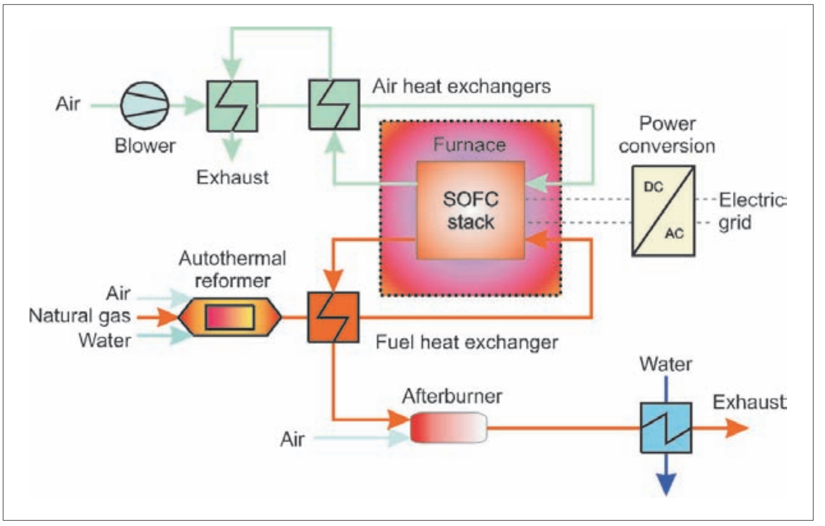


Figure 4.16. System lay-out of the grid connected natural gas fuelled SOFC based 5 kWe power plant demonstration. The system consist of planar 5 kW_e stack, ATR, Hex for fuel, air and exhaust gas, catalytic after-burner, power conversion, grid interconnection, automation, measurement, control and safety system.

4.6.3 System modeling

The power plant modelling consists of the preparation of modelling tools for key system components. The developed tools were implemented into the Advanced process simulation environment APROS®. APROS, which has been developed for 20 years by VTT and Fortum Nuclear Services, offers tools, algorithms and model libraries for the full-scale modelling of dynamic processes with automation systems. An integral goal of the modelling work is to verify the applicability of the developed tools against experimental results obtained from the individual component level up to system scale.

4.6.4 Examples of results

Fuel processing

Reforming of fuels with commercial monolithic noble-metal catalysts has been performed in varying operating conditions. A natural gas reformer has been operated well for more than 10 000 hours as shown in Figure 4.17 and a diesel reformer has been operated well for a shorter period of time.

Pre-reforming in SOFC applications is necessary in order to remove the hydrocarbons higher than methane, which may coke the anode. Another important aspect of the pre-reforming is to control the methane content in the reformate fuel feed. As the steam reforming is endothermic, the stack temperature can be controlled with the methane content. Effective control of the methane content reduces also the need of excess air at the cathode otherwise necessary for stack cooling. In the experiments, it has been possible to vary the amount of methane in the fuel stream between 0 and 30 mol-% in a few minutes. Therefore, the amount of methane is a powerful and fast tool for controlling the stack temperature during system operation. Reformer is thus not longer only a fuel processor but it is a part of the system control.

Pre-reforming of diesel has been done successfully and faradic equivalent efficiencies between 75-80% have been reached. The average composition is adequate for SOFC applications (H_2 = 35 mol-%, CO = 12 mol-%, CO_2 = 9 mol-%, H_2O = 13 mol-% and N_2 = 31 mol-%). Only trace amounts of hydrocarbons (ppm-level) could be detected from the fuel stream. Carbon formation is not a problem during operation, including the

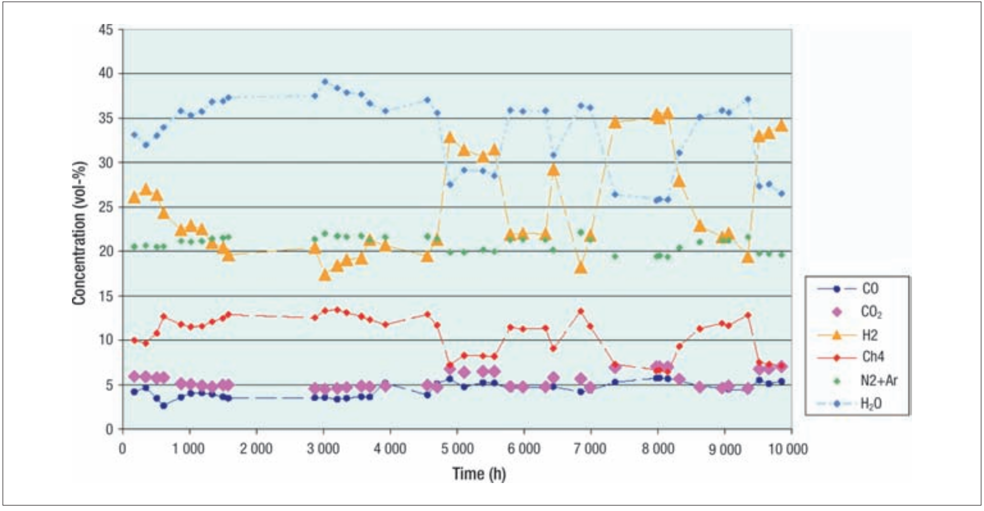


Figure 4.17. The natural gas reformate is well suited for SOFC operation and the main fuel components are hydrogen and methane.

start-up and shut-down procedures, for this diesel pre-reforming system.

In the case of natural gas, two different methods have been tested for sulphur removal. Sulphur odorants have been removed before the reforming unit by using commercial sulphur absorbent or from reformates after the reforming unit by using a zinc oxide bed. Both methods have been found to be effective enough and no sulphur can be detected after the sulphur removal units. In the case of diesel, sulphur has been successfully removed after the reformer by using a zinc oxide bed.

Cell and short stack testing

An example of a short-stack test is depicted in Figure 4.18. The purpose of the test was to study the effect of sulphur on the stack performance. Three different conditions were used during the test. Sulphur free fuel was used between 0–1000 h, sulphur rich fuel (2.8 ppm of H_2S) between 1000–2000 h, and sulphur free reformate between 2000–3000 h. As can be seen from Figure

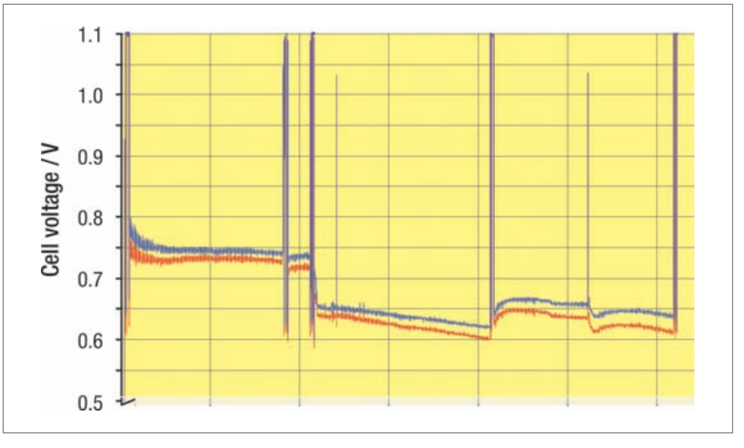


Figure 4.18. Cell voltages during the sulphur tolerance test of the short stack. The fuel (H_2 = 39 mol-%, CH_4 = 7 mol-% N_2 = 26 mol-%, H_2O = 28 mol-%) and air utilisations are 20%, and current density is 0.5 A cm^{-2}.

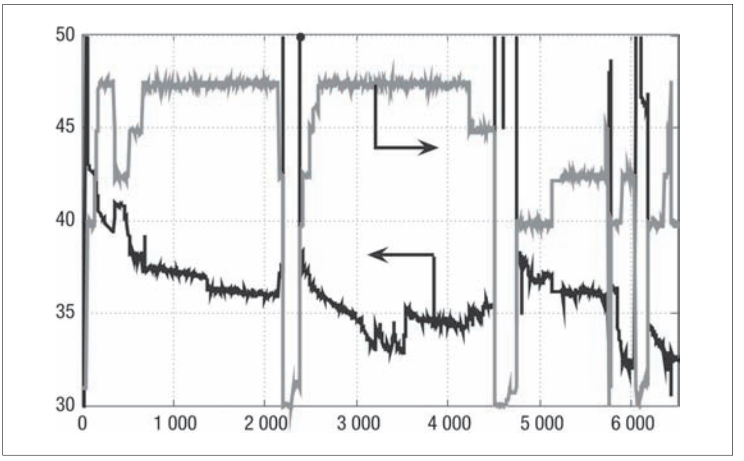


Figure 4.19. Long period experiments of the power plant demonstration. Degradation is about 1%/1000 hours at 0.35 A/cm[2] when fuel utilisation is 70%.

4.18, sulphur did cause an increase in the cell degradation. With the sulphur free fuel, the degradation rate was 6 % (0–1000h and 2000–3000h), and with the sulphur rich fuel (1000–2000 h), the degradation rate was doubled. Two kinds of sulphur poisoning could be found: reversible and irreversible.

System and BOP-component development

The power plant demonstration was started in May 2006 and the test continued for 7000 h (Figure 4.19). The power plant demonstration produces electricity to the laboratory grid in the power range of 3–6 kW_e depending on the operating parameters.

System modelling

A dynamic system model of the SOFC power plant demonstration has been composed and it comprises all main components of the real system: the SOFC stack situated in a furnace, autothermal reforming (ATR) unit, catalytic afterburner and anode and cathode side heat exchangers. Additionally, the model includes piping with heat losses along with appropriate valves and other basic components. Furthermore, basic control systems have been implemented in the model. Two different models have been used for the modelling of the SOFC stack: a 0D-model requiring low CPU time and a more accurate 1D-model capable of delivering the temperature distribution in co- and counter-flow SOFC stacks. The 1D-model has been developed by FZJ and it has been implemented to APROS in a trilateral project between VTT, FZJ and Wärtsilä Corporation. The system model has been verified against experimental results obtained from the actual power plant demonstration.

4.6.5 Conclusions

Good facilities for research and education have been created to the Finnish enterprises and universities. Simultaneously, very successful work in selected areas such as fuel processing, cell and stack testing, system development and modeling has enabled the construction of a successfully operating 5 kW_e SOFC based power plant demonstration.

Impacts

In addition to the general impacts on creating human resources and facilities for the development of SOFC technology the project has given strong support for Wärstilä and other companies in their development work trough developing modeling and hard ware and educating personnel. During this short period the SOFC research group has grown to such international standard that it now coordinates an 11 million euro projects including nine participants from different European countries. Important developments are natural gas reformer, diesel reformer, catalytic after burner, control systems for research facilities and demonstration units as well as soft ware tools for dynamic simulation of balance of plant components and the demonstration power plant itself.

Acknowledgement

Finnish Funding Agency for Technology and Innovation, the participating companies, Research Centre Jülich and Energy Research Centre of the Netherlands are gratefully acknowledged.

Networking

The FINSOFC project includes four research groups from Helsinki University of Technology, research groups from Tampere University of Technology and from Technical University of Lappeenranta. It also includes the following industrial enterprises. Wärtsilä, Fortum, Neste Oil, Verteco, Patria Vehicles, Gasum, The Finnish Gas Association, EON Finland, Helsinki Energy, Hamina Energy, Joroinen Energy.

European cooperation includes bilateral cooperation with ECN in Holland and FZJ in Germany. Cooperation with more than 20 companies and research organizations in Europe is realized trough the EU projects Real-SOFC and FCTES^{QA}. EU cooperation is also realized trough the VTT participation in formulating EU FP7 strategies by participation in the Strategic Research Agenda group in 2004–5 and the responsibility of stationary applications in the EU HFP Implementation Panel in 2006.

International cooperation is realized trough the participation in the IEA Advanced Fuel Cells Implementation Agreement ExCo and the Annexes SOFC and Stationary Applications.

References

1. Rolf Rosenberg, Jari Kiviaho, Matti Valkiainen, Posteri, 2002 Fuel Cell Seminar, Palm Springs, California.
2. Reetta Karinen, Diplomityö, “Raskaiden hiilivetyjen höyryreformointi”, TKK.
3. Pekka Saari, Diplomityö, “Polttokennoyksikön verkkoonliitynnän kysymyksiä”, TTKK.
4. Jari Kiviaho, Suullinen esitys, “SOFC Research, Development and demonstration in Finland”, IEA Annex XIII Meeting 18.11.2002, Palm Springs, California.
5. Timo Hämäläinen, Artikkeli, Kauppalehti Extra 22.4.2002, “Polttokenno tähtää kaupallisiin sovelluksiin”.
6. Jari Kiviaho, Suullinen esitys, “Status of SOFC Research, Development and demonstration in Finland”, IEA Annex XIII Meeting 22-23.9. 2003, Juelich, Saksa.
7. Matti Lindfors, Suullinen esitys, “SOFC system modelling using ChemSheet simulation model”, IEA Annex XIII Meeting 22-23.9.2003, Juelich, Saksa.
8. Mika Jussila, Diplomityö, “Polttokennokoelaitteiston automatisointi”, TKK.
9. Reetta Kaila, Posteri, “Autothermal reforming of hydrocarbons to H2", Towards a Hydrogen-based Society- kurssi, 9-5.8.2003, Tanska.
10. TV-esiintymiset mm. “Pallo Halllussa” sekä TV1:n opetusohjelmassa.
11. Jari Kiviaho, Suullinen esitys “SOFC Research, Development and Demonstration in Finland”, IEA Annex XVIII Meeting 1.11.2004, San Antonio, Texas, USA.
12. Kiviaho Jari ja Rosenberg Rolf, Fuel Cell Seminar, Technology, Markets and Commercialization, Abstract, sivut 5-8, 2004.
13. Sanni Mustala, Diplomityö, “Application of ferritic stainless steel as bipolar plates for solid oxide fuel cells”, VTT.
14. Kaila, R. K., Niemelä, M. K., Puolakka, K. J., Krause, A. O. I., Posteri, “Autothermal Reforming of n-Heptane and n-Dodecane on Nickel Catalysts”, 11th Nordic Symposium on Catalysis, Oulu, Finland, May, 23-25, 2004.
15. Kaila, R. K., Krause, A. O. I., Posteri, “Steam and Autothermal Reforming of Higher Hydrocarbons”, 7th Natural Gas Conversion Symp., Dalian, China, June 6-10, 2004.

16. Jari Kiviaho, Suullinen esitys, “The Finnish Public SOFC Research program”, 2004 Fuel Cell Seminar, 1-5.11.2004, San Antonio, Texas, USA.
17. Kaila, R. K., Krause, A. O. I., Suullinen esitys, “Autothermal Reforming of Diesel fuel to Hydrogen Rich Fuel Gas”, 7th Natural Gas Conversion Symp., Dalian, China, June 6-10, 2004.
18. Kaila, R. K., Krause, A. O. I., Studies in Surface Science and Catalysis: Natural Gas Conversion VII 147, sivut 247-252, 2004.
19. Petri Kanninen, Erikoistyö, “Kaasupulssien vaikutus kiinteäoksipolttokennon toimintaan”, TKK.
20. Electrochemical Characterization and Modeling of Anode Supported Solid Oxide Fuel Cell. Noponen, Matti; Halinen Matias; Kiviaho Jari, Solid Oxide Fuel Cells (SOFC-IX). Eds. Singhal S.C.; Mizusaki J. The Electrochemical Society Proceedings Volume 2005–07. Pennington, NJ, USA (2005) Vol. 1, 544-553.
21. Durability of Anode Supported Solid Oxide Fuel Cells on Pre-Reformed Natural Gas. Noponen, Matti; Halinen Matias; Kiviaho Jari; Saarinen, Jaakko, 1st European Fuel Cell Technology & Applications Conference. Editors Moreno Angelo; Lunghi Piero; Bove Roberto. Proceedings of the 1st European Fuel Cell Technology & Applications Conference. Rome, Italy (2005) 13.
22. Dynamic Model of 5kW SOFC CHP Power Plant. Jaakko Saarinen, Matias Halinen, Matti Noponen, Jukka Ylijoki, Jari Kiviaho, 1st European Fuel Cell Technology & Applications Conference. Editors Moreno Angelo; Lunghi Piero; Bove Roberto. Proceedings of the 1st European Fuel Cell Technology & Applications Conference. Rome, Italy (2005) 96.
23. 5 kW SOFC Power Plant Test Station. Matias Halinen, Jaakko Saarinen, Jari Kiviaho, Matti Noponen, 1st European Fuel Cell Technology & Applications Conference. Editors Moreno Angelo; Lunghi Piero; Bove Roberto. Proceedings of the 1st European Fuel Cell Technology & Applications Conference. Rome, Italy (2005) 11.
24. SOFC System Development in VTT. Jari Kiviaho, Matias Halinen, Matti Noponen, Jaakko Saarinen, Rolf Rosenberg, 1st European Fuel Cell Technology & Applications Conference. Editors Moreno Angelo; Lunghi Piero; Bove Roberto. Proceedings of the 1st European Fuel Cell Technology & Applications Conference. Rome, Italy (2005) 8.
25. Cell testing practise in FINSOFC-project (esitys). Jari Kiviaho, IEA Annex XVIII SOFC Meeting, Quebec City, Canada, 2005.
26. Reduction of cells with reformate (esitys). Jari Kiviaho, SOFCNET -meeting, St. Andrews, Scotland, 2005.
27. Implementation and verifiaction of a dynamic solid oxide fuel cell system model -diplomityö. Vesa Ruusunen, TKK, 2005.
28. Kiinteäoksidipolttokennostojen mittausaseman rakentaminen ja automatisointi -diplomityö. Jukka Göös, TKK, 2005.
29. FINSOFC – The Finnish National SOFC Development Program, Jari Kiviaho, Rolf Rosenberg VTT, Heikki Kotila Tekes, Erkko Fontell Wärtsilä Corporation, The European Hydrogen and Fuel Cells, Technology Platform Annual Event 17. –18.3.2005.
30. FINSOFC2002–2006, Rolf Rosenberg, Technology Platform Operation Review Days, Brussels 8th-9th December 2005 .
31. Fuel Cell Modeling Activities at VTT Technical Research Centre of Finland. Noponen, Matti Invited presentation: Comsol Users Conference 2006. Copenhagen, Denmark. 1 - 2 November 2006.
32. Testing of SOFC cells and stacks at different conditions. Kiviaho, Jari; Noponen, Matti; Halinen, Matias; Saarinen, Jaakko; Rosenberg, Rolf. Invited presentation: 31st International Cocoa Beach Conference & Exposition on Advanced Ceramics & Compositions, Daytona Beach, Florida, USA, January 2007.
33. Dynamic model of 5 kW SOFC CHP power plant. Poster abstract. Saarinen, Jaakko; Halinen, Matias; Noponen, Matti; Ylijoki, Jukka; Kiviaho, Jari. Paper accepted to: Journal of Fuel Cell Science and Technology, August 2007.
34. Durability of anode supported solid oxide fuel cells on pre-reformed natural gas. Noponen, Matti; Kiviaho, Jari; Halinen, Matias; Saarinen, Jaakko. Paper accepted to: Journal of Fuel Cell Science and Technology, November 2006.
35. SOFC System Development in VTT. Rosenberg, Rolf; Kiviaho, Jari; Halinen, Matias; Noponen, Matti; Saarinen, Jaakko. Paper accepted to: Journal of Fuel Cell Science and Technology, May 2007.

