Intelligent Energy Systems

A White Paper with Danish perspectives

2010

Danish ICT and Electronics Federation

Danish Energy Industries Federation

Partnership for intelligent energy systems

Foreword

This White Paper is intended as a basis for developing a partnership and a strategy on intelligent energy systems including all stakeholders: businesses, energy companies, research institutions, energy consumers and public authorities.

The partnership initiative for intelligent energy systems is initiated by The Danish Energy Industries Federation together with DI ITEK (the Danish ICT and electronics federation for it, telecommunications, electronics and communication enterprises), EC Power A/S, Dong Energy A/S, Danfoss Solutions A/S, Dantherm A/S, Vestas A/S, Siemens A/S, SydEnergi Partner A/S, Technical University of Denmark (DTU), Aalborg University (AAU), the network VE-net and Ea Energy Analyses A/S.

The White Paper has been prepared by Ea Energy Analyses with valuable assistance from the project participants.

The project is funded by the participants with support from the Energy Technology Development and Demonstration Program of the Danish Energy Agency (EUDP) and from SydEnergi.

Report outline

The proposed partnership initiative is presented in the first section: "Strategy and partnership for intelligent energy".

The remaining chapters 1-9 of the report constitute the White Paper. Chapters 1 and 2 introduce the energy system, chapter 3 discusses the markets for energy and reserves, and chapter 4 covers some of the new active elements in the system – consumers and storage. Key technologies and solutions of the intelligent energy system are outlined in chapter 5, and chapter 6 describes the strategies for smart grids pursued by the EU, the International Energy Agency and the USA.

Selected Danish research, development and demonstration projects related to demand management and other smart grid solutions are briefly described in chapter 7, and chapter 8 outlines current Danish policy and initiatives working towards the intelligent energy system.

A list of references is given in chapter 6, and appendix 1 contains a preliminary list of potential members of the partnership.

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Strategy and partnership for intelligent energy systems

Purpose of partnership

Intelligent solutions will enable a much more efficient utilisation of the infrastructure in the energy system. When fossil fuels are gradually replaced by renewable energy in energy production, an enhanced efficiency will save society substantial investments in transmission network capacity and conventional back up production capacity that otherwise would have been necessary.[1]

The partnership finds that developing such intelligent solutions is a potential growth area for national business and employment as well as export. The partnership aims at realising this potential via a number of initiatives. The partnership will:

- Develop a strategy for research, development and demonstration of intelligent solutions,
- Promote cooperation among stakeholders in business, authorities and research,
- Suggest new initiatives and point out barriers for development of intelligent energy systems,
- Promote practical demonstration of intelligent energy system solutions in a cooperation between businesses, authorities and research,
- Gather and disseminate results from existing and future Danish and international research, development and demonstration projects, and
- Assist partnership members in prioritising their effort among all the different opportunities and activities related to transition to an intelligent energy system.

Partnership vision

The energy system must evolve in order to meet agreed environmental and geopolitical goals.

The vision is to create a flexible and intelligent energy system that can deliver a high level of security of supply and is able to efficiently integrate a high share of sustainable technologies, e.g. wind power. The intelligent system is <u>dynamic</u> in all its elements and <u>robust</u> with respect to incorporating potential new resources, technologies and solutions that the future may bring.

[1] According to European Climate Foundation: Road Map 2050, A practical guide to a prosperous low-carbon Europe, 2010, demand response can reduce grid and back up investment by 20-30%.

Background for the partnership

Climate challenge, global environmental concerns and the need for security of energy supply imply that renewable energy resources will become increasingly important in the energy system.

Integration of more renewable energy in the years ahead is a political priority, and Denmark as well as the EU has adopted targets for the share of renewable energy in 2012 and 2020. In 2020, 30% of Danish energy supply is to be renewable energy - a substantial share of total energy production. Hence renewable energy can no longer be considered an adjunct to conventional energy production – if anything it will be one of the main sources and it has to be integrated smoothly in order to ensure that the energy system continues to function adequately. Renewable energy sources such as wind are fluctuating and require balancing and reserve capabilities in the energy system. Should renewable energy be integrated solely in the conventional manner it would demand huge investments in grid and electricity production capacity. Therefore intelligent solutions that enable a more efficient use of the energy resources and infrastructure should be introduced.

This challenge will be even greater in the long term, when fossil fuels are to be phased out entirely of Danish energy production. The Danish government has committed to setting/suggesting a timeframe for when Denmark can become independent of fossil fuels, as well as a strategy for how this aim can be achieved. The EU also moves in this direction: Prior to the COP 15, in Copenhagen, December 2009, the EU put forward an offer to reduce greenhouse gas emissions by 30% in 2020 and up to 95% in 2050, provided an international agreement could be reached at the conference.

Distributed energy resources and fluctuating energy production challenges the balancing of the power system. Integration of renewable energy necessitate additional regulation and interaction in the entire energy system – that is both power and heat sectors, and in time the transport sector as well. It implies new ways of coordination between consumption, production and storage of energy, and it implies a more dynamic and extensive power transmission internationally.

However, many unexploited possibilities for meeting these demands exist, particularly regarding communication and automation. Making use of intelligent energy solutions will be essential in order to ensure a future sustainable, secure and efficient energy supply. Developing an intelligent and dynamic energy system that matches the future need is an important – if not the most important – system challenge ahead of us.

Meeting this challenge has a high priority in Denmark due to the already high share of wind power in the Danish energy system and specific plans to increase this share. This is, however, not an isolated Danish effort. The EU has in their *SmartGrid* vision singled out a number of priorities, for example: Real time communication and market based coordination between many entities including consumers and all kinds of production.

The USA has similar visions for a *Smart Grid*. It is a global movement and development, which with respect to technology development and potential commercial opportunities, is important.

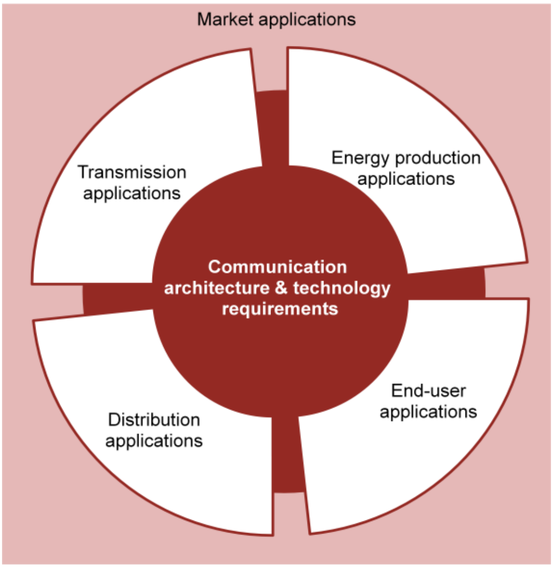

Exhibit 1: Main components in the intelligent energy system. Coordination is facilitated by advanced markets and efficient communication.

The changes will involve all parts of the energy system – hardware, including grids, communication and markets. Many traditions must be challenged to develop this new energy system. Energy demand will become an active part in the system, competing with energy generation in a market system where small and large units can compete on a level playing field.

A dynamic price signal at all levels of the energy system is a prerequisite for an intelligent system. The overall dynamic price signal should be composed of a number of price elements, each reflecting the dynamics of a given element of the energy system. The logic of each system element must be reflected in the related price element. The individual price signals will at times move in opposite directions, and at other times in the same direction.

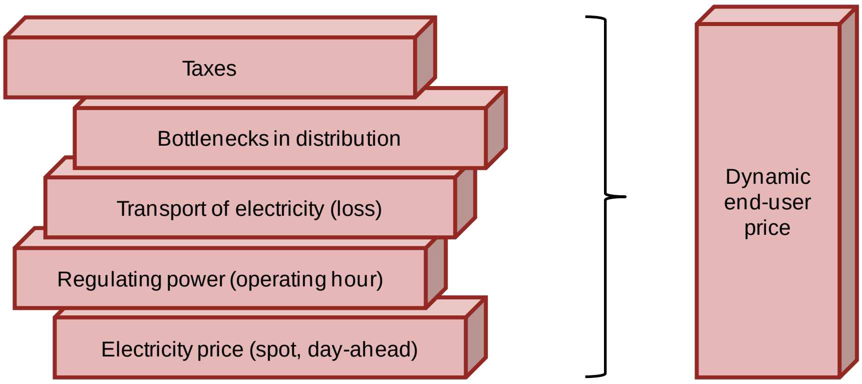

Exhibit 2: Components of the electricity price in an intelligent energy system. Each element may have a dynamic component.

Today an industrial end-user may benefit from varying spot prices. In the intelligent energy system also the other elements would vary by hour or minute. With the proper infrastructure in place it can be less costly to signal an infrequent situation with congestion in the distributions grid, than to invest in expanding the grid capacity.

Partnership mission

The partnership wishes to draw attention to the business potential related to a commercialisation of intelligent energy system solutions. Danish businesses have essential expertise in this area.

The partnership will focus its effort in three areas where Denmark has a particularly strong basis:

1. **System solutions**. The intelligent energy system is not about a single component, but instead about the interaction between many elements. Denmark is ideally suited for development of intelligent solutions that combine different parts of the energy system due to our already substantial wind energy production and our wide-spread combined heat and power production.
2. **Market solutions**. Relative to the average international level of competition in the energy sector, the market system for electricity is well developed in the Nordic countries. Hence Denmark has the chance to shape the energy markets of the future including products and solutions related to market implementation. Both Nord pool markets and the markets for ancillary service are important markets.
3. **Demonstration**. Practical demonstration of intelligent solutions will in many cases depend on a co-operation between various/numerous stakeholders. There is a strong Danish tradition for co-operation that can be used to our mutual benefit and provide cutting edge results applicable internationally.

The partnership wishes to develop Danish positions of strength via an efficient cooperation and coordination between public and private efforts. The partnership envisions that stakeholders meet on ”neutral ground” and through open dialogue identify important issues and challenges leading to creation of a common strategy for development of the intelligent energy system. Development of a white book on the intelligent energy system will provide an overview and common understanding of the core issues, challenges and opportunities that may form an initial basis for starting/opening the dialogue.

An essential goal for the partnership is to connect research and development with authorities and businesses, plus potential investors and consumers in order to close ´the gaps in the value chain' – such as lack of opportunities for demonstration of new solutions that could lead to new commercial products. This is particularly important from an international perspective.

The strategy should contribute to forming a common framework for prioritising and coordinating the Danish efforts and public means in research, development and commercialisation of intelligent energy system solutions and how it is coordinated and prioritised. An important step is the establishment of state-of-the-art experimental facilities. The strategy must build on Danish positions of strength in both research and business sectors – the aim being to further a timely transition to an intelligent Danish energy system, and at the same time to elevate Danish concepts and solutions to a global level, thus paving the way for future business successes in the international markets. The partnership welcomes the Danish Government's allocation of substantial funds to research activities within energy systems of the future, i.e. via the Danish Council for Strategic Research.

On the basis of the strategy the partnership will issue its recommendations to the Danish Government concerning initiatives to promote intelligent energy solutions. One example is the introduction of dynamic energy taxes. Similarly, recommendations may be given to the EU, TSO's and energy market operators concerning EU regulations and market designs.

Areas of interest

The challenges related to large amounts of fluctuating resources in the energy system can – for a large part – be resolved by applying intelligent technologies and solutions. This includes among other things:

- Better (i.e. faster and more comprehensive) control systems,
- Smaller production units and demand with the ability to up and down regulate fast,
- Energy storage – including thermal storage and electric vehicles,
- Demand response, including smart metering system, and
- A market system geared to reflect the dynamics of consumption and production.

There is a significant potential for solutions that optimise the energy system as a whole – from production to distribution and consumption – both in electricity, heat and transport. Such intelligent solutions are based upon data from the entire system being collected and distributed in real time in order to optimise system operation. In this way losses can be avoided and production and consumption can be timed optimally leading to economic benefits. Challenges regarding data ownership and sensitive data security should be resolved.

A major subject is IT systems linking together the different parts of the value chain and making it possible for network operators to react faster, for example in case of faults or breakdown, or making it possible for consumers to react quickly to price changes. The overall idea is that IT and communications technology can be utilised in order to optimise the efficiency of the individual parts of the energy system as well as create an efficient interaction between the elements. Danish companies possess cutting edge knowledge in this field, and several projects have already been carried out in Denmark that could be marketed internationally.

Another priority area is optimal system regulation. In the conventional system the dynamic is limited – often it will take hours to start up additional power production capacity and it can only be regulated within a narrow margin – with considerable costs. Thus it is interesting to focus on the regulation capabilities of smaller production units such as the local combined power and heat plants (CHP). Their dynamic properties fall between those of the large power production units and the very small (micro) plants.

MicroCHP and many forms of consumption can be started/stopped or regulated within seconds. At the same time microCHP enables an efficient co-production of heat and power. The benefits of CHP can thus be extended into areas outside the current district heating areas. Any allocation of balancing or reserve power to dynamic resources or consumers must respect transient stability conditions and protection.

Specific partnership initiatives

The Partnership will identify a number of specific priority projects to be started before the end of 2010. Among those are:

- Development of a strategy for research, development and demonstration of intelligent solutions.
- Organisation of a demonstration project involving congestion management in distribution grids, including dynamic control of demand and local generation. Use of advanced methods for monitoring load conditions.
- Long-term heat storage (weeks, months) and CHP. The storage concept and economy in a future scenario with a high share of wind power is of interest.
- Testing of dynamic prices in a district heating system to activate optimal heat storage in the houses.
- Smart box demonstration. A smart box is a two-way information hub between customer appliances, the meter, the retailer and local network operator. Introducing a smart box allows separating the various information functions from the basic meter function.

Experimental verification

There is an expressed need for experimental verification for research, development and demonstration. The partnership strategy will support establishment of state-of-the-art facilities, open for both public and private activities and enabling experimental activities for systems, subsystems and components. Facilities used by both private companies and universities could also work as a catalyst for the creation of innovation networks and support integration of research results into commercial technological products of the industry.

Since the development of intelligent energy systems has gained considerable attention it is likely that more research, development and demonstration projects will be carried out in the coming years. This effort should be coordinated between all the stakeholders. The partnership strategy should contribute to forming a common framework for this effort.

Incentives to intelligent solutions

One of the challenges in developing and establishing a market for intelligent technologies and solutions is the lack of incentives in the current market and thereby lack of progress. It might develop into a vicious circle where low demand for intelligent solutions limits the dissemination, which in term limits development of new products and methods.

The Partnership will point out where incentives to intelligent system solutions could be introduced or strengthened.

Activities by partnership members

Example (other examples to be included, if partnership members wish):

PowerLabDK

PowerLabDK is an experimental platform for electric power and other types of energy. PowerLabDK will be established through a consortium agreement between four parties: Centre for Electric Technology (CET) at DTU, Risø DTU, Copenhagen University College of Engineering (IHK) and Østkraft, the energy company of Bornholm. Furthermore, the collaboration includes a large number of companies within the energy business.

The PowerLabDK facilities create a unique research platform, ranging from flexible fundamental research laboratories to large-scale experimental facilities and a complete full-scale power distribution system, which will be a data source and platform for full-scale experiments. The experiments can be combined with advanced real time simulations.

PowerLabDK enables development of the future intelligent energy system that can handle the future expansion of renewable energy sources and a long-term vision of a fossil free society.

