Future Challenges of the Danish Power System

Results of Ecogrid.dk – Phase 1

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***Abstract*—This paper summarizes the key findings from the first Phase of the Danish Ecogrid project which aims at developing long-term solutions that can contribute to a goal of 50% wind energy in the Danish power system by 2025.**

I. Introduction

For the EcoGrid project phase I a unique combination of scientists, experts and industry stakeholders with different background and experiences were put together to work towards one common objective:

> *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 phase I was to make a general description and analyses of demand and development of the Danish power system with increased volumes of renewable energy.

This paper provides an overview of the key results of the EcoGrid Phase 1 project and is based on the executive summary.

The executive summary as well as the detailed work package reports are are available at: http://www.energinet.dk/en/menu/R+and+D/EcoGrid/EcoGrid.dk.htm or http://www.ecogrid.dk/

II. Future Challenges

In Denmark, there is a common understanding among politicians and the public about the need for a sustainable energy system with a high share of renewable energy sources. Without this consensus, Denmark would probably never have experienced the wind power industry "adventure". Neither would Denmark have achieved its ambitious national energy policy target of wind power. Development of wind power in Denmark goes well beyond 1500 MW in 2005, which was the first Danish national target of wind power (formulated in the Danish Energy Action Plan "Energi 2000" from 1990). In 2000 the total wind power capacity was approximately 2 200 MW.

Today installed wind power capacity in Denmark has increased to 3180 MW and wind power generation corresponds to approximately 20 per cent of the total Danish electricity consumption in 2008. In the Governments "Energy Strategy 2025" a new target of 30 per cent renewable energy in 2025 is set out, implying a doubling wind power capacity.

In the opening remarks, the authors of the EcoGrid phase I report have a clear message to the public:

"*Increasing the use of wind energy is not only a matter of deciding to install new wind farms. Providing technical solutions to enable these goals is a complex undertaking. High penetration of wind energy will influence the security of supply and the efficiency of the power system as a whole if not accompanied by major changes in system architecture and operation"* (WP 2-Synthesis).

The Ecogrid authors first appeal is:

- Do not limit the discussion on wind energy penetration to the challenges concerning cables and wind power locations
- Start thinking of the Danish power system as a whole
- Denmark is a part of an international power market

One consequence of the Danish renewable energy policy target is that existing thermal power generation must give way for wind turbines in an energy future where wind power generation covers 50% or more of Danish electricity consumption. Increasing wind power generation has implications for the development of the rest of the power system as well; the grid, operation of central and decentral units, energy flows, investment decisions, etc.

By nature wind power is variable and partly unpredictable. It is variable because the electricity production depends on wind speed and the predictability is limited in the sense that it depends on the accuracy of wind power forecast tools.

The variability of wind power means that systems are needed to utilize the wind power in an economic way, and that other types of generation are needed when no wind power is available.

Increase of wind power generation means that more balancing resources should be available. When the wind power generation is lower than expected up regulation is needed, and when the wind generation is higher than expected down regulation is needed.

The central power plants are currently important domestic providers of flexibility and balancing resources, especially to balance demand and supply in critical situations. The key challenge of the future power system is that

- The need for such balancing services will increase because the installed wind power capacity will reach 6000 MW in a power system with a load in the range of 2100 MW to 6300 MW (2008). At present wind power already covers the entire demand in many hours. In the future this will happen more frequently and the need for down regulation will increase significantly.

- The balancing capacity must be provided by other sources because there will be less capacity of thermal power plants currently providing these resources available in the future. Old thermal units will be phased out of the system and not necessarily replaced.

So far, Denmark has to a large extent benefited from the provision of significant amount of such services to come from import and export managed by the electricity markets, in particular the connection to the Nordic power system dominated by hydro generation. This means that access to foreign resources (import/export) helps Denmark to balance the power system due to variability and forecast errors of today's wind power generation. More wind power will increase the imbalances in the Danish power system and new local resources must be activated.

Hence a crucial question is whether Denmark to the same extent can rely on the electricity markets to cover its increased need for system services or to what extent Denmark has sufficient domestic solutions available in a future with 100 % more wind power capacity installed. That is: what should replace the current central power generation units that provide this support to the system?

The increase in Danish wind power is likely to take place in an international market context where other countries also increase their own wind power generation. This may also increase competition for the balancing resources offered by the Norwegian and Swedish hydro power, and increase the cost of these resources. Increased competition and higher prices may require:

i) increased market integration and development of common market solutions;
ii) a greater need for new domestic sources of system services;
iii) development of end-user markets.