36. Experimental Study of Anode Gas Recycling on Efficiency of SOFC. Noponen, Matti; Halinen, Matias; Saarinen, Jaakko; Kiviaho, Jari. Presentation accepted to 2006 Fuel Cell Seminar. Honolulu, Hawaii. 13–17 November 2006.

37. Characterization and Control of Autothermal Reformer for SOFC Applications. Halinen, Matias; Noponen, Matti; Saarinen, Jaakko; Simell, Pekka; Kiviaho, Jari. Presentation accepted to: 2006 Fuel Cell Seminar. Honolulu, Hawaii. 13–17 November 2006.

38. Computational determination of suitable operation parameters for SOFC stack at various current levels. Saarinen, Jaakko; Halinen, Matias; Gubner, Andreas; Noponen, Matti; Ylijoki, Jukka; Froning, Dieter; Kind, Andrea; Kiviaho, Jari. Presentation accepted to: 2006 Fuel Cell Seminar. Honolulu, Hawaii. 13–17 November 2006.

39. Finnish Platform for SOFC Research and Development. Kiviaho, Jari; Noponen, Matti; Halinen, Matias; Saarinen, Jaakko; Rosenberg, Rolf. Presentation accepted to: 2006 Fuel Cell Seminar. Honolulu, Hawaii. 13–17 November 2006.

40. Dynamic Co-Simulation of a Solid Oxide Fuel Cell (SOFC) and the Balance of Plant (BoP) by Combining an SOFC Model with the BoP-Modelling Tool APROS. Gubner, Andreas; Saarinen, Jaakko; Ylijoki, Jukka; Froning, Dieter; Kind, Andrea; Halinen, Matias; Noponen, Matti; Kiviaho, Jari. Lucerne Fuel Cell Forum 2006 (EFCF 2006). Lucerne, Switzerland, 3–7 July 2006. Conference CD. European Fuel Cell Forum (2006).

41. Installation and Operation of kW-Class Stacks from Jülich in External Laboratories. Vinke, Izaak C.; Erben, Reinhard; Song, Rak-Hyun; Kiviaho, Jari. Lucerne Fuel Cell Forum 2006 (EFCF 2006). Lucerne, Switzerland, 3–7 July 2006. Conference CD. European Fuel Cell Forum (2006).

5 ICT

5.1 Introduction

It is apparent that technical development ICT and automation has brought new opportunities for local power production. On the other hand, while small plants are usually low cost in building, the added cost of including expensive data communication systems or remote operation systems can be too much. The combination of new hardware, communication, and software technologies creates opportunities to achieve two-way interaction with all kinds of power network nodes, customers and customer equipment and to more autonomous, flexible self-managing (self-configuring and self-healing) system of networks. These novel ICT-enabled solutions will be key contributors in realizing reliable and efficient power distribution systems with high degrees of distributed power production.

Data collection and communication in distributed energy systems still vary with plants and functions. To some extent these are already automatic, but in data processing this is seldom the case. Some data is still collected manually and even sent by mail for further processing for statistical or custom purposes. However, the development in the field is rapid and there are various activities in e.g. the EU-funded programmes. Due to the rapidly developing data acquisition and transfer, many new functions are becoming possible. As sites may be small in size and numbers,

Netcontrol Oy

Netcontrol Oy, which specialises in monitoring and controlling systems for power production and supply, has developed a local automation system for operating and monitoring power plants and large companies in the industry sector. It is also used for monitoring and controlling the grid in railway traffic. The innovation was funded by Tekes.

The monitoring and controlling system plays a decisive role in distributed energy systems. The system must constantly signal information on the network's operability and production, and control new challenges of the energy production in the grid. A failure in the controlling system may paralyse the entire power supply chain.

Netcontrol's automation system can be used for monitoring and controlling both the grid and the power production. Control features enable the registering of the events in the grid in real time, detecting problem situations and alarming and reporting them. Additionally, automation operations can be constructed to quickly locate the failures in the grid and automatically define the point of failure. In power production, the system is being used particularly for the control and optimisation of the production. The system continuously calculates the most cost-effective way of producing power.

The focus has been in local information traffic between different appliances and between appliances and central control unit. The system enables the information traffic of the distributed energy systems and centralised monitoring, control and optimisation of connections. Hundreds of systems have already been sold in Finland, Norway, Sweden and Estonia.

expensive and sophisticated information systems will not be rolled out everywhere.

The ICT solutions to provide for such needs already exist today. It has therefore not been the objective to develop new ICT technology, but rather to apply existing technological solutions in the energy sector. The fast development in automation in general makes even the latest technology soon outdated, unless it immediately finds its way to the marketplace.

5.2 List of projects

Mikkeli Polytechnic
Development of automation and data transfer for small heat centrals
Date of funding decision: 27.5.2004
Research project, finished

VTT Industrial Production
Local energy resources in distributed energy systems
Date of funding decision: 26.6.2003
Research project, finished

Helsinki University of Technology
TCP/IP achitecture in control of distributed generation
Date of funding decision: 12.6.2003
Research project, finished

University of Vaasa
Information map for energy system management
Date of funding decision: 5.6.2003
Research project, finished

5.3 Automation and data communication for small heating centrals

Mikkeli Polytechnic

Traditionally, the automation of small boiler plants especially in district heating systems is implemented with unit controllers and alarming is often implemented with a simple one-way alarm system. Small plants usually work as a standalone unit and are not expensive to build, so it is not economical to include expensive data communication systems and remote operation sys-

Technology Centre Oy Merinova Ab

Technology Centre Oy Merinova Ab has analysed the possibilities for using mobile technologies in controlling interruptions in power supply. The findings show durations of failures caused by storm etc. can be shortened with help of remote controlling of delimiters in medium voltage power distribution network. The remote controlling can be carried out by several different technologies.

The foundation of the Merinova research was in the possibilities of data and communication technologies to improve traditional modes of operations used in power supply. The project mapped out remotely used appliances in the grid using telecommunication technologies such as GMS, GPRS, 3G and WLAN.

As a case study, a remotely controlled and monitored model for managing the delimiters in the medium voltage power distribution network was analysed and carried out. Currently, fixing a power failure caused by storm can take hours, especially in the countryside where the power lines are long. For example, if a tree falls on the power transmission line in storm, power transmission must be cut off for the duration of repair.

tems into them. Main goal of this project was to investigate the automation and communication in small boiler plants, and to lower the threshold of implementing automation systems and remote controlling in small units by designing cheaper and more easily adaptable automation systems.

The basis of the work in the project “Heat data – automation and data communication in small boiler plants” carried out by Mikkeli Polytechnic was to find out the current needs and difficulties in the field of automation systems for small heat and steam boiler plants. A part of this research was a communication technology research which was done to serve the needs of remote controlling and monitoring of plants and systems.

The goal of the research was to create solutions to help automation system and equipment manufacturers, users of automation systems and technology development companies to create and adapt cheap, reliable and profitable automation systems for small units. An important task in achieving this goal was to design a reliable and exact alarm information system and a two-way communication system.

The first phase of the project was to find out the actual needs and problems currently arising within the energy companies and automation manufacturers. Three individual researches for different types of boiler plants were done by interviewing a large variety of companies and combining the results together. This research clearly indicated that the interest and need to develop and make use of automation systems, alarm systems and communication systems was real.

With the help of a study about automation systems and their usage in heat supply systems and boiler plants, research has been done in several different business areas to find out the actual needs and requirements of automation systems and to design solutions to those.

A research about communication systems and different possibilities to transfer data between units and controllers was done by comparing different data transfer technologies, their advantages, disadvantages and costs and by designing and describing a reliable and secure wireless communication system to be implemented within a heat supply system.

This project adds valuable information about new product and service possibilities to companies operating at the energy and automation industry. The project produced several research reports and implemented pilot projects to test the research results in practice. The needs and possibilities of developing automation systems in boiler plants where analyzed including customers' needs. Current automation systems and their usage in heat supply systems were evaluated with the possibilities for wireless communication technologies to be used in the controlling of a district heating system.

The actual research- and development cases where specifically targeted at the enterprises involved in the project.

A pilot project to combine heat system automation to existing real estate automation system and to enable remote controlling and monitoring of a heat plant was carried out as was a pilot project to implement a reliable communication system to be used in remote controlling and monitoring.

The results of this project serve energy companies in their daily operation and for the manufacturers, increase the potential of designing new products and systems to both Finnish and export sales. With the help of the research results, manufacturers of boilers, boiler plants and automation systems can develop their products to be more competitive and gain more possibilities to sell their products, automation equipment and software. Real estate automation manufacturers can widen their area of business to the heat supply systems. Co-operation of boiler automation and building automation systems brings advantage to both parties.

The pilot projects were implemented in an actual environment and within real use cases, so the results provided real-world information about the current situation in the energy enterprises, the actual needs and problems to be solved and finally, tested solutions to those problems.

5.4 Management of local energy resources in distributed energy systems

VTT, Technical Research Centre of Finland

Society is utilising more and more information and communication technologies and it is becoming more dependent on reliable energy resources. There will also be more distributed energy resources connected to the electrical network. The coordinated management and automation of such resources becomes more important and includes new challenges and possibilities. Distribution requires new ways of working and management of processes producing integrated added value. In the area of distributed energy three commercial levels can be seen: services supporting the business and business networks, management and utilisation of local energy resources and control of individual production and consumption units. Information and communication technologies and automation are essential in gaining the aims and in developing the means and tools for controlling this kind of systems (production, transfer, distribution, storage, use).

The aim of the project "Management of local energy resources", carried out by a consortium led by VTT was to describe the area of distributed energy systems and identify the most important systems and implementation concepts related to them. The focus of the research was on systems less than 500 kW. New and emerging business models and implementation methods were utilised and taken as a starting point. Descriptions of cases of distributed energy systems were used to concretise the areas of the research.

Development needs and opportunities

It is a challenge to make small generation connected to the distribution network economically feasible. Development in automation and ICT, however, brings some opportunities that on a medium long term might change the situation. The most difficult issue is to find a path to develop the necessary technologies, as they are based on a developed infrastructure and far standardised basic solutions.

For developing energy management systems, an open architecture is of vital importance. This brings new components and brings competition that can drive costs down. Also, it must be possible to combine different components such that control, maintenance and trade functions can support each other. Continuously advancing ICT a will drive this development.

Grid connection has long been a tumbling stone for distributed generation. Although there has been a change in the tariff system, there is still a need for cheap solutions based on readily available components and semiconductor technology. Rather the demand is on the side of the network operator. Distributed generation requires advanced standardised solutions that are not presently available although work is in progress. The fast development in automation in general however makes new standards soon outdated, which is a challenge.

In addition to technology, also new business models are needed to create functional business networks. Also operational processes are to be developed and tested. There is also a need to develop model for contractual agreements within the value chains. The contractual status of an independent power producer is weak.

It is apparent that technical development ICT and automation has brought new opportunities for local production. The remaining problem is to find an infrastructure where these solutions can be planned and operated feasibly. As there are a number of technologies approaching breakthrough, it would be practical to create a focused strategy for piloting and monitoring new energy system solutions. Such a system would include standard solutions for grid integration and metering and demand side management of both power and heat to optimise production. The ICT solutions to provide this already exist today.

The ambition has been to identify and lay the groundwork for industrial development projects in the field. These could most feasibly advance through pilot demonstrations of small scale generation. At best, these would also show how a network of small specialised companies can operate an advanced system. Possible sites where distributed generation could be combined with research and monitoring activities should be mapped in order to enable monitoring the joint activities of free agents on the energy market. Such a mapping could also support a higher grade of automation in small-scale generation and would be necessary for the advancement of any Plug&Play-solution in grid connection.

5.5 TCP/IP-architecture in control of distributed generation

Helsinki University of Technology

The data communication requirements and capabilities of distributed energy resources vary today a lot with the considered type of power plant and information. Much of the reporting is still done manually for statistics or state authorities for example. However, the branch is developing fast, with demonstration and R&D projects in national and EU research programmes.

The production of a power plant is basic information used in energy trade, grid tariffs, taxation, production statistics as well as grid and electricity system operation. With an advanced billing metering solution, active and reactive power as well as power quality and power failures could be monitored. The monitoring and control of distributed power plants is developing towards remote use and condition monitoring. This increases the amount of data communication and the needs for data analyses. The meteorological conditions collected by the power plants can also be used for simulations models and statistics. Advanced data communication solutions can further be used for automatic alarms and fuel delivery applications.

The ambition in the project *"TCP/IP- architecture in distributed generation control"* carried out by a team led by the Helsinki University of Technology was to organize a multi-level protocol for flexible joint organisation of several communication networks in one system. The work aimed at defining the possibilities and needs for data communication and screening thus possible services. Thus service business opportunities related to distributed generation can be identified.

Data collection and communication in distributed energy systems still vary with plants and functions. To some extent these are automatic, but data processing seldom is. Some data is still collected manually and even sent by mail for further processing for statistic or custom purposes. However there is rapid development in the field and there is a lot of activities in e.g. the EU-funded programmes.

The most interesting feature is of course production data, being a principal magnitude in energy trade, network and system control, cost allocation, taxation, statistics, etc. In addition, it is of interest to owners, shareholders, O&M and other service providers. Energy metering is often double and stored in as well the plant controller as in billing meters. It can be read on site or remotely and is further processed according to needs. Some critical operations require real-time information on production, whereas others use only cumulative figures hourly or monthly. Central and even automated processing would make many things easier. With developed metering, many other things than just active and reactive power can be metered. Most important are features related to power quality and information on disruptions. Such multi-purpose solutions should be used instead of having separate sensors, meters and communication tools. In distributed generation there is in general a need or an opportunity for more efficiency and for cost-cutting solutions in data acquisition and processing.

Another important part is plant control and management, where remote solutions are being more prominent. This significantly increases the amount of data and analysing. So far, small units have operated unilaterally, without regard for system needs. With more and more local production it will come under control of the distribution grid, energy system or producer. In addition to producing active power, plants can contribute to reactive power control or other predetermined of real-time guidance.

Condition monitoring will become more advanced as technology is developed, components become cheaper and self-diagnosis of components will be usual. If data is processed ands analysed to the extent that an alarm is sent to a central control only in abnormal cases, the amount data communication is significantly reduced. Remote control as a function or even outside service will thus become more general.

Other features are information on plant operations that can be used in models, statistics and public information. In addition, data communication can be used for fuel deliveries and programming automatic alarms. Metering systems and data has to be compatible with other used formats. There is no point in creating new protocols, but it is in the interest of e.g. the grid operator, that production data has the same format as consumption data. Weather data should be compatible with information from weather stations etc.

Reports

Paikallisten energiaresurssien hallinta hajautetussa energiajärjestelmässä. Valkonen, Janne; Tommila, Teemu; Jaakkola, Lauri; Wahlström, Björn; Koponen, Pekka; Kärkkäinen, Seppo; Kumpulainen, Lauri; Saari, Pekka; Keskinen, Simo; Saaristo, Hannu; Lehtonen, Matti. 2005. VTT, Espoo. 87 s. + liitt. 58 s. VTT Tiedotteita - Research Notes: 2284. ISBN 951-38-6532-0; 951-38-6533-9. http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2283.pdf.

Hajautettujen tuotantolaitosten tiedonsiirtotarpeet ja -valmiudet. Lemström, Bettina; Holttinen, Hannele; Jussila, Matti. 2005. VTT, Espoo. 62 s. + liitt. 10 s. VTT Tiedotteita - Research Notes: 2283. ISBN 951-38-6529-0.

6 Manufacturing technology

6.1 Introduction

One of the promises of small-scale generation lies in being able to utilise developed industrial manufacturing to move from economy of scale (i.e. large power plants) towards economy of numbers (i.e. large number of power plants) and thus significantly reducing costs. At the same time, it needs to be understood that the advanced manufacturing solutions need big markets to pay back the investments.

