EcoGrid dk

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Steps toward a Danish power system with 50% wind energy

EcoGrid.dk Phase I

WP5: Activities for EcoGrid phase II

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WP5: Activities for EcoGrid phase II

Ecogrid Phase 1

Final Report

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1 INTRODUCTION

This report is part of the EcoGrid.dk project phase 1 initiated by Energinet.dk and the result of work package 5 dealing with proposals for future steps toward a Danish power system with 50% wind power.

The EcoGrid.dk project has the objective to develop new long term technologies and market solutions for power grid and systems, with reference to the Danish power system. The project is divided into phases, from phase 0 to phase 3. The focus of the phases is:

- Phase 0: Preparation of project description etc.
- Phase 1: General description and analyses of demand and development of the Danish power system with increased volumes of RE.
- Phase 2: Specific projects, analyses and recommendations to Energinet.dk with main focus on research activities
- Phase 3: Technologies are implemented in real environment and demonstrated with subsequent adoption and implementation in Energinet.dk.

The objective of EcoGrid work package 5 is to suggest future research and development activities in EcoGrid.dk. The future activities will consist of related activities of which some should be directed within an EU framework (EcoGridEU). The delivery of phase 1 work package 5 is a packet of proposals to be used as input to Energinet.dk when formulating EcoGrid.dk phase 2.

To reach the ambitious goal of a Danish power system with 50% wind power penetration requires a complete and complex landscape of research, development and demonstration activities covering a wide range technologies and solution. As more wind power will be connected to the Danish electric power system in the coming years, the effort must be focus on developing practicable solutions that can directly been demonstrated and implement in the Danish power system.

The proposed EcoGrid activities in this report are considered as important elements of the future research and development activities to enable 50% wind power penetration in the electric power system. The intension of the activities is to help to provide the right solutions at the right time and to fill-in important needs currently not taken care of by other research and development activities e.g. funded by national programs etc. Focus is concentrated on research and development activities suggested for next phase of EcoGrid. General recommendations regarding e.g. regulations and policies will be provided in the EcoGrid phase 1 summary report.

2
CRITERIA FOR SELECTING PROPOSALS

For selecting and suggesting prioritized technologies and solutions to be addressed in future EcoGrid.dk activities criteria for selecting activities has been analysed, discussed and applied. The developed criteria are:

- Technologies and solutions, which shall be target for future EcoGrid activities, shall have high impact to the overall EcoGrid goal of enabling 50% wind power and other renewable energy sources in the grid.

- High priority should be given to topics, which will not be dealt with in near future, if EcoGrid do not take care of it. Technologies and solutions covered by other national activities and programs should have lower priority within the EcoGrid project to make efficient use of resources even though the relevance may be very high for the electric system.

- Technologies and solutions shall fit with national and international visions and overall strategies for future development of the electric power system.

- Future activities should provide technologies and solutions, which are robust for different future developments. The solutions should be relevant even in “worst case”. High risk activities are accepted if the expected impact is high.

- Results should be directed toward comprehensive system solutions addressing future challenges operating a power system with high share of renewable energy.

- The technologies and solutions should be international acceptable, and based on Danish strength positions and must be highly relevant for the Danish energy system.

- The activities should be focused on research and development enabling practical demonstration in future steps.

Furthermore more practical considerations should be given when selecting proposals for future EcoGrid activities. These are:

- Coordinated with expected available resources for EcoGrid, phase 2.

- Coordinated with and provide basis for the planned EcoGridEU project, which will focus on demonstration of new marked-based distribution system operation enabling active end-user (demand as well as generation) participation.

- The overall activities must be organised in well-defined packages with clear targets and limited interdependency and based on efficient teams.

Finally the conducted work in work package 5 will point at activities, which are not possible or feasible to carry out within EcoGrid phase 2, but e.g. are feasible for inclusion in the PSO-programme or other programmes. These activities are described in section 5c of this report.

3
PREVIOUS PSO APPLICATIONS

Several research project applications regarding control of power systems with large share of renewable energy sources have been submitted to the PSO research programme in 2005 and 2006. Energinet.dk decided to pull out these applications from the PSO programme to form the basis of EcoGrid.dk. As part of the work these applications has been reviewed and used as input and inspiration for identification of future activities. An overview of the previous applications and their contribution and mapping to the EcoGrid phase 1 project can be seen in table 1. These can together with results from EcoGrid phase 1 WP2-4 be used as a base of ideas when formulating proposals for future steps.

PSO-project	Topic	Application	Contribution to EcoGrid vision	Mapping to EcoGrid WP's
2005-2-6301	Reliability studies	Development of probabilistic analysis tool for demand response technologies	Increase integration of RES using demand side options.	WP4/ task4
2005-2-6383	Phasor measurement units	Use of simultaneous measurements for dynamically estimating system stability.	Increase in integration of RES and distributed generation with less necessity of reinforcements in the transmission system	WP4/ Task4
2005-2-6405	Communication and information systems	Development of international protocols for communication with distributed energy sources	Standardized control system for use in grids with high integration of distributed production	WP2/ Task1
2006-1-6376	Grids with distributed production	Assessment and modelling of distributed generation grid strategies currently in development	Better basis for selection and application of future power system control schemes	WP2/ Task1