PowerLabDK aims to support research that is difficult or impossible to undertake in conventional facilities and to support the whole of the research and innovation process, from fundamental theoretical and experimental research to controlled large-scale and full-scale experiments. PowerLabDK is open and accessible to researchers from universities, research institutions and private companies. PowerLabDK hereby also has the potential to function as a catalyst for the creation of innovation networks related to intelligent energy systems, and support to integration of research results into commercial technological products.

It is the priority of PowerLabDK to develop and be a part of international cooperation with leading foreign research facilities and research groups.

PowerLabDK is targeting an integrated research, development and demonstration effort among a number of target groups:

- Researchers from universities and research institutions in need of experimental verification of theory, models etc.
- Transmission system operators (TSOs) and distribution system operators (DSOs) who need testing of system solutions, control strategies and technologies,
- Energy companies who want to increase their turnover via developing new business opportunities based on new technology,
- Industrial companies who want to test subsystems, equipment and components,
- Industrial companies working on the interaction between generation units and electric energy system concerning control and regulation, and
- Stakeholders from all groups working on technologies (both hardware and software) aimed at development of the interaction between generation and consumption of electricity.

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1 Introduction to white paper

The long-term vision for the Danish energy system is independence from fossil fuels. Studies show that such a transformation is technically possible by 2050, and the transformation is possible using technologies that for the most part are well known today. However, there will still be a need for a continued development of new sustainable energy technologies and systems.

A long-term Danish energy system based on indigenous energy resources can be obtained most cost effectively via a combination of initiatives up to 2050:

- A massive development of wind power,
- Substitution of fossil fuels by electricity and biomass, biogas and waste,
- Implementing the smart grid,
- Exchange with neighbouring countries, and
- A considerable level of energy savings and improvement of overall energy efficiency.

A number of analyses and reviews in progress look into the structure of a future energy system based on renewable energy. The analyses agree on the expectation that primary energy demand in 2050 will be dominated by wind power and biomass, biogas and waste. Another common feature is that electricity demand is expected to rise heavily – a doubling to a trebling is not considered unrealistic up to 2050. This is caused among other things by electricity replacing fossil fuels in the heat and transport sectors due to dissemination of heat pumps and electric vehicles. For this reason alone, intelligent solutions are necessary.

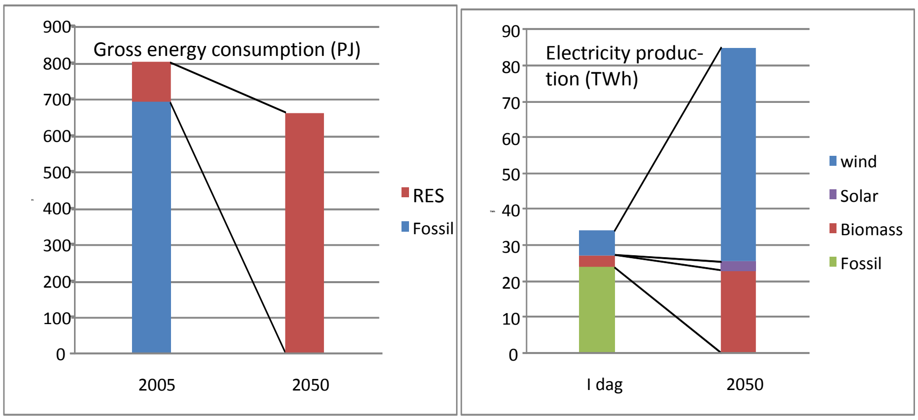

*Exhibit 3: Danish gross **energy** consumption (left) and **electricity** production (right) today and 2050.*[2]

The scenario with a fossil free future is one of many possibilities. Other scenarios may weight CO_2 reductions higher and give less priority to reduction of fossil fuels. This may give way for the use of coal and CCS (carbon capture and storage). However, also

[2] Ea Energianalyse: Scenarier for det danske energisystem i 2020 og 2050, for Miljøstyrelsen 2008.

in such a future it is likely that wind power will play an important role and many of the challenges with developing a dynamic energy system will prevail.

A future dynamic energy system must deal with a number of challenges, including:

- The security of electricity supply during times without wind.
- The security of supply in a system with a large share of fluctuating electricity production and few central power plants, i.e. how to secure the system against blackouts, etc.
- How to facilitate a dissemination of electric vehicles without huge expansion of the electricity distribution networks. In addition, how to ensure utilisation of electric car batteries as a means of electricity storage.
- How to ensure a dynamic and efficient interaction between electricity and heat sectors.
- How to activate national means for system regulation when interconnectors to abroad are full.
- How to use communication and computing measures in order to limit energy consumption.

Development towards an energy system independent of fossil fuels will challenge the current energy system nationally as well as internationally. The transmission networks were developed during the second half of the 20th century and in large parts of the world they are they are approaching their limits already today. At the same time future responsibilities of the networks such as maintaining security of supply and integration of large amounts of renewable energy imply that management of the system will become an increasingly extensive and complex task.

The transmission system must therefore be utilised in a more efficient and dynamic way, using new tools and technologies. This is one of the elements in the smart grid.

Development of the intelligent energy system has been compared in significance to the development of the national and international freeway system during the last century, or the development of the internet during the last decades.

The exhibit below shows electricity demand in a possible future scenario for 2050. The increasing electricity demand is due to electricity replacing fossil fuels in other sectors such as heating and transport.

It is vital for the development of an energy system independent of fossil fuel that a considerable amount of this ”new” electricity demand is flexible. The demand must to a certain extent be dynamic and adaptable to when the electricity production takes place. A considerable share of electricity production in 2050 is expected to be based on wind which is fluctuating. Therefore, a considerable share of future electricity consumption must be flexible.

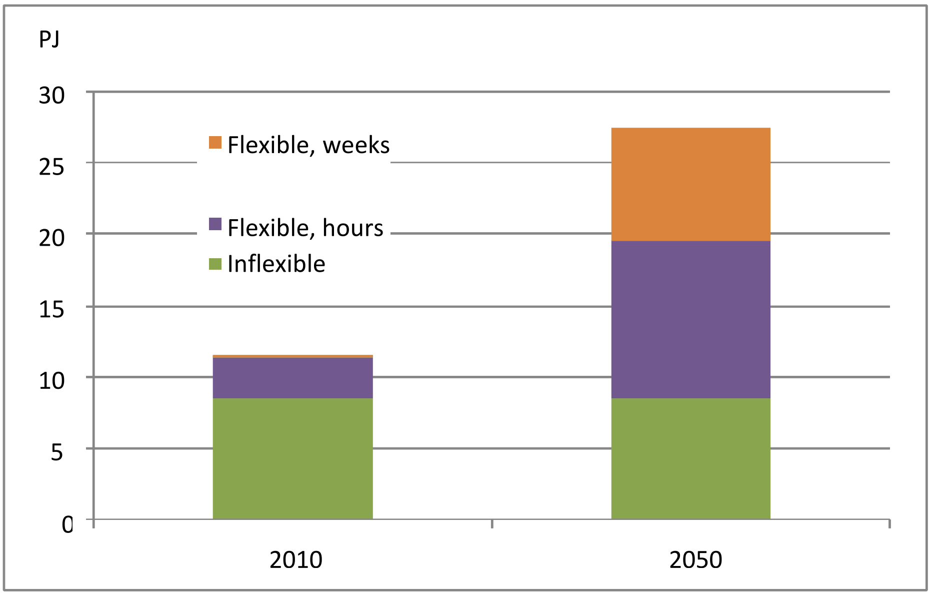

Exhibit 4: Potential for demand response today and in a 2050 scenario where electricity replaces fossil fuels in heating, transport etc.[3]

The intelligent system must ensure that the flexibility of this large future electricity demand is utilised as effectively as possible.

1.1 Definition of intelligent energy systems

There are many conceptions and definitions of the intelligent energy system depending on different starting points. However, there seems to be a consensus that from an infrastructure point of view, an intelligent grid is the infrastructure connecting energy demand and supply using the latest developments in digital technology and communication technology in order to increase efficiency, reliability and security of the system. In a wider context, an intelligent system facilitates a high degree of interaction between electricity, heat and gas sectors.

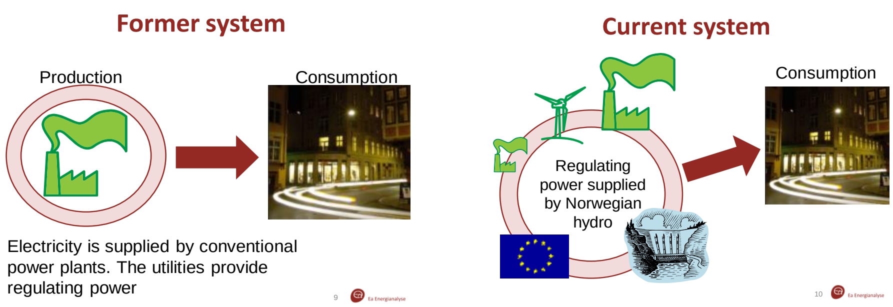

Exhibit 5: Nordic system development from 1980's to today where electricity is produced by many sources including wind power. The system is balanced to a large extent by means of Norwegian and Swedish hydro power.

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[3] Estimated by Ea Energy Analyses

The energy system is being transformed from the former centralised producer-controlled system to a system much more decentralised and consumer-interactive.

This transformation involves all stakeholders in the sector: Energy producers, energy suppliers, Transmission System Operators (TSOs), Distribution System Operators (DSOs), technology suppliers, suppliers of energy services, energy customers as well as regulators and other authorities.

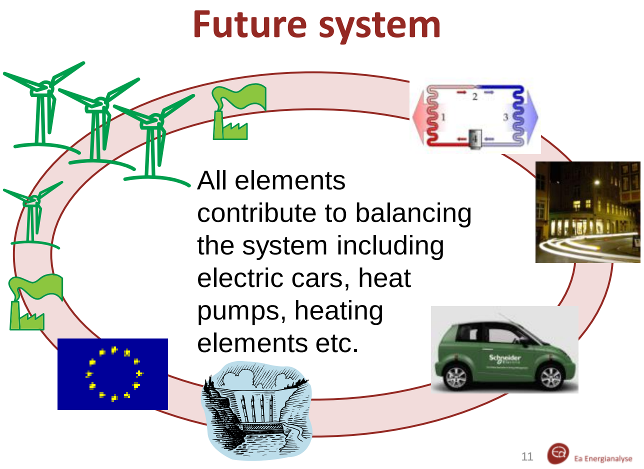

Exhibit 6: Future system in which all units – including consumption - contribute to balancing the system by means of intelligent system technologies and solutions.

In its Energy Policy Report 2009, the Danish Government describes ways in which energy will be produced and consumed in the future:

"The society of the future will use energy intelligently. In the society of the future, we will use as little energy as possible through energy savings, and the energy we use will come from renewable sources. Moreover, in the green and smart society of the future, our homes will be low-energy homes, perhaps even plus energy homes which generate more energy than they consume. We will have heat pumps, and our electric cars will recharge over night when electricity prices are at their lowest. The individuals and enterprises of the green and smart society will demand intelligent, energy-saving and climate-friendly technologies."[4]

The intelligent energy system is developed by bringing the philosophies, concepts and technologies that enabled the establishment of the internet to the energy system. Many of these ideas are already in operation. Yet it is only when they are empowered by means of the two-way real-time communication and "plug-and-play" capabilities that exemplify the intelligent energy system that genuine breakthroughs begin to multiply.

[4] The Danish Government: Energy Policy Report 2009, febr. 2010.

Important elements in this development are demand response, advanced metering infrastructure (AMI), and visualisation technology.

The US Department of Energy lists five fundamental technologies that will drive the intelligent electricity grid:

- Integrated communications, connecting components to open architecture for real-time information and control, allowing every part of the grid to both 'talk' and 'listen'.
- Sensing and measurement technologies, to support faster and more accurate response, such as remote monitoring, time-of-use pricing and demand-side management.
- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics.
- Advanced control methods, to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event.
- Improved interfaces and decision support, to amplify human decision-making, transforming grid operators and managers into visionaries when it comes to seeing into their systems.

Existing grid	Intelligent grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralised generation	Distributed generation
Hierarchical	Network
Few sensors	Sensors throughout
Blind	Self-monitoring
Manual restoration	Self-healing
Failures and black-outs	Adaptive and islanding
Manual check/test	Remote check/test
Limited control	Pervasive control
Few customer choices	Many customer choices

Exhibit 7: The intelligent grid compared with the existing grid.[5]

1.2 What the intelligent energy system is not

The terms "intelligent energy system" and "smart meters" are often confused. They are not the same thing. Metering is just one of hundreds of possible applications that constitute the intelligent energy system; a smart meter is a good example of an enabling technology that makes it possible to extract value from two-way communication in support of distributed technologies and consumer participation.

The intelligent energy system is the collection of all technologies, concepts, topologies, and approaches that allow the silo hierarchies of generation, transmission, and distribution to be replaced with an end-to-end, organically intelligent, fully integrated

[5] Hassan Farhangi: The Path of the Smart Grid, IEEE power and energy magazine, jan/feb. 2010

environment where the business processes, objectives, and needs of all stakeholders are supported by the efficient exchange of data, services, and transactions.[6]

[6] Ibid.

2 The energy system

The Danish energy system is characterised by an intensive use of combined heat and power and renewable energy sources, especially wind power, which were developed in close relation to the development of the three national grids: Power, district heating, and natural gas. Denmark is geographically located between the Nordic countries (with its high share of hydro power) and the continent and has an extensive exchange of power and natural gas with the neighbouring countries.

Today's energy system is the result of decisions taken over more than a century. This gradual development is reflected in the structure of the energy system, which in most cases is designed to meet basic engineering requirements; energy is produced to fulfil the needs of energy consumers, and made available according to these needs.

However, a new supply structure based on variable energy resources such as wind power will require a much more flexible energy system, and one which includes flexibility among energy consumers as well as suppliers. Thus the core of an intelligent system should include rapid communication between energy producers and energy consumers.

Rapid communication might well be based on real-time pricing. Under such a system, the real-time cost of energy is signalled to consumers who then respond by demanding more or less energy, according to whether the price is low or high. This would allow consumers to make productive use of a surplus of low-cost wind power, and restrict demand when supplies are scarce.[7] The aggregated response from demand can develop so that demand not only is a price taker, but in many cases a price maker.

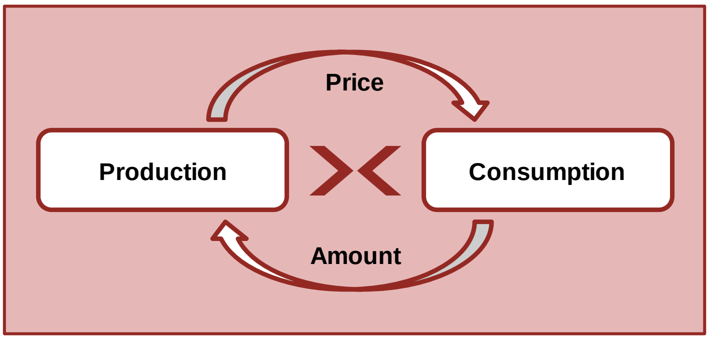

Exhibit 8: Dialogue between energy producers and consumers can match demand to supply by adjusting prices. Inspired by Morthorst et al, 2009.

The Danish energy system is today characterised by a high degree of diversification and distribution. Increased production of renewable energy in the future, primarily as wind power, must interact with the entire energy system effectively if it is to displace

[7] Morthorst et al: Challenges for a future Danish intelligent energy system, Risø Energy Report 8, 2009

as much fossil fuel as cost-effectively possible in the electricity, heat and transport sectors. In this respect, flexibility will be a key concern.