All which provide increased flexibility and balancing resources from additional sources. Other regulatory conditions such as environmental concerns, emissions of green house gases etc., and a ban on new overhead lines, will further influence the size and magnitude of the "Danish" power system challenge. Still, it is clear that solutions have to be found via a combination of international markets and agreements, and domestic means and measures.

III. General conclusions

In 2025, wind power capacity in Denmark is expected to reach 6 GW or approximately twice as much as today. Consequently, the power system will be required to increase the balancing capacity correspondingly.

At present, the Danish wind power challenges are amplified by the increasing wind power installed in our surroundings. In total 29 GW wind power installed in Denmark and Germany (2008) [1]. Hence, Denmark, Germany and the Netherlands benefit from balancing services supplied from Norway and Sweden. There is currently competition for scarce balancing resources due to limited HVDC transfer capability between the two regions limited to 4.2 GW.

In the future, these problems become more urgent. For example the generation of wind energy in Germany has been estimated to reach between 32 and 59 GW in 2025) in the scenarios developed in the project (WP 3). Most of the German wind power generation is planned to be located in North Germany, hence reasonable close to the Danish border. This means that the total German and Danish wind power capacity could increase from today's 29 GW up to 38.5 GW or from 29 GW up to 65 GW depending on the scenario. The required "domestic" balance services/measures in Denmark would be very different in the two cases.

Without new steps the operation of the Danish power system will come become challenging and there is no simple solution to handling the future challenges with 50 % wind power. Denmark will enter an undiscovered territory where no other country has shown the way.

The Need for a Redesign of the Danish Power System

Doubling the share of wind power is likely to require a profound redesign of the power system architecture within the next 10-20 years. Development shows that consumers are becoming more aware of the environmental impact of the energy and transport system and seek greater ability to manage their own electricity use and contribute to system flexibility. New distributed energy resources such as solar, micro generation and storage allow the consumers to produce their own "green" electricity as well as selling excess electricity.

Today, the grid is primarily a vehicle for moving electricity from generators to consumers. Tomorrow's power system should include diverse and distributed energy resources[2] as well as accommodating electric vehicles. This will require two-way flow of electricity and information as new technologies enable new forms of electricity production, delivery and use. New solutions, including a wider use of

[1] European Wind Integration Study (EWIS), 2008
[2] Distributed energy resources are generation, storage and demand response connected to the distributions system

ICT [3] and automation will be necessary, as well as a reinforced grid and improved trading opportunities. Without this, there is a risk of insufficient system security and reliability, as well as inefficient utilization of new wind power capacity.

In EcoGrid phase I, WP 2 discusses possible challenges and requirements to the future power system in more detail. According to the experts, a robust power system (organization, distribution of responsibilities, information and IT solutions) must enable active involvement from large wind power farms and distributed energy resources, electric vehicles to take (more) active role in market balancing and supply of system services. The changes required in the current system architecture will depend on several factors, e.g. expected development in international markets, development of competitive domestic balancing services and customers' demand for new energy management services and clean vehicle transport solutions.

To what extent should Denmark rely on international balancing services in 2025?

All four scenarios described in WP 3 show that it is not likely that Denmark can rely on international markets to provide operating reserves and sufficient balancing services to the same extent as today in a power system with 50 % wind power. However, the availability and cost of balancing services from neighboring countries are likely to differ significantly depending on the future development.

The challenges related to international developments include:

- The availability and cost of balancing services from neighboring areas;
- International security rules, including shared reserves and system services;
- International market design rules, including market coupling;
- International market prices paid for excess Danish wind power generation;
- Demand for transit through Denmark – which affects grid operation and frequency of internal bottlenecks.

To what extent these challenges related to international development will have an impact on the Danish need for additional system support from domestic solutions is uncertain, but considering different international future development scenarios makes it possible to identify the relative importance of some of the above challenges.

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Four scenarios with different challenges are considered:

- *The Grønnevang scenario*, characterized by ambitious renewable targets, weak international coordination and significant reductions in electricity demand seems to be the most challenging scenario (in terms of wind power surplus and need for internal balancing sources). In this scenario, international market solutions are not provided and the general flexibility of the systems is low.