Although industrial manufacturing was one of the most active areas of the programme, only two research projects were financed. Also, these were not pure research projects but to a large extent project pre-feasibility activities, where eventual ideas for development projects were pre-assessed. However, the ideas and concepts presented in these projects have to some extent been carried forward in the various industrial development projects.

6.2 List of projects

VTT, Technical Research Centre of Finland
Material and manufacturing technologies in small and medium sized boilers

VTT, Technical Research Centre of Finland
Advancing the competitiveness of distributed energy systems

Reports

Ilola, R, Juvonen, P., Virta, J., Eklund, P. ja Flyktman, M., Pienten ja keskisuurten polttokattiloiden materiaali- ja valmistustekniikat. TKK Raportti MTR 1/05, Espoo, 15 s.

7 Business models

7.1 Introduction

From the national point of view, the main challenges and goals for the Finnish companies and other organizations are to find out the way to penetrate into the changing value chain through the new business models. According to the pre-analysis[5] for Tekes, DENSY technology program were recommended to be directed to the following three main areas:

1. Design and development of products and production technology that is suitable for small scale systems, high volume production and also consumer markets.
2. Development of networked business models and networking among producers of distributed energy systems and related services.
3. Research and development of advanced technology in the field of distributed energy systems.

The same Report[1] shows that the main interests for the DG business and technology development in surrounding EU countries, e.g. Germany, Sweden and Denmark, lie principally in the renewable sector. Biomass installations already feature prominently, where on-site generation of feedstock is available, and windpower is increasing. The use of gas turbines, gen-sets and other DG technologies will also feature within the overall power mix, whether it be grid-connected or stand-alone, although only where it is economically prudent or necessary. It is believed that renewables will account for a major proportion of the DG energy-mix along with substantial amounts of new technologies, such as fuel cells and MCHP contributing to the general equation.

On the other hand, according to the Report[1], environmental considerations will come to play an increasingly important role in the formulation of energy policy. In the new EU countries, e.g. Poland and Estonia, the market for distributed generation systems is in its infancy but will grow at a rapid pace over the next five years. Distributed generation is able to bridge part of the capacity gap potentially left by the closure of inefficient, pollutant coal fired plant. As small-scale facilities require a smaller amount of initial investment than large power plants, more investors qualify for entering the power generation market. Accordingly the market for distributed generation systems will show impressive growth.

The market seems to be very prominent for the DG service and technology companies. However, there are some major restrictions[1] or even barriers for them. The existing energy generation and distribution systems and investments are still having a major role in energy production through the large capacities developed and available in the hydroelectric and nuclear power sectors. DG will struggle to compete with the grid electricity. In addition, market liberalization is not yet a driver either in Finland, as in many EU countries still retain a monopoly in power production and distribution. So far, DG is limited to some small hydro pumps and stations that provide both baseload and peakload power as well as limited amount of wind capacity in the remote area of the country. Currently, with cheaply available electricity, the opportunities for large-scale business in DG industry are not abundant.

5 Frost & Sullivan and Electrowatt-Ekono, 2002.

Partnering in the UK

Tekes, Finpro, Helsinki School of Economics (HSE), Motiva and nine small to medium sized enterprises in the energy sector started a project aimed at mapping out best operating models for exports and finding local partners.

The purpose was to promote Finnish enterprises' access to the UK market. In the collaborative project the market is approached using new models of operation. Also, the internationalisation of small and medium sized enterprises is studied in theory and practice. HSE is keeps track of the project, consults enterprises as needed and publishes an academic study and a publication directed to the enterprises. The target is to create an operation model for internationalisation that can be largely applied.

There are nine Finnish enterprises in the project : Hydrocell Oy, Alufer Oy, Laatukattila Oy, Netcontrol Oy, NHK-Keskus Oy, Process Vision Oy, Puhdas Energia Oy, Vapo Energia ja Verteco Oy.

In the UK, Hydrocell was looking for a larger market than Finland for its fuel cells. Once a suitable partner had been found, the sales started, too: Hydrocell supplies fuel cells to be used as power sources for fuel cell bikes and scooters as well as in different measuring systems.

"We want to find applications with large volumes in order to achieve the benefits of volume production. For example, with regard to the fuel cell bikes, we want to establish direct contacts through the entire value chain, from the bike manufacturer to the retailer. In the future, the cells will be installed in the bikes at the factory", says Hydrocell's CEO Tomi Anttila.

Penetrating into the misty future

As it has been shown[1], the DG market is still emerging and it needs very strong leadership from the large leading companies, and especially, a radical intervention of the authorities to make market increase faster. DENSY Programme has been an opportunity to penetrate into the DG business being as an accelerator for the development. DENSY Programme consists of four main research areas through which TEKES has been supporting the development of the DG business in Finland. The focal areas of the Programme are shown in Fig. 7.1.

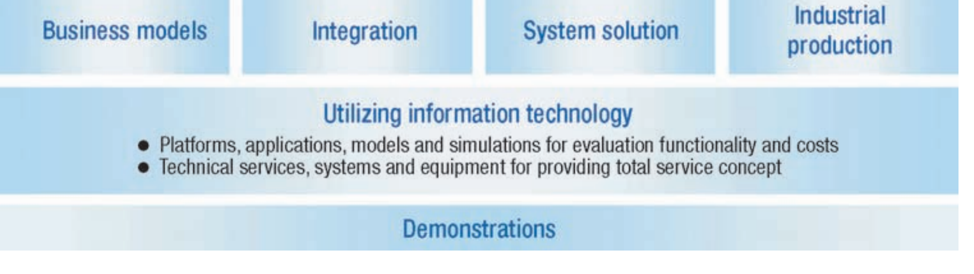


Figure 7.1. The focal areas of the DENSY program, Tekes.

In the business concept research of the Programme, several research projects (Fig. 7.2) have been conducted to create new knowledge of future business opportunities, to form optimal business concepts, and to make demonstrations for business use.

The overall *scope* of the research projects:

- Define value chain, business opportunities, and customer benefit

The main *Objectives* of the research projects:

- Commercialization of new technologies and services
- Formation of business networks
- Benefiting from the changing business environment

According to the following research projects, the business development of the DG is mainly related to the investments in existing systems and the intervention of the authorities. The future business development depends on the saturation point of the returns of the present investment. In other words, the business will increase when the returns of investments in new DG technology will be more profitable than the past and present investments.

This inflection point can also be affected by the authorities. According to the research projects, the most potential and strongest way in generating new business is to force companies utilize new technology through the legislation. This concerns only the areas with the well-developed infrastructure. At the same time, there are areas where such dilemma does not exist, e.g. Africa, South-America, and Far East. Due to that they are able to pass obsolete technology and can directly utilize advanced Distributed energy generation technology.

In the following chapters, several business oriented research projects of DENSY Programme and their main findings will be introduced. The main interest in business research was to reveal future business opportunities for the companies and to test them among the business network. In the first part, the development of the DG business opportunities and the main drivers for them will be discussed and the new business models for the utilization of the opportunities will be shown. In the second part, several business and technology demonstrations will be introduced. Finally, the main findings and future challenges will be presented.

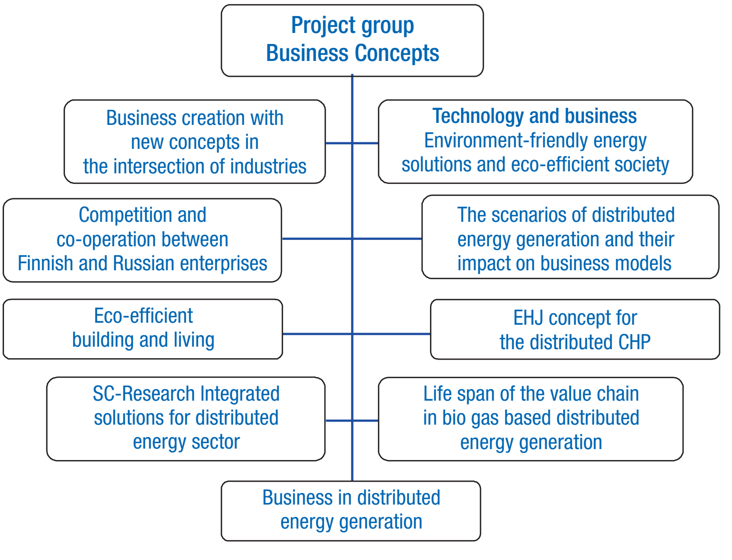


Figure 7.2. The business oriented research projects in Densy Programme.

7.2 List of projects

Lappeenranta University of technology, Technology Business Research Center
Business creation with new concepts in the intersection of industries
Date of funding decision: 7.2.2006
Research project, ongoing

Tampere University of Technology
Electricity network business development, part 2/3
Date of funding decision: 6.5.2004
Research project, finished

Lappeenranta University of Technology, Telecom
Business Research Scenarios for distributed generation
Date of funding decision: 22.4.2004
Research project, finished

University of Vaasa, Lévon-institute
Business models in distributed generation
Date of funding decision: 22.4.2004
Research project, finished

VTT Processes
MULTIPOWER development platform
Date of funding decision: 15.4.2004
Research project, finished

Lappeenranta University of Technology, Research Centre for the N
Competition and co-operation between Finnish and Russian companies
Date of funding decision: 18.3.2004
Research project, finished

Kymenlaakso Polytechnic
Environmentally benign eco-efficient society
Date of funding decision: 22.12.2003
Research project, ongoing

Seinäjoki Polytechnic, SC-Research
Integrated solutions for distributed energy sector
Date of funding decision: 18.9.2003
Research project, finished

VTT Building and Transport
Eco-efficient construction and housing
Date of funding decision: 26.6.2003
Research project, finished

VTT Processes
An Energy Management System for distributed co-generation
Date of funding decision: 18.6.2003
Research project, finished

Tampere University of Technology
Energy logistics
Date of funding decision: 18.6.2003
Research project, finished

7.3 Future business opportunities in the field of distributed energy systems

7.3.1 The future business development and potential markets

Lappeenranta University of Technology
TBRC ”Hajautetun sähköntuotannon tulevaisuusskenaariot ja vaikutukset liiketoimintamalleihin”, Research project

The background of the project

The liberalization of the energy market opens up a variety of business opportunities for new actors in the various phases of the value chain of the energy generation. Besides large projects in energy generation, the need for the development of small-scale and local solutions is greatly increasing all over the world. The growing demand for energy, the utilization potential of local energy resources, the profitability of the combined generation of electricity and heat and the development in renewable energy techonologies drive the expansion of distributed energy generation. At the moment in Europe, the market for distributed systems is increasing by 15% on a yearly average, and in undeveloped markets the increase has even been many times faster.

The business potential and appeal of distributed energy (DE) systems are strongly enhanced by global trends: securing of basic welfare, increased importance of environmental values, liberalization of the energy market, development of technology, depleting of fossil energy sources and growth in the demand for renewable systems and cogeneration.

The decrease in fossil fuel resources and the resulting increase in the costs for centralized generation along with strong environmental values encourage the development of DE systems technology. There is also need for the development of business so that the potential demand for technologies could be attained. When developing business operations, it is especially important to notice in what direction the demand and the market will change in the future. Some of the most remarkable future trends in this sector are the ever-growing need for energy and securing of basic welfare in the fast developing and newly-industrialized countries. In the future this may lead to a growing demand for DE systems of which the market has already showed some signs.

The main targets of the project

The DE business sector is composed of local system technologies in the generation of electricity, for heating and cooling purposes and related services. The field covers a wide array of fuels and production technologies which are characterized by small scale and short distances to consumption units. The Densy technology programme with Tekes, the Finnish Funding Agency for Technology and Innovation, focuses on generation units for individual buildings, town blocks or factories and systems catering for them. The maximum size of these installations varies between 10 to 20 MW.

The objective of this report is to examine the current techno-economic state of DE systems, to determine the sector's future business development paths and to find new business opportunities for Finnish companies up till the year 2019. Commercial opportunities will be presented with new business concept descriptions. Furthermore this report proposes to evaluate the commercial potential of DE systems particularly in developing countries, where extensive distribution networks are still non-existent, and to provide companies with suggestions and advice to exploit this potential.

Methodology of the project

The Tekes Distributed energy systems technology programme (DENSY) studies local small-scale systems for energy conversion, generation and storage and related services. The two-year study described in this report is part of the DENSY programme and conducted in co-operation with the Technology Business Research Center (TBRC), Tampere University of Technology (TUT) and VTT Technical Research Centre of Finland. The objective of the study has been to find future commercial opportunities and business models for DE systems from the perspective of Finnish companies by the means of scenario studies and techno-economic analysis.

The first phase of the study has concentrated on the potential of renewable energy sources and the technologies exploiting them and produced roadmaps starting from the current state of all the six subject themes (Lehtinen & Wahlström, 2005) which propose to identify the direction of current development from a technological perspective. The techno-economic analysis conducted on the basis of a technological prospects analysis on distributed generation defines our current understanding about the costs of technologies utilizing different energy sources.

In addition to the technological prospects analysis, the first phase produced alternative scenarios for DE business development from the perspectives of both the experts and the actors. These scenarios created business ideas for new commercial exploits. The opportunities revealed in the alternative scenarios and created by the technology enable Finnish actors to challenge their current operations and develop new business models.

The second phase of the study aimed to find new approaches to future operation with business concepts. We examined business models and analyzed factors that have to be taken into account when planning new operations to develop commercial opportunities in the new market. Based on this we have created a concept that describes business models for new DE systems. This same concept can also help evaluate the current business models of companies operating in the field, providing information about the structure of current operations. This information can be further utilized when creating new business concepts and drawing conclusions about the sector's state.

In order to develop business and technology we have to know the market and its trends. Therefore we have analyzed the current state of the market and the development of the future business environment by making market reports based on existing market studies and other sources of data. In addition to understanding the market, we can illustrate the size of the demand for DE systems, which gives companies a better chance to identify the latent commercial potential in the market.

7.3.2 The technology potential for the business and the future scenarios

The main results

The liberalization of the energy market in the Nordic countries and elsewhere in Europe has created a variety of commercial opportunities for new actors in the various phases of the power chain. Besides large projects in power generation, the need for the development of small-scale and local solutions is greatly increasing all over the world. The growing demand for energy, the utilization potential of local energy resources, the profitability of the combined generation of electricity and heat and the development in renewable energy technologies drive the expansion of distributed energy generation.

When developing operations, we need to take into account particularly in what direction the demand and markets will change in the future. Some of the most prominent future trends in the sector are the securing of basic welfare, increased importance of environmental values, liberalization of the energy market, development of technology, depleting of fossil energy sources and growth in the demand for renewable energy systems and cogeneration. In the future this may lead to a strongly growing demand for DE systems of which the market has already showed some signs. At the moment in Europe, the market for distributed systems is increasing by 15% on a yearly average, and in undeveloped markets the increase has even been many times faster.

Based on the technological prospects analysis, the most attractive technologies from the perspective of Finnish actors were wind power, microhydropower, diesel and gas engines and bio energy, whereas the most interesting market areas were the EU-15, Russia, India and China. The created business concepts for each sector presented commercial opportunities for both system providers and component suppliers. Based on the scenarios and market analyses, the future market also presented opportunities for new service innovations which should be implemented as part of the business models for distributed systems.

The realization of DE system operations however requires from the companies the will to invest in the development and launch of new business activities. Therefore it is important for the companies to understand the magnitude of latent potential in the market to evaluate the profitability of investments. Depending on the risk-taking ability, this entails a strategic choice of either an offensive or defensive stance in the research and development of the technology as well as of business operations.

Easy and safe connection of DE systems to the power grid is a central factor in developing the market. Converting from conventional radial and one-directional power transmission to a situation where the direction of electric current may change and power failures may lead to power being blocked behind the failure, is a remarkable challenge for current protection logics and automation. R&D is needed all the way from protection philosophy to developing and testing practical solutions.

In addition to widely recognized technologies, such as wind power, the growing market for distributed generation offers significant commercial opportunities for rather traditional fields of energy technology, such as biomass combustion and microhydropower. Finnish expertise in combustion technologies should be supported and transformed into a business activity more efficiently. Microhydropower could also offer commercial opportunities for Finnish actors, even though business operations are at the moment limited. In addition to conventional technologies, we also have to consider investing into future solutions, of which solar panels appear the most promising area.

The report has examined distributed generation and distributed electricity generation in particular based on technological development prospects, analyses of cost efficiency and trends in future business operations. The study has provided four alternative scenarios and potential service concepts for the DE sector. Furthermore the report presents new business concepts for Finnish companies in the future market for distributed energy systems.

7.3.3 The main findings and future challenges

When developing companies' operations, further studies on the commercial prospects of DE systems could focus for example on finding out how to create efficient value networks that enable the cost-efficient supply of systems and related services into the global market. Additionally, the next step from modeling sector-specific operations could be to create company-specific business models. Realizing these would require deep understanding of the changes in the sector and specifically of the linkages between the sectors, namely of the convergence, and making internal company analyses and recognizing the companies' strategic resources.

Based on the technological prospects analysis, the most attractive technologies from the perspective of Finnish actors were wind power, microhydropower, diesel and gas engines and bio energy, whereas the most interesting market areas were the EU-15, Russia, India and China. The scenarios proposed to create descriptions about the future business environment so that factors affecting future operations and markets could be better taken into account when planning business operations. The created business concepts for each sector presented commercial opportunities for both system providers and component suppliers. Our study recommends investments in both of these. The future market also presented opportunities for new service innovations which could be implemented as part of the business models for distributed systems.