Thus an intelligent energy system has to:

- efficiently integrate large amounts of fluctuating renewable energy sources for power, heating, and transport,
- ensure that energy demand is met efficiently and appropriately - without compromising security of supply or consumer comfort,
- facilitate energy conservation and efficiency improvement, and
- ensure economic efficiency.[8]

2.1 The existing electricity grid

The power grid is the largest interconnected machine on Earth. From Ireland to Russia electricity grids are connected and supplying greater than 700,000 MW to more than 800 million inhabitants.

Historically, the electricity transmission system has had a single mission: Transporting electricity from producers to consumers with high reliability. Expanding the grid was the only option, and visibility within the system was limited. When the transmission grid was designed and built, energy efficiency, environmental impact and customer choice were not primary concerns.

The system today widely relies on 1900's technology since it was designed and established before the dissemination of computers. This implies considerable limitations in the flexibility of the system and it can potentially lead to environmental problems, as well as problems concerning security of supply and system security.

As to security of supply the socioeconomic consequences of power outages can be huge. In the US it is assessed that more blackouts and brownouts are occurring due to the slow response times of mechanical switches, a lack of automated analytics, and "poor visibility" – a "lack of situational awareness" on the part of grid operators.

The importance of a sufficient energy system is underlined by the fact that the national as well as international economy is increasingly relying on digital technology. In the 1980's electrical load from sensitive electronic equipment, such as chips (computerised systems, appliances and equipment) and automated manufacturing was limited. In the 1990's, chips share grew to roughly 10% and today, load from chip technologies and automated manufacturing has risen to 40%. This load is expected to increase to more than 60% of total load by 2015.[9] Therefore the reliability of the system is crucial.

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[8] Freely quoted from Morthorst et al.

[9] US Department of Energy: The Smart Grid, an Introduction, 2007

The digital development of society and economy also requires a certain quality of the electricity supply. Digital equipment is far more sensitive than analogue ever was, requiring tighter tolerances for voltage and frequency fluctuation. Power quality events – dips in voltage lasting less than 100 milliseconds – can have the same effect on an industrial process as a more general outage that lasts several minutes. A single such event can cost commercial facilities such as banks and data centres significant amounts of money. According to the Electrical Power Research Institute (EPRI), by 2011, 16% of the electric load in the US will require digital-quality power.[10] It should be noted that the so called UPS (uninterrupted power supply) systems can be used as protection against these events.

Structure

The traditional electricity grid is a strictly hierarchical system in which power plants at the top of the chain ensure power delivery to customers' loads at the bottom of the chain. The system is essentially a one-way pipeline where the source has no real-time information about the service parameters of the points of use. The grid is therefore "over engineered" to withstand maximum anticipated peak demand across its aggregated load. Due to the fact that this peak demand is an infrequent occurrence, the system is inherently inefficient.

To facilitate troubleshooting and upkeep of assets, the central generation companies have introduced various levels of command-and-control functions. A typical example is the widely deployed system known as supervisory control and data acquisition (SCADA). Although such systems give central generation companies limited control over their upstream functions, the distribution network remains outside their real-time control. This picture varies very little across the world.

[10] US Department of Energy: Smart Grid Stakeholder Book, Utilities, 2009.

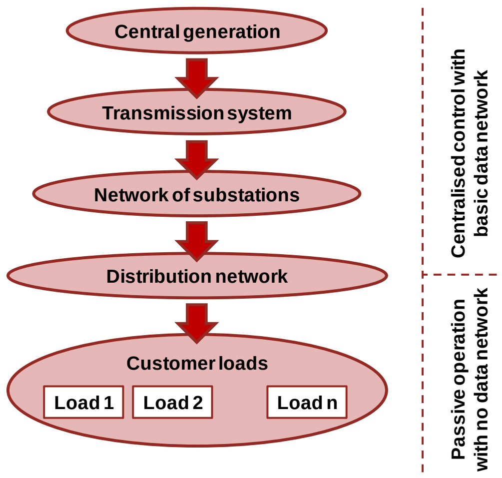

Exhibit 9: The existing grid.[11]

The foreseen increase in large offshore wind farms and in the amount of distributed generation will increase the intermittency of power generation. This means that other resources must be found to compensate for the fluctuating and limited predictability of power generated by wind turbines.

Fluctuating wind generation will affect the existing power system performance in several ways:[12]

- System balancing. The fluctuationg power generated by wind turbines should be balanced by other resources in order to ensure system stability. Measures should be found which can compensate for the intermittency. Such measures could be different types of energy storage, demand or generation units with characteristics compatible with wind energy in a 15 minutes to 1 day time scale
- Market performance. The electricity market is the modern tool for optimisation of power system operation within and across national borders. Increasing fluctuating generation, increased transit flows, trade limitations in neighbouring countries and other factors challenge the price formation in the market.
- System security will be affected as the share of central power plants will decrease and fewer large units will be available to supply ancillary services. Distribution system operators will get increasing responsibility for system operation due to the decentralisation of power generation. Furthermore, bidirectional power flows on the low voltage levels cannot always be handled properly by the existing grid control and protection systems. Novel solutions at the distribution level are required in order to ensure reliable and secure power supply.

[11] Hassan Farhangi: The Path of the Smart Grid, IEEE power and energy magazine, jan/feb. 2010 and Kim Behnke, EcoGrid EU - A Smart Grid prototype for the Future, 2010.
[12] Ecogrid.dk Phase 1, WP2: System Architecture, 2008

	Issues
System balancing	- Reactive power - Fluctuating wind
Market performance	- Price signal response - Market clearing in all circumstances
System security	- More bidding of ancillary services - Upkeep of voltage level

Exhibit 10: Overview of issues.

In principle the challenges to critical system performance identified above can be handled in two ways:

- The existing power system can be extended with more generation, stronger grid and transmission systems.
- Advantage can be taken of information and communication technologies on all system levels, the so-called intelligent or smart solutions.

These two ways to improve the performance are as such not alternatives, but complementary. However, the high cost of extending the system with more assets, compared with the much lower costs when using smart solutions based on information and communication technology, clearly speaks for the latter. This strategy has also been recommended by many international projects (IntelliGrid, SmartGrid etc.).

It should be noted that information and communication technology is the main enabling technology for realising many of the objectives of the future power system, such as robustness, customer involvement and market operation (see below). Furthermore, information and communication technology can also serve as an important means of activating existing, but unused, system assets.

These objectives can be reached by using information and communication technology to implement advanced communication, coordination, monitoring and control functions in the grid and its subsystems and components.

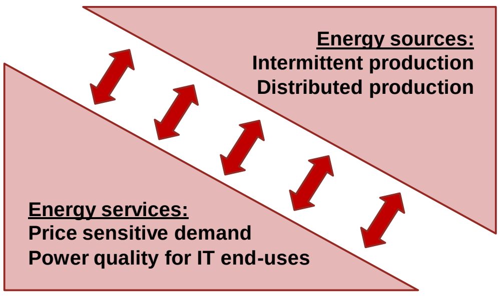

Exhibit 11: Challenges of the modern energy system.

2.2 Intelligent infrastructure

The electricity grid can be divided into a transmission level connected with a distribution level composed of a number of intelligent sub-grids in order to facilitate flexible and efficient system operation. Each sub-grid on the distribution level could furthermore include a number of micro-grids with local intelligence. The sub-grid structure can ensure efficient use of local resources, provide operational flexibility in critical situations and increase the security of supply.

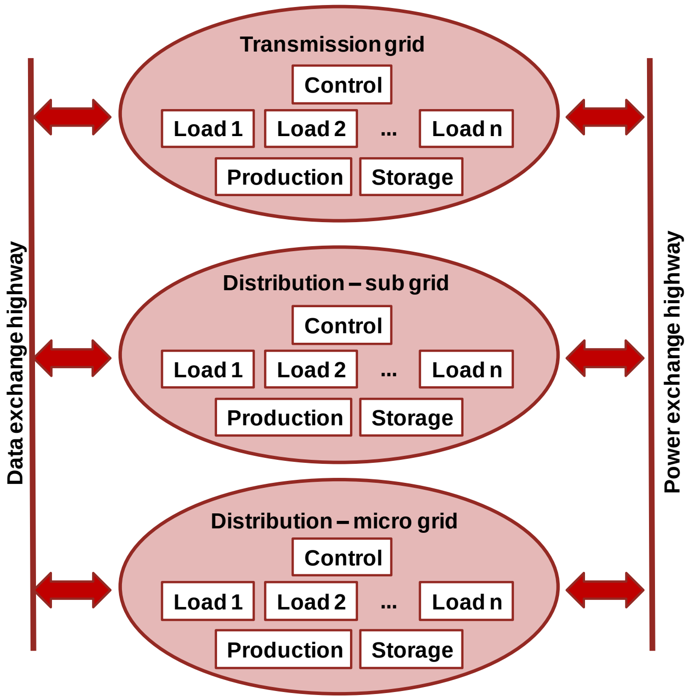

Exhibit 12: System topology for the intelligent energy system.[13]

It may in some special cases be relevant to establish a direct current (dc) network as a supplement to a general alternating current (ac) grid. This can be the case when a particularly high security of supply is required or e.g. in relation to local generation from photovoltaic, full cells or batteries. Many end-uses such as computers and TV are dc-equipments, and energy losses can be reduced with a central ac/dc converter. Such a system could include:

- Connection to the grid (feeder)
- Ac bus for ac loads
- Dc bus for dc loads and connection to energy storage and distributed generation
- Voltage regulation in steady state and in transient
- Fast real and reactive power compensation
- Fault detection and fault current limiting and isolation
- Autonomous distributed intelligent control for short-time-scale control
- Coordination and optimisation for longer-time-scale control.

[13] Inspired by Hassan Farhangi: The Path of the Smart Grid, IEEE power and energy magazine, jan/feb. 2010

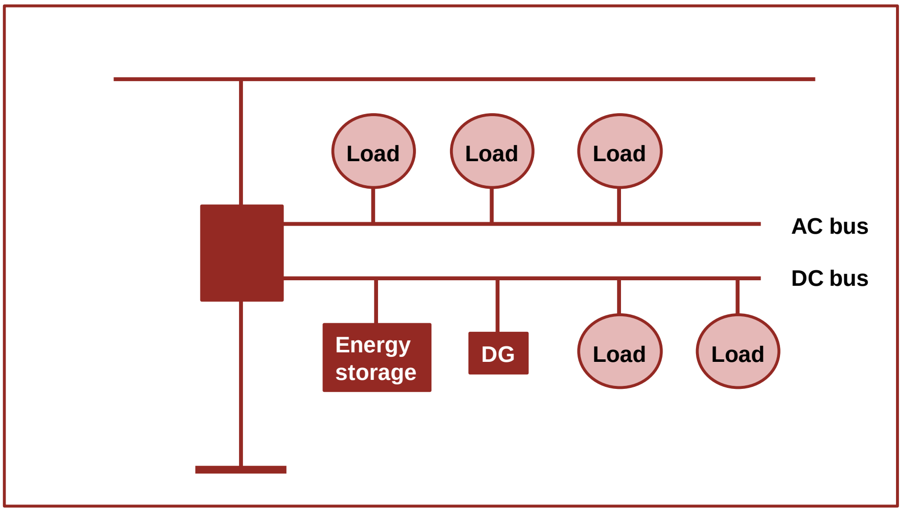

Exhibit 13: A local network with AC and DC. The local DC grid can be an efficient way of delivering high security of supply.[14]

A power system with a high penetration of fluctuating energy sources requires special consideration for control and coordination of the overall system monitoring, protection and operation. Since an increasing part of the generation units will be located at the distribution level, a more active role should be allocated to the DSOs, which are responsible for sub-grid operations. The coordination of the operation of the transmission and distribution levels should be increased.

	Conventional	CHP	Wind
Transmission			
400 kV	2,706 MW	-	-
132-150 kV	4,282 MW	-	329 MW
Distribution			
50-60 kV	431 MW	803 MW	19 MW
10-30 kV	24 MW	1,486 MW	2,062 MW
Low voltage	-	138 MW	761 MW

Exhibit 14: Danish generation capacity per voltage level.

The intelligent energy system includes generation, consumption, and storage technologies with information and communication technology (ICT) providing intelligence for more effective and flexible operation of these units on the grid. Distributed generation, consumption and storage units can support the grid with different types of local services such as VAR-control and frequency control.

Electric vehicles with local intelligence can provide e.g. temporary storage capacity to the grid. Other storage technologies and intelligent loads can respond to e.g. frequency deviations. Interconnection to the grid of local generation units must be facilitated through standard protocols for information exchange ("plug-and-play").

[14] Enrique Santacan et al: Getting smart, IEEE power & energy magazine Mar/Apr 2010.

3 Markets for energy and reserves

The market system is in many respects the most efficient way of implementing intelligence and dynamics into the energy system. The market system today is relatively new, and it will be a task for the partnership to point out where the market systems can be further developed and strengthened in order to promote intelligent solutions. In the following section, the elements of the existing electricity markets are briefly described, and some possibilities for development of this and other markets are outlined.

The Nordic electricity market is well-known for its high liquidity and its efficient market function. The Nordic electricity system has a peak demand of 63 GW. The exhibit below illustrates some of the major components of this market.

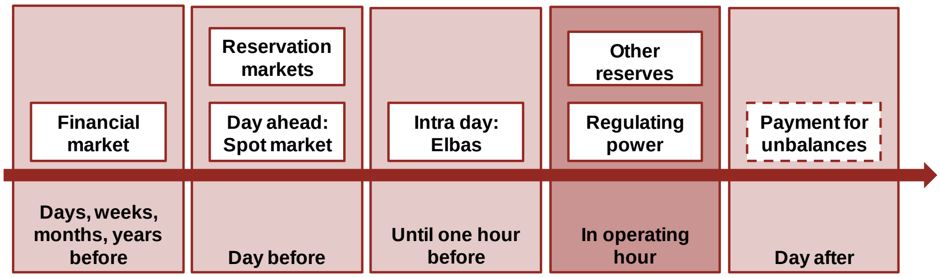

Exhibit 15: Different markets for different time scales – the Nordic set-up. The reservation markets include reservation of resources for the regulating power market and for other reserves.

3.1 Spot market

The central market is the spot market where a daily competitive auction establishes a price for each hour of the next day. The trading horizon is 12-36 hours ahead and is done for the next day's 24 hour period. Participants' bids consist of price and an hourly volume in a certain bidding area. Different types of bids exist, e.g. the standard bid for a specific hour, or several types of block bids.

The price is determined at the intersection between the aggregated curves for demand and supply for each hour – taking the restriction imposed by transmission lines into account. Many activities are focusing on activation of demand in this market – in the form of demand response. As of December of 2009, negative prices were allowed in the spot market. In addition, small generators are to a large degree active in the spot market. In April of 2009, 75% of all CHPs below 5 MW were in the spot market.

3.2 Financial markets

The financial markets trade futures and other derivatives which are settled against future spot prices. It is for example possible to enter a future contract for 100 MW next year. Such contracts manage risks, and in the absence of long-term physical contractual markets, are essential for the market participants.

Given that the time from fixing the price in the spot market, till actual delivery hours is up to 36 hours, deviations can occur. Deviations can for example come from unforeseen changes in demand, tripping of generation unit or transmission lines, or from incomplete prognoses for wind power generation.[15]

3.3 Elbas

Deviations from the planned demand and generation can be compensated by market actors in the Elbas market[16] up till one hour before the operating hour. However, the liquidity in this market is limited. Currently, the average trade in the Nordic area is 200 MW, with an increasing trend.