2007-1-7172	Virtual power plants	Automatic control schemes for integration of large numbers of micro CHP units	Micro CHP units will be able to macroscopically act as a conventional power plant and provide ancillary services to the grid, thereby increasing stability and reducing losses	WP2/ Task1
2007-1-7173	Active distributed energy resources (DER)	Full scale implementation of demand control technology in the Bornholm power system	Large scale integration of fluctuating energy sources in an system using demand control	WP4/ Task2
2007-1-7223	Control of wind turbines and photovoltaic units	Development of flexible control schemes at the converter level, and usage of power storage to operate units in both on- and off-grid mode	Increase in integration of wind turbines and photovoltaic units using advanced converter control schemes and power storage technologies	WP4/ Task4
2007-1-7370	Price signal control	Development of price signal control schemes, protocols, and experimental integration in laboratory. Analysis of customer behaviour in a price signal controlled grid	Theoretical and experimental knowledge of the behaviour of a grid controlled by the market and price signals	WP2/ Task1
2007-1-7472	Photovoltaic units	Development and evaluation of controllers in photovoltaic systems, enabling them to support the grid or operate in an isolated system using power storage technology	Better control and storage buffers in photovoltaic systems leading to improved transient stability and the possibility of voltage and frequency control	WP4/T2
2007-1-7216	Wind power forecasting	Enhancing and demonstrating methods for forecasting wind and evaluating the prediction uncertainty	Optimization of the integration of wind turbines in the grid, by having more accurate knowledge of prediction uncertainty in wind forecasts	WP4/ Task4

4
CONTRIBUTIONS FROM THE OTHER ECOGRID PHASE 1 WORK PACKAGES

4.1 Architectures

EcoGrid.dk phase 1 has explored new architectures for the future Danish power system with a large share of distributed generation. The exploration included a review of promising new technologies such as virtual power plants, micro-grids and agent technology which are under consideration and development in the international power system community. Suggestions for a new architecture were made on the basis of a requirements analysis with special consideration of the Danish power system.

A network of sub-grids

It has been concluded that it will be necessary to develop strategies for enabling the grid to operate as a network of sub-grids with well defined local responsibilities and a distributed supervision and control scheme providing the capability to operate the grid in a variety of modes depending on the status of sub-grids, ranging from normal operation with a fully connected grid to modes with a partially connected grid including sub-grids in disturbed operation. Such a strategy for grid operation including distributed functions for voltage control/reactive power control and demand side management will focus on control of normal operation but will not exclude the inclusion of functions for management of emergency situation (such as cells). An important part of the strategy development will be to define communication interfaces between sub-grids and interfaces which enable easy connection of new generation, storage units and loads.

Subgrid operation will enable the power system to take advantage of the distributed generation and provide an increased ability to handle disturbances in power supply grid operation so that major system breakdowns are avoided.

Apart from short term issues addressing the feasibility of sub-grid operation in the current power grid, this development will require consideration of the following more long term issues:

Principles of grid aggregation

The review of ongoing work on innovative technologies shows that there is lack of consensus on how to aggregate dispersed generation and loads into virtual power plants/loads. A similar lack of consensus or basic principles are lacking on the definition and functionality of sub-grids (e.g. micro grid or cells). More research is required in this area. Results in this area would also be important for defining sub-grid interfaces and for defining interfaces and delegation of control responsibility between TSO and DSO operated grids.

***S**ub-grid operating modes*

Sub-grid operation of the power grid will require definition of criteria for sub-grid operating modes, both on the overall grid level and on the sub-grid level. The criteria for defining sub-grid modes should also take into account operating modes for generation units, storage and loads inside a sub-grid considering that the actual dispatch of generation is market based (wholesale market, ancillary service market). Strategies for sub-grid operation should also include specification of strategies for mode transitions between different modes of normal and disturbed operation. Blackstart and handling of emergency situations like islanding, however, should not be the focus of the future EcoGrid activities as it will be investigated within the cell project.

Supervisory control of the grid

Subgrid operation will require development of subgrid mode indicators and principles for detection of subgrid mode failures e.g. based on the application of wide area measurement systems (WAMS).

4.2 International market scenarios

The development of wind power and more decentralized generation in the Danish system would probably not have been possible without access to international markets. The international markets provide an outlet for generation when there is a lot of wind, back-up power when there is little wind, and access to rapid regulation power, especially from the hydro-based systems, when wind power generation falls or increases rapidly. Similarly, the magnitude and nature of the system challenges related to further wind expansion in Denmark are related to the developments in the adjacent market areas; access to foreign markets, supply of system services, and competition for system services, international obligations, transit and trade flows, etc.

In EcoGrid.dk phase 1 four market scenarios have been developed for the market areas surrounding Denmark; Germany, Norway and Sweden. The analysis has taken the Energinet.dk scenarios for Denmark as the starting point. The main driving forces in the scenarios are international cooperation and environmental focus. The main purpose has been to identify how international market conditions can develop, and create a basis to analyze the implications for the system challenges of doubling the wind capacity in Denmark by 2025.