Companies should particularly follow the development of laws regulating the energy sector in the target market and the advancement of international treaties like the Kyoto Protocol. Countries' aspirations to pursue more environmentally friendly technologies can quickly change a technical solution to an economically viable form of production. In such a case, companies should be ready to respond to the demand quickly so that they are not left outside the market. It is also important to take into account natural conditions in different areas which may have a profound impact on the choice of optimal production technology. The choice of technology offered to the market is also essentially influenced by the state of the local infrastructure and the availability of fuels and primary energy.

With regard to technology, Finnish companies should in particular concentrate on new technology and high quality, because many conventional power plant components will be manufactured more cost-efficiently and locally in the countries of developing economies. New ICT systems specifically can offer companies the possibility to distinguish themselves from their competitors by technology. With DE systems, ICT and automation provide new prospects in developing highly automatized units which can utilize small local resources as a complete optimal solution. For example, it can be stated that a component in a DE system should be highly standardized, unmanned and remote-controlled. Standardizing enables big outputs and thus lower prices and also support the components' maintenance and connection to the grid. (Lehtinen & Wahlström, 2005) Besides standardizing, companies can benefit from bigger outputs thanks to modular components. The impact of these components on production will unfold over time when clients start to supplement and update their modular systems already in use.

The business concepts and models revealed the importance of value network management for system providers. The delivery of a product/service concept that is as cost-efficient as possible requires optimizing the entire value chain. Companies will have to choose, for example, the most suitable ones from different means of export, and to utilize local production resources when possible. Companies also have to face such strategic decisions as what to outsource and what to produce in-house. In the best possible scenario, component suppliers could multiply their turnover by transforming themselves into system integrators. This strategic choice however requires a successful gathering of local component suppliers together to form an efficient enough value network and to enable commercial activities. Integration know-how and system supplies are part of the Finnish high technology strategy.

7.4 Business potential in the field of distributed energy generation

University of Vaasa, Lévon-instituutti
Liiketoiminta hajautetussa energiantuotannossa.
Funding decision day: 22.4.2004.
Research project)

Business in distributed energy production was a program consisting of six separate but synergic projects with collectively shared objectives, theoretic background and vision of distributed production of energy by renewable regional sources. One of the aims was also to integrate the energy related expertise and strengths of the different institutes and disciplines in the University of Vaasa.

The objective of the project program was to outline business models for distributed energy production, including their contents and dependencies on the different dimensions of the prevailing operational environment. In defining the business models, particular emphasis have been devoted to competitive and resource environment and the value expectations of the potential clients. An integral part of the analysis is the objective to try to understand the models as parts of the whole of energy production and energy markets, as well as the regional and local economy.

The frame of the program was based on a "helicopter view" and outlining frame of distributed energy production and its typical situations, mainly based on the demand of energy and the supply of renewable energy sources in relation to the position in the energy infrastructure. In each situation we can outline an *operational concept* (Fig. 7.3).

According to it every local or regional unit always has to consist of several components, which must be integrated into one energy production solution. In each solution there are business economically profitable parts. However, it is essential also to distinguish and define the supporting components surrounding the business environment, enabling the social acceptance and feasibility in terms of both regional and local economy.

The research was conducted as 11 different case studies in the county of South Ostrobothnia. All cases were real biogas plant objects under a planning procedure and consideration of investment.

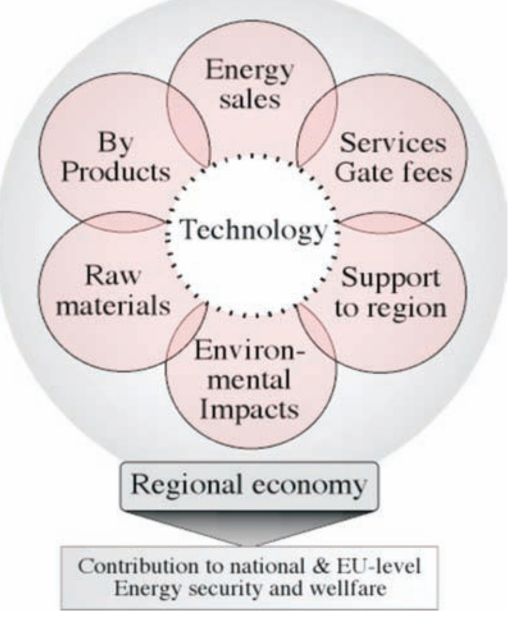


Figure 7.3. The operational concept for distributed energy production.

The project was partly financed by the companies involved in the cases. The research and its methodology was conducted as follows:

- Formation of the business concepts and economic modelling of the cases.
- Analysis and optimisation of the business concepts.
- Separate research on the attitudes of enterprises for implementing distributed generation of renewable energy.
- Separate research on the use and maintenance efficiency in six energy utilities.
- Formation of the biogas plant information map.

7.4.1 Business challenges and models

The core of the project results were the economic calculations for the cases. Simultaneously an economic calculation model for biogas plant investments was developed, and it was used and tested in the analysis and optimization phase. This model will probably be further developed into a product after the project. The data from the energy utilities' usage and maintenance were utilised in developing the model. The attitudes were found to be very positive towards the implementation of new technologies for utilizing renewable energy sources.

The best profitability in terms of business was attained in the concepts based on production and use of biogas as traffic fuel. Also their feasibility is still insecure, because the use biogas as traffic fuel demands a comprehensive infrastructure and a critical number of users already in the beginning. However, Swedish and German examples, and also domestic plans and the expanding network for the use of natural gas in Southern Finland show that this might be reality already in very near future. This also means that the studied cases are realistic.

In all the other alternatives and especially from the point of view of a private single investor, an investment in distributed energy production technology still seems questionable. This will be the result, when he evaluation of the calculations is based on very strict criteria for the profitability: According to them the investment should always be rejected when the pay back time exceeds 15 years. However, feasibility can not be analysed as black and white as this. Instead, at least the following aspects should be taken into account:

- The pay back time of 15 years is not particularly long in the energy sector, where investments often are discounted during even tens of years.
- With a reasonable public support (20–40%) investments in all the evaluated alternatives would have been profitable according to even more strict criteria (pay back time 8 years, internal rate 12 %)
- In the regional production solutions the pilot cases always include also other *value expectations* than business profitability. Among those of particular importance are benefits for farms in spreading the slurry of domestic animals, and the regional impacts on employment and economy, which, however, could not be quantitatively measured in this research.

7.4.2 The main findings and future challenges

Public support for utilising domestic renewables can be seen justified for a number of reasons: Replacement of fossil fuels and boosting energy self-sufficiency offers national strategic benefits, and also the stimulation of the local and regional economy and employment are among the highly positive impacts. A significant share the establishment of Finland's energy infrastructure has been publicly supported, the public interest being one of the core objectives. Privatisation and the market based interest do not come across as sustainable justifications for abandoning the old principles. Merely in terms of competition the situation is unfair, as the new solutions are emerging without support unlike the old ones. The national interest should be prioritised, still not forgetting the business interest.

It is clear that new innovations must surmount several thresholds, including the social acceptance, supportive constructions (like laws and regulations, institutions), and technical evolution, reflecting the findings of the research tradition of innovation diffusion: there are generalise able forms of development through successive phases. Distributed energy production and its technologies are in an early stage of development, while the conventional prevailing energy sector is at the opposite, mature end of the diffusion curve (Fig. 7.4). Typical features for the early stage are the following (also neatly depicting the state-of-the-art of distributed energy technology):

- Technical solutions are of the first or second generation, with poor technical and cost efficiency, high investment costs, and no benefits from mass production.
- The value chain of production is poorly developed, reflecting as inefficiency and poor profitability of the whole supply chain.
- Along with the curve the different dimensions tend to improve, which also can be anticipated from the point of view of distributed energy generation. This means especially an improved relative competitive strength compared with the use of fossil sources of energy, and a heavier political status.

What is known from our preceding research is that the resource base and energy self-sufficiency potential reaches nationwide from the peripheral country side to cities of up to 50 000 inhabitants. Corresponding data come also elsewhere from the Europe. This project shows that even business profitability is already now very near, and all the studied cases were highly feasible in terms of regional economy. Summarising these different factors, there is a remarkable potential for improving profitability and becoming more general for distributed generation of renewable energy. This might have significance for the whole energy strategy of the country.

The future development actions of the new emerging technologies can be categorised as follows:

- Influencing the general values and attitudes more favourable for the promotion of distributed generation of renewable energy
- Development and support of the expertise and capabilities for the new solutions from strategy to technologies

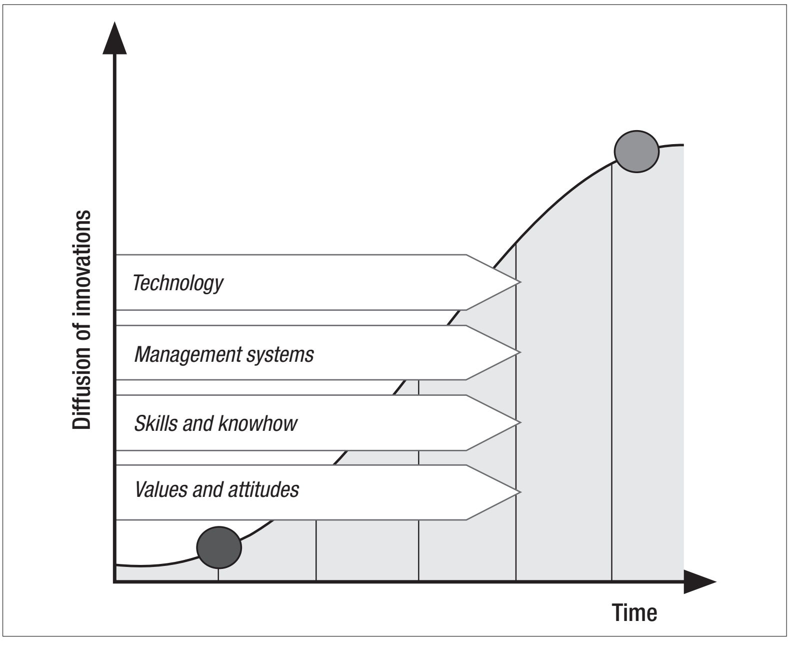


Figure 7.4. Diffusion of innovations and capabilities: the comparison of distributed (left, down) and conventional (right, up) generation of energy.

- Development of the management systems for distributed renewable energy systems
- Support and efforts on research, product development, demonstration and implementation of the new technologies for utilising renewable energy

From the market based point of view, it is important that the support will be directed towards the creation of prerequisites for the new solutions and structures instead of supporting the prices and hence confusing the markets. Subsidies for R&D activities and investments (establishment of infrastructure), and adjustment of laws, regulations and other general rules are among the actions that only will be necessary in the early phases of the development.

According to the results from this project it appears highly possible, even obvious, that distributed generation of energy by renewable regional sources will become more profitable even judged against purely business criteria. It can also be anticipated that it becomes a more general or even prevailing system in the countryside. This conclusion is supported by the public interest and general benefits. Public support would be useful for making the investments lighter and making the development faster, until the market based interest and the principle of business profitability can fully be exercised.

7.5 Business opportunities in the intersections of industries

Lappeenranta University of Technology,
Technology Business Research Center
Business creation with new concepts
in the intersection of industries.
Funding decision day: 7.2.2006.
Research project

The background of the project

Understanding the changes in business environment and possibilities to exploit emerging opportunities has become vital for globally operating organizations especially now when the traditional boundaries of the industries are eroded and new business opportunities are often emerging in their *intersections*. Due to that the changing industry structures and business environment demand new approaches to understand and recognize these new arising opportunities and develop them to successful business concepts. In an industry level, this has led to an increasing need to collect and utilize concrete information based on the industrial change and also anticipating the change which will help organizations to address the strategies needed in the future.

Different times have addressed the importance of diverse methods for analyzing industries and organizations. For instance, Porter's (1980) five force model has been among the most important models when analyzing competitive environment of organizations, industries and nations. At the moment, scholars of strategic management are focusing on networking and competencies needed in cooperation, as well as understanding the patterns of changes in new economy and digitalized value networks. Traditional models have, however, been criticized for e.g. their static nature and incapability to predict future development. This research project aims to integrate the methods to take better into account the proactive needs of industry analysis by combining the industry analysis and future study methods and developing applications for the innovative utilization of methods.

This two years research project called "Creation of new business concepts in the intersections of industries (Talikko)" examines the changing structures of three tightly interconnected industries, namely ICT, electricity networks and generation and forest industries. All these industries are important to Finland and especially to the area of South Karelia. Technology Business Research (TBRC) at Lappeenranta University of Technology (LUT) coordinates the project that is funded by Finnish Funding Agency for Technology and Innovation (Tekes) and several industrial partners from the three industries under consideration, namely UPM-Kymmene, TeliaSonera, Lappeenrannan Energia, Kainuun Energia, Fortum, and Lappeenrannan Kaupunkiyhtiöt.

The main targets of the project

The *primary objective* of this research project is to identify new business opportunities in the intersections of electricity networks and generation, forest, and ICT industries. The project also aims to find out how to exploit the recognized business opportunities at company level as well as to foresee with the companies involved what opportunities and threats the changes might bring for them. The *secondary objective* is to develop methodology for integrating industry analysis and company level business analysis.

The industry structures and the business environments are analyzed separately in each industrial sector with the help of quantitative and qualitative strategy analysis methods. The results of the analysis of each industry are then juxtaposed to reveal new business opportunities and technological applications located in the intersections of the selected industries. The research project continues the analysis of the recognized business opportunities on company level. The analysis reveals the gaps between the existing strategy and the emerging operations in business and technology development in the companies. The solutions to fill the gaps are developed by carrying out idea generation sessions to create a large number of ideas pertaining to new products, services and businesses with the help of the creativity methods. Finally the most potential ideas will be formulated as business concepts to enable effective implementation and piloting in the participating companies.

The issues aimed to be solved in the research project thus include:

- It is an accepted fact that the industry changes have impacts that are difficult to solve on a company level.
- It is an accepted fact that the changes and ruptures on industry level give risks and opportunities for individual companies. The results of this project are to give hints how to turn the changes and ruptures into opportunities in business.
- Simultaneously the project tries to fix procedures, methods and tools to analyze the changes and opportunities in clusters and on borderlines of industries.

Methodology of the project

The first stage of the project focused on clarifying the present situation of the industries under scope as well as identifying their main players (see the right side of the Figure). The output, state-of-the-art report, provides the critical discontinuities, main trends and their implications in technology and business development of the specific industry (examples of existing trends include e.g. the shift from centralized to distributed energy generation, and significance of ICT in the forest industry operations). It also made possible to focus the research to achieve the main objective of the project: to identify new business opportunities in the intersections of electricity networks and generation, forest, and ICT industries, and to find out how to exploit them on company level.

After the analysis of the industrial clusters, a three-round Delphi study was applied in order to identify the business opportunities that arise in the industry intersections. On the basis of the first Delphi round, four intersection areas were chosen in which the following Delphi inquiries concentrated on. The Delphi study was complemented with several specialist interviews. The four identified intersection areas are all quite wide business opportunities that embody several potential business concepts. In order to draw the analysis more on to company level, idea generation sessions and scenario workshops were held in Group Decision Support Systems (GDSS) laboratory. By exploiting the creative methods provided by the laboratory, a large amount of ideas pertaining to new products, services and businesses were created. Additionally, the generated ideas were analytically assessed, prioritized, and selected into the idea portfolio to recognize the most potential ideas. In conclusion, the analysis heretofore proceeded from the industry evolution to business ideas (called "top down analysis" in Figure 7.5).

The main objective of the so called "bottom up analysis" is to upgrade and concretize the gener-

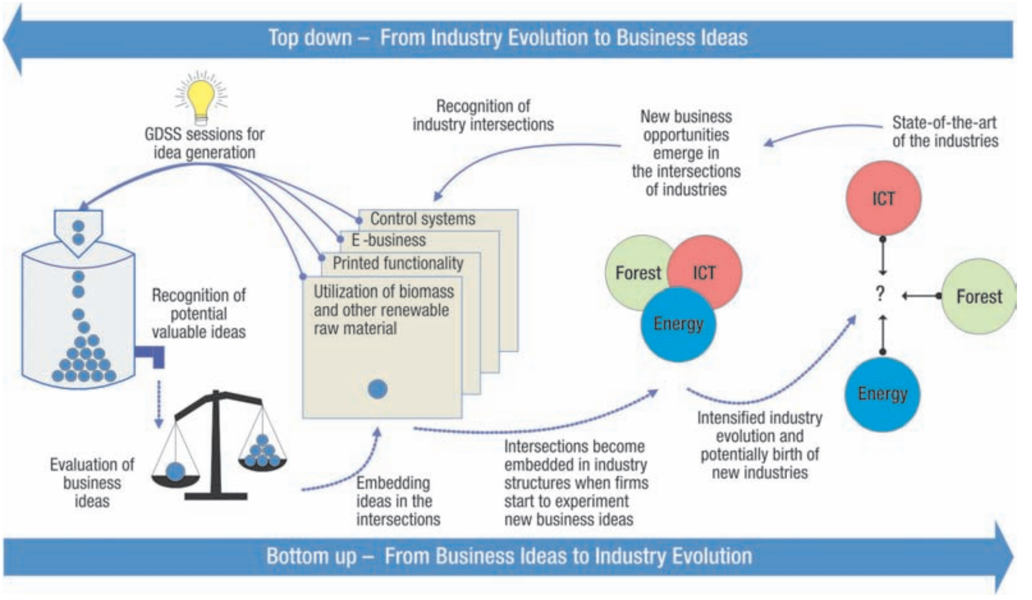


Figure 7.5. Framework of the Talikko research project.

ated ideas and recognize the most promising ideas (see the left side of the Figure). Several methods and techniques, e.g. clustering, are used when evaluating the ideas from the point of view of their strategic, organizational, technological and market fit. The target is to provide the companies with methods and information that support and help them make decisions regarding their future business strategies. In time, the ideas that are linked to the intersections can become concrete when companies start implementing the ideas into new products, services and businesses. In addition to the above-mentioned methodology, several other both qualitative and quantitative research methods (e.g. a scenario building approach) were utilized, and the results were reported in the scientific publications of the project.