- In *the international green scenario, Greenville*, more market based solutions and more international coordination should be anticipated, but also this is coupled with increased competition for the shared balancing resources. Increased competition means higher prices and the availability of balancing services from surrounding areas will depend on the competitiveness of domestic solutions.

- It is generally easier for Denmark to accommodate wind power in *the two blue scenarios (Blåvang and Blueville)*, where the development of renewables in other countries is moderate, and especially in the Blueville where international market development is encouraged.

The scenarios in EcoGrid phase I show that the extent to which resources will be available from surrounding markets, and the extent to which the challenges on Danish system operation is amplified by developments in neighboring systems, may be very different in 2025 compared to today. Planning for the accommodation of 50 % wind should take into account that the future is uncertain; we simply do not know which scenario will unfold in the end. Planning for the worst case may be unnecessary costly. And planning for the best case may seriously compromise system security and make it impossible to reach the target. Hence, a flexible strategy should be a key concern.

New domestic sources should be implemented for commercial reasons and for security reasons. The amount should be sufficient to form national alternatives to foreign commercial services and to form national backup during future international crises.

Many measures with high potential

The expert's general conclusion is that penetration of 50 per cent wind energy in Denmark is possible, but will require profound changes in the power system architecture.

The EcoGrid project, WP 4, has identified a number of promising measures with high potential. In different ways, these can contribute to system security and to meeting the increased need for balancing resources and technical reserves. Hence, the technical solutions exist but they have to be put together in a smarter way.

[3] Information and communication technology

Among the solutions are:

- **Further integration of different energy systems and technologies (heat, gas, bio energy and transport) can improve flexibility of the power system**, i.e.
  - There is a significant potential to use existing heat storage capacity in the Danish district heating system (combined heat and power or CHP), and the cost of additional heat storage is reasonable. Most of the Danish CHP plants are equipped with heat storage in order to make electricity generation less dependent on heat demand. The possibility for indirect storage of electricity in off peak situations is good (e.g. in periods where wind power production is high). Surplus electricity in 2025 can be absorbed in the district heating systems for at least 12 hours. As a rough estimate between 20 and 30 GWh energy can be stored as useful heat.
  - Dynamic use of other heat production technologies in the district heating system (electric heaters, large heat pumps and heat boilers) are important measures to make the system more flexible. Use of these measures makes it possible to utilize electricity production when prices are low or electricity production exceeds demand. At low electricity prices, an option is to stop the CHP production and produce heat on other production technologies. There is a significant potential of installing heat pumps combined with buffer heat storage outside district heating areas. The investment cost of large heat pumps is relatively high compared with electric heating (dump load). On the other hand the operation cost are low and a high frequency of low electricity prices can make heat pumps profitable.
  - In situations where an immediate increase of electricity is needed investment in new gas turbines, cooling towers can be attractive options. Micro generation/CHP provides a promising future solution as well.

  Further integration with transport, i.e.

  - The accelerating transition towards cleaner transport using plug-in hybrid and battery electric vehicles will create a new type of electric consumers with integrated energy storage in the traction batteries and ability to take only electric energy when it is more convenient for the electric system. Even though the plug-in vehicles will become an important measure in the integration of much more wind power the vehicle owners will do the major investment. Thus, the only additional cost to the electric power system associated with this measure will be building up new dedicated communication and control infrastructure.
  - There are estimations that up to 10 % of the passenger car and small van fleet in 2025 could be Plug-in Hybrid Electric Vehicles (PHEV) and Battery Electric Vehicles (BEV). This corresponds to a total number of about 200.000 vehicles with plug-in functionality in 2025. Just a quarter of these vehicles represent more than 100 MW flexible demand. The control system must prepare also for future vehicle to grid applications, i.e. vehicles that can export power from the battery to the grid (on long term).

- .**Need for new markets services to activate local small multiple resources**, i.e.
  - The potential for increasing the power system flexibility by using demand response solutions is significant up to 1.3 GW. A challenge is to activate not only a few energy intensive industry end-use customers, but also the many small electricity end-use customers. Measuring electricity by smart meters will allow the provision of prices that vary with time-of-use. This can for example allow small electricity consumers to benefit from in-home energy displays, home energy management system etc.
  - Currently the Nordic regulating power market is in practice limited to suppliers that can send plans and guarantee to be able to supply the balancing service. Further, the participants must bid minimum of 10 MW into the power regulating market. Many potential suppliers (wind power and micro generation) are in practice prevented from being active. In a well-designed real-time market, any producer (and consumer) who is able to adjust production or consumption should participate and get paid the prevailing prices. Subsidies for small generation could be changed and exposed to market prices, i.e. reducing the barriers for supplying balancing capacity.
- **Several options exist for grid connection of modern wind turbines.** Modern wind turbines (technology proven) can increase the flexibility (and value) of wind power in the power system. Thus there is no single technology, but rather a number of competing options for individual wind turbines and for wind power plants/farms (auxiliary equipment and flexible AC/DC interconnectors).