Some challenges occur in all scenarios. First of all there will be an increased need for balancing capacity and technical reserves. Second, there will be an increased demand for transfer capability. It is likely that there will be a shortage of transmission capacity because of public resistance, provisions that new transmission lines must be cables, and long lead-times in decisions and construction of new transmission lines. Moreover, price volatility in the wholesale market will increase, and this problem will be amplified by the shortage of transmission capacity.

The extent to which new interconnector capacity with neighboring countries will be built and common market solutions developed varies substantially between the scenarios. In the “ville” scenarios, which are characterized by market solutions and international cooperation, there is likely to be more transmission capacity and more common market solutions. However, in the *Greenville* scenario, Denmark will to a larger extent have to compete with other countries for the balancing resources. In the “vang” scenarios, countries emphasize national solutions. In both these scenarios there is a strong case for Nordic cooperation – in Blåvang because of a lack of market coupling with Germany, and in *Grønnevang* because there will be less international competition for balancing resources from Norwegian hydro, and at the same time, extensive wind deployment in north Germany poses an increased threat to Danish system security. In addition, system characteristics such as demand level and flexibility, and technology and fuel mix in generation differ among the scenarios.

4.3 Measures

EcoGrid phase 1 has described a variety of new measures enabling and optimising the integration of large scale renewable energy in the power system. It is concluded that most of these measures are expected to play a role in the future power system, some already on a short term while others require further development.

The most challenging task will be to balance the power and ensure the security of the system in an economic way. Part of the solution will be improved interconnections, especially to the flexible hydro power in the Nordic system. But since our neighbors also plan to use this flexibility to balance their wind power variability, other measures will be needed.

The need for other measures depends on the international scenarios. The worst case scenario is from this point of view the “grønnevang” scenario, with limited international trade, low electricity consumption combined with the high wind power capacity in Denmark. But all the international scenarios will require flexible power measures, and in order to in combination with promote these measures to the system, the infrastructure must be in place. This infrastructure consists of new market structures and new controls which fit into a new architecture and ensures an economic and secure operation.

Flexible power measures must be available to ensure the balance on all time scales, from the fast inertia (ms to s) and automatic frequency control (s to min) to the capacity related time scales (years). It is noticeable that the “new” measures mainly supports time scales up to max a few days, and for that reason the necessary capacity (with expected limited load factor) must be available to cover longer time scales. Reactive power and voltage control should be further supported by local CHPs, wind turbines, distributed energy resources and FACTS.

On the market side, the existing day-ahead market can co-exist with a near real-time energy market (e.g. 5 minute) and an ancillary service market to enable a more flexible and economic allocation of the necessary resources for frequency and voltage control.

Concerning control and ICT, the described measures are considered very important tools for dealing with ever changing and rapidly growing energy market combined with increasing renewable energy capacity, which makes monitoring, control and easy communication between different systems very important.

Application of new control, ICT and market measures will enable better coordination and better utilization of existing and new power measures, and generally speaking the control, ICT and market measures will provide less expensive solutions than new extra power measures. Never the less control, ICT and market measures can not replace the need for new flexible power measures in a future system with 50% wind power. Thus, the future solutions will include a combination of new power, control, ICT and market measures.

5
TOPICS TO ADDRESS

5.1 General considerations

As a feasible approach for achieving a manageable number of suggestions within the scope for phase 2, four coordinated work packages are put forward for phase 2. These could form different activities within one coordinated project or be split into separate projects. The suggested four activities are supplemented with recommendations of further important activities which the EcoGrid consortium suggest to be prioritised in future activities, possibly in other research programs.

The current research programs (PSO and EUDP) primarily cover renewable and environmental friendly technologies themselves. Also demand response technologies and energy savings are covered. New system architectures development, new market designs, and new control measures deserve much more attention in the future. The future system has to have the technical solutions available, but is equally important that they are used properly, i.e. development of proper ICT solutions, market solutions and control solutions should be prioritized. The system level problems, which also have been the starting point of most of the original suggested PSO-projects listed in section 3, are of major importance for the development of the future system with high share of renewable energy resources. It is therefore suggested, that future EcoGrid activities take the role to cover these areas and utilise the broad national competence established in the ongoing EcoGrid activity to develop new system level solutions.

Activities are suggested within the following areas – here showed in a non-prioritised order:

A. Development of tools for optimal operation of system with new balancing measures described in phase 1.
B. Develop new market design that encourage distributed energy resources (DER) to take part in the system balancing
C. Development of new coherent control architecture utilising DER for flexible, secure and efficient system operation based on subgrids based on ongoing developments with special emphasis on normal operation including direct control and market based incentives.

The activities are described below and short task-descriptions can be found in appendix A.

5.2 Suggested content for EcoGrid.dk phase 2

The following three main activities are suggested for EcoGrid.dk phase 2:

Activity A. Tool for optimal system operation with new balancing measures
The objective of this activity is to develop a decision tool to support the operation and short term planning of a power system area with large scale wind energy using new, flexible measures. This tool will consist of two main modules:

- A balancing resource status module
- A system status module

The balancing resource status module will give the system operator an overview of the current (real time) status of balancing resources available to the Danish power system, including new measures. The new measures that will be considered are:

- Storage capacity in the heat sector (CHP)
- Storage and generation capacity available from electric vehicles
- Balancing (up/down regulation) capacity available from demand response
- Up/down regulation available from wind farms

The above mentioned measures depend on their current state, e.g. options for integration with the heat system will depend on an average heat storage temperature and on the present heat consumption, and integration with transportation will depend on and current state-of-charge in car batteries. For the calculation of the potential wind power up/downward regulation input from wind power forecasts will be used under consideration of the uncertainty the forecast. Hence it is important that the module provides close to real-time information about the status of the balancing resources.