7.5.1 Potential business areas and ideas

In this research project, (1) *utilization of biomass and other renewable raw material* (intersection between the forest and electricity networks and generation industries), (2) *printed functionality* (intersection between the forest and ICT industries), (3) *control systems* (intersection between the ICT and electricity networks and generation industries), and finally (4) *e-business* (intersection between all the three industries under scope) have been recognized as the main industry intersections (see Figure 7.6).

With the help of the GDSS sessions these areas have been narrowed down into more detailed business ideas. For instance, in a workshop whose topic was printed functionality there were generated totally 56 potential business ideas or business opportunities. Continued handling of these ideas is taking place at the moment as our objective is to find a couple of the most promising ideas and then develop the ideas further together with the participating companies.

The work remaining for the rest of the project thus includes the recognition of ideas that hold the most potential, and organizing symposiums or workshops in which the work on the four evaluation dimensions (strategy, market, technology and organization) is continued on those ideas that were justified feasible for continuation. But, as the work is still in progress, the results will be reported in more detail later on.

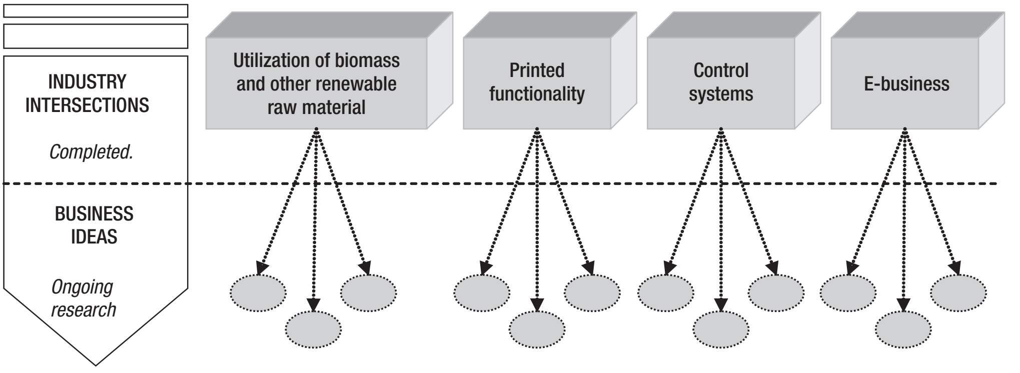


Figure 7.6. From industry intersections to more concrete business ideas.

7.5.2 The main findings and future challenges

As regards the main findings of the research project, the following four industry interfaces were thus evaluated as the most promising according to the specialists of the Delphi study: First, utilization of biomass and other renewable raw material refers to producing bioenergy, biofuels or other bio-based products from biomass. Especially in this project we are interested in forest-based biomass or wood-based biomass as it is the most interesting resource in the interface of forest and energy sectors.

Second, printed functionality means adding new functionalities into a flexible substrate, typically paper and plastics, in addition to regular graphical properties by using printing methods. As an example, e.g. the following ideas were developed in the joint idea generation session with the companies on printed functionality: Coding of local food – the product includes information regarding the area of manufacture, and each customer could find out with the help of a mobile phone whether the origin is situated e.g. less than 100 kilometers from the place of his or her residence. Another example of ideas refers to intelligent food packaging that recognizes each other and suggests recipes.

Third interface, control systems refer to automation systems in the interface of energy and ICT sectors which can be used e.g. for monitoring, controlling and reporting. Ideas developed in the joint GDSS session on control systems include e.g. connecting the workforce in the field into enterprise resource planning systems, and expanding distance control to low-voltage network.

Finally, electronic business (in short, e-business) is defined as utilizing ICT in the forest and energy sectors' business activities. Today, information management systems are integrated more deeply into business processes and they combine the actions of different networked organizations. With the help of the solutions offered by e-business, remarkable cost savings can be reached.

In the future, it would be interesting to apply the methodology of the Talikko research project in other industries as the methodology of this project is transparent and adaptable to other industrial sectors as well. Also it could be fruitful to expand the coverage of the value networks of industries with e.g. larger involvement of SMEs and customer interfaces.

7.6 Russian Business environment and business challenges

Lappeenranta University of Technology,
Pohjoisen ulottuvuuden tutkimuskeskus
Suomalaisten ja venäläisten yritysten kilpailu- ja yhteistyöasetelmat.
Funding decision day: 18.3.2004.
Research project

The main objective of the project was to analyze the success factors of Russian companies established after 1991 and the capability of Finnish companies to respond to the new challenges, such as increasing competition, in the Russian market. We studied Russian companies from the Finnish companies' viewpoint as potential competitors and business partners, in order to create new business models for Finnish companies' operation on the Russian market. The study concentrated on three sectors: food industry, ICT and logistics. Focus was also on the development of collaboration between companies in South-East Finland and North-West Russia.

Research topics:

- Competitiveness of new Russian companies - business models and structure of the competitiveness factors in three sectors under surveillance
- Future operation models - successful Russian companies, threats or opportunities for Finnish companies?
- Collaboration possibilities for enterprises in South-East Finland and North-West Russia - co-operation and subcontracting.

All three sectors, food industry, ICT and logistics, were studied separately and from different viewpoints. In regional collaboration part of the project these sectors were studied at the same report. All sectors are very interesting from foreign investor's viewpoint and could be described as the most promising sectors for new foreign investments. Final research reports concentrate on different parts of the value chain in these sectors e.g. food retailing, food supply chains and food processing.

Surveys and interviews among Finnish and Russian experts, between 10 to 40 experts in each study, were used as a research method. Information collected from these interviews was added to information collected from secondary sources; articles, magazines and Internet. Part of the study was done in co-operation with Helsinki School of Economics. Regular meetings and workshops were organized in order to accomplish the research objectives. Two reports finished by the Helsinki School of Economics are an excellent addition for the reports done at the Northern Dimension Research Centre.

7.6.1 Business challenges for the companies in Russian markets

All studied sectors, food industry, ICT and logistics, and regional cooperation between North-West Russia and South-East Finland open up attractive collaboration opportunities for Finnish companies as Russian companies develop their operations. The sectors participating in the research have a lot of potential from the point of view of Finnish companies. On the other hand, as Russian companies strengthen, they may become competitors for the Finnish companies. Thus, it is important to monitor the situation in Russia.

ICT industry has been growing strongly during the last 5 years. Russian government is trying to refocus the economy from oil and natural resource based economy to more high tech oriented economy. Thus, IT market and export of software development have increased significantly. The value of Russian ICT export in 2006 was about one billion euros, of which the share of Finland equates to 15–20 mln €. Moscow, St. Petersburg and Novosibirsk are the most significant ICT centers and provide plenty of opportunities for foreign investors. Finnish companies can utilize the proximity and size of Russian ICT market and low cost of labor and production factors. On the other hand, Russian companies look for new business opportunities and partners from Finland.

The growth of Russian food industry continues. Local companies have been able to grow strongly after 1998 crisis thanks to growing purchasing power of Russian consumers and high cost of imported products. The share of food retail in retail trade is around 50 %. The turnover of the producing and processing companies and the number of food retail stores has substantially increased. The volume of Finnish food exports to Russia is about 200 million euros. Mostly Finnish companies are gaining from the large size of the Russian food markets. In addition to large cities, more potential could be found in regions. The growth of Russian logistics sector is also strong, but it is threatened by competition from other countries.

7.6.2 The main findings and future challenges

The results of the project have been published in ten (10) extensive research reports and eight (8) academic conference papers. In addition, project results have been presented in more than dozen seminars and workshops with company representatives. Research team has also taken part in various academic conferences.

Overall the framework provides valuable information for future reference for foreign investors aiming at Russian markets. Results give an idea of the business environment in Russia. These studies help foreign companies to implement their strategies in Russia and do long term planning. For example, many Finnish food processing companies have entered Russian market, many of them with different entry modes but still successfully. The situation in the market requires frequent monitoring and planning in order the companies to keep their competitive advantages, business environment changes faster than in western countries.

Final reports of the sub-projects are published at the Northern Dimension Research Centre Publication series. These publications, which are considered to be the best and useful way to report the results for companies, are available for free of charge and they can also be downloaded from the project web page http://www.lut.fi/nordi.

7.7 Present and future business applications and challenges in the field of distributed energy generation

7.7.1 Integrated solutions for distributed energy sector

Seinäjoen koulutuskuntayhtymä,
Seinäjoen amk/SC-Research
Integrated solutions for distributed energy sector.
Funding decision day: 18.9.2003.
Research project

The background of the project

This explorative research project represented a horizontal approach to identifying, developing and delivery of product-service systems that are able to solve customers' problems, or improve their existing activities. The horizontal examination involved issues related to following areas: business concepts, integration, system applications, effective industrial production and ICT enabled improvements. In order to produce successful product-service solutions, all of the above key areas need to be addressed in the real world business, as well as in the research that seeks to produce valid and useful results.

The main targets of the project

SME's ability to offer full service solutions to the customers is bound to be rather limited. This is due to scarcity of resources available for the development, production and service delivery, not to mention performance guarantees. Production networks, which involve a number of specialized businesses, offer a solution that can potentially overcome the above-mentioned problems. In reality it is a major challenge to create, and run such operations effectively. There is a growing body of empirical research on SME's and production networks. This provided a knowledge base that was utilized in analysing the above type of problems.

Understanding of customers´ needs, requirements and capabilities to take-up new systems for distributed energy production is a fundamental

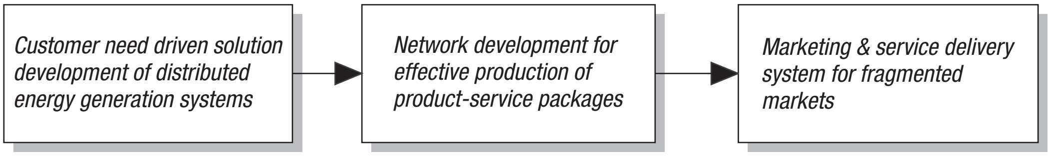


Figure 7.7. Key focus areas of empirical investigation.

issue for SME networks that aim at solution selling. There is very limited amount of research or business intelligence type of information on this type of matters. However, service research domain provides an approach that can offer a number of alternatives for rigorous analysis on this area. The knowledge in this area has been developed over the last 25 years time, and hence it is a valuable source of analytical tools that can provide advice for empirical business practice. The literature can address the main gaps between traditional industrial logic and service driven solution selling. A key issue here is the difference between traditional product/production oriented approach and a customer-need driven development of the product-service offer.

Fragmented nature of the distributed energy systems and SME production networks creates a very distinctive set of problems. These problems have many parallels with service delivery systems that utilize modularization/scalability on the production side, and strictly specified service scripts that provide management backbone for the franchised service delivery system. This stage of the research project combined and synthesized the collected empirical information and analytical results generated at the earlier stages. Critical discussions at the workshops organized for experts and business practitioners provided highly important 'acid test' for these findings and case studies to be presented for practitioner audience.

Methodology of the project

Because of the explorative nature of the research, the data collection was mainly based on practitioner and experts interviews supplemented by the relevant literature on the subject area. Existing market information provided the basis for the market analysis, service concept development and production network development. Interviews provided a vehicle that allows the 'grounding' of the theoretical material on the investigated service business cases. The empirical focus of the research was on the three different types of distributed energy generation:

- Thermal power: systems which extract thermal energy from the ground, or from the water
- Wood energy: systems that include harvesting, processing, logistics and equipments which turns wood into energy
- Waste based energy: systems that can use such problematic materials as vehicle tires and crushed vehicle interiors for sustainable energy production.

These empirical research areas provided a combination of different energy sources. Links with the business sector were also established through the following companies and their networks: Suomen Lämpöpumpputekniikka Oy (thermal energy), Veljekset Ala-Talkkari Oy (wood energy) and Pamac Power Oy (waste based energy).

In the first phase the research the most potential markets and customer groups were identified for the above type distributed energy generation systems. Information on these customers needs, requirements and potential for distributed energy system adoption were gathered from the existing research, customers themselves and from the key experts.

Potential producers of distributed energy systems formed the second main group of interviewees. Practitioner interviewees were supplemented by experts on the SME area and industry specific experts that have in-depth knowledge on manufacturing networks and distributed energy generation.

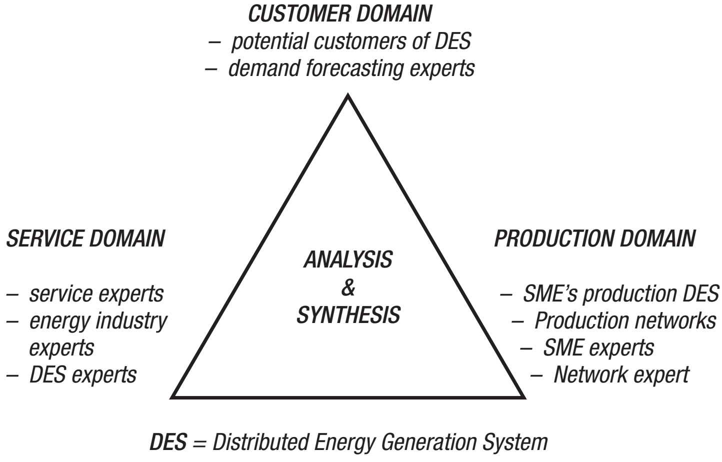


Figure 7.8. Data collection and analysis.

Interviewees with service experts contributed to the knowledge on potential service systems and the ways such systems could be developed. These interviewees included: a) service business experts that focus on service delivery, quality of service and joint production of service solutions, b) experts on distributed energy systems and c) leading industry practitioners and consultants.

The analysis and synthesis of the collected material provided realistic information on the potential and possible bottlenecks that are typical of service concept development in the DES area.

7.7.2 Integrated solutions and their potentiality in business

The key aim of the research project was to produce analytical information on the customer need based product-service system development in the area of distributed energy system. Such novel information was seen as a way to advance the understanding of the service concept development and product-service innovations in the focus area. This type of knowledge development is highly relevant for the decision makers and the research community alike. Rigorous analysis can provide a basis for further development of the generic research agenda on DES-services, and more specifically service solutions in the area of thermal, wood and waste based energy production. By producing rigorous research based information this project advanced service system development in the area of distributed energy systems in the three key areas:

- The analysis produced a more realistic view of the market potential and thorough understanding of customers needs in the focused business markets. After the most potential markets had been identified, the research analysed customer needs and preferences that provided the basis for service system development. Such knowledge was necessary because offered solutions have to be able to deliver solutions to customers' problems and add value to their existing operations.
- The key dimensions and components of the product-service system were specified on the basis of the market potential and customer needs profile. The aim was to create a basis upon which the businesses may develop modules, which can be utilized in building scalable product-service systems.
- The key dimensions and elements of the production network were specified on the basis of the identified product-service systems. The aim was to highlight the crucial features and development needs of the SME networks capa-

ble of delivering product-service systems for the identified customer groups. The generic knowledge on the production networks provided the platform for the more detailed development in the context of thermal, wood and waste based DES. By combining customer and service specific features in the existing body of knowledge, businesses can develop a better capability to build production networks that are able to deliver service solutions successfully.

Altogether the aim of above stages was to produce knowledge upon which sustainable revenue logic could develop for DES in the given context.

7.7.3 Practical applications of the results

INDIS research project was able to create several practical applications that are being further developed by the participating enterprises. The most promising applications in terms of business potential were:

- The development of larger scale, project-based business concepts for Suomen Lämpöpumpppu Oy
- New DES business concept was developed in the field of wood energy. It has been tested in highly developing markets in Slovakia and Slovenia. New distribution channels were also established in both countries.
- The development of new VETO product family in cooperation with external design company. The main target of the sub-project was to improve user-friendliness of existing stokers and feeders by new technical solutions related to installation and maintenance aspects.
- The development of 1 MW pilot plant and business concept for waste based energy. The field tests were made in cooperation with the local district-heating firm Kiviristin Lämpö Oy.

The new service-oriented business and human resource development within DES companies was also enhanced by organizing tailor-made training sessions.

7.8 Value chain life cycle in the energy production by Bio Gas

Åbo Akademi, Industriell ekonomi:
Biokaasuun perustuvan hajautetun energiantuotannon arvoketjun elinkaari.
Funding decision day: 29.11.2006.
Research project

Local biomasses constitute a considerable source of energy. Especially non-wooden biomasses are, however, widely unutilized as sources of energy although they can readily be used for the production of biogas. Biogas is today commonly produced as a byproduct in waste treatment and can be utilized as a fuel in heat and power production as well as in traffic. The technology both for producing and using biogas is generally available. However, the biogas business is still not widely considered an attractive and profitable branch of industry. This is mainly due to two reasons. First, the small size and variation of the biomass sources makes it difficult to rely on traditional industrial paradigms based on large scale and centralized production. Second, the business as a whole is scattered and the coordination between the involved industries (e.g. environmental protection, agriculture, heat and power production, traffic fuel distribution and car sales) is non-existent. As a consequence of the two above mentioned reasons most plants are subject to high capital and operating expenditure. The lack of coordination and clear interfaces, roles and responsibilities also leads to a high degree of uncertainty which raises the investment threshold.