In order to have stability in the Nordic electricity system[17] different criteria must be met at all times:

- The frequency of the synchronous system must lie between 49.9 and 50.1 Hz,
- The time deviation of the synchronous system shall be within the range [-30s, 30s]. Time deviation is found by integrating the frequency deviation from 50 Hz,
- The requirement on the "control area" in UCTE between western Denmark and Germany,
- The transmission capacity must not be exceeded at any line.

In the hour of operation, several types of reserves ensure stability of the system. The reserves can be grouped into automatic and manual reserves. The system criteria are initially managed by the automatic reserves. These reserves are activated automatically, but are expensive and have limited capacity. In order to re-establish the availability of the automatic reserves, regulating power is utilised.

3.4 Regulating power

Regulating power is defined as increased or decreased generation that can be fully activated within 15 minutes. Regulating power can also be demand that is decreased or increased. Activation can start at any time and the duration can vary. For example, 50% of all up-regulating periods last for less than 3 hours. 12% of all periods are more than 12 hours.[18]

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[15] In Togeby et al, 2009, the structure of prognoses error in wind power forecast is described. The largest absolute errors occur when medium wind speeds are expected. It is also shown that the errors are larger in the last hour of the day compared to the first hour, indicating the 12-36 hours prediction as part of the day-ahead marked.

[16] Elbas is a continuous cross border intra-day market that covers both the Nordic countries and Germany.

[17] Norway, Sweden, Finland and Eastern Denmark constitute one synchronous area. Western Denmark is part of the central European synchronous area UCTE (Union for the Coordination of Transmission of Electricity). As of July 2009 the 6 European TSO associations have merged into ESTO-E, covering all Europe. The electricity system is still divided into the same synchronous areas, now called Regional Groups (RG). Thus, Eastern Denmark is a part of the RG Nordic and Western Denmark is a part of the RG Continental Europe.

[18] Energinet.dk: Market Data (Western Denmark, 2002-2009). www.energinet.dk

Regulating power can be an attractive market for dynamic consumption due to the frequent occurrence of negative prices.

	Generation	Demand
Up-regulation	More	Less
Down-regulation	Less	More

Exhibit 16: Definition of up- and down-regulation.

Balance responsible market actors make bids consisting of amount (MW) and price (DKK/MWh). All bids for delivering regulating power are collected in the Nordic Operational Information System (NOIS), and are sorted in a list with increasing prices for up-regulation (above spot price) and decreasing prices for down-regulation (below spot price). The TSO facilitates the activation of the cheapest regulating power taking into consideration possible congestions in the transmission system.

In Denmark, Norway and Finland reservation markets exist. Resources can receive a payment for being active in the regulating power market. The Norwegian market, RKOM, is active for up-regulation in winter periods only.

There is an interaction between the spot market and the regulating power market. The reservation market is used to attract sufficient resources to the regulating power market. For example, with high spot prices it is so attractive to produce for the spot market that a reservation price is needed to maintain capacity for up-regulation in the regulating power market – and vice versa for low spot prices. The reservation price is established based on the amount needed by the TSO and bids from potential suppliers.

The costs for activating regulating power are passed on to the balance responsible agents after the day of operation. Today, most demand is not active in the regulating power market, and therefore must pay the cost of unbalances without benefitting from the many examples of very low prices in the regulating power market.

3.5 Other markets

Other electricity services include a set of reserves, e.g. frequency controlled reserves that are automatic reserves with the purpose of maintaining the stability in the power system after a major disturbance and to counteract other imbalances.

In West Denmark (UCTE) these are: Primary reserve (more or less power, proportional to the deviation from the target frequency of 50 Hz) and secondary reserve (also called Load frequency control, which is designed to maintain the planned exchange with Germany). In East Denmark (Nordel) the function corresponding to the UCTE primary reserve is divided into frequency controlled normal and disturbance reserve. Nordel does not use a function similar to the UCTE secondary reserve.

Primary reserves and frequency controlled normal and disturbance reserves are required based on daily auctions with blocks of 4-hours bids. Suppliers of these services can receive a reservation payment.

3.6 Possible future markets

The market for electricity has developed quickly during the last 10 years, and further development can be expected. One area of possible development is to develop the market design and rules so there will be a level playing field for traditional large generators, decentralised generation, as well as small and large scale demand. In many aspects it is clear that the current rules have been developed mainly for the traditional large generators. E.g. it is required that suppliers of regulating power must be equipped with real-time measurements. This is relevant in relation to traditional power plants, but very expensive if 10,000 electric vehicles or heat pumps would deliver regulating power.

In EcoGrid[19] it is suggested to develop a new market especially suitable for small generators and demand. The idea is to broadcast a price each 5 minutes, and potential suppliers can react to these prices. The main difference to today's system is that the active participants do not need to give bids or promise a certain reaction. Due to the fact that there are a large number of participants the impact can predicted by statistical methods. This is expected to activate a major resource of controllable demand and thereby make the electricity system more dynamic in a market based way.

[19] Please, see section 7.4.

4 Active elements in the intelligent energy system

The intelligent energy system implies introduction of dynamic and active participation in all aspects of the system – that is those elements of the system that are more or less passive today. The major new active elements are the end-users of energy, as well as small producers. Many new commercial opportunities exist in the intelligent energy system to do with facilitating the way in which these elements can be activated smoothly, efficiently and in a user-friendly fashion. Storage also has the potential of being a major asset for the intelligent energy system.

4.1 Consumers as active elements

In intelligent energy system discussions, the concept of "the prosumer" has been introduced. The new energy prosumer is an energy market participant who both produces and consumes energy. This term describes the energy customer who produces wind, solar or battery (PHEV) power for sale to the grid and also consumes energy provided by the grid. In the future world of distributed production, prosumers use buildings and transportation to both utilise energy and provide energy to the grid.

A more intelligent system will give consumers the power to participate and choose. Two-way communication can create a dialogue between utilities and consumers, thus enabling consumers to see what electricity they use, when they use it, and how much it costs. Consumers will be able to manage their energy costs proactively, whether that means investing in intelligent, energy saving end-use devices, selling energy back to the utility for revenue, or as a means of exercising environmental stewardship.

From the utility perspective, "customer participation" will enable utilities to enlist consumer demand as another resource, offsetting the need for additional power generation. With assistance from customers, utilities will be able to help balance supply and demand and ensure reliability by modifying the way they use and purchase electricity. For the first time, residential customers will have the same types of demand-response options as many large commercial and industrial customers enjoy today.

For customers in general, the value of demand response increases with the amount of price fluctuation. For an individual customer, the value depends on the price paid each hour, not on the average price or price variations. That is, average incentives for all customers may be small, but customer demand profiles vary considerably, and incentives for some customers might be quite high.

With high price volatility the profitability of certain new technologies increases. Frequently occurring low hourly prices facilitate substitution from other fuels to electricity, e.g., switching from other heating technologies/fuels or from transport fuels to electric vehicles.

In terms of short-term national welfare gains from demand response, during the period from 2001 to 2008 the potential gain for residential users in Denmark (including grid payment and taxes) was on average less than 0.5 % of the annual electricity bill paid by customers.[20] However, integration of a larger share of fluctuating wind power is expected to increase price volatility. This will encourage demand response, which also facilitates the integration of wind by counteracting fluctuations in supply. Zero prices in periods with excess wind power have been an argument for increasing demand response, and the decision in December of 2009 to use negative power prices in the Nordic area will encourage this.

Looking at national welfare effects, the important effect of demand response is a reduction of demand at high prices. Assuming realistic demand elasticities, welfare gains relate mainly to periods with high prices; to obtain substantial welfare gains from low-price periods, demand elasticities have to be high. In the future, demand elasticities may become larger due to the introduction of enabling technologies, such as automatic disconnection of appliances when the price becomes high.

The incentives for customers to shift their demand in time depend on the price differential over a suitable time interval. Price differentials over two, four and 12 hours are substantial in Denmark, mainly due to demand variation and, to a limited extend, to fluctuations in wind power. In the future, electric vehicles will be able to take advantage of price differentials when charging their batteries. The same applies to heat pumps, hot water tanks, etc.

In spite of the fact that long-term welfare gains are evaluated to be substantial, short-term gains seen in the market so far have been small, and new incentives are needed to increase demand response. In order to achieve an efficient market, fixed additives should be minimised and replaced by percent-based additives. This is of particular importance when looking at the very high fixed price-additives (mainly taxes) placed on residential consumption in Denmark.

The existing hourly market should be supplemented with hourly metering, so that customers can be billed according to hourly consumption and prices. Customers with a high consumption in expensive hours should pay the cost and should not be allowed to select an average rate. If and when a real time market place is established, then customer billing should also be real time based.

Technologies making it easier for customers to react to changing prices should be introduced.[21] In addition, development of devices and solutions enabling customers to respond to prices should be based on open standards in order for all appliances, etc. to be able to participate. It is important that solutions and technologies are user friendly, and that customers are able to control their level of comfort.

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[20] F.M. Andersen et al: End-use behaviour, incentives and measures, in Risø Energy report 8, 2009.

[21] Ibid.

Data security and privacy

The construction of an intelligent system hinges on data access in multiple directions and levels in order to operate effectively and efficiently. The design of the system components must reflect and accommodate this need for data while at the same time ensuring system security and protection of private data of businesses and households. This sentiment is reflected by a statement from the Technology Action Plan in December of 2009:

"Extending an IP-based network to the meter level opens up the potential for both internal and external hacking. To protect against those threats, the structure of the system architecture should be considered carefully. By having a distributed intelligence in the system grid single point failure can be mitigated".[22]

Consumer involvement applications and solutions (i.e. advanced metering infrastructure and demand side management) put privacy interests at risk because information is collected on energy usage of a particular household or business. The consumers remain able to decide who will have access to which kind of information about their "energy profile" so that human privacy right and confidential business information is respected. Furthermore, equal access to data (given with consent from the consumer) for the market actors and the consumer is necessary for market competition and a well functioning market. To this purpose, privacy impact assessment may be used to analyse the consequences of planned new developments before launch.

4.2 Energy storage

The need for energy storage[23] in a future energy system dominated by renewable energy depends on many factors, including the mix of energy sources, the ability to shift demand, links between the different energy carriers and the end-use of the energy. Since energy storage always brings extra costs and energy losses, it should be used only when it increases the value of the energy sufficiently from the time of storage to the time of use.

However, increased use of storage implies new perspectives: Storage opportunities bring about a weakening of the link between production and consumption, and electricity can become a true commodity. Seen from a market perspective, without a storage component the market will not function properly and price spikes, instability and volatility will remain chronic problems.

District heating systems, as used in Denmark, already incorporate substantial thermal energy storage. This is feasible due to the low cost of excess heat associated with power production, and the relatively low cost of thermal energy storage in the form

[22] Technology Action Plan: Smart Grid, Major Economies Forum on Energy and Climate, December 2009

[23] For the sake of simplicity, only heating and not cooling requirements are mentioned in this section although cooling requirements and technologies such as ice storage may be relevant in the Danish system.

of hot water. As wind power penetration increases, there will be more hours of low or even negative power prices. Conversion of electricity to heat (by heat pumps or direct electric heaters) will therefore become more attractive, leading to an increased demand for heat storage capacity.

In a power system that generates electricity solely from thermal and fluctuating sources, system stability and security of supply are only possible, if either thermal plants can meet the entire peak demand, or if the system incorporates large-scale energy storage. In a future power system that is independent of fossil fuels, it may not be realistic to have enough production capacity in thermal biomass power plants to meet peak demand. Large-scale electricity storage and a high degree of interaction with neighbouring countries will be needed to ensure that power from fluctuating sources will always be available during the hours of peak demand.

In electric power systems, the role of storage can be divided into two tasks:[24]

- Energy shifting: The movement of bulk electricity in time, either as consumption (charging) or supply (discharging). The amount of energy stored needs to be large and the storage method relatively cheap. Suitable technologies are for example pumped hydro and compressed air storage.
- Power balancing and quality issues: Rapid response covering smaller amounts of energy. This is suited to batteries and fuel cells, whose comparatively high costs can be justified by the higher value of the electricity stored.

At production level the balancing of supply and demand is challenged by the limited predictability of supply due to fluctuating resources, demand variations, and that demand is stochastic by nature while at transmission level energy storage can be applied to improve power quality. The table below shows some of the common system tasks that energy storage can help provide.

	Typical effect	Activation time	Cycles per year
Operating reserve	100 MW	Hours	20-50
Load levelling	100 MW	Hours	250
Black start	100 MW	Hours	Seldom
Power quality	< 1 MW	Minutes	< 100
Transmission stability	100 MW	Seconds	100
Power oscillation damping	< 1 MW	Seconds	100

Exhibit 17: Functionality requirements of storage options at production and transmission level.[25]

Some storage technologies are mature and have been applied for many years while others are still being developed. The increasing need for storage options has led to an intensive search for new and improved solutions. Traditionally electric energy was

[24] C. K. Ekman et al: Energy Storage, in Risø Energy report 8, 2009.

[25] SWOT analysis of utility-side energy storage technologies, Stijn Cole, Dirk van Hertem, Leonardo Meeus, and Ronnie Belmans, Leuven University.

converted to another energy source for storage. Two relatively new technologies – superconducting magnetic energy storage (SMES) and supercapacitors – however, contradict this adage since they allow direct storage of electric energy.[26]

Thermal energy storage technologies	**Heating**	**Electricity**	**Transport**
District heating system	●		
Hot water tanks	●		
Floor heating systems	●		
Heat pumps	●		
Phase change materials	●		
Direct electric heaters	●		
Pumped hydro		●	
Underground water storage		●	
Compressed air energy storage		●	
Flywheels		●	
Superconducting magnetic energy storage (SMES)		●	
Supercapacitors		●	
Flow batteries		●	
Batteries		●	●
Hydrogen fuel cells			●

Exhibit 18: Types og energy storage.[27]

Due to the sheer market potential for electric vehicles these could become a significant factor in energy shifting. Recent advances in storage for transport, based on both batteries and fuel cells, are promising. It appears that lithium ion technology may allow battery-powered cars to throw off the slow, short-range and dowdy image that has plagued electric vehicles to date. Society's need for transport and the car industry's desire to fulfil this need profitably are important drivers for the development of mobile energy storage.[28]

The exhibit below presents the rated power and the discharge time of a number of storage technologies.

[26] Ibid.

[27] The intelligent energy system infrastructure for the future, sep 2009, Risø

[28] Ibid.

