INTEGRATION OF DISTRIBUTED GENERATION INTO MV DISTRIBUTION GRID IN NORWAY – THE NAMSSKOGAN CASE.

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ABSTRACT

Integration of DG into MV distribution grids in Norway means integration of small hydro power units. Most of the DG potential in Norway is located in rural areas with weak MV grids and low consumption. This paper describes the situation in Norway regarding integration of DG into the MV grid. The paper also describes the challenges DSOs face regarding integration of DG and a particular case from Namsskogan is used as an example.

INTRODUCTION

The focus on integration of renewable energy sources into the electricity system leads to an increase in the amount of distributed generation (DG) in the system. It is expected a significant growth in the amount of DG in Norway due to the common market of green certificates in Norway and Sweden.

The introduction of large amounts small scale DG units will impose challenges for the electricity distribution companies. Norwegian distribution system operators (DSO's) are experiencing that DG units in operation are causing problems e.g. due to limited transfer capacity in the existing grids, and violation of voltage quality threshold values. Large scale integration of DG may also affect the overall transmission grids, having significant impact also beyond the distribution systems.

This paper will describe the situation in Norway regarding integration of DG into the distribution grid. The paper will also describe what challenges the distribution companies face regarding integration of DG. A particular case from the Namsskogan area in mid-Norway will be used as an example to show how the distribution company in the area has handled the specific challenges.

DISTRIBUTED GENERATION IN NORWAY

Electricity generation

About 95 % of the electricity generation in Norway comes from hydro power. The installed hydropower capacity is about 29.6 GW and the number of hydropower stations is about 1250. Table 1 shows the electricity generation in Norway 2010.

Total consumption of electricity in Norway 2010 was 131.9 TWh. About 22 % of this is related to energy-intensive industries.

Table 1 Electricity generation in Norway (2010) [1]

Hydropower:	117.9 TWh
Wind power:	0.9 TWh
Thermal power:	5.6 TWh
Total	124.4 TWh

In Norway there is a large potential for DG based on renewable energy sources (RES), mainly hydro and wind.

Hydro potential

The Norwegian Water Resources and Energy Directorate (NVE) have calculated the potential for electricity generation from hydro as shown in Table 2. The potential for small hydropower generation is calculated to be about 25 TWh.

Table 2 Potential for hydro power generation in Norway (TWh/year) [1]

In operation	123.4
Under construction	1.4
Approved for construction	2.0
Concession applied	7.0
Potential new production > 10 MW	6.5
Potential new production ≤ 10 MW	16.5
Total	156.8

Wind potential

The generation from wind is only about 1 TWh. Another 10.1 TWh (3.9 GW) have got concession and 64 TWh (21.5 GW) are under consideration by NVE (source: www.nve.no).

Most of the wind power generation will be located and concentrated in larger wind farms along the Norwegian coast. The wind power will therefore normally be connected to the main distribution grid (66-132 kV) or the transmission grid (300-420 kV), and hence not considered as a DG issue.

Photovoltaic (PV) potential

Norway has, due to its location, poor conditions to take advantage of solar energy. While the sunniest places in the world receive annually about 2500 kWh/m^2, the radiation in Norway varies between 700 and 1100 kWh/m^2. The variations are also large over the year. On a clear sunny summer day the southern Norway receives about 8.5 kWh/m^2 while radiation on a cloudy winter day can be as low as 0.02 kWh/m^2. The potential for PV generation is not cost-effective compared to other renewable energy sources (RES) like small hydro power generation in Norway today. This might change in the future.

DG location
Due to the Norwegian topography with a scattered population, the grid is relatively weak in many locations. Low load density in rural areas leads to much use of overhead lines (MV and LV), with long feeders which are vulnerable against climatic stress such as wind, ice and snow. New distributed generation is often expected to be developed in these rural areas.

NORWEGIAN REGULATORY FRAMEWORK

The Norwegian distribution companies are obliged through their network concessions to connect DG to the grid, provided that this is the socio-economic right thing to do. The decision of what is socio-economic optimal is however not a simple question to answer. The distribution companies therefore acknowledge a need for revising existing planning methodology and practice in order to deal with introduction of DG in the distribution system in a better way.

NVE regulates the Norwegian network companies through a revenue cap (RC). Economic and direct instruments are combined in the regulation in order to reach an optimal adaptation and at the same time avoid unwanted external effects. This is why the power networks are subject to many sets of rules in acts, regulations and licenses which govern their duties and rights. These rules are the basis for the power networks' activity, and shall ensure that the companies operates and develops their network in an optimal, safe and socio-economic way.

Connection charge
Network companies may require a connection charge to cover the costs of connecting new customers to the network or cost of reinforcing the network for existing customers. The objective of the connection charge is to make the customer responsible for the costs related to a new connection or an upgrade of the customer's existing network connection. Costs not covered by the responsible customer, but by the network company will increase the network company's allowed income, and hence, be dispersed to all customers through increased tariffs.