Aim

The purpose of the project was to analyze the value chain for industrial production and consumption of biogas in heating, cogeneration or transportation. The study covers the entire lifecycle from initial project preparation to operation. Based on the analysis the interfaces in the value chain lifecycle are specified in order to achieve a sound division of roles and responsibilities. This will enable companies to focus on a specific nice in the value chain while at the same doing business with other companies. A understanding of the interfaces will also enable other companies to enter the value chain thus increasing the volume of the market. The project involved the department of Industrial Management at Åbo Akademi as well as the following companies which represent different roles in the value chain of industrial production and consumption and the different stages of the project lifecycle.

- Biovakka (biogas production)
- Watrec (engineering)
- St1 (distribution of transportation fuel and power production)
- Autotuojat Ry (Finnish car imports and sales)
- Gaia Power (optimization of distributed cogeneration)

Present state of use of biogas

Biogas production and use

Biogas production is today largely part of treating organic waste in agriculture (manure), organic industrial waste, sewage treatment and water purification. Landfill gas is also collected. Biogas, by which is usually meant methane (CH4) derived from anaerobic fermentation, is by itself a greenhouse gas about 20 times more harmful than CO2. Because of this biogas is often burned in a flare whereby it is converted into the more benign CO2. The percentage of methane in biogas usually varies between 30% and 70%. Depending on the raw material there can also be other chemical components in the gas such as chlorides. In addition to gas the production of biogas discharges a water rich in nutrients and compost.

Biogas is highly similar to natural gas and can be used both in heat and power production and in transport. Most of the biogas plants have an on-site engine or turbine that operates in a CHP mode. In some cases the biogas is also used directly for heating (since the beginning of the 2000's most of the biogas produced in Finland is utilized and not simply flared). There are also examples, especially in Sweden, of biogas being used as a transportation fuel. However, most of these applications are limited. The production of biogas is largely dictated by the amount of waste to be processed. Biogas by itself is seldom considered a product to be sold. The principal, if not only, source of income for biogas plants is the treatment of waste.

The low energy density of biomass also makes for a distributed structure of biogas production. Biomasses can be economically transported only short distances (often under 20 km) which leads to a comparatively small resource base and thereby a biogas plant that is small compared to other kinds of energy refinement installations. Only certain biomasses which can be classified as hazardous waste are transported longer distances.

Biogas technology

The technology for biogas production is generally available. However, compared to other, more mature, industries, such as power production and shipbuilding, biogas plants do not present a high degree of standardization or modularization. This can be seen as due to the small series and also to characteristic of the business at present. It seems, there are many small or medium sized players who have developed their own applications of the core systems and buy the rest (balance of plant items) on a project by project basis, where little attention is paid to repeatability and maintainability of the installation.

Distributed energy production

As a result of the liberalization of the electricity business the optimal size of the power plants has decreased in the western world. The smaller size enables proximity to the final customer which thus enables the utilization of the heat (CHP and CHCP), smaller transfer deficits and also lower transfer costs. The smaller size and the lower tied equity enable the so called peak-shaving function in which the plant is used only during the more profitable seasons. During the last decades the technical development, especially in the field of information, automation and communication technology has led to the point where decentralized energy production and in particular smaller independent plants are economically feasible to build.

The increased competition and also the inhabitants' resistance towards building new power grids have led the development to building smaller grids which are located closer to the final consumer.

There are several benefits with decentralized energy production. The shorter distance to the final consumer enables decreased transfer losses and utilization of the heat capacity. Because of the higher efficiency coefficient the smaller plants are in addition more environmentally sound than the larger centralized plants. A smaller plant enables also utilization of smaller energy sources which is particularly important when it comes to biogas, waste gas and waste incinerators. The decentralized system is as well more reliable because it consists of several geographically scattered small plants (under 50MW). Due to this the investment threshold is lower than the centralized ones. This favors above all areas with no electricity and areas where the supply of is insufficient because it is possible to erect the grid gradually according to demand.

The problem with decentralized systems is, however, the high investment costs which decreases their competitiveness. When it comes to equipment the field faces a vicious circle: the customer (the operators) would be interested if the prices were lower and the supplier could lower the prices if the clients were prepared to buy more. Another dilemma is the old-fashioned way to design the power plants. This design procedure applies better to larger plants (over 100 MW), which leads to excessive designing when it comes to smaller plants. In order to lower the overall cost, an operational plan that takes into account both specific customer needs as well as the plant's life cycle, and allows for production of larger equipment series must be developed.

In addition to the above mentioned facts there are also some misconceptions in the public discussions when it comes to decentralized energy systems. We feel that these misconceptions should be taken into consideration.

In the energy business, there is an obvious bipartition between heat and electricity. In the electricity field the CHP business is not understood and is not included when calculating profitability. Heat is still often seen as a deficit which can be utilized – but not as a product which could be sold. Respectively the heat suppliers are reluctant to simultaneous production of electricity even if the profitability would be higher.

The development of the field is also slowed down by the varying regulations. Every grid operator has own equipment and tariff rules which makes it difficult to offer and supply standard plants. It is notable that there are no legal barriers for decentralized energy production. The challenge lies by the grid operators.

Another challenge in the field is considered to be the large spectrum of equipment and independent electricity providers. The independent electricity provider is considered as a risk because they could uncontrolled supply electricity to the grid with their own equipment. This is though an artificial problem. Every grid operator has full rights and possibilities to set requirements both for equipment and delivery times as well as for the quality of the electricity.

Distributed energy production is a suitable complement to biogas production. Since biogas production by its very nature is distributed it makes it natural to have a small power plant as a consumer of the gas. Biogas on the other hand is a suitable supplier of fuel for distributed power production. It is generally considered that for distributed power production to be profitable it has to be unmanned which in turn requires either liquid or gaseous fuel. Local consumption of the gas also decreases transportation costs and also provides a truly independent streak to the power supply since it is based on local raw materials. Since biogas plants for most part are small (under 2 MW) including them in the bigger portfolio of a power producer would also enable emissions trading, something which at present is not possible for an operator of an individual small plant.

However, in order to provide a basis for large scale utilization of biogas in distributed power production the questions of quality and availability have to be settled. The power producer is committed to providing power at certain agreed times. In doing so the power producer relies on the gas provider to provide required amount and quality of gas. At present biogas producers are not considered fuel suppliers by the power producers partly because they doubt the ability and commitment of biogas producers to provide the gas. To create demand for biogas and turn it into part of the established fuels for power production biogas producers need to eliminate doubt regarding these issues.

Biogas in transportation

Biogas in transportation is a high quality fuel which, just as natural gas, has low emissions. However, the use of biogas in transportation is today limited. This is partly because the use of gas in transportation is still limited compared to liquid fuels, but also because of concerns which are specific for biogas.

The first problem can be seen as the chicken-and-the-egg problem. Since there are very few gas-driven cars there is little incentive to invest in filling stations, yet as long as there are few filling stations there is little incentive to purchase a gas driven car although gas presently costs about half as much as gasoline. However, the situation is not that bleak. First of all, the focus needs to be on gas-filling stations, not just biogas. Biogas and natural gas complement each other, they are not competitors. Second, the number of gas filling-stations in Finland is actually increasing steadily. However, customers (both consumers and industrial customers) have to be made aware of both the number and the location of filling stations as well as the different cars, trucks and buses available.

A second problem is the limited number of car models which are available because the market is limited. This decreases the willingness to purchase by not satisfying the customer's need and also by having a lower second-hand value, odd cars tend to have a much lower second-hand value.

The third problem is specific for biogas. Biogas, with its multitude of small manufacturers is considered an unreliable source for the kind of large scale supply needed for transportation. Negative experiences of first generation biodiesel (RME) appear to have tainted the name of biofuels. Car sales are clearly skeptical of both the ability and commitment of small scale biogas producers, i.e. farmers, to ensure continuous, reliable supply of high-quality fuel. To ensure quality and availability the transport sector stresses the need for gas distributors which are able to coordinate availability and ensure quality.

Method

The value chain starting from biomass to power or car use was analyzed for dependencies in the in the process. By identifying the dependencies between the different actors in the process the interfaces between them can be defined and the division of roles and responsibilities be established. During the past two decades modularization has become an increasingly important means for competing in many high volume industries. At best it has provided a basis for virtual enterprises, where companies temporarily join forces in order to exploit occasional business opportunities. This is partly what goes on in project business, such as engineering and construction. However, the ease of integrating products, services, technologies and knowledge in delivery projects is quite often far from being virtual, which in part is based on the ability to mix and match and substitute the components (and companies) in a product (Garud and Kumaraswamy, 1995; Sanchez and Mahoney, 1996). These are indeed desired directions for many project-based industries as well, however difficult to achieve due to some fundamental differences, such as discontinuity, uniqueness and complexity. In essence, complex system interdependencies, varying demand and small batch sizes make it difficult to reap often expected economies of scale. Furthermore, due to customer outsourcing suppliers are increasingly asked to deliver integrated systems on a turnkey basis, that is, to assume responsibility for the design, systems integration and construction of the product as well. In fact, in some industries customers are demanding the supply of so called integrated solutions (Davies, 2004), rather than separately buying design, equipment and a construction contract. This is to say that integrated solutions providers have to consider their system (and its structure) from several life-cycle perspectives.

7.8.1 Analysis and Value creation through applications

Today biogas is considered solely a by-product of waste management and agriculture and the utilization is only based on the energy contents of the available biomass. In this case it is other incomes such as waste management fees which are the corner stones of the business. For now there are consequently no business models in the field which would have been developed on an energy production basis; sold either as heat or/and electricity or a transport fuel.

The goal of the research is thus to create a business model that combines all the biogas business activities:

- Biomass production
- Biogas production
- Energy distribution and sales

Since the sales of gas cars is relatively new (compared to the production of electricity and/or heat) it is reasonable to consider it as an independent field. Furthermore the model is to cover every life-cycle phase in the value chain:

- The development of the project (Concept)
- The execution of the project (Project)
- Operation (Use)

Figure 7.9 shows the main business activities of the business where the information flow is

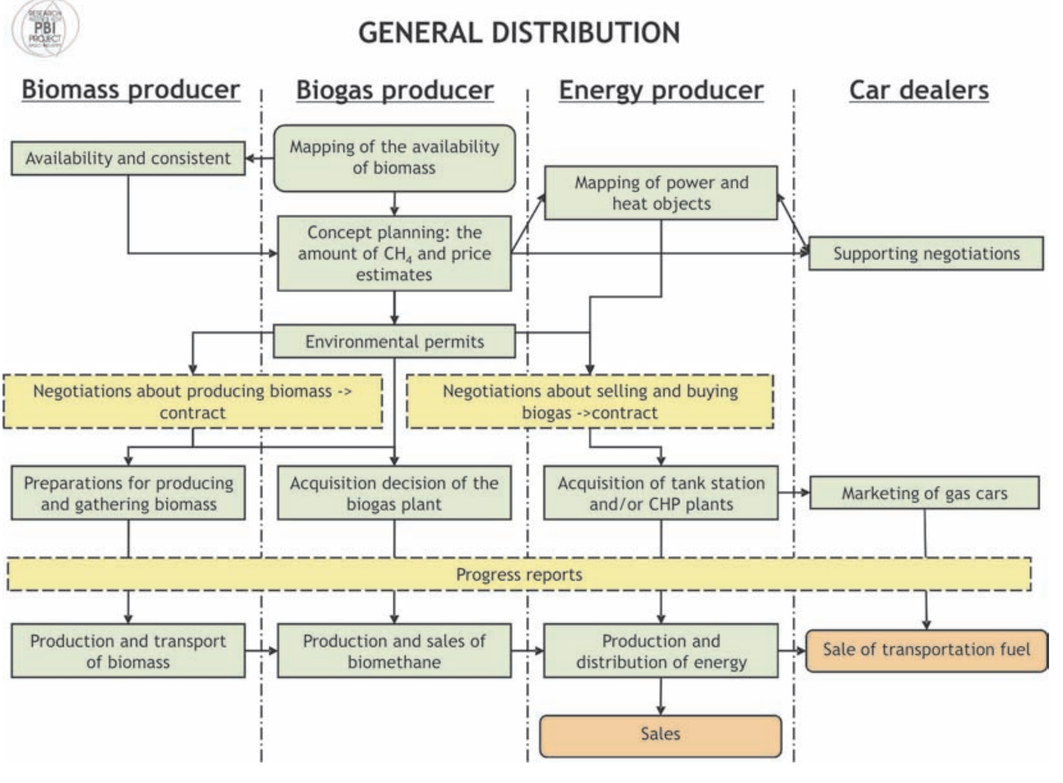


Figure 7.9. The role distribution from planning and execution to operation in the biogas business.

roughly presented during the phases listed above. In the next chapter we will study responsibilities and information flow in every phase of the value chain.

The business model is based on a clarification of the interfaces between the main parties in the biogas value chain which are integrated into each other. The purpose of the business model is to clarify the role division of the parties. For each party the responsibilities and expectations are clarified for each phase of the project lifecycle. The business model thus covers the entire project lifecycle from conceptual development to operation and maintenance. The interfaces and the responsibilities that are included in them are specified on a generic level, not a contractual or project-specific level. The aim is to ensure that each party has a clear understanding of how the value chain functions on a general level and a detailed understanding of his own part in it. The role definitions are not limited to a mere technical level but also include more governance related aspects such as regular mutual reporting that improve overall performance and also decrease uncertainty, something which is crucial as the industrial segment is started. Thus the business model should not be seen as an expert system but rather as a playing field which is based on a division of responsibilities that takes into account technical as well as social matters on the basis of which business can be based.

7.8.2 The main findings and future challenges

In order to establish use of biogas on an industrial scale it is necessary to also focus on the structure of the business and the value chain as such. n doing so it is necessary to take into account technological conformities involved in each phase of the project lifecycle. The technical conformities are used as a basis for clarifying the commercial interfaces and the division of roles and responsibilities.

Clarifying the roles and responsibilities is key element in establishing the value chain. For example in the biogas value chain the necessary technology has been long available commercially yet biogas has not taken off as part of the energy infrastructure. This is largely because lack of clear interfaces with clear division of responsibilities and expectations for each party in relation to the other parties in the value chain.

The unclear interfaces lead to both direct and indirect costs which hamper the business and thereby inhibit the benefits arising from a functioning industrial segment. Unclear interfaces leads to over-engineering rather than standardization which raises investment costs. Lack of standard solutions also affects plant operations which in turn lead to lower profitability. Unclear interfaces raise the investment threshold. They can also lead to an institutional lack of trust which can be seen in the fact that both the power generation and transport sectors do not trust the farming sector to be able to become integrated suppliers in the respective industries.

By clarifying the interfaces between the parties and integrating the different businesses (cultivation, gas production, power production and transport) in a way that takes into account the specific conformities of each business segment a basis for investment is created. This type of overarching solution is necessary. Merely focusing on a single link in the value chain is not enough if the chain as such does not exist. The value chain is established by clarifying the commercial linkage between two forms of already existing commercial activities for example cultivation and electricity consumption.

The project is still ongoing. The key parties in the value chain, biogas to power and biogas to transportation have started coordinating their activities. The business model is at the moment being tested by companies themselves and corrections are being made to model. By the end of the year a fully function business model for the industrial utilization of biogas is expected.

7.9 Eco-effective society and economic energy production solutions

Kymenlaakson ammattikorkeakoulu Oy,
Tekniikka ja liiketalous:
Ympäristöä säästävät energiaratkaisut
ja ekotehokas yhteiskunta.
Funding decision day: 22.12.2003.
Research project

The background of the project

The low grade residual heat will be produced in the industry in overcapacity. Better utilization of the residual heat is necessary to improve the environmental friendly energy production. The generation of the residual heat from the industry or other sources into the electricity would increase the degree of environmental friendly energy utilization.

A new eco-effective energy production system, developed by Deveinfo Oy, was tested at laboratory scale at KYAMK earlier with proper preliminary results. However, to be able to find out the capability of the system under the conditions relevant for practical application a pilot scale tests were necessary.

The main targets of the project

The main objective of the project was to find out the performance of the new environmental friendly energy production system and it's viability under dynamic long trial run conditions corresponding to 5000 operating hours at Sammalsuo dumping site. However, due to long delays during the construction and manufacturing phase, the targeted 5000 h operation was revised down to about 1000 hours. Additionally relevant environmental and techno-economical issues of the 50 kW_e-system will be investigated.

Methodology of the project

To meet the challenge the project has been split in four main stages:

- Planning and design
- Manufacturing the main equipments, construction and assembling
- Testing
  - short term tests at KYAMK test facility and Sammalsuo Pilot Plant
  - long term test at Sammalsuo Pilot Plant
- Relevant environmental and techno-economical analysis

The project has started in Spring 2004. The pilot process has been designed at first in regard to the main components such as LM-turbine, generator, transformer etc to be able to start the equipment testing. Due to too long delays of the supplier of the first combustion unit, the supplier for the gas combustion system, that produces the required steam for the LM-turbine, was changed. The piping, electrical and measurement systems have been designed by KYAMK assisted by outside contractors and partners. The design has been carried out in co-operation with partners. The research part has been carried out by KYAMK including the measuring, sampling, information system and the process flow sheet. The designing of the main components have been conducted by Deveinfo Oy et al and KYAMK. The LM-turbine has been designed and manufactured in Kotka and the new combustion unit later in Ristiina. The generator and transformer and the necessary research test and measuring devices have been purchased. The system is able to produce electricity of 50 kW. The test facility for main component testing has been designed and built at KYAMK. The simplified process flow diagram has been illustrated in Figure 7.10.

