POWER SYSTEM PLANNING IN DISTRIBUTION NETWORKS TODAY AND IN THE FUTURE WITH SMART GRIDS

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ABSTRACT

This paper is about electric power system planning in Norwegian medium and low voltage distribution networks. The paper describes some of the challenges regarding electric power system planning today. The biggest challenge is the lack of control of the operating conditions in these grids. It is comparable to driving in the dark. With the introduction of ICT into the power system, the light will come on and new possibilities will occur. But the distribution system operators will also face new threats related to data security. The electric power system planning in the future will follow the same methodology as today, but many new factors must be taken into consideration.

INTRODUCTION

Many believe that the electric power system is currently undergoing a profound change driven by a number of needs, for instance the need for environmental compliance and energy conservation. An aging infrastructure creates a need for increased condition monitoring in order to maintain high reliability. There is also a need for improved operational efficiencies and customer service. The changes that are happening are particularly significant for the electricity distribution network, where traditional and manual operations, along with the electromechanical components, will be transformed into a “smart grid”. This transformation will be necessary, for instance to meet environmental targets, to accommodate a greater emphasis on demand response, and to support distributed generation, electric vehicles and storage capabilities.

These needs and changes present the power industry with the largest challenges it has ever faced. On one hand, the transition to a smart grid has to be evolutionary to keep the lights on; on the other hand, the issues surrounding the smart grid are significant enough to demand major changes in power systems operating philosophy.

The Norwegian distribution networks have been developed over many years and have a relatively small amount of active elements, such as generators and demand side management. The networks are dominated by passive elements, principally uncontrolled loads. In the future the loads will become more dynamic and controllable due to more active response from customers and the expected introduction of electronic control and regulation systems. At the same time the introduction of advanced metering systems (AMS, smart meters) will provide the network owner with a lot more data.

The introduction of more active elements will require new and improved methods for planning and estimation of loads and generation in the future distribution network.

NTE Nett is the system operator of a distribution network in the county of Nord-Trøndelag in Central Norway. The MV and LV systems include more than 13400 kilometers of overhead lines and cables.

The paper describes how the planning process in NTE Nett is today and what might change when distributed energy resources (DER) are integrated into the network. The paper also describes the new challenges and possibilities the distribution system operator (DSO) will face regarding network planning within smart grids, and it gives inputs to how the future planning process can be.

CHALLENGES IN TODAY´S DISTRIBUTION NETWORKS

Load profiles. Only annual or monthly energy consumption in kWh is known for most of the customers. For larger customers (>100.000 kWh/year) hourly metering is available. Standard variation curves for each type of customer are used in calculations. This results in inaccurate calculations and might lead to wrong decisions.

Voltage level in MV and LV distribution network. The voltage level at the connection point for the customer shall, according to the Norwegian PQ Code (FoL)[1], be between U_n ±10%. In today’s distribution network only the voltage at the feeding point of the MV grid (the 22 kV bus bar in the feeding substation) is monitored. There is no voltage metering further out in the network and voltages must therefore be calculated. This means that it is not known whether or not the voltage at the connection point for the customer is within the requirement given by the FoL.

Weak grid. About 40 to 50 % of the LV distribution network in Norway have an impedance higher than the reference impedance defined by IEC [2] [3]. This means that the network is weak and that customers might affect the voltage quality in their neighborhood when using ordinary electrical appliances. The network is especially affected by three phase motors. It is estimated that the costs for upgrading the LV grid in Norway will be between 2 and 15 billion EUR [2].

LV with isolated neutral. Norway is a bit special since most of the LV distribution grid is 230V with isolated neutral. Many Norwegian distribution companies are gradually transferring it to 400V with grounded neutral, but it will take many years before this is 100 % completed. In NTE today about 10 % of the distribution transformers transforms to 400 V. These transformers represent 28 % of the total distribution transformer capacity.

Integration of DG. Distributed generation (DG) in Norway today is mostly small hydro power plants in rural areas. These areas often have low grid capacity and low load. One example of such an area is Namsskogan [4]. In this 1416 km^2 area the maximum load is 1.2 MW (17.3 GWh/year, 900 inhabitants) and the potential for new DG is 73.6 MW (258 GWh/year). There is no extra capacity for integration of new production in today's grid in this area. More than 8 million euro has to be invested in the grid in order to integrate all this production.

