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# Index - Final Report

# 1. Final report

The final report must be prepared in English. Please fill in the following sections of the template.

## 1.1 Project details

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| **Project title** | Planlægning af smart grid distributionsnet - SmartPlan |
| **Project identification** | 2011-1-10680 |
| **Name of the programme which has funded the project**<br><br>(ForskVE, ForskNG or ForskEL) | ForskEL |
| **Name and address of the enterprises/institution responsible for the project** | Dept. Electrical Engineering, Technical University of Denmark |
| **CVR** (central business register) | 30 06 09 46 |
| **Date for submission** | 14.10.02 |

## 1.2 Executive summary

The project participants are:

- CEE, DTU Elektro (project coordinator)
- SEAS-NVE
- Dansk Energi

One of the main goals in the Danish energy policy is to increase the amount of renewable energy in the energy mix to 30% of the energy in 2025. This will, to a large extent, mean an increase in the amount of wind energy and it is expected that in order to reach those goals, the fraction of wind energy will have to be 50% of the electricity by 2020.

Due to changes in the way electrical energy is produced and used, distribution network operators must adapt to changing usage patterns: The penetration of renewable energy will continue to grow and electricity is expected to increasingly substitute fossil fuels in areas such as transportation and building heating and cooling.

The conventional response to these changes would be an expansion of grid capacity to ensure that the grid is operated within the required limits. However, this approach would require large and expensive investments. Active supervision and control of a large number of small energy resources - a key element of the "smart grid" concept - is widely assumed to be a more economical alternative [1]. As smart grid technologies are being introduced to meet this goal, it is necessary for DSOs to be able to assess these technologies' impact on grid operation and to integrate them in their network design and planning procedures.

Planning, design, dimensioning and operation of distribution networks presently rely on rules based on low-resolution statistical data and approximations based on experience. Existing planning tools were not originally designed to take actively controlled elements into account.

The purpose of the project has been to identify limitations of existing simulation and planning tools for distribution grids, with a particular focus on the challenges imposed by the introduction of Smart Grid technologies. The project was organised in four work packages:

- WP1: Development of scenarios for smart grid cases (SEAS-NVE).
- WP2: Survey of the state of the art of network planning tools for distribution grids (Dansk Energi).
- WP3: Modelling (CEE, DTU Elektro).
- WP4: Demand specification for future tools (CEE, DTU Elektro).

In WP1 two model grids were defined. They were defined based on a statistical analysis of the grid of SEAS-NVE. They represent a suburban grid with detached houses and a summer house area grid. The grid parameters were based on the length of feeders, number of costumers, number of cable cabinets and number of costumers per cabinet. Further, a number of scenarios for PV, heat pumps and EV were defined for future scenarios to investigate the impact of those types of consumption at different penetration levels.
The load scenarios clearly show that it is the voltage level which first deviates from the required operating range. Thus, there is room for larger loads if the output voltage from the substation can be optimally set and/or varies according to type and size of the load.
The construction of the model grids and the load calculations have shown that there are many variations among the operating conditions of low voltage grids, and therefore there is no fixed optimal setting of the substation's tap changer which fits all distribution lines in all conditions. In the procedure for design and commissioning work for the 10kV substation, compensation is made for voltage drops from the 50 kV station and the low voltage distribution lines' design using the tap changer. However, the calculations show that it is also the load type's (producing or consuming) effect which ought to affect the setting of the 10kV station; only in this way may the cables' capacity be utilised better.
The second work package contains a survey of network planning tools for distribution grids as well as it seeks to uncover which tools and planning procedures are used by the Danish DSOs and it further provides an overview of the capabilities of the used tools.
Moving to a future with SmartGrid changes the requirements to the planning tools. While Danish DSOs currently largely use self-developed programs for planning of the 0.4 kV grid, these programs are not suited for grid planning in a SmartGrid context. The introduction of large amounts of distributed generation and flexible loads at the 0.4 kV level increases the complexity of the 0.4 kV grid to a degree, which these simple self-developed programs are unable to handle. These changes in the 0.4 kV grid require an evaluation of the entire grid with these new elements. As our knowledge of these elements and their rate of introduction grow, evaluations will likely have to be carried out regularly over the coming years in order to ensure that the grid will be able to handle the relevant operating cases. It will thus be convenient to have these models in a single place, further driving the use of commercial software. At the 10 kV level, companies are largely using commercially available tools.
All the commercially available tools have the necessary components for the present state of grid planning and can assist with all the tasks in the current planning routines. These include load flow, contingency, short circuit and motor start analysis. Protection co-ordination tools aid the planners in designing the protection system so selectivity is maintained where possible. Tools like NEPLAN and PowerFactory are fairly well prepared for SmartGrid with a wide range of existing models, their support for custom models and additional features such as transient simulation and harmonics analysis. However they are not asset databases and converting necessary data from GIS systems introduces a possibility of compromising data integrity. NetBas with its unified GIS and analysis capabilities does not have this conversion issue and thus data integrity can be considered better. However its network analysis tools are not as developed as those of NEPLAN and PowerFactory. All of these tools need further development to facilitate planning of a SmartGrid.