Preliminary tests in regard to equipment and from low to medium pressure testing have been carried out at KYAMK test facility, that is able to operate up to 5-6 bar steam pressure measured at the entrance of the LM-turbine. The targeted 10 bar steam pressure at the turbine entrance can be reached only at the Sammalsuo Pilot Plant that was assembled ready for equipment and pre process testing in summer 2007. Due to technical difficulties in assembling phase that has been solved now the capability to supply electricity into the 400 V grid continuously will be ready first at the beginning of September 2007. The pilot plant has been presented in Figure 7.11 and a simplified assembling of the main equipments has been shown

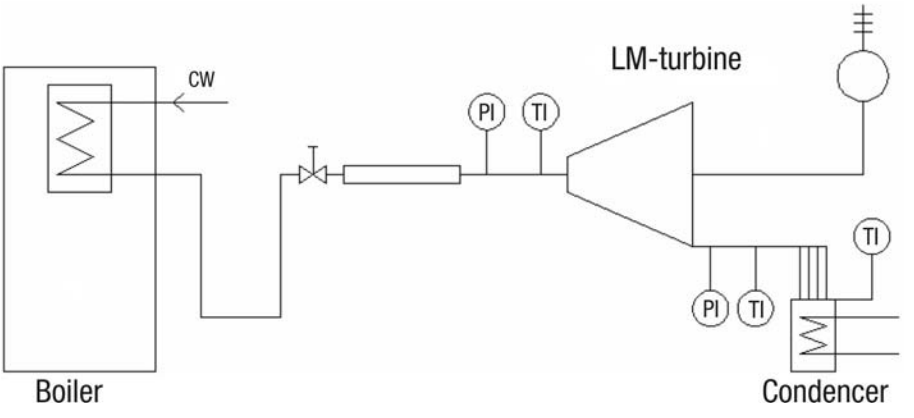


Figure 7.10. A simplified flow sheet of the test bank facility at Kyamk for LM-turbine testing up to 5–6 bar pressure at the entrance of the turbine.

in Figure 7.12. The pilot plant consists of following main components:

biogas combustion unit with steam generator, that supplies the steam to the LM-turbine, is connected to the main biogas line of the Sammalsuo Dumping Site.

The combustion unit shown in Figure 7.13 is located in the first container.

LM-turbine, connected to combustion unit with insulated piping and necessary auxiliary measuring and monitoring devices.

LM-turbine is connected to a condenser and generator with electricity producing capacity of 50–55 kWe. LM-turbine, condenser and generator system are located in second container as shown in Figure 7.14.

Figure 7.11. Sammalsuo Pilot Plant.

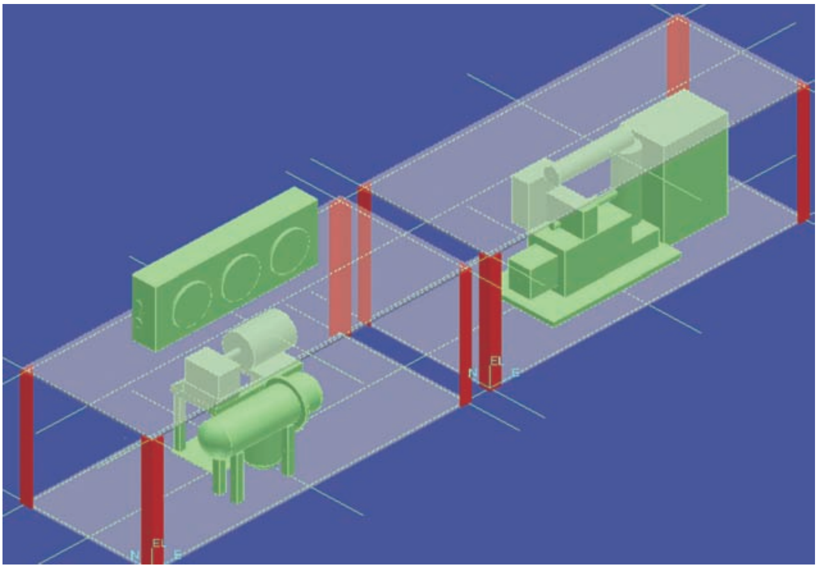


Figure 7.12. A simplified assembling of the main equipments at Sammal-suo dumping site.

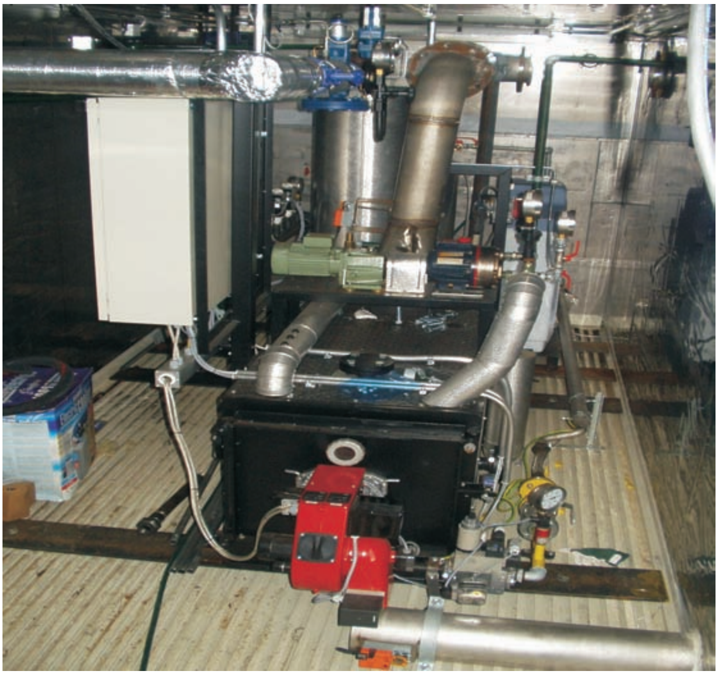


Figure 7.13. Biogas combustion unit with steam generator.

Figure 7.14. LM-turbine (back) connected to a condencer (left) and generator (right).

A simplified testing program has been presented in table 7.1.

Table 7.1. Simplified testing program.

Tests	**Equipment testing**	**Process Testing: Low & Medium Pressure Tests up to 5-6 bar at LM-turbine at Kyamk**	**Pilot testing: High Pressure Tests up to 10 bar at LM-turbine at Sammalsuo Pilot**	**Status**
Short term tests	LM-turbine at Kyamk	Kyamk	Sammalsuo Dumping Site	
• number of test series	40	20	none	**done**
• number of tests per day	1-4	1-2	none	**done**
Pilot tests short term	Biogas unit LM-turbine	several start up tests several short term start up tests	several start up tests several short term start up tests	**done**
Pilot tests Long trial run	**Biogas unit LM-turbine Generator connected to 400 V grid**	**1**	**1**	**to be carried out at Sammalsuo pilot plant in September 2007**

7.9.1 New business concepts and economic solutions

The main results

Several short term test series were carried out during the year 2006 and in the first half of the year 2007 in the test facility of Kyamk. In short term tests at Kyamk up to 14–18 kW_e depending on the shaft speed (190–300 rpm) could be produced. Also short term start up tests with and without LM-turbine have been carried out at Sammalsuo Pilot Plant for fine tuning the system and necessary adjustments have been made.

Due to technical difficulties occurred in the assembling phase in regard to connect the system in the electrical network no long run test could be started yet. Due to delay occurred in the assembling stage and redesigning of an equipment that will be connected in the electrical cabinet, was ready for installation at the end of August. Therefore the connection into the 400 V electrical grid can be carried out at the beginning of September. The project status is ongoing.

7.9.2 The main findings and future challenges

Practical applications of the results

- Due to ongoing project no final results regarding the long run tests can be presented here yet. According the revised schedule the project should be completed at the end of September 2007. It is estimated that until then only 1/10 of the targeted time of the long run test can be completed at Sammalsuo Dumping Site.
- Due to a preliminary co-operation agreement an equipment manufacture can utilize the system in his specified program so far specified terms of a successful completed trial run are fulfilled.

Suggestion for future work

Due to delays the long term test run can be completed only partially during the remaining time frame of the project. However, the trial run may be continued outside of the project so far new a financial aid has been placed.

7.10 Eco-efficient housing and housing area

Valtion teknillinen tutkimuskeskus,
VTT Rakennus- ja yhdyskuntatekniikka:
Ekotehokas rakentaminen ja asuminen.
Funding decision day: 26.6.2003.
Research project

The project focused on concept solutions for eco-efficient housing and decentralized, distributed energy systems suitable for small scale construction of housing areas. The concept solutions were developed for networked production. Business and operational models for company networks were analysed accordingly. The project supports local building products' industry by knowledge sharing and showing new business opportunities.

7.10.1 Model solutions for eco-efficient housing

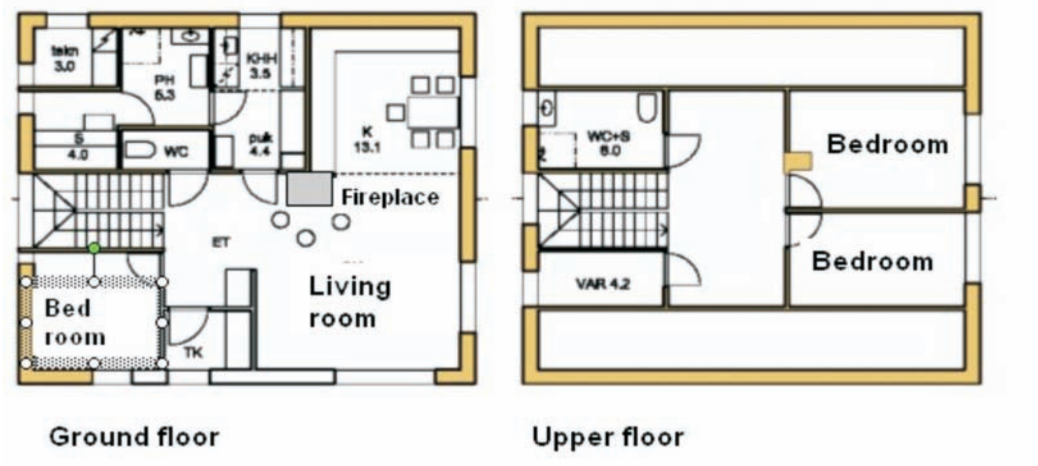
A model house was designed according to the desired performance characteristics describing the user requirements and environmental targets of the house. VTT's requirement's management tool EcoProp (2003) was used in setting the requirements. Requirements for the technical design were derived from the performance requirements:

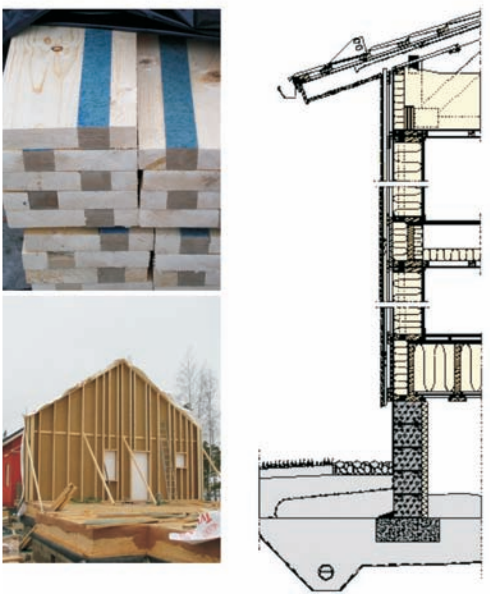
- The house is adaptable with regard to both size and floor plan
- The wooden house serves for short delivery cycle at site and simple thermal insulation system. The load-bearing wooden frame is single-framed allowing for high levels of insulation. Comfort is taken into account in all dimensioning of structures.
- The house is energy-efficient. The heating energy demand of the house is less than 50% compared to a house according to national building code of 2003, and less than 35% compared to typical buildings before 2003. Heating energy consumption can be decreased further by building service systems. Appliances and heating and ventilation equipments are energy labeled (class A)
- The house has a long-service life. The durability of the wooden envelope structures is im-

proved by environmentally friendly wood preservatives. The coloring of the house is based on tinctures traditionally used in wooden houses. The house has a tilted roof for facade protection.

- The house has a good and healthy indoor climate. The adaptability of the house is taken into account in the design of building services. The materials and solutions support good and healthy indoor environment.

The house can be built using local resources. The house should fit for both rural areas and dense town areas. Full scale adaptability is a difficult task to achieve for a common model house design. The solution was to allow different floor plans within the structural modules, and to make it possible to build different apartment sizes from 73 to 195 m^2 with the same basic foot print of the house. As the house has either 1½ or 1¾ story the upper floor can be finished later-on depending on the needs of the family, Figure 7.15. Building services systems are designed for the maximum size of the building. Routing of building service's systems can be placed in the internal floor. The bathroom, sauna and room for technical equipment is





Component	Structure	Thermal transmittance U, W/m^{2}K
Exterior wall	Finishing Vapor and air barrier Wooden frame with thermal break +thermal insulation 245 mm Wood fiber board 25 mm (Windproof insulation 50 mm)	0,15 (0,13)
Floor with crawl space	Flooring Plywood 18 mm + air barrier Trussed floor c = 400 mm +thermal insulation 400 mm Wood fiber board 25 mm (Windproof insulation 50 mm)	0,15 (0,13)
Roof	Roof trusses + thermal insulation 500 mm Air and vapor barrier Finishing layers	0,1
Window	Wooden window - frame 133 - 173 mm - sealed unit with Ar-fill and selective coating - exterior glazing	0,8 - 1,1

Figure 7.15. Model house

a prefabricated module. Kitchen is directly connected to the module, and upper floor bathroom locates directly above the module. This enables short routing of ductwork, electricity and water and sewage systems.

7.10.2 Decentralized energy systems for housing areas

The houses are designed so that the larger is the house the less energy by m^2 it consumes. The maximum heating energy demand can vary between 70–50 kWh/m^2, which includes energy produced for heating and hot water, and fire wood used in the fire places. The peak auxiliary heating energy power is restricted to 35 W/m^2.

Typical heating system in Finnish houses is direct electric heating system. To be able to reduce the number direct electric heating systems and at the same time the power demand of an area, builders need to have other possibilities. Local distributed heat networks were considered as a municipality offered network Three alternatives were considered for a distributed heating energy network:

- High temperature biomass plant (T = 80/43 °C) using local energy sources.
- Centralized ground heat distribution system (T = 50/40 °C) with separate hot water system
- Distributed low temperature ground heat system (T = 2/-1 °C) with individual heat pumps.

These systems were compared to direct electric heating systems. A cost analysis showed that the low temperature distributed ground heat system (Figures 7.16 and 7.17) is cost efficient for both the municipality with regard the construction costs and the builders with regard the life-cycle costs. The investment cost for the ground collector systems ranges roughly from 10 up to 50 €/floor-m^2 of houses. The costs are dependent on the plot ratio of the area, and the heat source. With a low rural plot ration the costs for a total network is high. If the network can be divided into sub networks, the costs will be reduced down to 25–35 €/floor-m^2 even in a low density areas.

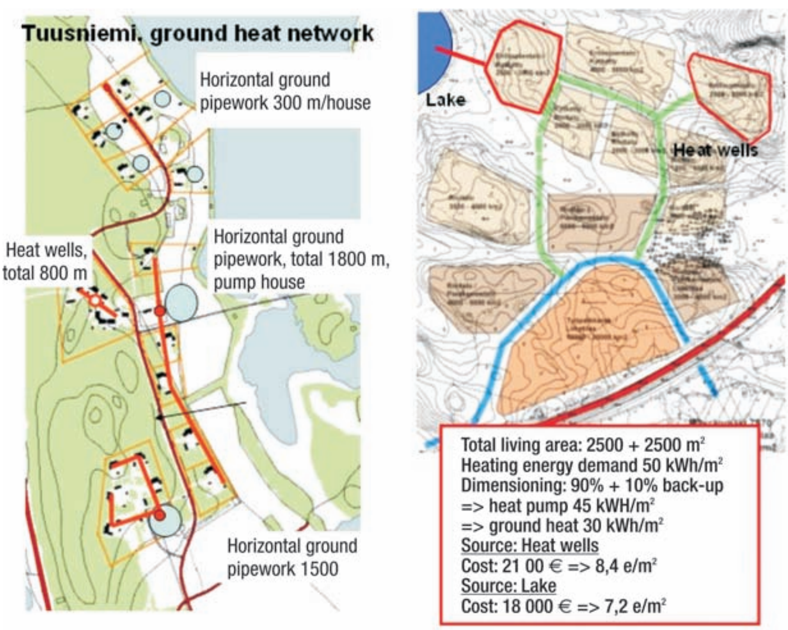


Figure 7.16. Ground heat network examples.