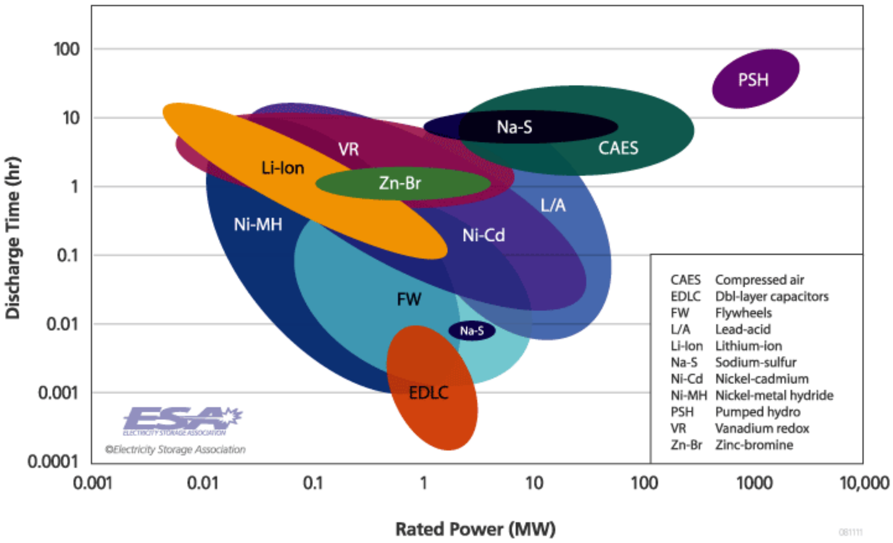

Exhibit 19: Electricity storage by technology.[29]

Power applications, such as uninterruptible power supply (UPS) backup for data centres and automotive starting batteries, represent the largest market for lead-acid batteries, whereas laptop batteries and power tools have fuelled incredible growth for lithium-ion. For bulk energy storage in the system grid, pumped hydro power plants dominate, with approximately 100 GW in service around the globe.[30]

As with the other elements of the energy system the environmental impact of energy storage technologies must also be considered. The most obvious concern is the safe and cost-effective recycling or disposal of batteries and their electrolytes. In addition, the use of rare materials can be a concern.

4.3 Grid elements – potential advantages

The exhibit below sums up advantages and potential gains related to implementation of the smart grid for the different grid elements. The summary is based on analyses from a number of major European development projects according to Energinet.dk.

[29] Capturing Grid Power, Bradford Roberts, IEEE power & energy magazine. July/August 2009
[30] Ibid.

Grid element	Smart Grids applications enable	Potential
Electricity system including TSO	Reduction of electricity consumption	5-10 %
	Reduction of peak load and average load	5-20 %
	Integration of more renewable energy than what the grid was designed for	15-20 %
	Reduction of CO_2-emissions due to lower losses	5-20 %
	Reduction of grid loss in the transmission network per kW transported	0-2 %
	Increased potential for dissemination of electric vehicles	90-100 %
Customers	Increased quality of electricity supply	2-10 %
	Fewer outages	2-10 %
	Reduced energy bill	0-10 %
	Added customer satisfaction	5-10 %
	More choices for customers	10-20 %
DSO and owner of network	Increased lifetime for the grid and its components	10-20 %
	Reduction of operational costs	0-30 %
	Better (dynamic) grid planning, avoided grid invest-ments	25-40 %
	Reduction of grid loss in the distribution grid per kW transported	20-30 %
	Fewer investments in grid reinforcements i.e. when electric vehicles are integrated	30-80 %
Energy traders	Increased supply of new sales products to customers	10-50 %
Electricity distri-bution compa-nies	Increased supply of new products to the DSOs (i.e. ancillary services)	15-50 %
	Adjustment of capacity to fuel savings and CO_2-quotas	25-55 %
	Better economy for investments in renewable energy	10-30 %

Exhibit 20: Smart Grids – advantages, inspired by Energinet.dk, 2010. The indicated potential is a rough estimate.

HVDC-lines

In the traditional (AC) electricity transmission grid the only way to control the power flow is to adjust the output from the power plants. The power flows in the grid according to the least resistance (Kirchhoff's 2. law), like water in pipes. In contrast to AC lines, DC lines like the Great Belt HVDC line can be controlled accurately. The Great Belt transmission line will for the first time connect East and West Denmark directly.

HVDC-lines are also used is the Swedish SydVästlänken. The blue line in the map (left) will be HVDC. The Great belt and the SydVästlänken are expected to have significant impacts on the price formation as well as the efficient integration of wind power in Denmark.

Siemens has delivered the two converter stations that are part of the Great Belt connection**.**

5 Intelligent systems

Management and control in a future energy system based on renewable resources is at the same time a huge challenge and a huge opportunity. Today substantial parts of the energy system, particularly at the distribution level, are without real time control, and implementation of the intelligent and dynamic energy system will imply introduction of information and communication technology in all parts of the system, creating new business opportunities for suppliers of such solutions. In the following section some of the key challenges and opportunities are outlined.

5.1 Management and control, system operation

In order to secure efficient operation and security of supply, energy producers and system operators use a number of management and control systems. One of the most common is Supervisory Control and Data Acquisition (SCADA). Even though these systems enable some control over production and transmission, distribution is largely without real time control due to lack of information and communication systems.

The following four challenges to system operation and control related to **distributed generation** have been identified:[31]

- Inaccurate assessment of system conditions. The massive distribution of the generation and the complexity of its dynamics make it difficult to evaluate the dynamic changes in the overall state of the power system, especially short-term stability margins and resources available for control.
- Less efficient under-frequency load shedding (disconnection of consumers). In case of under-frequency the present load shedding schemes will disconnect local areas, which are selected in advance. With a mixture of consumption and local generation in the distribution systems a disconnection of an area might remove more generation than consumption. However, almost all over the country new schemes for automatic under frequency load shedding are in place, thus eliminating this effect.
- More complicated and time-consuming restoration after faults. The generation resources available for fault restoration will be highly distributed and therefore require sophisticated control and coordination mechanisms in order to ensure minimum time for restoration of normal operation.
- Local black-start capability requires new protection schemes. Distributed generation can potentially reduce the duration and size of power outages by enabling local black-start. However, this will require development of new sophisticated protection schemes. Present operational rules impede or even prevent local black-starts from decentralised units, and the new schemes should take into account the local operational conditions caused by such actions.

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[31] Eco Grid, WP2, System Architecture, 2009

In addition, the following two challenges to power system security caused by the fluctuation of wind generation have been identified:

- Reduced provision of ancillary services from central thermal units. The central conventional units are to be phased out and other means of delivering ancillary services should be developed based on ICT facilitated coordination and control of distributed generation plants.
- Forecast errors and inaccurate assessment of system conditions. The difficulty of predicting the amount of energy produced by wind turbines makes forecast errors unavoidable and will require countermeasures to ensure system balance. In addition to the distributed nature of the generation mentioned above, the intermittency also contributes to inaccurate assessment of power system conditions.

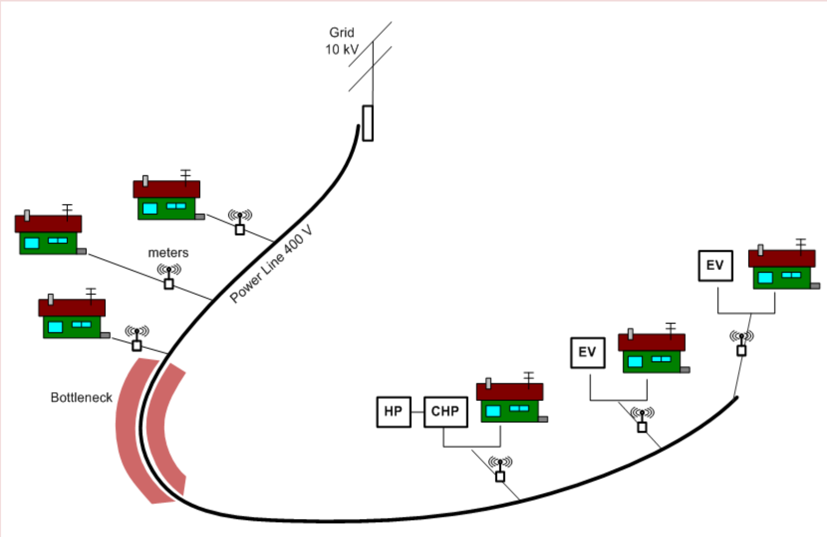
The system security challenges created by increasing the share of distributed and fluctuating generation can be met by a range of measures. The energy storage capability in the district heating systems and (later) electric vehicles can be used to compensate for fluctuating generation. New types of ancillary services including microCHP plants, electric storage, and curtailed wind power can be utilised.

Control of the transmission and distribution grids can be better coordinated. Generation and demand can be better separated in the distribution grids and better information on the status of the distribution sub-grid and the neighbouring sub-grids can improve assessment of overall system conditions.

Control, supervision and co-ordination

The increased share of wind power will require changes in the control architecture of the power system from the present hierarchy towards a more decentralised structure enabling local control decisions. This change is necessary in order to reduce the amount of information required for centralised decisions, facilitate more autonomy in the operation of subsystems in disturbance situations, and to enable owners of small generation and consumption units to participate in the market.

Bottlenecks in distribution grid



Example of a distribution grid with local congestion. CHP = Combined Heat and Power (micro generation), HP = Heat pump, EV = Electric vehicle

When a distribution grid is overloaded, utilities have traditionally had only one tool: They would increase the capacity of the grid. With an increased number of heat pumps and electric vehicles, bottlenecks in distribution grids may occur often in the future. Information Technology and modern meters may open new possibilities to deal with local bottlenecks. Dynamic prices can give an incentive to adapt electricity demand and local generation. Micro generation, heat pumps and charging of electric vehicles have large degrees of freedom. Dynamic prices can be simple Time-of-use prices (with a fixed profile), Critical peak prices (e.g. with high or low prices announced with a days notice) or more complex concepts with real-time prices. Dynamic prices can also include the impact of losses in the grid.

E.g. EC Power delivers micro generation with controllers suitable for all types of dynamic prices. EC Power has developed and patented a system for monitoring local grids based on measurement at the individual end-user.

Changes are required in grid control, protection and supervision as well as in control of individual units and in the coordination of many units. The following issues have been identified:[32]

- The control of the power grid could be decomposed in a sub-grid structure. The transmission level should be considered as one sub-grid and the distribution level should be composed of several sub-grids connected with the transmission level. Distribution level sub-grids are subordinate to the transmission sub-grid with re-

[32] Eco Grid Phase 1, WP2: System Architecture, 2009

spect to overall system control but have also local control authority. The interaction between sub-grids is specified by sub-grid interfaces.

- The distribution of generation to the distribution level will require new schemes that allocate responsibility for control of reactive power between the transmission and distribution levels. [33] Grid codes[34] must be updated according to the new conditions.
- As to grid protection, intelligent wide area protection of the grid is required. Furthermore, the high degree of distributed generation may create bi-directional power flows on the local level, and new protection schemes should be developed that allow this without causing a protection action.
- Real time state estimation and real time fault prediction is required. The increased amount of fluctuating generation creates more dynamics and more uncertainty in evaluation of system states. Accordingly, there is a need for improved techniques for real time estimation of system states and fault prediction on both the system level (wide area) and more local subsystem levels. Such methods should take advantage of Phasor Measurement Unit technology (see below).
- The increased complexity of system operation require improved SCADA systems (supervisory control and data acquisition) for visualisation of system information, for decision support systems using information from state estimators, and early warning systems to support operators in supervisory control of the grid.
- Finally, intelligent control and coordination of units is needed. Control schemes for coordinated operation of a large number of wind turbines should be used to smooth out the variability in generation patterns from individual wind turbines. Control schemes for CHP plants should be improved so that they can contribute with services such as energy storage and reactive power.

[33] Reactive power occupies capacity in the electricity grid. At the same time reactive power is necessary in order to maintain voltage or for example for start up after a blackout. Reactive power is managed primarily by means of neutralising/compensation and by providing sufficient resources to establish and regulate system voltage. Wind power can be a challenge in relation to reactive power. Modern wind turbines can, however, contribute to maintain voltage and small scale CHP can contribute to locally solve challenges with reactive power.

[34] Grid codes are a set of requirements that must be fulfilled in order for the network to operate satisfactorily. The codes include requirements regarding tolerance, control of reactive power, control of active power, protective devices, and power quality.

Control of modern wind power

Modern wind power plants target performance on par with, or better than, conventional power stations, and offer functionality to allow market participation.

Grid code compliance is achieved by means of the wind turbines and their master plant control system. In cases where additional reactive power is required, modern wind farms easily include switched reactors/capacitors and SVCs or STATCOMS (FACTS devices), all integrated into plant-level control. Through high-order control and communication, deterministic properties are realised for wind power plant active power control, and reactive power control. These support overlaid control schemes such as voltage control, frequency control, or reservation of active power margin for balancing/reserve usage. These same control architectures and communication protocols prepare wind power plants to offer future services, such as power system stabilisation.

Other features of importance include short-circuit current contribution from turbine and plant. Variable-speed turbines employing power electronics provide short-circuit characteristics that differ largely in amplitude and content from that of synchronous machines. This calls for revised protection settings within and up-stream of wind power plants. Modern tools allow the protection engineer to deal with these changes in plant characteristics.

I.e. Vestas Wind Systems can provide dynamic control of wind turbines in order to supply regulating power and other ancillary services.

Many small generation, consumption, or storage units should be aggregated into virtual units[35] so that they can coordinate their operation on the energy market. This aggregation will require interfaces for exchange of system status and price information.

[35] A virtual power plant (VPP) is a cluster of distributed generation installations (such as microCHP, wind-turbines, small hydro, etc.) or consumption units that are collectively run by a central control entity. The concerted operational mode shall result in an extra benefit as to deliver peak load electricity etc at short notice. The individual units of the VPP are not necessarily located in the same area or at the same voltage level.

	Tasks
Transmission	1. Transmission fault location
	2. Phasor measurement unit (PMU) data collection and management
	3. System-wide phase quality monitoring, integration with asset management
	4. Asset condition monitoring (advanced sensors)
	5. Real time state estimation
Distribution	6. Distribution fault location
	7. Distribution system management with automated reconfiguration
	8. Distribution state estimation (performance optimisation)
Customer integration	9. Web-based energy use information for customers
	10. Real time pricing information for customers
	11. Monitoring and management of distributed resources

Exhibit 21: Examples of use cases for deriving requirements.[36]

The exhibit above lists some the key applications that are required in order to move towards a more intelligent energy system.

5.2 Smart metering

Advanced Metering Infrastructure (AMI) is an approach to integrating consumers based upon the development of open standards. It provides consumers with the ability to use electricity more efficiently and provides utilities with the ability to detect problems in their systems and operate them more efficiently.

AMI enables consumer-friendly efficiency concepts like “Prices to Devices” to work as follows: Assuming that energy is priced on what it costs in near real-time – a Smart Grid imperative – price signals are relayed to “smart” home controllers or end-consumer devices like thermostats, washer/dryers and refrigerators . The devices, in turn, process the information based on consumers’ learned wishes and power accordingly. Because this interaction occurs largely “in the background,” with minimal human intervention, there are substantial savings of energy that would otherwise be consumed.[37]

[36] EPRI, July 2008, Utility experience developing a smart grid roadmap.

[37] US DOE: The Smart Grid, An Introduction, 2008

Smart meters

Smart meters will play a significant role in the creation of a smart grid, as it is widely recognised that to deal with the intermittency of renewable technologies – their variability and unpredictability – an integrated control of both energy supply and demand will be required.

Smart meters are the next generation of electricity (or gas or heat) meters. They are different from old-style meters as they are able to transmit and receive data, to and from the energy supplier, rather than just generating a read-out. They also provide a digital display for the consumer showing their total current power consumption along with approximate figures for cost and CO_2 emissions, and comparisons of energy use on a daily, weekly or monthly basis. Conventional meters only show the consumer their current power usage. They do not communicate with the energy supplier and have no control over energy usage. A new generation of wireless home energy meters are on the market, with a wider range of user friendly capabilities, including looking at costs, CO_2 emissions, as well as power usage.