The system status module will provide an assessment of the current (real time) need for balancing capacity. The need for balancing capacity depends on system stability, congestions and other issues that are to a large extend already integrated in Energinet.dk's operation. The system status module aim's at taking the already existing knowledge (for instance from the SCADA system) within Energinet.dk and integrate this knowledge into a simplified dynamic power system model (for instance in PowerFactory) together with the input from the balancing resource status module considering real-time available balancing capacity. The balancing options must be models with the relevant dynamic properties and at the real location in the power system.

The simplified dynamic power system model will be used to set-up a number of worst case situations, such as loss of a major interconnection, which can be re-run every 10 to 20 minutes considering the real time status in the power system and the available balancing reserves.

For system operation the results of the simulations can be used by the system operator to take certain actions, such as redefining available transmission capacity or down regulating wind power. In the long run, the tool will provide Energinet.dk with the general information if sufficient balancing resources are constantly available or if additional incentives need to be developed so that more balancing capacity is developed by the different market participants.

Activity B. New market functions for DER participation in system balancing

Near real-time adjustments of the electricity system is crucial for an economic and safe operation. The current market and system operation procedures are designed for a traditional electricity system dominated by large power plants.

In this activity a new market and operational set-up is developed and analysed. Focus is on ways to activate new resources for the normal operation, intra hour regulation. The goal is to obtain improved market dynamics with a minimum of administrative overhead. The set-up should be relevant for all types of demand and generation, and should make technologies compete based on technical and economic features.

Several detailed designs are possible. One example is maintaining the Spot, Elbas and bilateral markets as the basis for planning for the system operation, and then changing the set-up for regulating power to a system with a one way price signal, which all market participants could subscribe to. The price signal could e.g. be broadcasted every five minutes. Response should be voluntarily (but exposed to varying prices) and no plans should be submitted and no reservation price should be paid. Reaction should be metered and payment arranged after the day as known e.g. from today's spot market.

In this activity different designs are studied, including different time intervals. Critical issues like stability, predictability and the possibility of misuse of market power will be analysed for different market designs.

Together with the elements from Activity A this part will provide a valuable starting point for the planned EcoGridEU project. It is suggested to start these activities as fast as possible to enable inputs and preparation of the EU activities.

Activity C. New coherent control architecture utilising DER for flexible, secure and efficient system operation

The purpose of this activity is to develop, evaluate and optimize a new power system architecture with emphasis on two selected key aspects (reactive power/voltage control and near real-time market) for a target system to be demonstrated in phase 3. Future power systems will be based on an increased integrated control of the distribution and transmission systems and active network functions on the distribution level enabling increased participation in the market and delivery of ancillary services. Development of a coherent and consistent control architecture will be the prerequisite for releasing the potential of many of the resources in the distributions networks as well as for an overall economic optimal system design. Without a coherent and consistent architecture the future required system costs will become unnecessary large.

The control architecture should be developed with respect to overall design including integration with suggested new sub-architectures, state/transition design, plans for mitigation of disturbances through intelligent control of grid-subgrid interactions (control actions, state transitions etc.), and grid and sub-grid normal state optimization. The following selected key aspects will be developed within the architecture:
Development and analysis of voltage control/reactive power control approach based on agent based sub-grids considering reliability issues and subgrid interface
Development and analysis of solutions for managing grid operation issues by a near real-time market interaction (e.g. congested lines, optimum response to security and stability issues, dynamic tariffs for losses, voltage quality etc.).

The analysis and optimization of the complex interactions between the technological infrastructure (the grid), the supply and the demand side and the market in these will be based on a developed simulation platform. There is especially a need for an integration of existing modelling, simulation and optimization tools and tools which allow explorative assessment of system interactions on various levels of detail.

The investigations will be based on 1-2 case studies (e.g. Bornholm) and the developed platform can be used to develop other aspects, e.g. simulation of virtual power plant and vehicle to grid approaches.

The outcome of this activity will be development of a coherent control architecture based on sub-grids. As part of the activity a simulation tool will be available enabling analysis of architecture design for a variety of power system aspects.

Relations between activities

The suggested activities should be considered as key elements in a coherent portefolio of activities carried out by Energinet.dk, universities and research institutions, energy companies and industrial stakeholders including activities within national and international programs. The position of the suggested activities within this larger framework is illustrated in the following graph.