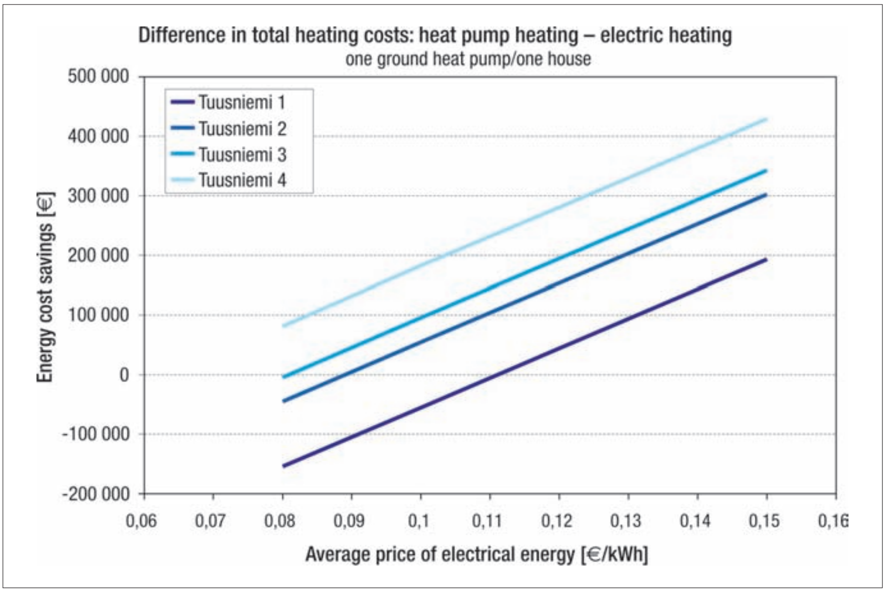


Figure 7.17. Heating cost differences between local distributed system and direct electric heating at a time of use of 30 years. The costs include network construction costs and heat pumps, maintenance costs, running costs etc. The cost based benefit improves if the plot ratio of the area is high (Tuusniemi 1), or if one heat pump can serve for two houses.

7.10.3 Business opportunities

Business opportunities for energy efficient single-family houses do exist. The market attitudes are changing towards eco-efficiency, although very slowly. Climate change is the main driver in this change. In order to make use of the opportunities, the current locked-in patterns that keep the alternatives from receiving wider acceptance need to be changed. In the case of eco-efficient single-family houses, the lock-in situation stems from a set of interrelated rules that together prevent the present state from changing.

To be able to achieve a wider market position of eco-efficient construction, new kind networking is required. Strategic niche management shows in this perspective the possible ways through narrow market niches to market acceptance. Niche management is based on technology demonstration to make the technology well-known. As the market success increases, the development of the concept can be promoted. The success requires also socio-economic acceptance. There are two possible ways:

- The product (whole building) is allocated to a specific market segment. The producer needs to create a differentiation strategy to serve this market segment.
- The product is allocated to a network operation. The production network has to be able to manage the whole building approach, and to create a new production culture for construction.

The segments of the Finnish housing market have not been defined. It has been anticipated that the demand for eco-efficient housing grows from academic families with children, but there is no clear evidence on that. It is also quite uncertain that market orientation based on market segments would change the processes and market situation to enable the market penetration. The notion of socio-economic regime can be used to conceptualize the situation.

The development of a housing area can be carried out as a network operation. To make the concepts into economically viable housing areas, three requirements need to be fulfilled in order to gain larger markets or to create local markets for local contractors:

1. An open concept is needed for to create wider markets for eco-efficient houses and housing areas. A company network requires instructions and quality assurance methods to be able to produce the solutions at the required quality level.
2. Model solutions proved economically viable technologies for eco-efficient housing areas. However, operational models with regard to eco-efficient housing areas are needed for individual regional contractors to help for cost efficient production
3. The funding schemes for eco-efficient housing area need to be developed. This includes the sharing of risks, costs, and revenues. Also, organization of maintenance and running procedures for distributed energy systems need to be solved.

The major target area for export of eco-efficient housing area is Russia, and specifically the area of St. Petersburg, and China.

7.11 EHJ Concepts of distributed CHP

Valtion teknillinen tutkimuskeskus,
VTT Prosessit:
Hajautetun CHP:n EHJ-konsepti.
Funding decision day: 18.6.2003.
Research project

In recent years, the CHP technology development allows for smaller and smaller CHP plants being economically feasible. Whereas micro-CHP in the range suitable for households and small businesses is being tested all over Europe, also plants in the size of 500 kWel...10 MWel are becoming more and more economically attractive. Industries with a large heat load are or will be changing their boilers to CHP plants hand in hand with rising electricity prices and CO2 emission costs.

One of the bigger obstacles on this road is the resources needed to manage these plants in an open energy market environment. The more degrees of freedom a CHP plants has, the more management

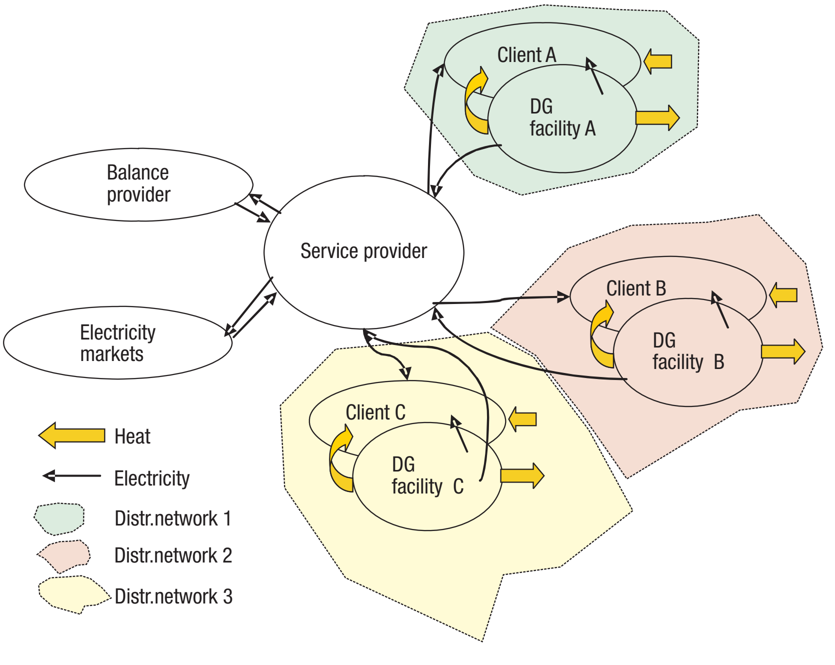


Figure 7.18. A service provider who operates several distributed generation (DG)-facilities in the de-regulated electricity and gas markets. The DG facilities in this project were seen as CHP-units producing both heat for local use and electricity. The production, and consumption through DSM, are optimised for all members of the service provider.

it will need to make the best use of its possibilities: heat load and electricity load forecasts, market price information management and participation in the markets, production optimisation, commercial balance management etc.

The target of this project was to develop a concept of an energy management system for a power company, an end-user or a service provider who operates several CHP-units in the de-regulated electricity and gas markets. VTT, the technical research centre of Finland (www.vtt.fi) was project responsible research partner and Gaia Group Oy project research partner. Partakers in the steering group, as well as part financiers, were Gasum Oy, KSS Energia Oy, Porvoon Energia Oy, and Vantaan Energia Oy.

The development work first off defined the requirements and gathered information of existing programmes. The second result of the project was an implementable concept for an energy management system including assessments of development contributions for the implementation. The third result of the project was a draft research plan for a follow-up project regarding the implementation and piloting of the concept.

7.11.1 New business solutions for and through EMS of distributed CHP

The first two project results are found in the research report EMS Concept for Distributed CHP (in finnish: Hajautetun CHP:n EHJ-konsepti. Göran Koreneff, Eero Vartiainen, Pekka Koponen, Seppo Kärkkäinen. Projektiraportti PRO1/P7005/04 (31.1.2004). Public. 39 p. + app. 15 p.) The research has also been actively brought forward in DENSY seminars and workshops.

The third result, the research plan, was used to set up an industry driven follow-up project.

Whereas large utilities have both software needed as well as human resources available, small CHP plant owners and/or users are lacking in this area. Software designed for larger utilities is too expensive, and too demanding on human resources, to be used in the small circles of distributed CHP. Energy management systems delivered with small CHP plants on the other hand will be quite restricted especially in an open electricity and/or gas market or for a multiple location concept.

Several researches in Europe concerning distributed resources focus on the role of an aggregator, who manages several, physically as well as fiscally separated resources. The aggregator could be the owner of one or all of the resources, or an independent agent managing the resources optimally and to the benefit of all parts. Wind power plants are a good example of distributed resources to already be manageable by an aggregator. CHP plants, having more degrees of freedom due to both steerability and the mass of products to steer (heat, electricity, steam, fuels...), are in need of a more complex EMS. A variety of combinations of CHP plants and sites and end-users allow for, and even demand, a multitude of new business solutions. This project's focus was on the EMS needs of an aggregator managing three separate locations, whereof two had CHP plants and one was just an end-user of electricity. The solution derived at in this project is extendable to more sites of varying composition.

Main criteria of feasible EMS-related business solutions are:

- EMS must be able to manage several separate producers and end-users of both electricity and heat, and preferably also steam as a separate product
- EMS must be able to manage several fuels, and preferably allow for fuel markets
- Each end-use site may have a different electricity or fuel (natural gas) distribution tariff as well as a tariff for feed-in of electricity
- EMS should be easy to install and maintain
- EMS should be easy to use, demanding only a minimum of human input to run
- The EMS should be modular to allow for easy module replacements as well as future extensions
- EMS modules should be inexpensive

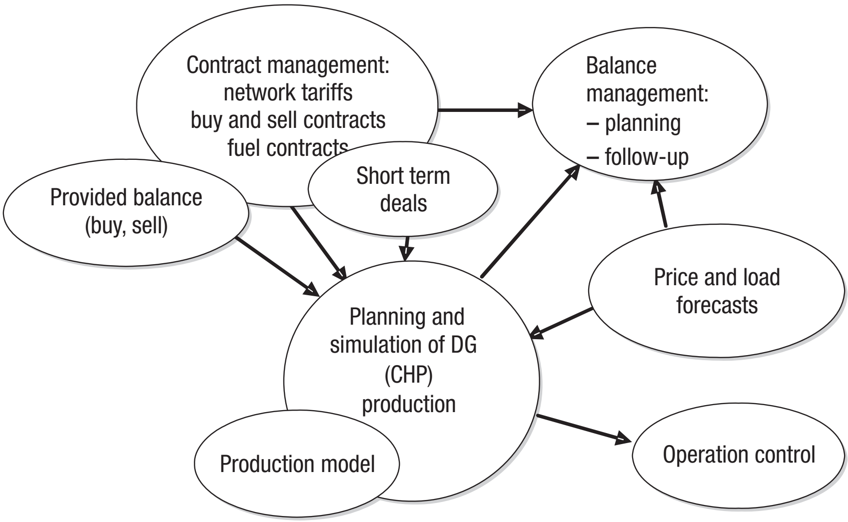


Figure 7.19. EMS concept for management of several distributed CHP plants as well as end-users.

7.11.2 The main findings and future challenges

The first future challenge of the project was to set the development of a prototype into gears. The challenge was successfully met.

The EMS concept for distributed CHP was turned into a software program in an industry driven project 2004–2005 led by Gaia Group Oy and involving Gasum Oy, KSS Energia Oy, Keravan Energia Oy and Metso Automation. The software met all criteria set up in the research project.

The severely delayed mushrooming of small, end-user driven distributed CHP plants in Finland has left the software for the time being in limbo here, so marketing has been stretched to other more advanced EU-countries, e.g. Denmark and the Netherlands. With the Kyoto period 2008–2012 at the doorstep and with some rather heavy EU-decisions for the year 2020 already made, one cannot but anticipate a rapid market development for distributed CHP and related software.

EU-targets (ESD, the energy service directive) of a 9 % improved energy efficiency by the year 2016 for sectors outside the emissions trading scheme as well as improved end customer information systems (two-way-metering etc) will advance active end-user reactions and demand side management. These features' relations with the developed EMS concept should be further studied, and implemented into the pilot program.

7.12 Conclusion – the future needs and opportunities

Referring to figure 7.19, we argue that the research programs within the area of business models provide significant input on the subject of distributed energy production. In addition to the projects related to technology and governance emphasis needs to be put also on governance and business. Together governance and technology form the frame for the distributed energy industry (fig 7.20). Technology forms the micro-level where individual challenges in distributed energy production are addressed. The governance level is the macro level where distributed energy is addressed from a regulatory and political perspective. Between these two levels is the Meso level, i.e. business level, which concerns one of the most important issues: how the business of dis-

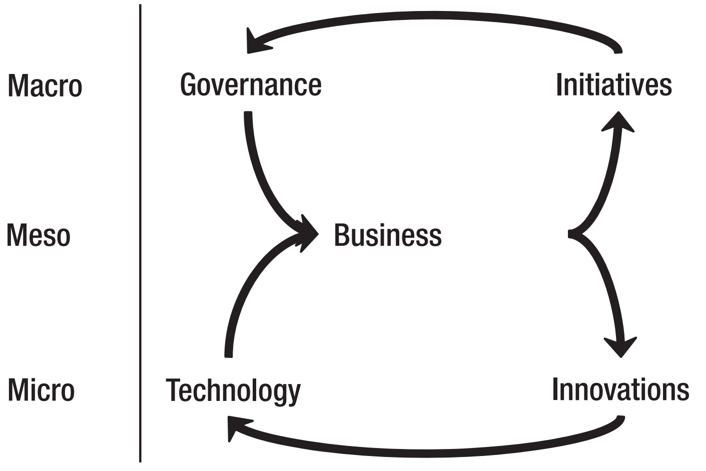


Figure 7.20. The interplay between technology, governance, and business.

tributed energy production need to be carried out and how the distributed energy industry should be structured. Thus it deals with questions relating to transactions, strategy and organisations.

As business expands, the industry develops and the demand for new technological solutions and manufacturing techniques arise. Standardization also increases together with attempts to increase efficiency through economies of scale. At the same time, industry influences the political and regulatory environment either by its own initiatives or by initiatives that derive from the effects the industry has on society. Thus two self-reinforcing loops arise and propel the overall field forward. To do so all three levels have to interact and develop, making it necessary tom combine knowledge in the fields of technology, business and governance.

In a field such as distributed energy generation, which is nascent and has not yet reached maturity on any level, focus on all three levels is important. There exist needs for technological solutions that enable both the commercial and the regulatory measures. At the same time, there are needs for regulatory development that creates room for the application of the different technologies available. Last but not least, the commercial methods for utilizing the technology within the regulatory perimeters are needed. These three dimensions need to advance more or less parallel to each other – if one lags then the other two will be slowed down or stop altogether.

As it is, in this context, both the technological Micro level and the regulatory Macro level have advanced. Technologies have been studied and developed and although there still is a need for further development in order to raise efficiency and cut costs, there are already many technologies and solutions available for commercial operation. The regulatory environment has also developed. Perhaps most importantly connecting a small power plant to the grid is no longer cumbersome and discriminated against. However, on the commercial level the development has not been as fast. This can partially be seen in the fact that distributed energy production has not arisen on a commercial scale whereas both technologies and regulations enabling distributed energy production have arisen. This should not be seen as proof that distributed energy production is not commercially feasible. Instead it shows that no functioning and profitable model for business based on distributed energy production has yet been fully developed and tested.

Although, within the Densy program has been significant research into the area of business models only one of the research projects have gone so far as to piloting the business model. In research and development work piloting is an important step. In the natural and technological sciences piloting, i.e. the practical testing of one's theories, models and assertions is common practice – proof of which is not only all the new solutions that are brought forward but also the numerous ideas that have been disproved. Unfortunately, the tradition of testing ideas and theories is not nearly as usual in business studies – i.e. the field of how business is done in a certain industry.

There are several reasons for the lack of piloting and testing of business models. First, the field of business studies has experience in developing new models but lacks the experience and traditions for implementing them. There are no established rules-of-thumb, gates, tasks, milestones, performance meters or benchmarks. Second, most companies also focus more on innovation and initiatives that derive from their existing business models. Developing a new business model from the existing conformities of technology and regulations can in practice mean developing a new company or division, learning new ways of doing things and accepting new truths. A new business model may even pose a threat to the existing business model – as for example distributed energy could do to business models that are based on centralized solutions. Third, since the concept of piloting business models and management theory is unclear financiers such as Tekes are put in an awkward position. Without a clear concept for how a business model will be implemented financiers can not demand a clear and well thought-out plan for how the implementation, piloting and testing of the models will be carried out.

There would be clear benefits from testing business models by piloting them in companies. First, by testing the models it is possible identify weaknesses in the underlying theories and assumptions thereby contributing to business studies and the study of the particular field. Second, testing and piloting the business model is also the best way to ensure that the companies concerned are able to take concept into practice and thereby benefit from the basic research being carried out at universities. Third, even if the model were to prove unworkable that would in itself contribute to overall knowledge and function as a basis for further theories and models.

Therefore, we suggest that Tekes put focus on how business models in different technology programs are implemented in practical "piloting" cases– the steps, tasks, gates and milestones. This would benefit not only the field of distributed energy but also other areas of business and the related technologies. An industry field develops from technical and regulatory conformities that set the stage for the industry. In this setting business models are needed to facilitate the utilization of technological and governance structures. Piloting, testing and implementing business models starts a virtuous circle where industrial utilization becomes commonplace which leads to increased production, increased economies of scale and new initiatives and innovations.

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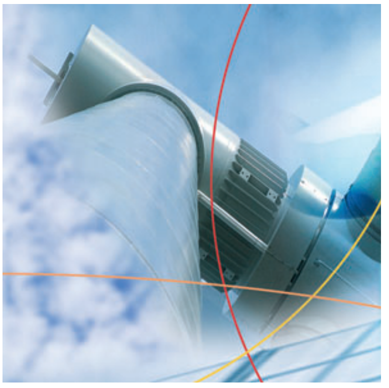

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