Smart meters will enable demand response – that is actions taken to reduce the energy demand by end users. When the price of electricity for instance increases during periods of peak demand, energy efficiency measures using automated control of appliances, etc. can be implemented. Fridges for instance can be instructed to temporarily turn off at times of peak demand, automatically switching back on if the temperature inside the fridge rises too high. In periods of high demand and low electricity supply, smart meters could communicate with electric cars that are parked and fully charged, enabling the cars' batteries to provide power into the grid.

Similarly, it is possible for grid operators to remotely adjust thermostats etc. in customers' homes to reduce load on the system. In turn, the utility will have to offer their customers an acceptable tariff to accept this arrangement. This also links smart metering into home automation technology.

Meter communications can be either from the meter to devices inside the building, from the meter to the energy company, or both. There are number of communication technologies for both cases, including GSM[38], power line carrier, and radio. Each communication system has advantages and is appropriate for different geographical situations and customer types.

[38] Global System for Mobile Communication

ChoosEV intelligent charging station

The ChoosEV charging station delivers intelligent charging in that the consumer may choose the most environmentally friendly and cost optimal time for charging.

The ChoosEV charging station has an intuitive web based user-interface that makes it easy for the consumer to choose to charge when the price is right or when the electricity production is least damaging to the environment. The consumer uses the ChoosEV website to communicate her/his choice as well as when the vehicle must be ready for use. The charging station then selects the hours that provide the best result given the conditions specified by the consumer. The hours are selected freely and do not have to be consecutive.

In order to provide an incentive for economic and environmentally friendly choices, the consumer has access to an overview of the environmental impact of the chosen charging of the vehicles. As an extra service to the consumer the website includes a map over all ChoosEV charging stations in Denmark with information on exact addresses, whether the station is free or busy, and the possibility to reserve a time slot for charging.

Examples of user-interfaces:

Standards

It is important that all intelligent metering systems in the future are inter-operable. This means that if one energy supplier installs one type of smart system into a property, the basic functions of the meter at the heart of the system must be able to be used by a different supply if the customer chose to change supplier.[39]

The European Commission has issued a standardisation mandate[40] to the European Standardisation bodies (CEN, CENELEC, ETSI) requiring them to develop European standards to define smart meter functionality and communications. This is intended to develop a European market for smart metering. A report from the Smart Meters Co-ordination Group is expected by the end of October 2010.

5.3 Intelligent grid technologies

The following subsection describes a number of key technologies enabled by the intelligent grid. This is far from an exhaustive list, however, in terms of business opportunities these technologies and solutions are considered among the most important.

The key to implementing the intelligent energy system is comprised of two things: Two-way communication and an open architecture enabling a ”plug-and-play” environment. Two-way communication can make the energy system dynamic and interactive in real-time, and the open architecture can enable all elements in the system to talk, listen and interact easily and securely.[41]

Efforts are continuously made in order to improve the system, and new components, materials, and technologies are developed and applied. According to the US Department of Energy the so-called FACTS - Flexible AC Transmission Systems - are central, as are components like advanced energy storage, advanced fault current limiters, superconducting transmission cables, microgrids, advanced switches and conductors and solid state transformers.[42]

As for system control, methods to monitor power system components enabling rapid diagnosis and timely appropriate responses are being developed. These methods involve widespread application of computer based algorithms in all parts of the system. It will also support the market, efficient operation and asset management. Sens-

[39] www.ds.dk

[40] The Standardization mandate M/441, issued on 12th March 2009 by the European Commission to CEN, CENELEC and ETSI, in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability

[41] Plug and Play is a concept developed in the IT sector. It is a network architecture designed to simplify home networks. With Plug and Play it is easy for consumers to connect PC, printer and other office equipment. PnP uses a common protocol to transfer data between the connected devices. The technology can be used by practically all control systems and network devices – wireless or not.

[42] US Department of Energy: What the Smart Grid means to America’s future, 2009

ing and measurement technologies will enhance power system measurement and facilitate transformation of data into information to evaluate the health of equipment, support advanced protective relaying and enable customer choice. Improved interfaces and decision support will enable grid operators and managers to make more accurate and timely decisions at all levels of the grid, including the consumer level.

FACTS

FACTS (Flexible Alternating Current Transmission Systems) is an umbrella term that encompasses several technologies designed to enhance the security, capacity and flexibility of power transmission systems. FACTS manage to increase the existing transmission network capacity while maintaining or improving the operating margins necessary for grid stability. More power reaches consumers at a lower investment cost and with less of an impact on the environment.

Wide Area Measurement Systems (WAMS)

Faults like short-circuits in the transmission network, or tripping of large generating units may result in instability of the electric power system, and cascade line tripping leading to a blackout. In order to prevent such a situation, and ensure the secure operation of the electric power system after severe faults, supplementary control and special protection can be used. To this end, various types of FACTS devices and turbine fast valving or generator tripping are utilised. The main problem with the practical application of supplementary control and special protection in large-scale power systems is proper coordination of all control devices and special protection used in the system.

Properly coordinated control of large-scale electric power system can be done with the help of wide area measurement systems (WAMS) based on phasor measurement units (see below) synchronised by GPS.

Phasor Measurement Units (PMU)

PMU is one of the technologies expected to gain widespread dissemination. The PMU monitors the phase angle at different places in the system (i.e. Denmark and Norway) using – among other things - GPS technology. The measurements can be clocked in microseconds. These huge amounts of data can be processed into information on the development of phase differences in real time – and thereby possible risks for voltage collapse can be predicted.

Many blackouts occur when the phase difference gets too big and the voltage can therefore not be maintained. Thus it is of great importance for the security in the system that it is possible to take countermeasures against a wholly or partial breakdown of supply. PMU technology has been compared with the medical sector's "MRI" scan of the system in contrast to the X-ray of yesterday. Beside the possibility of preventing blackouts, the technology is also able to limit the extent of blackouts and contribute to counteracting overload and congestion in the networks.

State estimators

A state estimator is a calculation tool designed to create an overview over the entire state of the power system. It models the network and the flows, and based on numerous measurements (some of which are erroneous) the model creates a comprehensive description of all power flows, a list of potential outages of plants and other components in the system, as well as suggestions for preventive action.

The model is a real-time model and a quasi-static mathematical representation of the current conditions in the power network. The model is extracted at intervals from snapshots of real time measurements (analogue measurements and the status of switching devices) as well as static network data (basic configuration and parameters). State estimation is the key function for obtaining such a real-time network model.

Real time modelling requires the establishment of a dynamic database. This is performed by a data acquisition function, which processes both analogue and status data. Analogue measurements include power flows, power injections, voltage magnitudes, phase angles, and current magnitude measurements, whereas the status data consists of data concerning the network configuration. The static data base contains network basic configuration data along with parameter data (e.g. line impedances). If a state variable can be calculated from the available data (both dynamic and static), it is considered to be observable.[43]

MicroCHP

Micro combined heat and power (or microCHP) is cogeneration of heat and power in the single/multi family home or small office building.

In many cases large-scale CHP systems primarily generate electricity, and heat is a useful by-product. Contrarily, micro-CHP systems, which operate in homes or small commercial buildings, are driven by heat-demand, delivering electricity as the by-product. Due to this operating model, and because of the fluctuating electrical demand of the structures they would tend to operate in, micro-CHP systems will often generate more electricity than is instantly being demanded.

MicroCHP is most widely used in Japan, and in Europe in Germany and the UK. To date, microCHP systems are typically attractive to consumers through a "generate-and-resell" or net metering model wherein home-generated power exceeding the instantaneous in-home needs is sold back to the electrical utility.

[43] Ecogrid.dk WP4 s. 276

The technologies used for microCHP include Stirling engines, steam engines, gas turbines, diesel engines and Otto engines, but also fuel cell micro-CHP is being developed.

MicroCHP use a variety of fuels; natural gas is common, but depending on fuel prices, other fuels such as biogas, LPG, vegetable oil (such as rapeseed oil), woodgas, solar thermal are possible.

Heat pumps

Due to their ability to generate heat (or cooling) based on renewable energy and their storage potential, heat pumps are one of the key technologies in the intelligent energy system. When equipped with smart control systems heat pumps are an excellent means of creating interaction between electricity and heat production and consumption – both when used in large scale district heating systems and in individual households or businesses. Further development of the efficiency and smart capabilities of heat pumps should be an obvious area of interest both for research, and for businesses.

The international market for heat pumps is steadily increasing, and at the same time large efforts are being made to decrease energy use in buildings through regulations and standards. Passive house concepts and zero emissions buildings are becoming increasingly popular, and this could further improve market conditions for heat pumps in the future.

Intelligent appliances

Major home appliance manufacturers are preparing for the intelligent energy system. Whirlpool, the world's largest manufacturer and marketer of major home appliances, has announced that it plans to make all of its electronically controlled appliances compatible with the intelligent energy system by 2015. The company will make all the electronically controlled appliances it produces – everywhere in the world – capable of receiving and responding to signals from the intelligent energy system.

GE's smart appliances – or demand-response appliances – include a refrigerator, range, microwave, dishwasher and washer and dryer. Currently running as a pilot program, these appliances receive a signal from the utility company's smart meter, which alerts the appliances – and the participants – when peak electrical usage and rates are in effect. In the pilot program, the signal word "eco" comes up on the display screen. The appliances are programmed to avoid energy usage during that time or operate on a lower wattage; however, participants could choose to override the program.[44]

[44] US Department of Energy: What the Smart Grid means to Americas Future, 2009

Home automation

As the amount of controllable fittings and domestic appliances in the home rises, the ability of these devices to interconnect and communicate with each other digitally becomes a useful and desirable feature. The consolidation of control or monitoring signals from appliances, fittings or basic services is the aim of Home automation.

Home automation technologies are viewed as integral additions to the Smart Grid. The ability to control lighting, appliances, heat, ventilation, air condition as well as intelligent applications (load shedding, demand response, real-time power usage and price reporting) will become vital as intelligent system initiatives are rolled out.

Home automation can provide a remote interface to home appliances or the automation system itself, via telephone line, wireless transmission or the internet, to provide control and monitoring via a Smart Phone or Web browser.

In simple installations this may be as straightforward as turning on the lights when a person enters the room. In advanced installations, automated tasks may include setting the heat or air conditioning to an energy saving setting when the house is unoccupied, and restoring the normal setting when an occupant is about to return. Other tasks could be engaging in automated demand response, for example, switching off freezers for short periods during peak load.

Home automation systems contain countless possibilities for synergy with other services such as home security, and they can be extended into a variety of (more or less exotic) areas such as use of domestic robots, automated pet feeding, plant watering, etc.

Smart box

It is often implied that the meter technology should be expanded so as to be able to handle all communication related to the functioning of the intelligent energy system. This is, however, not a natural given. Another option exists, namely the so-called “smart box” that functions as a two-way information hub between customer appliances, the meter, the local energy production, and the energy network operator. The advantage of separating the various information functions from the basic meter function (i.e. passively metering energy consumption and sending on this information to the network operator) is related to data security.

It is important that transmission of metering data is of high security, and the information flow from the meter to the network operator can best be protected by limiting the number of functions and actors using the same portal. The communication of data from the meter or the network operator to the smart box does not require the same level of security. The level of security of the various interfaces between the smart box and other elements can thus be varied depending on the need for security.

Furthermore, separating metering from the other functions gives stakeholders – other than the network operators – access to this market, and provides greater freedom of choice to the consumers.

It is important in the design of the smart box solution to consider interoperability of systems and devices as well as privacy issues. An open source/standard approach can provide the flexibility needed to accommodate future technology development and consumer services where a host of different manufacturers contribute. The smart box does not have to be limited to handling energy related services, but could also be expanded to include, for example, internet shopping services for food and goods.

An integral aspect of improving consumer choice and engagement in the market is to ensure that every consumer can access their own historic consumption data for free, and in a common format that they can easily use to compare offerings/upload onto switching websites to find the best deal. Consumers should have the choice to share this data for free with whomever they decide.

6 International strategies

6.1 European Union

Since 2006, when the EU Commission issued the ”Vision and Strategy for Europe’s Electricity Networks of the Future” the EU has worked on the intelligent energy system. The basis for the European effort has been the challenge of implementing the internal market for energy, and at the same time maintaining security of energy supply and realising environmental and climate goals. At the same time a considerable need for new investments in energy production, as well as transmission and distribution capacity are foreseen over the next decades.

Research and development

As for research, within the framework of the European Technology Platform, SmartGrids a Strategic Research Agenda has been developed in a co-operation between researchers, business and authorities. The Agenda proposes which research areas should be given priority.

Financing takes place within the framework of existing arrangements and schemes i.e. the 7th Framework Programme, and it is a priority to mobilise and coordinate other private and public resources i.e. national schemes, structural funds, the European Investment Bank, etc.[45]

Furthermore, the 750 million EUR initiative ”Intelligent Energy Europe” supports projects developing better methods, tools and technologies for intelligent energy production and consumption in Europe.[46] Among other things, Intelligent Energy Europe has funded the network ESMA - European Smart Metering Alliance – which consists of businesses and organisations working for the promotion of smart metering in Europe.[47] Smart Metering is defined as having the following features:

- Automatic processing, transfer, management and utilisation of metering data
- Automatic management of meters
- Two-way data communication with meters
- Provides meaningful and timely consumption information to the relevant parties and their systems, including the energy consumer
- Supports services that improve the energy efficiency of the energy consumption and the energy system (generation, transmission, distribution and especially end-use).

[45] European SmartGrids Technology Platform, Directorate General for Research, 2006
[46] http://ec.europa.eu/energy/intelligent/
[47] www.esma-home.ea

Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)

One interesting project supported by the European Commission through the IEE program is the Smart-A project (Smart Domestic Appliances in Sustainable Energy Systems). The project assessed the potential synergies from coordinating the energy demand of domestic appliances with the generation of electricity and heat from renewable energies or cogeneration with other load management requirements in electricity networks.

The project concluded that some individual appliances – i.e. electric heating and water heaters, washing machines and tumble dryers - are more suited for load management than others – i.e. ovens and stoves. Of the total demand response potential by smart appliances of some 60 GW in 2025 in Europe, the project estimated 40 GW is economically viable. The highest value of controllable load was found in countries and regions with a generation system with low flexibility, or with high penetration of wind power. The project also concluded that development of adequate business models for the operation of smart appliances and related incentive schemes for households is very important. I.e. incentive mechanisms are needed that collect part of the economic benefits within the electricity sector and direct them to the smart households.[48]

Task Force on Smart Grids

In November of 2009 the Commission set up a task force to draw up recommendations concerning the functionalities required of smart grids and the need for standards, as well as recommendations for regulation on data safety and the roles of the actors involved in developing intelligent grids. The task force is due to report its first findings in June of 2010. After hearing the initial results of the task force of experts the Commission will decide whether to launch a new initiative on smart grids.

Smart meter systems

The EU has issued an obligation for member states to prepare 10-year plans for implementation of smart meter systems. However, within 18 months from the coming into force of the regulation, member states can assess the economic feasibility of smart meters. The goal is that by 2020, 80% of those customers for whom smart meters are economically feasible should have them installed.

Smart grid and infrastructure development

The smart grid and the issue of integration of wind energy are also on the agenda in connection with development of Trans European Networks. The EU Commission plan for European Economic Recovery includes 15 energy projects - 6 CCS (Carbon Capture and Storage) projects supported with 1 billion EUR and 9 offshore wind energy projects supported with 565 million EUR. Among those are Kriegers Flak in the Baltic Sea,

[48] IEE: Smart A, Smart Domestic Appliances Supporting the System Integration of Renewable Energy, prepared by Christof Timpe, Öko-Institut e.V, November 2009

including a coordinated connection to the grid between Denmark and Germany and the COBRA Cable – an interconnector between the Netherlands and Denmark that directly connects wind parks in the North Sea. The Cobra Cable constitutes the start of a proper North Sea Grid.