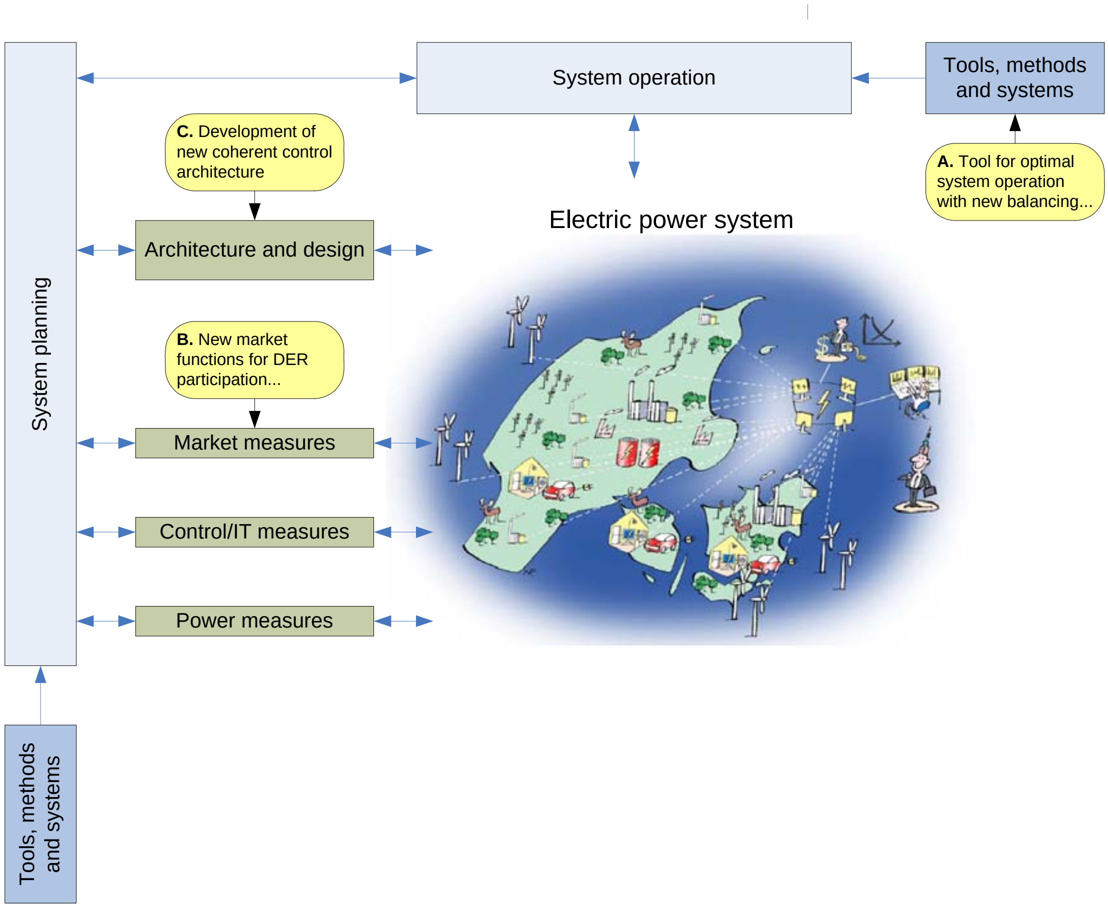

Figure 1: Overview of relations of the suggested activities.

5.3 Other important topics to be addressed

During the EcoGrid.dk phase 1 project an additional number of highly relevant research and development topics have been identified. The topics could be part of a future EcoGrid.dk activity, future PSO calls and/or another relevant context.

The EcoGrid.dk consortium suggests that Energinet.dk prioritize these topics in one or several of the mentioned programs. The topics are:

Capacity market: Most of the present base load power plants are likely to be replaced before 2025. The future operating mode of CHP units will be far from base load operation. Therefore a new generation of CHP units for more intermittent operation will be required. Phase one does not include recommendations on the replacements and it is an open question if the present market can provide sufficient incentives for development efforts and investments in new capacity. An update of the market design should therefore be considered. Daily peak power could be a separate element of the market while energy might loose its dominating role.

Electric vehicles-storage technology: The electric vehicles will probably play an important role in the economic and reliable operation of the Danish electricity grid with 50% wind power penetration. From the electricity grid perspective, it will be mainly a storage device for smoothing the power fluctuations from renewable resources especially wind power. In this context, it is necessary to develop optimal architectures (central/distributed charging systems, owner structures, metering systems etc.) to facilitate intelligent charging and discharging (sourcing power to the grid) of electric vehicles (charging based on electricity price signal etc). In addition to developing architectures it should have high priority to develop electric vehicle integration technology (electric vehicle virtual power plant technology etc.). It is also necessary to study the effect of the electric vehicles on the electricity grid. This will require development of models and new power system and electric vehicle modelling and analysis tools. Although simulation studies can be a basis for implementation in this case it is imperative to perform real demonstration projects. The main aim of such demonstration projects will be to examine:

a. interaction between electric vehicles and wind power,
b. effect of storage in the context of Danish electricity grid,
c. develop market structure and integration solutions

Utilization of PMU measurements in system operation: PMU installations worldwide bears witness to a general belief in the value of the additional phase information in the PMU voltage and current measurements including solutions enabling operation of power system with very high share of renewable energy. Within many power system technologies the exploitation of this information is under development but need much more attention to develop optimal solution to support operation of the power system with large share of wind power which is of special interest in a Danish context. Development areas include visualization methods for control room applications, stability margin evaluation, early warning methods etc.. Serious obstacles for utilising PMU measurements in the power system are reliance on GPS satellites and a communication system. These problems must also be addressed and handled.