The DSO may split the connection charge between customers that are connected at the time the installation is brought to completion and customers that will be connected at a later point in time, but no later than 10 years after completion of the installation.

Regarding integration of DG and using the existing network capacity, the prevailing principle is first come first served. The optimal procedure is regional coordination and planning of the DG integration and allocation of the costs of the network reinforcement to all the DG units. In many cases the DSO has to do some funding in advance.

Tariffs for input of power
Input power tariffs consist of an energy component that varies with the customer's power input and a fixed amount.

The energy component shall reflect the costs of a change in energy loss when one extra kWh is transmitted (marginal loss). The energy component is calculated individually for each separate input point. A producer may have a favourable location in the network, where increased production reduces network loss. In such cases the producer is paid for energy input (or reduced charge).

The national grid input tariff shall be normative for the fixed component by power input into distribution networks. This input tariff for 2010 was NOK 0.008/kWh (about EUR 0.001/kWh). Settled production volume shall be based on the power plant's median annual output.

CHALLENGES FOR THE DSO

The introduction of large amounts of DG in MV networks will impose challenges for electricity distribution companies [2].

Technical challenges, e.g.:
- Voltage problems in high load/low production and low load/high production situations
- Stability requirements for DG units
- Reliability considerations concerning new failure sources in the network (DG units, control and protection equipment)
- Strategies for handling islanding situations
- Protection schemes for DG units and the need to coordinate between units

Economic challenges, e.g.:
- How to split costs between the DSO and DG owner regarding grid reinforcements?
- How to split costs between different DG owners in the same area – connected to the same grid?
- How to calculate benefits for the network related to DG integration
- What economic risk to take when connecting DG

Planning challenges, e.g.:
- Capacity problems at all voltage levels due to increased influx of DG
- Largest DG potential in rural areas with almost no load

- Challenges related to getting correct data for DG units to decide their stationary and dynamic behavior in the network
- The need to supplement load flow analyses with dynamic analyses, voltage quality simulations and measurements etc.
- The potential for DG in an area will not be built out at the same time. How shall the DSO take into account those that might come later? Shall the grid be reinforced so that all the potential can be connected without any further reinforcements?

Small hydropower plants are usually located in small rivers without reservoirs. The DG generation is lowest during winter because the rivers often freeze and there is no water running. The generation is usually highest in the spring when the snow is melting. The peak load usually occurs during winter. Peak load and peak generation will not be in phase.

Considerations regarding power quality (PQ)

The Norwegian PQ Code (FoL) [3] is more rigid than the European standard EN 50160 [4]. Table 3, Table 4 and Table 5 shows the differences between the two standards.

Table 3 Voltage variations

FoL	U_n ± 10 % (1 min rms) 100 % of time
EN 50160	U_n ± 10 % (10 min rms) 95 % of time

Table 4 Voltage dip

FoL	1 % < U_{ref} < 90 % Duration from 10 ms to 60 s Tolerance limit for number of voltage changes are defined
EN 50160	U_{ref} < 90 % Duration from 20 ms to 60 s

Table 5 Rapid voltage changes (FoL)

Rapid voltage changes	Maximum limit per day (24 h)	
	$0.23 \le U_n \le 35$	$35 < U_n$
$\Delta U_{stationary} \ge 3$ %	24	12
$\Delta U_{max} \ge 5$ %	24	12

The limits in FoL are the same in every grid, but the DSO can in special cases agree on other limits in written agreements with customers.

Voltage regulation with DG

Figure 1 shows a voltage profile during peak load for a 22 kV line with DG units connected about 1 and 15 km from the feeding point. The figure shows voltage profiles with:

- No DG
- DG with no voltage regulation (Q_{gen} = constant)
- DG with voltage regulation ($Q_{gen} \neq$ constant)

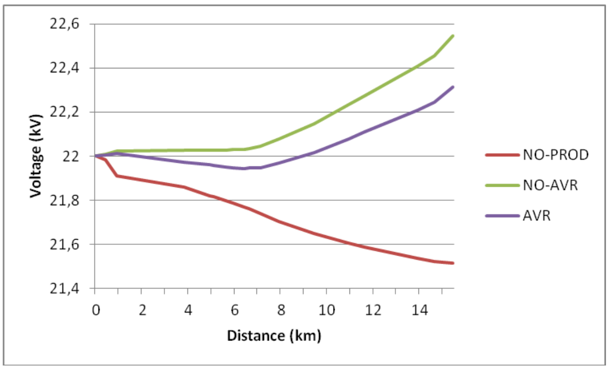

Figure 1 Example of voltage profile for a 22 kV line with DG units connected

The voltage variation close to DG units far out in the grid will be large depending of the DG generation. Special care has to be taken in order to stay within the limits specified in FoL. Possible measures to control the voltage can be:

- DGs with synchronous generators and automatic voltage regulators (AVR)
- Power electronics combined with capacitors and inductors (SVC or STATCOM)
- Transformers with automatic tap-changers
- Transformers with automatic voltage regulation (like Magtech Stabilizers)
- Reinforce (oversize) the grid

The DSO can put requirements to the DG for voltage control:

- Fixed cos(φ) or cos(φ) as a function of active production (P_{gen})
- Voltage at terminal points within certain limits

NAMSSKOGAN

Namsskogan is an area in Norway with huge potentials for small and medium hydro power stations.