There might be voltage problems when DG is connected far from the feeding substation in a relatively weak distribution grid. Figure 1 shows an example of how the voltage can vary along a 22 kV line as a function of the distance from the feeding substation (strong connection point with fixed voltage). In this example the high load is about 3.8 MW and a DG of 5 MW is connected approximately 16 km from the substation. The highest and lowest voltage will occur in situations of low load with DG connected and high load with no DG, respectively.

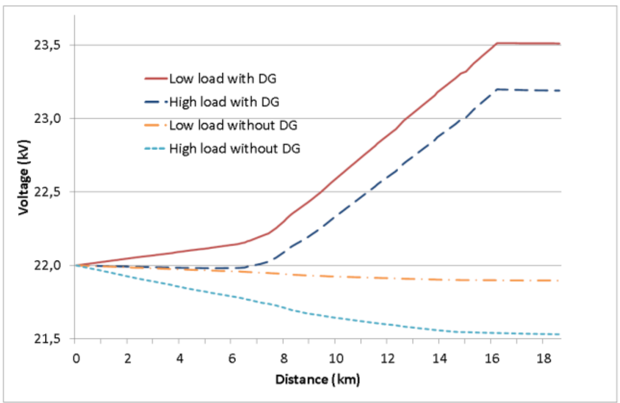

Figure 1 Example of voltage profile for a 22 kV line with a DG unit connected

POWER SYSTEM PLANNING TODAY

Methods for power system planning are described in *Planning book for power system planning* [5]. The methodology is shown in Figure 2.

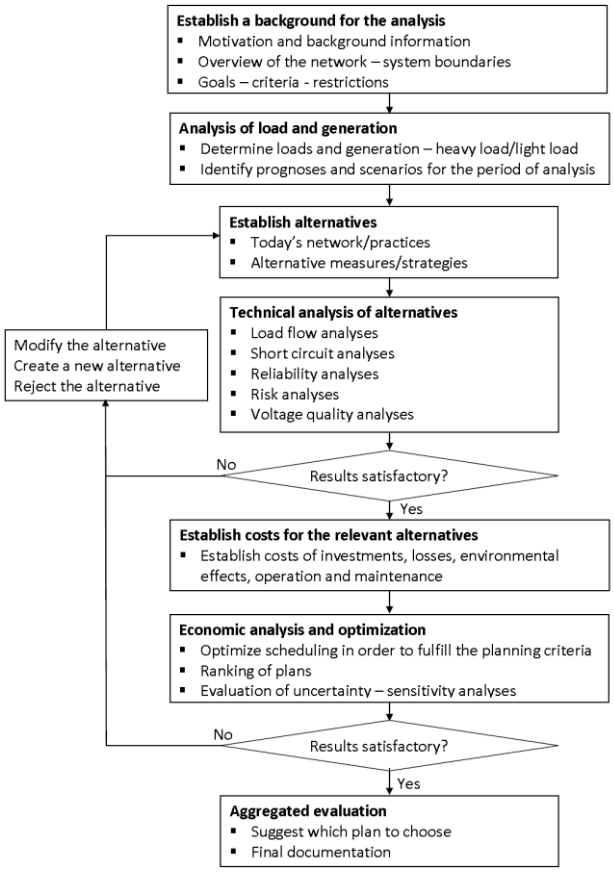

Figure 2 Planning methodology for electrical networks [5]

The quality of information about loads and production is essential for the technical analysis of alternatives. Differences between estimated (calculated) and real load flow might lead to over- or underinvestment in the grid.

Today, only available information is consumer category (household, office building, industry, agriculture, etc.) and annual electric energy consumption for most of the customers. Standard load profiles and prognoses for the different consumer categories are used. When calculations are performed on the MV grid, the LV network is usually not included because of the complexity and the size of the calculation model and limitations in the calculation program. Instead, the LV network is represented as one single load connected to the low voltage side of the distribution transformer. The same standard load profile and prognosis are used for all these loads.

For generators the generation is registered on an hourly basis, but for power system planning either maximum or zero generation is used. According to the present Norwegian regulation, the grid operator cannot put restrictions on time and level of production for a generator connected to the grid.