Ancillary service market: Provision of ancillary services will be a critical element in a power system with 50% wind power. To ensure sufficient resources and enable overall economic optimal solutions proper market incentives should be provided to system users (both generation and demand). Possibilities for market based solutions should be exploited, e.g. related to reactive power/voltage control, system inertia etc. Ancillary service markets and new market functions for DER participation in system balancing (activity B) can be developed as an integrated framework.

System awareness related to active distribution networks: Methods for increased system awareness of distribution networks should be developed to obtain better awareness at transmission level about the overall system state. This will contribute to a reliable operation of a power system with high DG penetration. This can e.g. be based on novel methods and online measurements at the interconnection points.

Optimization of transmission system operation with distribution systems with islanding capability: Work is ongoing in Denmark as well as in the international power engineering community regarding intentional island operation of distribution systems. Important examples of this is the Energinet.dk cell project and the EU Microgrids project. To maximize the benefit of this capability novel operational methods of the transmission system should be developed. The simplest approach is to let all distribution grids go into islanding operation if severe contingencies approach/occur. This requires that the distribution grids have sufficient resources to do so. Some distribution grids may need extra time to prepare for intentional islanding, some distribution grids may just be capable of providing certain support to the transmission grid and some distribution grids may be operated in a state from where islanding is possible but with extra costs. To maximize the economic and reliable operation of the system, methods, which optimize the system operation and in an intelligent approach utilize the different capabilities of the different distribution grids, should be developed.

Furthermore the following recommendations are given by the EcoGrid consortium:

- The suggested topics for phase 2 deals with system aspects of the future power system. Energinet.dk therefore plays a key role in the suggested future activities. The ongoing phase 1 of the project has been financed by PSO-funding, and Energinet.dk only had limited capability to take part in the activities. Future activities are expected to be financed directly by Energinet.dk and good possibilities for direct interaction with Energinet.dk should exist. To ensure development of solutions with maximum value for the system and maximum impact of results a strong anchoring in and ongoing interaction with Energinet.dk technical experts is important. This includes experts from the planning, market and operation departments. However, in which way, in which tasks and on which levels are of course entirely up to Energinet.dk to decide.

- The nature of phase 2 will be technology development of solutions, which can be demonstrated in phase 3. This is very different from phase 1, which has provided a broad technology overview by many participants. To provide the solutions in phase 2 it should be based on tailored and efficient teams with the time allocated to go into the requiring development tasks.

- Several activities regarding new system architectures, new market designs and new control measures are suggested. The need for development of new solutions and technologies within these areas is more extensive than what is possible to deal with within the EcoGrid project. It is therefore recommended that existing research programs start including research on these areas.

6
PROPOSED PROCESS

This document delivers suggestions for prioritised activities for the future EcoGrid project. It is recommended that these suggestions are carefully discussed between Energinet.dk and representatives from the EcoGrid consortium. The discussion should address Energinet.dk interests and the suggested activities and recommendations. This discussion should also include coordination with planned internal Energinet.dk development activities e.g. The Electric Power System 2025. It is suggested that the discussions lead to an adaptation of the relevant elements into a project description for phase 2. It is recommended that the teams for the different work packages are put together based on the tasks to be solved.

A
DETAILS FOR TOPICS TO ADDRESS

Subject	***Activity A.* Tool for optimal system operation with new balancing measures**
Main area	System operation (Control/IT measures)
Objective	The objective of this activity is to develop methods and tools to support the operation and short term planning of a power system area with large scale wind energy using new, flexible measures. The new flexible measures are intended to supplement thermal units and interconnections to ensure power balancing and system security. The new measures that will be considered are integration with the heat sector, integration with transportation, consumer demand response and wind farm control.
Outcome/deliverables	The delivery of this activity is a power system awareness tool, which will help the operator to assess the system state with respect to stability and power balancing. These aspects become much more complex in the future power system, since they will involve not only significantly more wind generation, but also new measures to ensure stability and balancing resources.
Tasks	The work will be organised in the following work packages: *A1. Modelling of new flexible resources: Aggregated simulation models (CET, Risø DTU)* Based on the findings in other projects (Ecogrid.dk phase 1 and Demand Frequency Response), aggregated simulation models for the selected flexible resources will be developed. The aggregated simulation models are important sub-module for the balancing resource status module. The models contain the price responsive dynamics of the resources and take into account the expected restrictions that reflect the trade-off between the flexibility which the costumer will offer and the economic benefits the costumer can be offered. These restrictions will be quantified by defining user profiles specifying e.g. acceptable indoor temperature intervals, freezer temperature intervals, car battery SOC restrictions etc.