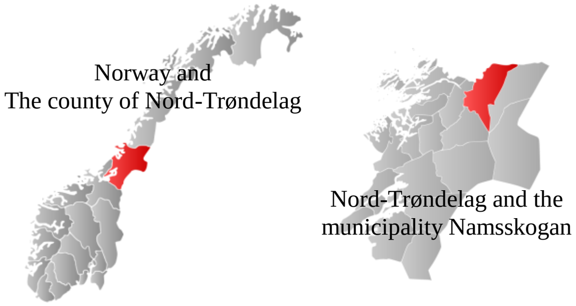

Figure 2 Namsskogan in Norway

Table 6 Key figures

Area	1 416 km^2
Inhabitants	926 (01.01.2011)
Peak load	1,2 MW
El consumption	17,3 GWh/year
Potential new DG	73,6 MW/258 GWh/year

Today's distribution network

A lot of the distribution network in Namsskogan today is built during the 1950's and 60's and it is designed for load supply in the area. The peak load is only 1.2 MW and is not expected to increase much in the near future. The population today is 926 people and is still declining as it has done for the last 40 years.

The main challenge in today's distribution grid is the long length of the feeders, combined with the location of the new DG-units. Approximately 32 MW of new planned production is located 20-35 km north of today's main feeding point. Another 7 MW is located 35-50 km north of today's feeding point. The rest of the potential is located south of and relatively close to the existing feeding point.

One DG-unit was connected to the existing grid in 2009. Load-flow analyses indicate that the existing grid has no capacity for further DG connections due to thermal limits and voltage restrictions according to the Norwegian PQ-codes (FoL). Several alternative solutions have been analyzed in order to find the optimal technical and economic solution for this area.

Even a massive reinforcement of the 22 kV grid will not be sufficient to connect all the DG-units. The feeder lines will be very long (up to 50 km) and will cause high transmission losses and large voltage variations close to the DG-units and also on the whole feeder.

Grid solution for DG integration in Namsskogan

Since the load-flow indicates that it is difficult and expensive to connect the DG-units in Namsskogan to a reinforced 22 kV, the next step was to consider an expansion of the main grid in Namsskogan (132 kV).

Since most of the potential is located approximately 20-30 km from today's feeding point, the solution proved to be a new feeding point close to this area. In addition to the DG-potential in Namsskogan, there are also plans for building a new 32 MVA hydropower station about 7 km north of today's feeding point.

A new 132 kV overhead line is planned from today's feeding point to connect the planned 32 MVA hydropower station to the grid. From this new power station the 132 kV line is planned to continue about 13 km further north to a new 132/22 kV transformer station. About 32 MW of DG-units will be connected to this new transformer station by one or two new 22 kV overhead lines. The rest of the DG-units (7 MW) will be connected to the same new station through reinforced existing overhead lines.

The new solution proved to be the most cost-efficient solution that allows all of the potential DG-units to be connected. In addition the solution will make it possible for further connections later if more projects should appear (some smaller wind farms are under consideration in the area).

The cost of the solution will be split between the DSO, the owners of the DG-units and the owner of the larger hydropower plant. Since the solution can handle almost the whole potential for DG in the area, the DSO will take the risk and do some funding in advance for future plans. The solution will also provide better reliability for all the customers in the area and the neighboring area.

CONCLUSION

The introduction of large amounts of DG in MV networks will impose challenges for electricity distribution companies. For the DSO the biggest challenge is to find the optimal technical solution. First there is the uncertainty about the amount of DG. What is the total potential in the area and how much of the potential will be realized. The DSO has to be active and try to coordinate the DG integration. The DSO must also evaluate the risk and decide in what degree it shall do some funding in advance.

Then the DSO has to find a solution for the reinforcement of the grid to integrate the future DG in the area. Voltage control and operating conditions within the limits defined in the Norwegian PQ code (FoL) is essential.

DG is usually unregulated generation. Integration of large amount of DG will result in frequency problems in the system unless the amount of regulated generation is similar increased. This is an increasing problem for the transmission system operator (TSO) already today. Regulated generation in today's system is not more valued than unregulated generation. Unregulated generation might in the future in some extent be compensated with regulated loads. But this will most likely not be sufficient.

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