Figure 3 and Figure 4 show calculated and metered load during one year and one week for the 22 kV MV grid supplied from Steinkjer feeding substation (NTE Nett). There is good correlation between the load profiles. The calculated values are about 30 % higher than the metered values. Calculated values are based on statistical values (extreme loads) while the actual load is influenced by the weather situation and temperature, as many Norwegian households use electric energy for space heating.

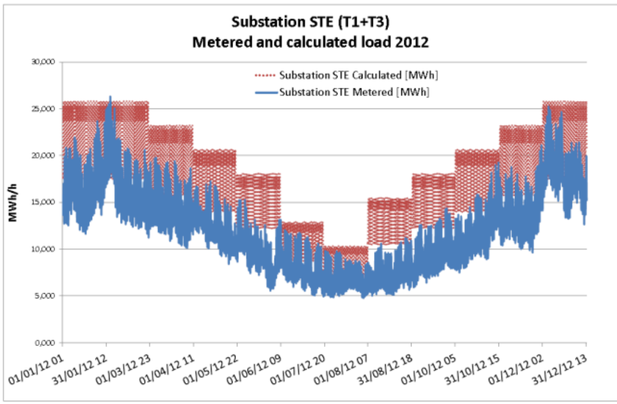

Figure 3 Example of calculated and metered load profiles for a feeding substation over a year (4500 customers)

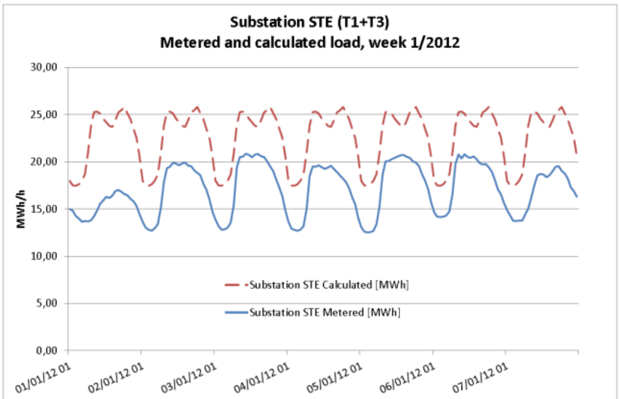

Figure 4 Example of calculated and metered load profiles for a feeding substation over a week (4500 customers)

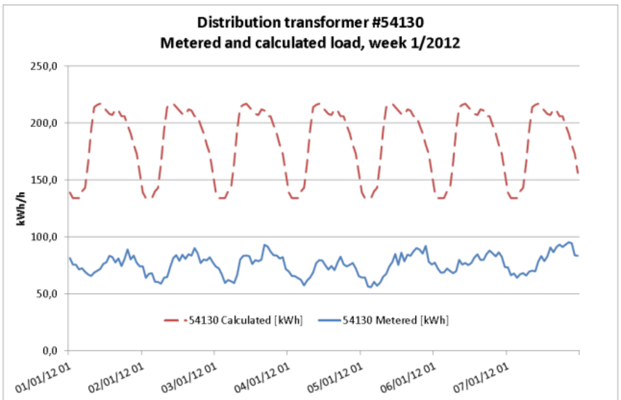

Figure 5 Example of calculated and metered load profiles for a distribution transformer over a week (43 customers)

Figure 5 shows similar load profile for one particular distribution transformer connected to this grid. There is less correlation between the load profile the more detailed the analyses gets. In Figure 5 the metered load varies more and is only just half of the calculated load.

NEW POSSIBILITIES IN SMART GRIDS

By 2017 every electricity meter in use in Norway shall be a smart meter [6]. With these new meters we can get a lot of valuable information for use in power system planning can be obtained:

- Hourly load metering
- Voltage quality registration (voltage level, hourly average, maximum and minimum)
- Load interruptions. Registration of interrupted power and duration, energy not supplied (ENS)
- Earth-fault registration
- Fault localization

Also extended use of sensors and automation will provide valuable information that can be used in power system planning:

- Improved condition monitoring and state estimation
- Improved/optimal operation. Automation.
- Faster fault localization and fault correction. Self-healing grid.

When discussing Smart Grids today, flexible loads, demand response (DR), demand side management (DSM), dispatchable loads, aggregators and smart homes are often mentioned. These subjects are relevant for reinvestment plans (when to reinvest), but have less relevance for power system planning (long term investment plans) [7].

Smart Grid provides the possibility to perform better state estimation of the grid and thereby make better maintenance and reinvestment plans possible in the future.