In the future planning tools and operational tools (monitoring, decision support etc.) are expected to be much closer integrated with each other, thus there will be a need for these tools to share information. Load conditions, operational state and customer behavior information will be passed on from the operational tools to the planning tools, so current and near future conditions can be evaluated. The results of these evaluations will be needed by the operational tools to provide decision support to the operators. This increased information sharing will likely be facilitated either by consolidation of the tools into large systems or by open standard interfaces between the tools.

The work in work package 3 was to investigate limitations of existing simulation and planning tools for distribution grids used by the Danish DSO's by applying the tools to relevant grid scenarios, in view of the potential challenges imposed by the introduction of Smart Grid technologies as active parts of the distribution grids.

Based on the survey of tools, presented in WP2, the two most popular simulation tools have been selected for the investigation. In WP3 work has been carried out trying to identify the limitations in terms of simulation capabilities and the user experience coming from applying the tools to smart grid cases considering the implementation of smart grid solutions and corresponding necessary functionality.

A steady-state and a dynamic component analysis of the grid model have been presented based on time-series simulations with a comparison between different voltage profiles.

The low-voltage distribution grid model has been developed and implemented in NEPLAN and DIgSILENT Power Factory to study load flow, steady-state voltage stability and dynamic behavior of the components.

Comparing the power flow calculations, using the two software packages, we can conclude that there is an insignificant difference between them. The parameters and simulation models for all the components are slightly different.

The comparison between the simulation tools has shown a good alignment and the possibility to use them for further developments, regarding the integration of smart-grid technologies. It means that this work could be used for development and improvements of the models for different components placed along the feeders in a future smart-grid distribution network.

The work in the project has also shown that it can be quite laborious to set up specific simulation scenarios when particular types of load such as space heating and control of e.g. load are involved. In the tools applied in the project there are different means to automatically specify, setup and run the simulations, however, they are still not appropriate in the cases with new types of components that includes coordinated control.

Further, from the simulation results it can be deducted that it is necessary to develop a method for grid design of active distribution grid that generalize the control behaviour of the active components to eliminate the dependency of individual control strategies.

It can also be concluded that the existing method of sizing the grid has to be revised to encompass new load patterns from new types of load. For units that provide flexibility these load patterns will also depend on the overall state of the grid since the flexibility could be applied at the TSO level for system balancing or at the DSO level for congestion management or voltage control.

The analysis performed by previous projects e.g. Edison project covers a wide range of studies focusing on EV-related technology characterization and integration, impact analysis of EV integration on power quality on a few network representatives that include both LV and MV levels, as well as recommendations of emerging network components such as fast-charging stations.  These analyses provide an important reference for Distribution Network Planning

(DNP) planners to handle the specific challenges of EV integration at the planning stage. Research efforts performed by iPower provide a much more general support to DNP, and the deliverables cover preliminarily many of the elements needed in the near-term DNP approaches. However, most of the work delivered by these projects has diverse targets and lack of a streamlined framework to integrate them into the DNP procedure. For instance, the lack of developing and utilizing benchmarked representative distribution networks to a great extent limit the findings of these studies. A further development of smart planning elements will need cooperation between academia, DSOs and other relevant stakeholders in order to align the individual effort and maximize their value.

In addition, special features of the Danish energy systems must be considered and framed better in the process of updating the DNP procedures and tools. The features include, but are not limited to

- high amount of renewables,
- the large-scale role out of smart meters,
- the lack of information of LV networks,
- the DSM products are typically designed for power balancing,
- the planning and operation criteria as well as the planning tools adopted by different DSOs are not the same,
- the regulatory framework of the Danish energy sector.

It can therefore be concluded that with the very significant changes to the power system in the coming years to enable it to economically integrate very large fractions of renewable energy in particular wind and solar, and as fossil fuels are increasingly substituted with electricity for space heating/cooling and transportation there will be a need for a more active distribution system which includes more measurements and more actively controlled components. In particular it is necessary to be able to handle the changes arising from new types of components expected to be connected to the grid and the flexible demand being controlled by Aggregators in response to market signals. These changes requires that the way that the distribution grid is designed also changes so that it is able to handle new ways of interaction between components many of which will include some form of storage.
The project has shown that the tools can to a large extent simulate the new cases, however, the project has also shown that it can only be done in a quite laborious way and that it is necessary to revise the distribution network planning procedure. The new procedure will have to be able to handle the effect of the changes in correlation between loads both internally with groups of similar consumption types and between the various types. The planning procedure will also have to be able to handle active control of the consumption units both in situations where the control is due to needs at the system level and particular in the case where the flexible demand units are delivering services to the distribution grid.
Further, as new sources of data will be more widely available e.g. in the form of AMI data or data from embedded measurements at substations the network planning procedure can be updated to take these sources into account. This could also lead to a more general revision of the design procedure that is based on quality of service and statistical metrics rather than the present one that is based on analysis of estimated worst cases.