6.2 The US

The current US administration is committed to development of the intelligent energy system or Smart Grid for reasons that differ somewhat from the European agenda. The grid situation in US is characterised by a lack of sufficient investment in the transmission networks over a number of years. The system is rundown and is expected to become insufficient to meet the needs of increased load and increased electricity consumption in the coming years.[49] In the recent decades the American society has experienced an increased frequency of blackouts and brownouts leading to considerable losses for businesses and society. Department of Energy estimates that power failures (blackouts and brownouts) results in costs for the American society in the amount of 150 billion USD each year. This is the equivalent of 500 USD per American citizen per year.

Secondly, development of Smart Grid is one of the elements of the federal effort to restore the American economy after the financial crisis. The American Recovery and Reinvestment Act contains more than 80 billion USD investment in sustainable energy technology, including 11 billion USD to Smart Grid initiatives and installation of 40 million smart meters at American consumers.[50]

The US administration defines the following Smart Grid characteristics:[51]

- It will enable active participation by consumers. It will give consumers information, control and options that will enable them to engage in the electricity markets. Grid operators will treat willing consumers as resources in the day-to-day operation of the grid, and well-informed consumers will modify consumption based on the balancing of their demands and resources with the electric system's capability to meet those demands.
- It will accommodate all generation and storage options. All types and sizes of electricity generation and storage systems can be integrated using universal interoperability standards supporting ”plug-and-play”. Large central power plants, wind, and solar as well as smaller distributed resources such as electric vehicles can contribute.
- Smart Grid will enable new products, services and markets.
- It will provide power quality for the digital economy. It will monitor, diagnose and respond to power quality deficiencies resulting in a reduction in business losses currently experienced by consumers due to insufficient power quality.

[49] According to IEA Energy Outlook 2009 US consumption of electricity is expected to rise 30 % by 2030.
[50] www.recovery.gov, The Act, febr. 2009
[51] Office of Electricity Delivery and Energy Reliability: A vision for the Smart Grid, 2009

- It will optimise asset utilisation and system operation. The smart grid will improve load factors, lower system losses and improve outage management performance. The availability of additional grid intelligence will give utilities knowledge to build what is needed, when it's needed, to extend the life of assets, to repair equipment before it fails unexpectedly, etc. and thereby keep prices down.
- It will anticipate and respond to system disturbances. It will "self-heal" by performing continuous self-assessments to detect and analyse issues, take corrective action to mitigate them and, if needed, rapidly restore grid components or network sections. It will also handle problems too large or too fast moving for human intervention.[52]
- The smart grid will operate resiliently against attack and natural disasters. It will incorporate a system-wide solution that reduces physical and cyber vulnerabilities and enables a rapid recovery from disruptions.

According to a number of studies, there are considerable benefits for society in adopting the smart grid. A survey from 2007 indicates that over 20 years, between 46 billion and 117 billion USD could be saved in the avoided cost of construction of power plants, transmission lines and substations.[53] Distributed generation can significantly reduce transmission-congestion costs, currently estimated at 4.8 billion USD annually. In addition, smart appliances costing 600 million USD can provide as much reserve capacity to the grid as power plants worth 6 billion USD.[54]

With respect to dissemination of smart meters, the European Smart Metering Alliance (ESMA) estimates that based on current levels of activity, the large majority of smart meters being installed are in the US and Canada, although planned roll outs in Europe could reverse this situation. ESMA also points out that the extent of the roll out of smart metering in the US is highly relevant to developments in Europe, as it could affect the opportunities to develop business in Europe, and might influence the development of standards.[55]

6.3 The International Energy Agency (IEA)

The IEA Implementing Agreement on Electricity Networks Analysis, Research and Development (ENARD) was established in 2006 with a view to facilitating the uptake of new operating procedures, architectures, methodologies, and technologies in electricity transmission and distribution networks, such as to enhance their overall performance in relation to the developing challenges of electricity markets, renewable integration, network renewal and network resilience. Participants include Austria, Belgium, Denmark, Finland, France, Great Britain, Italy, the Netherlands, Norway, South Africa, Spain, Sweden, Switzerland, and the USA.

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[52] See below regardingPMU and State Estimators.
[53] Pacific Northwest National Laboratory: The Smart Grid and Its Role in a Carbon-constrained World, 2009.
[54] Smart Grid Benefits, Department of Energy, Modern Grid Strategy, August 2007.
[55] ESMA: Annual Report on the Progress in Smart Metering, April 2009

The vision of ENARD is to inform governmental officials, policymakers and key industry stakeholders of the pertinent issues relating to current and anticipated developments in electricity transmission and distribution networks, thereby furthering the fulfilment of the objectives of the IEA's G8 Gleneagles Program of Work.

The core objectives of ENARD are:

- Collation, exchange and promulgation of information and data in relation to current and *anticipated electricity T&D developments* within the participating countries and associated program activities.
- In-depth review and analysis of the associated key R&D, design, operational and management issues in relation to electricity *transmission* networks.
- Complementary in-depth review and analysis of a range of key issues relating to the R&D, design, operation and management of electricity *distribution* networks.
- In-depth review and analysis of prevalent and anticipated *regulatory frameworks* and their associated impact on the economic evaluation and optimisation of network asset portfolios.

There are at present 42 IEA Implementing Agreements, and in addition to ENARD in particular, two other Implementing Agreements address issues relevant to the development of intelligent energy systems:

- Demand-side Management (launched in 1993, www.ieadsm.org),
- Climate Technology Initiative (launched in 1995 as part of the UNFCCC meeting and formally an Implementing Agreement as of 2003, www.climatetech.net).

7 Selected Danish projects and cases

Since the beginning in the late 90'ies, and intensifying from 2005, a large number of research, development and demonstration projects have been carried out. Some, but far from all, are mentioned in the following section. Looking back on the projects, there is a trend regarding increasing estimates of technical and economic potential for demand response and other smart grid solutions; growing as technical options are developed and analyses are refined. It is important that new research, development and demonstration efforts build on the results from these projects.

7.1 Concept for controlling the power system

Energinet.dk is in the process of developing a 'Concept for controlling the power system', which sets out an overall Danish plan for how the Danish power system should be controlled in the year 2025.[56] The concept will be developed in a broad, interdisciplinary cooperation between Energinet.dk and industry.

7.2 The TWENTIES project

Energinet.dk, DONG Energy, Risø DTU and Siemens Wind Power together with a number of international partners,[57] are participating in the so called Twenties project starting in the spring of 2010 and concluding in 2013. The Twenties project consists of a number of development and demonstrations projects with the aim to develop new modeling tools and new operating support tools for a power system with large amounts of wind energy in joint operation with thermal plants.

The project budget is 60 million EUR, and the project is partly financed by EU's 7th Framework Programme.

7.3 The Cell project

The Cell project develops, tests, and conducts full-scale pilot testing on a new intelligent control, regulation and monitoring concept for the Danish power system in a specific grid area. The Cell project is being conducted by Energinet.dk in close cooperation with SYD ENERGI Net.[58]

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[56] Energinet.dk: System Plan 2009. First result will be published August 2010.

[57] REE, Spain, TenneT, Holland, RTE, France, Iberola Renovables and Gamesa Innovation and Technology, Spain, AREVA, ABB, Siemens, 50 Hz Transmission and a number of European universities.

[58] Energinet.dk: System Plan 2009

Power Hub project

Dong Energy's Power Hub project is designed to mobilize, control and optimize small power production and consumption units. The concept is to operate these units (such as biogas engines, industrial heat pumps, emergency genset, sewage treatment plants, and electric vehicles) according to demand and prices in the power system.

The Power Hub is basically an information technology solution that can be gradually extended. Through a two-way communication, the idea is that private and commercial consumers "lend" power to Dong Energy in exchange for a favourable rate. In this way gaps in the power system between peak loads and very low loads, which occur when wind is strong or when the wind suddenly drops, can be bridged. Thus, consumers and partners have the possibility to participate in balancing the wind power. When there is much wind energy in the system, thousands of consumer units can be switched on, and when the balance in the grid changes, selected units can be switched off.

By involving smaller production and consumptions units when balancing the electricity system it is possible to:

- integrate a larger amount of renewable energy in the electricity system.
- operate power plants more efficiently by avoiding 'up-and-down' readiness.
- avoid electricity overflow where wind turbines have to be switched off.
- make it possible for consumers to adjust consumption in accordance to power availability and price.

7.4 EcoGrid.dk and EcoGrid.eu

The aim of the EcoGrid.dk project was to develop new long-term technologies for the power grid and system that can contribute to realizing the Danish Energy Policy goal of 50% wind energy by 2025.

The specific task of the EcoGrid.dk was to make a general description and analysis of demand and development of the Danish power system with increased volumes of renewable energy. The analyses describe different solutions with respect to new power system architecture; it examined the consequences of future market developments and identified new measures ("building blocks") to support the overall goals and functions of the future power system.

EcoGrid.Eu is a future full-scale demonstration project on the island of Bornholm, which will develop and test the optimal utilisation of local, renewable energy sources, for example through the utilisation of electricity consumers' flexibility.[59]

[59] Ibid.

The aim is to demonstrate the extent to which Smart Grid solutions can help to integrate up to 50 per cent renewable energy into the power grid, while still ensuring that this takes place on market terms. The project is seeking support via the EU's 7th Framework Programme for Research.

7.5 Demand response in households with electric heating

The project **Demand response in households** demonstrated how electrically heated households can respond to fluctuations in electricity prices. More than 500 households participated in the demonstration project.[60]

The experiment showed that informing the participants about the fluctuation of the electricity prices and pointing out the most expensive hours did not in itself lead to any significant effect. Only participants with installed automatic devices to control the consumption had a significantly lower total consumption. The participants in the demonstration project saved 100-200 DKK/year by adjusting their consumption according to the electricity prices.

An interesting side effect of the demonstration project was that the households saved between 1,500 and 3,000 DKK/year just by participating in the project. However, they did not obtain these savings by adjusting their electricity consumption, but simply by buying their electricity at spot prices during the experiment instead of the fixed price they normally pay through their default supply company.

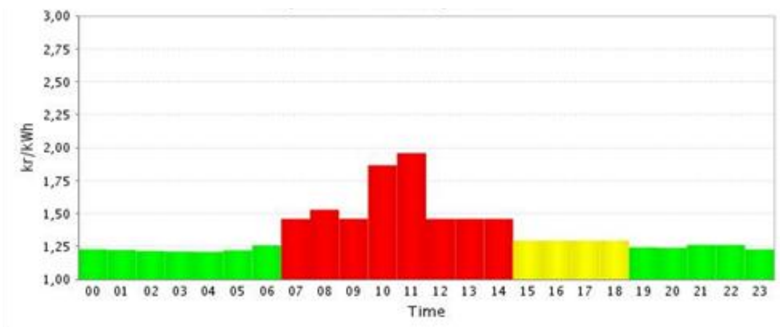

Exhibit 22: Spot prices e-mailed to households. The same colour coding was used to program the set-points of the electric heating, e.g. the household could decide to reduce the set-points in red hours with 1°C and increase the set-point in the last green hours 2°C.

7.6 Demand response as regulating power

The aim of this project was to create awareness in industry regarding possible economic gains by exercising demand response and delivering reserve power. The project also aimed at making it easier for businesses to evaluate their potential and to develop the market setup regarding agreements between participants.

[60] The project was carried out by the Danish Energy Industries Federation, Danfoss, Siemens, SEAS-NVE, Syd Energi and Ea Energy Analyses and was financed by Energinet.dk and the participating companies.

The project is in the process of being completed and one of the main findings is that industrial producers are currently not interested in participating in the market for reserve power due to the economic and administrative conditions at the moment.

7.7 Demand as frequency controlled reserve

In order to maintain frequency stability i.e. the balance between generation and demand, power system operators must procure sufficient reserves. Frequency control in the Nordel system is taken care of by frequency controlled normal operation reserve (FNR) and frequency controlled disturbance reserve (FDR). Imbalances in inter-regional power flow are allowed within the capacity limits.[61]

Demand can act as frequency controlled reserve, and this feature is already used today for large units.[62] However, household scale electricity demand can also be utilised by including a local frequency measurement to the control.

The frequency quality in the Nordic system has been decreasing in recent years due to reasons including hourly market operation and contingencies. In 2009 the frequency was below the normal range (49.9-50.1 Hz) 0.7% of the time. This is up from 0.15% of the time in 1995. With a low frequency, part of the reserves has already been activated and hence the system is less robust against a major failure.

Within this project the potential and economy of electricity demand as frequency controlled reserve and compatible loads in Denmark were investigated. In addition control logic was designed, power system impact was investigated, potential business models were evaluated, and an implementation strategy has been suggested.

In Eastern Denmark, for which detailed investigations has been made, the potential volume of DFR compatible loads is up to 218 MW, which is much more than the present 78 MW frequency controlled disturbance reserve. Device types include, but are not limited to, electric water and space heating, refrigeration, freezing, washing, tumble drying, and air conditioning etc. Industrial demand may add to this potential.

The project is currently followed by an implementation and practical demonstration project scheduled to take place 2009-12.[63] The follow up focuses on investigating the appropriate use of demands as frequency reserve with strong focus on hardware development and demonstration in a practical power system based on previous research. The objectives of the project are:

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[61] Demand as frequency controlled reserve, Ørsted DTU and Ea Energy Analyses, 2008

[62] In Sweden all electric boilers and heat pumps above 5 MW is required by grid code to disconnect at low frequencies. Units above 35 MW must disconnect at frequencies below 49.4 Hz. This frequency is below the level where all disturbance reserves already are utilized. Svenska Kraftnät (2001): Affärsverket svenska kraftnäts föreskrifter och allmänna råd om utrustning för förbrukningsfrånkoppling. SvKFS 2001:1.

[63] DTU, Center for Elteknologi: Demand as frequency controlled reserve - implementation and practical demonstration, 2009-12. Partners: Ea Energy Analyses, Vestfrost, Danfoss, Østkraft

- Practical hardware development of the technology for frequency controlled demand.
- Validation and evaluation of the technology's field performance of reserve provision. Evaluation of the technology’s actual impacts on appliance operation through large-scale demonstration of 200 of such devices.
- Testing and further development of monitoring methods for DFR appliances concerning the needs of the transmission system operator. Obtaining first-hand experience and feedbacks, and evaluating customer's acceptance of the technology.
- Further development of DFR control logics to fulfil specific rules of UCTE and Nordel.