SOME NEW CHALLENGES INTRODUCED WITH SMART GRIDS

Smart meters and extended use of sensors in the distribution grid, will provide a lot of useful information, but the amount of data will be enormous (data tsunami). New and better systems (hardware and software) have to be developed for handling all this information.

Smart Grids deployment depends on the merging of ICT (information and communication technology) and the electric power system. Data from meters and sensors will be used real-time in controlling and operating the power system. Data security will be a very important issue. There will always be a risk that someone hacks into the systems and take control and do some damage, like for example disconnecting of customers/production. This risk must be minimized in order to obtain a secure and sustainable electric power system.

A lot of new components will be introduced into the electric power system (telecom, sensors, meters, PLC, power electronics, control systems, etc.) How will these new components affect the system reliability? Every system and component can fail. Advanced systems can increase the system reliability, but they can also reduce the system reliability if they are uncritically installed.

The introduction of new components and systems into the distribution grid means that the DSOs need new competence in order to maintain and operate the system. One of NTE's strategies is that all the electrical power technicians in the company shall be trained in ICT during the next five years.

POWER SYSTEM PLANNING IN THE FUTURE WITH SMART GRIDS

Power system planning in the future with Smart Grids will follow the same methodology as today (shown in Figure 2), but many new factors have to be taken into consideration.

Integration of distributed generation into the medium voltage grid will change the grid from being passive (power flows in only one direction) to active (power flows in all directions). This will result in larger voltage variations and might demand more equipment for voltage regulation and control.

Smart meters in every connection point between the distribution grid and the customer will provide a better basis for calculating load profiles and prognoses. This again will provide better load flow calculations and better basis for making optimal investment decisions.

Smart meters can also provide valuable information about outages (where, when, duration and energy-not-supplied) at each connection point.

The effect of demand response (DR, how customers respond to changes in electricity price) and demand side management (DSM, e.g. how an aggregator actively controls parts of the load for many customers in order to offer balancing services to the system operator), can be significant for operation and short-term planning.

The introduction of new technology and new operating and control systems will affect the system reliability. The number of interruptions, the amount of energy-not-supplied (ENS) and costs-of-energy-not-supplied (CENS) will depend on the system configuration. At present the effect these new technologies and systems will have on system reliability are not known.

Electronics and ICT systems have relatively much shorter technical operating lifetime corresponding to traditional electric power systems. Transformers, overhead lines, cables and switches today have an estimated lifetime of 60-70 years. Will it be possible to obtain the same estimated lifetime of components in the future as today?

CONCLUSION

The future active and smart electric distribution grid will provide the DSOs more insight and information about the operating conditions in the grid. The DSO will start to drive with the lights on instead of driving in the dark. This increased insight can be used to make better long-term investment plans.

The integration of ICT into the power system increases the risk for unauthorized access to sensitive data and vital operation and control systems. ICT security will be very important.

The future planning methodology will be the same as today, but a lot of new factors and aspects have to be taken into consideration during the planning process.

REFERENCES

[1] NVE, "Regulations relating to the quality of supply in the Norwegian power system," ed: Ministry of Petroleum and Energy, 2004.

[2] H. Seljeseth, K. Sand, and T. B. Solvang, "*TRA 7203 Håndtering av utfordrende elektriske apparater som tilknyttes elnettet (Norwegian)*. (Dealing with challenging electrical appliances connected to the electricity grid)," Sintef Energy 2012.

[3] IEC, *TR 60725 Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current [smaller than or equal to] 75 A per phase*. Geneva: International Electrotechnical Commission. Technical Committee, 2012.

[4] E. Tønne, K. Sand, J. A. Foosnæs, and R. Paulsen, "Integration of Distributed Generation Into MV Dsitribution Grid in Norway - The Namsskogan Case," presented at the CIRED Workshop 2012, Lisbon, Portugal, 2012.

[5] "Planning book for power system planning," ed. www.planbok.no: Sintef Energy, 2012.

[6] *Regulations on metering, billing and coordinated action in power sales and billing of network services*, www.lovdata.no FOR 1999-03-11 nr 301, 1999.

[7] J. A. Foosnæs, E. Tønne, J. O. Gjerde, and V. Hyde, "Demand Side Management (DSM). What are the potential benefits?," presented at the Cired 2013, Stockholm, 2013.