## 1.3 Project results

The main conclusions of the project are:

- new types of load and active control will require an update of the procedure for design and planning of distribution grids.
- The tools currently used by the DSOs include both in-house developed tools and commercial packages
- the in-house tools are not suited for future smart grid cases

- the commercial tools are better suited and currently being developed to better fit future operating cases
- development of standard representative model grids will significantly improve the development of tools and design procedures
- It is necessary to further investigate how active control of the distribution grid can be included in the planning of distribution grids
- The very significant changes in the operating conditions of the distribution grid could imply a change in design philosophy towards a Quality of Service based approach.

Additional results from the project can be found the publications that have been prepared as part of the project. The publications come in two forms: project deliverables in the form of report and conference presentations.
The project has produced the following deliverables:

- SmartPlan WP1 - Development of scenarios for smart grid cases
  Claus Jensen, Dorte Nielsen, Jens Ole Pihl-Anderen, Carsten Fosvang
- SmartPlan WP2 – Survey of the state of the art of network planning tools for distribution grids
  Jasmin Mehmedalic

- SmartPlan WP3 – Modelling
  Lucian MIHET-POPA, Xue Han, Henrik Bindner

- SmartPlan WP4 Demand specification for SmartGrid-oriented distribution network planning tools
  Shi You, Henrik W. Bindner, Xue Han, Lucian Mihet-Popa

The project has further been presented at conferences:

S. You, et al., An overview of trends in distribution network planning: A movement towards smart planning, accepted by 2014 IEEE PES Transmission and Distribution Conference & Exposition,2014

Development and modeling of different scenarios for a smart distribution grid. / Mihet-Popa, Lucian; Han, Xue; Bindner, Henrik W.; Pihl-Andersen, J.; Mehmedalic, J., 2013 IEEE 8th International Symposium on Applied Computational Intelligence and Informatics (SACI). IEEE, 2013. p. 437 - 442.

Grid modeling, analysis and simulation of different scenarios for a smart low-voltage distribution grid. / Mihet-Popa, Lucian; Han, Xue; Bindner, Henrik W.; Pihl-Andersen, J.; Mehmedalic, J., 2013 4th IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe). IEEE, 2013.

Simulation models developed for voltage control in a distribution network using energy storage systems for PV penetration. / Mihet-Popa, Lucian; Bindner, Henrik W., Proceedings of the Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2013. p. 7487 - 7492.

## 1.4 Utilization of project results

The results of the project have contributed to the awareness of the state of the art in the area of distribution system planning in the context of smart grids.
The results of the project will be utilized and further developed in several ways:

- further activities to develop a distribution network planning procedure that include actively controlled DER units, utilizes new sources of data e.g. AMI data

- development of simulation and analysis tools that addresses the short comings identified. This will include automatic setup of simulations appropriate grids with active components distributed in the network analyzed.
- extend the work to include methods for integration of distribution system markets and their impact on network planning.
- development of standard model grids with appropriate loads, layout and similar for investigation and comparison of design and analysis methods

Since a significant potential of the economic benefits of smart grid is improved utilization of the network assets it is essential that to provide ways of realizing this potential. A cornerstone for that is that the distribution grid can be operated less conservatively but still as reliably as in the present situation. The results of the project and their further development will contribute to that.

The outcome of the project will be used as basis for new project activities by the partners.

## 1.5 Project conclusion and perspective

The main conclusions of the project are:

- new types of load and active control will require an update of the procedure for design and planning of distribution grids.
- The tools currently used by the DSOs include both in-house developed tools and commercial packages
- the in-house tools are not suited for future smart grid cases
- the commercial tools are better suited and currently being developed to better fit future operating cases
- development of standard representative model grids will significantly improve the development of tools and design procedures
- It is necessary to further investigate how active control of the distribution grid can be included in the planning of distribution grids
- The very significant changes in the operating conditions of the distribution grid could imply a change in design philosophy towards a Quality of Service based approach.

It is a essential that smart grid technologies and their impact on the operation of the distribution system is included in the grid planning procedures since a significant part of the anticipated benefit from investments in smart grid technology comes from saved or postponed investments in distribution system capacity. It is further essential that the impact can be included in a non-conservative manner to allow maximum utilisation of all grid assets. Tools for analysis of the future distribution grid are therefore a key element and the project has identified that the state of the art tools are not well suited for this future situation.

It is therefore important that the distribution grid planning procedure including the necessary tools are being developed and adapted to this new situation.