BENEFITS OF VOLTAGE MEASUREMENTS WITH SMART METERS

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ABSTRACT

Voltage quality is becoming more and more important in distribution grids, not at least in Norway that has a large share of weak grids. Although voltage monitoring is not mandatory when smart meters are rolled out in Norway in 2019, it gives an excellent opportunity to gain a huge improvement in observability of the distribution grid. Measurements from smart meters can amongst others be used to monitor for dangerous faults that today can go on undetected for a long period of time. Voltage monitoring can also, by using a small amount of statistical data, give an in depth overview over the available voltage margins in all parts of the grid, and to uncover parts of the grid that need reinforcement. It can also be useful for handling customer complaints.

INTRODUCTION

Voltage quality is getting more and more important as the dimensioning factor in low voltage distribution grids in Norway. The level of reinforcement of the Norwegian low voltage network has dropped since the deregulation in the early 1990's and Norway has now a large share of weak distribution grids. A survey [1] performed in 2012 by Energy Norway and six DSOs indicate that close to 50 % of the low voltage grid customers in Norway has a weaker supply than a grid with network impedance equal to the IEC reference impedance. This is partly caused by Norway having a high percentage of 230 V delta networks. A recent survey performed by the Norwegian regulator show a similar situation. Figure 1 show the average short circuit capacity found in the first survey.

Short circuit capacity in percentage				
< 350 A	350–500 A	500–750 A	750–1 kA	>= 1 kA
6.2 %	7.5 %	13.5 %	13.2 %	59.7 %

Table1. Average short circuit capacity in Norwegian low voltage networks. Results from 2011-2012 survey.

A growing number of energy efficient appliances that draw high power over a short period of time have caused an increase in customer complaints. An increase in distributed generation has also contributed to an increase in voltage quality challenges and customer complaints. Mitigation by always reinforcing the grid (i.e. to IEC reference impedance) is very costly; in Norway this would cost approximately 14 billion euros. Smart grid technologies have the potential to reduce these costs**.**

The topic of this paper is the unique opportunity to achieve a new dimension of observability in LV grids when smart meters are rolled out (in Norway by 2019).

REALLY SMART, SMART METERS

In order to fulfill the Norwegian regulation, only a simple meter that can measure energy consumption over 15 minutes and 1 hour is required The additional costs for buying a smarter meter is small compared to the other costs for the smart meter roll-out (planning, customer contact because many meters inside customer's house/apartment, installation of new meters, communication system and software). A slight increase in the meter cost would therefore have marginal impact on the total roll out cost. Some smart meter vendors already include quite simple voltage quality measurement in their low-cost smart meters. More advanced voltage quality measurements and event detection is also available, and there is at least one manufacturer that offer such meters to a standard low price with the advanced features turned off. If the DSO wishes to use these features, they can pay an additional cost to unlock and start to use the advanced features without changing meters.

BETTER OBSERVABILITY

Smart meter roll-out is a **unique** opportunity for huge improvement in the low voltage network observability. While TSO's have good observability in the main grid by using fault recorders, power quality measurement instruments and protection/relay operation logs/history, the observability decreases for lower voltage levels all the way down to the low voltage network. This is the situation in most countries today, including Norway.

BENEFICAL EVENT DETECTION

In addition to simple interruption reporting, smart meters can also be used to detect important events such as:
1. Faulty/missing neutral wire (4 wire wye network)
2. Missing phase (3 wire delta/4 wire wye network)
3. Phase to ground faults (3 wire delta network)

There are already smart meter manufacturers that include several types of such event detection; some also include this in their low cost meters. In Norway there have been cases with both faulty/missing neutral (230/400 V wye), missing phase and phase to ground faults (3 wire delta) that not only caused damage to electrical equipment, but also started fires, and caused injuries and even death.

Fault situations in the low voltage network such as interruptions, missing phase, too low or too high voltages and phase to ground faults will often go undetected by the DSOs until customers alert them about the problem. During the night potentially dangerous faults can stay undetected for hours, and if the fault only affect single customers it can be days and weeks (during holidays) before the faults are detected/reported. Damage to electrical equipment and more importantly, fires has occurred under such conditions.

VOLTAGE QUALITY MONITORING

Voltage quality monitoring can range from very basic and simple measurements of only the long term RMS voltage variations, up to advanced measurements including harmonic voltage and flicker measurement. At what level smart meter voltage quality monitoring should be performed can be debated, but monitoring with low cost smart meters at household customers should probably be kept relatively basic and simple. This can still be very useful both in day to day network operation and network planning. Many network operators have limited knowledge about the voltage margins left in their low voltage feeders. As long as 230 V +/- 10 % is not exceeded, the voltage margin can simply be expressed as:

$$U_{margin} = (U_{min} - 207\text{ V}) + (253\text{ V} - U_{max})$$

Where U_{min} is the lowest measured voltage in the LV feeder and U_{max} is the highets measured voltage in the LV feeder. Experiences among Norwegian DSOs have shown that calculations of LV network voltage margins based on NIS (Network Information Systems) can give large errors compared to the real situation as verified by performing measurements. The cause is often not component data errors in NIS, but rather quite large errors in the estimated customer load. This will improve when 1 hour interval energy metering is in place, but even then it can be large differences between 1 hour average load measured and 10 minute [2] or 1 minute [3] maximum load required for voltage margin calculations/simulations for comparing with voltage quality compliance limits.