	A2. Forecasting sub module of new flexible resources (IMM, CET, Risø DTU) New tools, also operated as sub-modules for the balancing resource status module, for forecasting the flexible resources will be developed, taking into account the price responsive behaviour of the resources. The forecast systems must be able to predict the effect of the physical restrictions modelled in A1. This can e.g. be done by training the forecast systems with a long sequence of simulations with the A1 tools. *A3. Offshore wind power plants sub-module: modelling, control, forecasting and uncertainty (Risø DTU, Energynautics, CET, wind power industry)* This task will include models of wind power plants from previous projects, especially “Operation and control of large wind turbines and wind farms” (PSO 2002) and Power fluctuations from large offshore wind farms (PSO 2004). The following will be included for the individual offshore wind farms (taking into account technology): • real time estimation of the available power from wind farms. Some work is done here in a master thesis for Nysted, but this work is based on a wind power technology which is not uses widely any more (Combi Stall). • reactive power and voltage control capability of wind farms • frequency control support incl. virtual inertia. • modeling and forecasting of available wind power. *A4. Balancing resource status module (Energynautics, Risø, CET)* The task will focus on developing a functional balancing resource status module which uses the sub-modules developed in A1, A2 and A3 in combination with input from existing Energinet,dk systems such as available capacity on interconnections and data from wind forecasting systems. The result will be a tool that that presents in almost real-time the available balancing resources ranked based on technology and shown for different areas, e.g. for Western and Eastern Denmark. *A5. Development of fast, simplified dynamic power system model (Energynautics, Risø, CET)* The simplified dynamic power system model of Denmark will be developed in close cooperation with Energinet.dk. It is the aim to set up a set of worst case situations, such as loss of a major interconnection, which can be re-run every 10 to 20 minutes considering the real time status in the power system and the available balanc-

	ing reserves (input from A4). If possible, the dynamic model should incorporate existing PMU measurements and be developed into a simplified, fast state estimator tool. It is expected that Energinet.dk will be closely involved in defining the details of the system status module and the structure of the dynamic power system model, hence the details of his task will be further outlined in cooperation with Energinet.dk In general terms, it is the aim of the system status module to provide the operator with the available information to support allocation of the relevant resources to ensure system security and balancing. The tool will analyse the current system state by: • Simulating certain faults in the power system to analyse the impact on local voltage drop and possible cascade failures. As the conditions in the power system change continuously, different sets of possible faults as well as different network configurations must be considered depending on the actual system state. The results will give an indication of the level of balancing reserves as well as reactive power control capabilities needed (its location and quantity). Furthermore the tool could provide valuable input regarding the required minimum transmission capacity to neighbouring countries for balancing purposes and possible options for reconfiguring the network topology in case of faults, for example by actively using subgrids to support the high voltage network. • The impact of wind forecasting (and its uncertainty) will be considered in separate sets of simulations, i.e. different long-term (up to 1 day) simulations considering the uncertainty in the wind forecasting to determine the range of balancing resources needed in the next 24 hours. The *system status module* will be based on PowerFactory (DIgSILENT) simulation software and will be tested/validated against simulations performed by Energinet.dk. In addition, new simulations with the simulation model will be performed and fed into the awareness tool to demonstrate and validate it. Preferably, this is done with data for a specific case which can be demonstrated in full scale in future project (Ecogrid phase 3).

Potential contributors	DTU (Risø, CET and IMM), Energynautic, ECON, EA Energianalyse, Energinet.dk.
Budget estimate	6-7 mio. DKK + Energinet.dk participation.
Other information	The activity is planned to run in 3 years. It will be based on the work of permanent research and development staff, although some well defined tasks may be outsourced as e.g. master projects. The project in general – and work package 4 in particular – depends on the involvement of Energinet.dk. The details of the system status model and the final deliverable must be outlined in close cooperation with Energinet.dk, however, the principal idea is to develop a tool similar to the GEMAS system developed and operated by REE, the Spanish system operator. REE notes that the tool “fills the gap in the field of real time transient stability assess-ment applications that could, with certain simplifications, provide confident limitations depending on the real-time scenario. The GEMAS tool is able to simulate every 20 minutes three phase solid faults in the bus bars of 70 different substations. Satisfactory results are obtained using pseudo-dynamic or ‘switching studies’ with static power flow applications. Generation units are modified to Norton equivalents and loads are con-verted to constant admittance models as well. The tripped generation is estimated by comparing residual voltage at the wind farm connection buses with the sensitivity of the turbine technology since technology information of every wind turbine connected to the network is known.” Contacts to REE exist to discuss the experience with the GEMAS tool in more detail.

Subject	***Activity B. Development of near real-time market with expanded market functionality***
Main area	Market measures
Outcome/deliverables	Complete and documented design of demonstration project with near real-time markets with highly improved short term dynamic
Background	It is difficult for small scale actors to participate in the current regulating power market. The idea is to supplement the current regulating market with a real time market and in this way attract new sources, e.g. demand, micro generation, small CHP and wind power. Several detailed designs for this real time market are possible. One example is maintaining the Spot, Elbas and bilateral markets as the basis for planning for the system operation, and then changing the set-up for regulating power to a system with a one way price signal, which all market participants could subscribe to. The price signal could e.g. be broadcasted every five minutes. Response should be voluntarily (but exposed to varying prices) and no plans should be submitted and no reservation price should be paid. Reaction should be metered and payment arranged after the day as known e.g. from today's spot market.
Tasks	**B1: Review of existing real time markets**, e.g. in Australia and US (PJM, New York, New England). A detailed description is established including analysis of benefit and drawbacks seen from market participants, DSO's and TSO's point of view. **B2: Single technology perspective: Optimal response to near real-time prices** (with unknown future prices) from selected technologies e.g. demand (e.g. traditional electric heating and dump load), wind power, micro generation and traditional CHP. Based on detailed data for each technology an optimal response is developed based on simulated prices and including start/stop costs for each technology. Experiments with different time intervals (e.g. 1, 5 10 and 15 minutes). Technology data could e.g. be taken from Balmorel database and expanded with start stop cost information. **B3: Monitoring and predicting** responses to near real-time price signals. Demonstration of various techniques for monitoring the response to a near real-time market, including sampling techniques, regression analyses and time series analyses. Focus on accuracy and prediction of unusual events (e.g. extreme prices, extreme temperatures etc.). Test of methods with actual data series, e.g. from CHP on the market and demand response experiments.