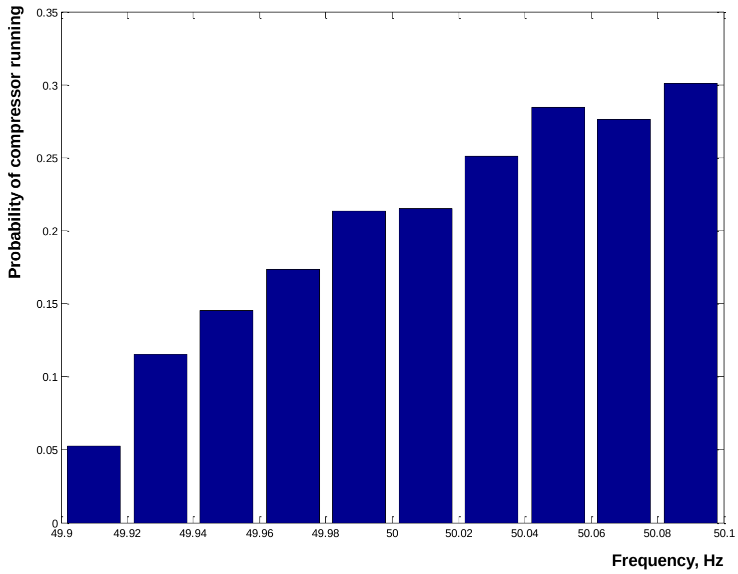

Exhibit 23: Test results with bottle cooler with DFR control. By manipulating the set-point for the compressors on/off cycle the appliance act as a frequency reserve – and the temperature of the cold bottles are practical unaffected.

7.8 Edison project

Electric vehicles (EV) represent a unique opportunity to shift the energy consumption in the transport sector from fossil fuel, to fuel based on renewable energy e.g. electricity produced from wind turbines, photovoltaics, or via biomass in combined heat and power plants. To utilise the full benefit of the interaction between EVs and the power grid with a large amount of power from fluctuating sources implies development of systems that enables EVs to charge when there is a surplus of energy in the system, or by resupplying energy to the grid when there is a lack of power in the system.[64]

[64] EDISON is an abbreviation for "Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks". The EDISON project is an international research project partly publicly funded through Energinet.dk's research programme FORSKEL. Project manager is the Danish Energy Association.

Danish industry is involved in technologies that are essential to a widespread use of EVs, such as strategies for optimised battery charging/discharging, and power electronics related to battery charging/discharging. The Danish competence can be utilised to develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies. Furthermore, the Danish electric power system provides an optimal platform for demonstration of the developed solutions, and thereby, provides the commercial basis for Danish technology export.

The advantage of being a “first mover” constitutes a business advantage, as well as a possibility of a strong Danish influence on future standards for system integration of EVs.

The overall purpose of the EDISON project is to gather research institutions and major industry enterprises and to cover all stages from research, through concept and technology development to demonstration. This project focus on the two first parts: research and concept and technology development.

The project also includes proof of concept where the developed technologies will be tested on a few EVs and charging stations installed in grid on the island of Bornholm. Bornholm is chosen for the pilot test because it gives a good opportunity to show the interaction between wind turbines and EVs in an isolated system. After a successful proof of concept test, the project expects to be ready for a large scale demonstration by the end of 2011.

7.9 Agent based control structure

The project ”Agent based control structure in power systems with considerable decentralized production”, looks into the potential of agent technology, and its benefits and drawbacks when applied to control of the Danish electricity system with its high share of local power production that makes flexible control particularly important. In order to limit the size and complexity of the project, one or two representative subsystems were chosen based on experiences from previous and ongoing projects, i.e. Energinet.dk’s Cell project (Holsted) and DTU/Risø’s project ”Power systems operation and control for integration of large scale wind energy” (Brønderslev). [65]

Control strategies for the power grid are fundamentally dependent on its structure and dynamics, as well as production and consumption patterns. Hence the project aims at developing the criteria that should be applied in selected operational situations by partitioning of the chosen subsystems. Instead of a static division of the electricity system in for example cells or microgrids, the project allows a dynamic partitioning based on the actual operational situation.

[65] Project partners: Technical University of Denmark, Department of Electrical Engineering, Centre for Electric Technology, Risø DTU, Dep. Wind Energy Syd Energi, Syd Energi Net A/S, Dong Energy.

It is assessed if the networks can be partitioned dynamically based on a constitution of network areas defined in advance. The partitioning will be able to include more than one voltage level and take into account a considerable decentralised production. Every network area will include a sub structure in the electricity network including the control and regulation functions belonging to it. In a given operational situation a choice is made between alternative possible network divisions based on a set of heuristic rules implemented in an agent structure. The agents are supplied with knowledge about strategies for choice of networks division that can be deducted from PMU measurements, data on the supply situation (i.e. transit), operational experience and analyses of the control and regulations characteristics of the network areas (i.e. their ability to deliver ancillary services).

The project also assesses to what extent agent based solutions can be used in selected cases to implement flexible protection solutions at a systems level (advanced protection schemes).

7.10 Demand response with interactive meters

Dong Energy has carried out a demonstration project for demand response in selected office- and shop buildings. In hours with extraordinary high electricity prices common facilities like ventilation and cooling were switched off. Supply could also be switched off by the TSO Energinet.dk when regulating the system.

The aim of the project was to demonstrate the ability and suitability of interactive meters in order to realise demand response and regulating effect in commercial buildings and public institutions, and to register user response to the disconnections lasting up to 3 consecutive hours in every 24 hours. The project should provide technical and economic findings regarding demand response in this user segment.[66]

The results of the project were:

- Selected facilities like ventilation, cooling and electrical heating can be disconnected 1-2 hours without inconvenience for the user. Disconnections beyond this timeframe can cause nuisance in extreme situations such as a hot summer day or a cold winter day.
- The user should be involved in the planning process, and passing on information to all users that disconnections for short periods of time can occur is very important.
- It is technically possible to establish and manage databases on facilities that continuously and automatically can activate demand response in response to price developments in the spot market or to a need for balancing the system.

[66] Project web site www.flexel.dk (only in Danish)

- There is a technical/practical potential for demand response in this user segment; however, the economic potential is much smaller than the technical potential. Based on 2008 prices it will only be feasible for installations over 40 kW to participate in a market for demand response.
- The potential can be utilised as regulating power and reserve power.

The overall conclusion of the project was that it is technically viable to manage and activate demand response in larger office buildings and public buildings. However, the economics (based on 2008 prices) is not very attractive for neither customer nor electricity company because of the infrastructure investments needed in order to realise demand response. In addition, there is relatively more effort required when managing many small installations compared to larger ones, i.e. 500 KW and above. Therefore it could be more favorable to focus on larger industrial facilities such as emergency power units, freezing units in cold stores and the like. They have a potential of a scale that should be the starting point of the effort. Over time the infrastructure will become cheaper and thereby feasible for demand response in smaller units and facilities such as office buildings.

7.11 FlexPower

A higher share of wind power is expected to increase the need for regulating power. Regulating power is used to balance the electricity system in the short term. Regulating power is today mainly supplied by central power plants, in combination with import/export to hydro power plants in Norway and Sweden. With a heavy effort to increase wind power it is likely that the capacity of central power plants will decrease in the future.[67]

This project will investigate a possible extension of the current market for regulating power. The core idea is to design and test a real-time market with minimal administrative overheads that can make it possible for electricity demand and micro generation to deliver regulating power. A specific market design is put forward as a starting point: *By broadcasting a price signal for each five-minute intervals, an incentive is given for adjusting electricity consumption or small scale electricity generation.*

This design will be further developed and tested during the project. Results of the testing are expected to be strong documentation that it is possible to supply stable, reliable, and low cost regulation power from demand and small scale generation.

The suggested arrangement should be seen as a supplement to the current market for regulating power.

Many of the techniques for communicating, controlling and predicting developed in relation to the proposed market for regulating power can also be used in a broader

[67] FlexPower 2010 consortium: Actua, Eurisco, Enfor, EC Power, SEAS/NVE, Ea Energy Analyses and DTU: Risø, Informatics, CET

set of services. Therefore the project also includes activities focused on other control purposes, such as local congestion, voltage control, automatic reserve, etc.

7.12 Demonstration project: Back-up generation as regulating power

From 2004-2007 the TSO in East Denmark, Elkraft System, conducted a demonstration project where demand and industrial back-up generators were used as regulating power.[68] 30 companies participated and a sum of 33 MW regulating power was controlled. Typical capacities of existing back-up generators are from 100 kW to 1 MW. As part of the demonstration the rule mandating that the minimum bid size per balance responsible is 10 MW was removed. In addition, a number of electricity demands were included in the system, e.g. pumping in a water plant. A software system was developed with a simple web interface for bidding and a GPRS-relay and Voice mail for activation. Automated aggregation was performed and integrated in existing market systems. A number of tests documented a short start-up time in the order of 1 minute. A high degree of security was realised, which was essential for the participating institutions, which included hospitals, IT-centres and airports.

In the 2009/2010 winter the Swedish TSO Svenska Kraftnät entered an agreement with a number of back-up generators to act as peak load generators in Sweden. 66 MW effect was activated this way.[69]

Exhibit 24: A mobile back-up generator participating in demonstration project about new sources for regulating power.

7.13 The Sino-Danish Centre for Research and Education

A Sino-Danish Centre for Research and Education is being established at the Graduate University of the Chinese Academy of Sciences in Beijing. An agreement to this effect was signed in Beijing in April of 2010.

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68 Demand Response Progress in Scandinavia. Flemming Birck Pedersen, Energinet.dk.
Små kraftvarmeværker skal hjælpe med balancen i el-systemet. Flemming Birck Pedersen, Energinet.dk. Elteknik 5/6, 2004.

69 Svenska Kraftnät (2009): Effektreservsupphandling 2009/2010

The centre aims at becoming a bridgehead for Danish knowledge in China, based on research consortia between Danish universities and the Chinese cooperation partner. The Sino-Danish Centre will create a platform for Danish research and education in China and build a stronger Danish-Chinese collaboration within research. The university centre will offer a framework for Danish-Chinese research projects, PhD programmes and joint Master's programmes. Energy, including wind power integration is one of five priority research areas for the centre.

The university centre is expected to accommodate 300 master's degree students, 75 PhD students and 100 researchers, with about one-half from each of the two countries. It will cost about DKK 100 million a year to run the new university, which will be financed jointly by the Chinese University, the Danish universities and the Danish State.

8 Danish policy and initiatives

8.1 Authorities

Danish authorities are in the process of introducing a number of initiatives suited to promote demand response and smart grid solutions. A number of analyses and reports are due in mid 2010, and by the end of 2010 these can form the basis for possible further initiatives:

- Danish Energy Agency will issue a memorandum on dynamic energy tariffs - that is tariffs that are true to cost with a flexible component - by June 1st, 2010.

- By mid 2010 at the latest, the Danish Energy Agency will issue minimum standards for electricity meters in order to secure they are sufficiently intelligent. At the same time the Danish Energy Agency has initiated talks with the industry organisation Danish Energy Association about dissemination of smart meters to all consumers by 2020, beginning with consumers with a yearly consumption above 50,000 kWh, plus consumers with heat pumps and electric vehicles.

- By the end of 2010 the Danish Energy Agency will issue a plan for the framework for establishing battery charging stations for electric vehicles in Denmark.

- The Ministry for Taxation will issue a memorandum on the possibilities for dynamic energy taxes by June 1st, 2010. In addition, the minister for taxation has proposed a bill making permanent a scheme with lower taxes on electricity used in heating elements in the district heating systems. That will maintain an incentive to utilize wind electricity for domestic heating rather than exporting it abroad. The bill is expected to be passed in this parliamentary term.

- The transmission system operator Energinet.dk is in the process of analyzing how the market for regulating power could be developed in order to enable smaller power production units as well as power supply to participate. A report is expected by June 1st, 2010.

- Energinet.dk also participates in a number of research and development activities regarding smart grid solutions – see section 7. A demonstration project on heat pumps in 300 households is of particular interest.

8.2 Danish research programmes

The Danish Government has initiated several support measures to spur on the development of an intelligent energy system.

The Energy Technology Development and Demonstration Program (EUDP)
EUDP or the Energy Technology Development and Demonstration Program, supports the development and demonstration of new energy technologies. The program is headed by an independent Board, appointed by the Minister for Climate and Energy. The secretariat is located in the Danish Energy Agency. The programme was established by law in 2007 and in 2010 has a budget of 400 million DKK for distribution.

Nordic Energy Research offers grants to projects and Danish companies and universities - research institutions participate in projects supported by the programme. The Nordic Energy Research Programme is financed mainly by national programs and the Danish contribution is financed by EUDP.

Green Labs
One of the aims of the Green Vision of the Danish Government is to turn Denmark into a "laboratory for green technologies" with the best framework conditions possible for the business community throughout the innovation chain from new ideas in R&D, to demonstration and proof of concepts, and further on to commercialisation. The Government has granted 210 million DKK over a period of three years to support the construction (not operation) of a few test laboratories – so called Green Labs – in cooperation with the industry where businesses can demonstrate and test new green technologies in full scale and under realistic circumstances. While the EUDP is aimed at development and demonstration, the Green Labs programme support the construction of facilities to demonstrate and test the same technologies on a large scale. The first round of funding consists of 60 million DKK and is expected to be released in December 2010.

ForskEL
According to the Danish Electricity Supply Act, The Danish Transmission System Operator Energinet.dk, funds research, development, and demonstration in environmentally-friendly electricity generation technologies and a reliable transmission system. The focus areas are approved each year by the Minister for Climate and Energy. The annual financial frame is 130 million DKK.

ForskVE
According to the Law on the Deployment of Renewable Energy, Energinet.dk provides funding with a view to increasing the use of electricity-generating units with a lower electricity-generating capacity, focusing on photovoltaics, wave-power units and other RE technologies such as biogasification and stirling engines. For 2010, a budget of 25 million DKK was available.

ELforsk

According to the Danish Electricity Supply Act, The Danish Energy Association (the association of Danish energy companies) supports research, development, and demonstration projects aiming at more efficient electricity use. The programme focus areas are buildings, LED (Light Emitting Diode) lighting and cooling technology. Projects are prioritised according to the likelihood that the research results can lead to commercial products. The annual budget is 25 million DKK.

The Danish Council for Strategic Research (DSF)

According to the Act on the Research Advisory System, The Danish Council for Strategic Research supports research in areas politically defined. Programme Committees have been established, one of which deals with sustainable energy and environment. The funds allocated in 2010 to strategic research in sustainable energy and environment include 273 million DKK for projects concerning energy systems of the future, and 30 million DKK for projects related to climate and climate adaptation.

The Danish National Advanced Technology Foundation

The general objective of this programme, created in 2004, is to enhance growth and strengthen employment by supporting strategic and advanced technological priorities within the fields of research and innovation. The foundation aims to make a special effort to promote research and innovation in small and medium-sized enterprises. Support is not restricted to energy technologies but so far 20-30% of the budgets have been allocated to energy technology projects. It also includes R&D projects in the energy field. The capital of the foundation will be built up gradually in the period 2005-2012. In 2012, the aim for the foundation is for it to have capital of 16 billion DKK. For the year 2009 the Danish National Advanced Technology Foundation had 280 million DKK for distribution.

8.3 Review

The Danish Government has committed to put forward a timeframe for when Denmark can become independent of fossil fuels and a strategy for how this aim can be achieved. At the moment an independent Climate Commission is working on these issues and based on the final report from the Commission, the Government will put forward its strategy before the end of this election term.

It is self evident the strategy for independence of fossil fuels must include a plan for implementing intelligent solutions in the energy system. Until now there has not been an overall strategy for the smart energy system, and such a strategy is necessary if the goals are to be reached. The strategy should include national as well as international measures including development of common standards. There is also a need for a targeted and coordinated effort. At the moment a large number of initiatives are carried out in different sectors and institutions, and the overall effort could benefit from a larger degree of cooperation and common prioritizing. To this end, all stakeholders in smart grid solutions should be activated and included. The strategic partnership for intelligent energy systems is intended to contribute to this effort.

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