The first steps towards integration with heat demand have already been taken. After 2005 all CHP about 5 MW must sell electricity at market price. The subsidy has be maintained, but it has been made independent of the generation. This has helped to improve the timing of the generation, and e.g. reduced generation when electricity prices are low. The technological challenges are manageable, but legislation, communication and operational procedures may need improvements. Financing problems and risk distribution could also form barriers.

The new measures associated with a wider activation of local small multiple resources will not be possible without fundamental changes in regulation and infrastructure.

Serving electric cars and other measures in end-user installations will require more comprehensive changes as the power system must be able to interconnect with hundreds of thousand cars, which should be charged to fulfil customer needs, but can also support power system operation when required by providing balancing power. An update of the power system architecture will be a necessary preparation. The main purposes will be to improve customer service and to activate resources of active and reactive power in local grids.

The new infrastructure will require smart meters and two ways communication for all customers. The communication systems that the utilities are currently developing for smart meters will probably not be adequate to support a system with millions of end-user devices and installations. The communications needs associated with the collection of meter data are different from those of grid operation, e.g. additional bandwidth and redundant services will be needed for grid operations because of the large quantity of operational data. New (cyber) security issues will arise, as the installation of smart meters will create many new and potential access points that connect into grid operation system. In addition, grid code requires for new distributed generation as well as all new wind farms need to be adjusted to the new power system architecture.

It is difficult to point out "the winning solution". The challenge posed by doubling wind power capacity in Denmark has to be understood along several dimensions. New sources of system services have to be found and identified, both to meet an increased demand for system services and to replace the services offered by current suppliers. It will be necessary to provide the necessary infrastructure and incentives to create an environment, which will enable and encourage stakeholders to develop competitive measures. Moreover, initiatives must be taken to ensure that the need for flexibility in future power systems is understood and integrated correctly into the development of all new solutions.

IV. Recommendations

The specific task of the EcoGrid phase I report was to make a review of possible new power architecture, international perspectives and available technologies. Furthermore, the report proposes a selection of relevant future research and development activities for the next phase of EcoGrid.

The EcoGrid group also recommends activities that put emphasis on general strategic future activities, which could support the process toward a Danish power system with 50% wind energy and a system with a high share of local and distributed energy resources.

Development of a Danish EcoGrid Strategy 2025

A Strategy Task Force group led by Energi.dk should be created. The group should involve government authorities as well as representatives from the industry, energy sector (customers, distribution, retail service providers and generation), energy experts and universities. The Recommended activities are:

- Coordinate Energinet.dk activities with other energy and transport related activities, which influence power system operation, reliability and security;
- Develop a strategy of coordinated research, innovation, demonstration and system operation, including an educational program to define needed future skills and competencies;
- Initiate the establishment of a forum for discussion of issues related to responsibilities, legislation, regulation, taxation, subsidies, standards or other means that facilitate the deployment of a coordinated EcoGrid strategy;
- Further development of Energinet.dk's scenarios. Energinet.dk's own scenarios could be supported by assessments including:
  - International scenarios and their impact on the Danish power system
  - The future technology development and demand of distributed generation, storage and plug-in electrical/hybrid vehicles, energy management solutions/installations.
  - The development of smart meters and two-way communication and consequences of wider end-user participation in electricity markets

Management of an energy system in transition

- Develop a process for support the transition of the Danish Power System. Energinet.dk is facing ambitious goals regarding the accommodation of wind power and other renewable energies, the continuing development of power and information technologies and an uncertain future regarding international connections.

Strengthen the international efforts

Through international co-operation with other TSOs in Northern Europe Energinet.dk should continue its effort to:

- Develop efficient market(s) , which allow for active participation of local generation and end users in the spot-, intraday and regulating power markets;
- Improve the integration of the Nordic electricity market with surrounding markets, including the reinforcement of interconnections;
- Push for international standards for SmartGrids installations/appliances.