	B4: Market algorithms for manual and automatic input to near real-time price signal based on e.g. nodal pricing. The market solutions shall be developed for integration with the grid operational layer. The task will interact with task A4. **B5: System modelling of a system with hundreds of active market participants**, including CHP, micro generation, wind power and demand response (including dump load). An energy balance model is developed for the purpose. Input from B2 combined with detailed information e.g. about the Bornholm energy system. Different parameters are used between technologies as well as within technologies – representing different size and age as well as preferences and strategies. Total costs and the costs for end users, TSO, DSOs and producers are calculated for different strategies, including different levels of market participation and wind power penetration. A Monte Carlo type of simulation is implemented to describe the probability of different outcomes. The model set-up can include optimal solutions with full information used as benchmark, compared with simulationswhere market actors use rational strategies to cope with an uncertain future. Model formulation can take a starting point in the type of model described by in “Optimal drift af prioriterede anlæg” (RAM-løse EDB, 2004) **B6: Practical design of demonstration project** for near real-time price signals at Bornholm, including initial specification of IT systems and hardware needed for the demonstration project. Budget for demonstration project including relevant variations in technology and ambitions.
Potential contributors	CET, Ea Energy Analyses, Risø, EC Power, Energinet.dk etc.
Budget estimate	3-4 Mkr
Other information	The project could be realized in 2 years (main work in 2009 and 2010).

Subject	***Activity C. New coherent control architecture utilising DER for flexible, secure and efficient system operation***
Main area	System architecture
Objective	The purpose of this activity is to develop, analyse and optimize power system architectures with emphasis on two selected key aspects (reactive power/voltage control and near real-time market) for a target system to be demonstrated in phase 3. Future power systems will be based on an increased integrated control of the distribution and transmission systems and active network functions on the distribution level enabling increased participation in the market and delivery of ancillary services. Development of a coherent and consistent control architecture will be the prerequisite for releasing the potential of many of the resources in the distributions networks as well as for an overall economic optimal system design. Without a coherent and consistent architecture the future required system costs will become unnecessary high and insufficient adoptability of future needs.
Outcome/deliverables	Development of a coherent control architecture based on sub-grids. As part of the activity a simulation tool will be developed enabling analysis of architecture design for a variety of power system aspects.
Tasks	*C1: Overall architecture development* Develop control architecture with respect to overall design including grid-subgrid setup, interfaces, operational modes, controls, and grid and sub-grid normal state optimization. *C2: Simulation tool* The analysis and optimization of the complex interactions between the technological infrastructure (the grid), the supply and the demand side and the market in these will be based on new tools and models. There is especially a need for an integration of existing modeling, simulation and optimization tools and tools which allow explorative assessment of system interactions on various levels of detail. A tool for design and analysis will be developed. The tool will be based on an integration of power system simulation tools (e.g. PowerFactory) with high level tools for simulation of distributed optimization, control and market functions (multiagents). 1-2 case systems will be setup in the tool.

	C3. Reactive power/voltage control approach for sub-grids Development and analysis of voltage control/reactive power control approach based on agent based sub-grids considering reliability issues and sub-grid interface. Focus will be on voltage control/reactive power control approaches based on agent based subgrids considering reliability issues and emergency plans, e.g. if communication fails within the subgrid. Focus is on considering a large number of generation assets as well as a large number of controllable loads for various grid topologies (100's of loads/generation options). Simulations will be performed with the tool from A2 for the developed case systems to evaluate the developed approach. *C4. Reactive power/voltage control approach for the transmission grid* Development and analysis of voltage control/reactive power control approach in the transmission grid utilizing the reactive power control capability of sub-grids. Approach for optimal utilization of the sub-grid capability is developed. Different operational modes are considered. The approach should include optimization taking into account network congestions, dispatch of load and generation, network capacities and losses. *C5. Grid operation utilizing near real-time market* Development of solutions for managing grid operation issues by a near real-time market interaction in a sub-grid architecture (e.g. sub-grid interface management, congested lines, optimum response to security and stability issues, dynamic tariffs for losses, voltage quality etc.). This task will utilize the market model developed in Activity B. The market model will be integrated with the simulation model from C2 (e.g. by a standardized data format for off-line data exchange), and simulations will be performed for the developed case systems. The task will as a first step include review of international experience including the Pacific Northwest GridWise demonstration project. This task will provide important input to the planned EcoGridEU activity. *C6. Practical design of demonstration project* Design of demonstration project for voltage control/reactive power control approach including initial specification of IT systems and hardware needed for the demonstration project. Budget for demonstration project including relevant variations in technology and ambitions.
Potential contributors	CET, Energynautics, Risø DTU, AAU, Energinet.dk.
Budget estimate	6-7 MDKK

Other information	Project duration: 3 years.

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