Figure 1 show voltages measured at Hvaler during one day in August 2013 from almost 7000 smart meters. The voltage measurement shows that the margins in the grids during this summer day is almost fully utilized, as voltages ranges from 253 V (230 V + 10 %) down to 211 V (230 V – 8 %). It does however not make much sense to evaluate the voltage margin for several different low voltage networks combined, as shown in figure 1. When measurements for a complete transformer substation (like in figure 1) indicate small margins the conditions should be evaluated for the individual LV feeders below this distribution substation.

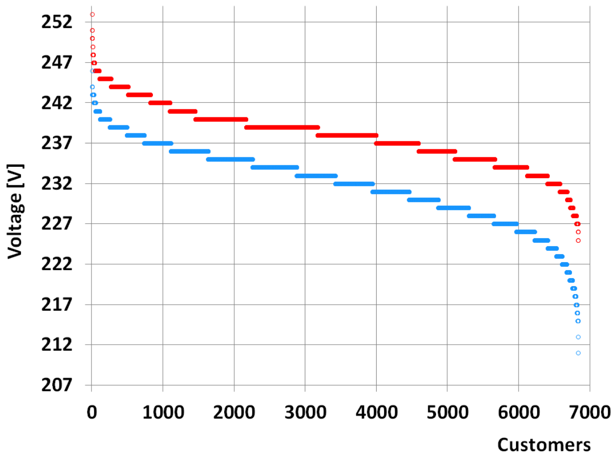

Figure 1. Voltages measured during one day in August 2013 from almost 7000 smart meters at Hvaler, Norway.

While figure 1 show the voltage conditions for only one single day it is of course necessary to evaluate data from at least a year, preferably several years to know the precise voltage margin available in the LV networks.

Some DSO personnel have been afraid that such large scale voltage quality measurements will cause very large amounts of data and will be both costly and difficult to operate. This does **not** have to be true! There are several ways to compress/reduce the amount of data. An example of an easy method is time aggregation based on the length of the observation interval. To measure for example whether customers in a LV feeder have voltages complying with the limit values in standards or regulations it may be sufficient to only collect two voltage values per customer (meter) per week. For the Norwegian power quality regulation this is very simple:

1. The meter measures all 1 minute averages of the voltage
2. Any 1 minute value affected by an interruption is discarded
3. The lowest and the highest of the remaining (accepted) values per week are compared with the regulation limit values

This means that in addition to the 168 weekly energy values that shall be collected, only two additional values are needed to check for compliance with RMS voltage limits.

It is not much more complicated to check for compliance with EN50160. However not only values affected by interruptions can be excluded. 5 % of the measured values can then be outside 230 % +/- 10 %.

Statistical data and event data

Large scale power quality monitoring with smart meters can collect both trigger based/event data, and statistical data. Trigger based/event data can typically be of great help in the day to day network operation, while statistical data can be of great help for both network planning and day to day network operation. It is often desired that the meter send and notify DSO personnel (push) trigger based event such as missing phases or interruptions. Statistical data such as the highest and lowest RMS voltages (per week or per day for every meter) can usually be collected together with the energy measurements (pull).

EFFICIENT NETWORK PLANNING

Information from smart meter voltage measurement shown in figure 1 give an easy and quick visual overview over the voltage margins left in the grid. This can be used to check compliance with standards and/or regulations, but also as an input parameter to grid planning. Experiences and knowledge from existing networks can be used in planning of new networks but also for long term planning of existing networks. In a survey SINTEF Energy Research made in 2004-2008 [4] data was collected from LV networks, and in some of them the DSO did not know that there was no voltage margins left. Voltage measurements from one such LV feeder is shown in figure 2. In the case of figure 2, the lowest 10 minute average voltage was 207 V at far end customer and the highest voltage was 260 V at transformer end customer. Figure 3 shows an example of how DSOs can get very good overview of the voltage margins with smart meters.

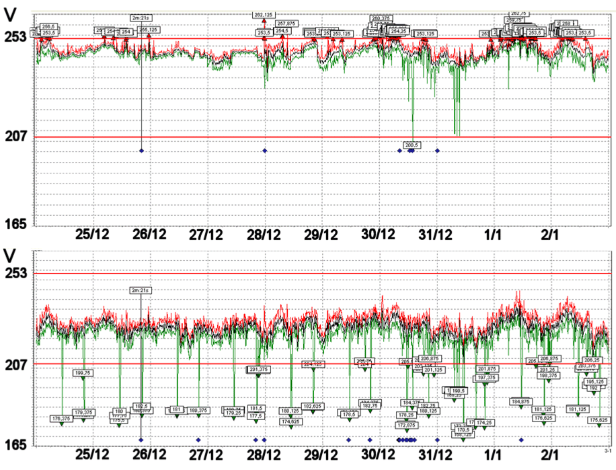

Figure 2. Voltage measurement in LV feeder with no voltage margins left and limit values were exceeded.

If the DSO want to verify the voltage margins for planning of future or even near future reinforcement needs, it will be possible with the data shown in figure 3 to rapidly view the conditions for each transformer. Only for transformers where there apparently are no margins left will it be necessary to spend a bit more time to evaluate the conditions in the individual LV feeders.

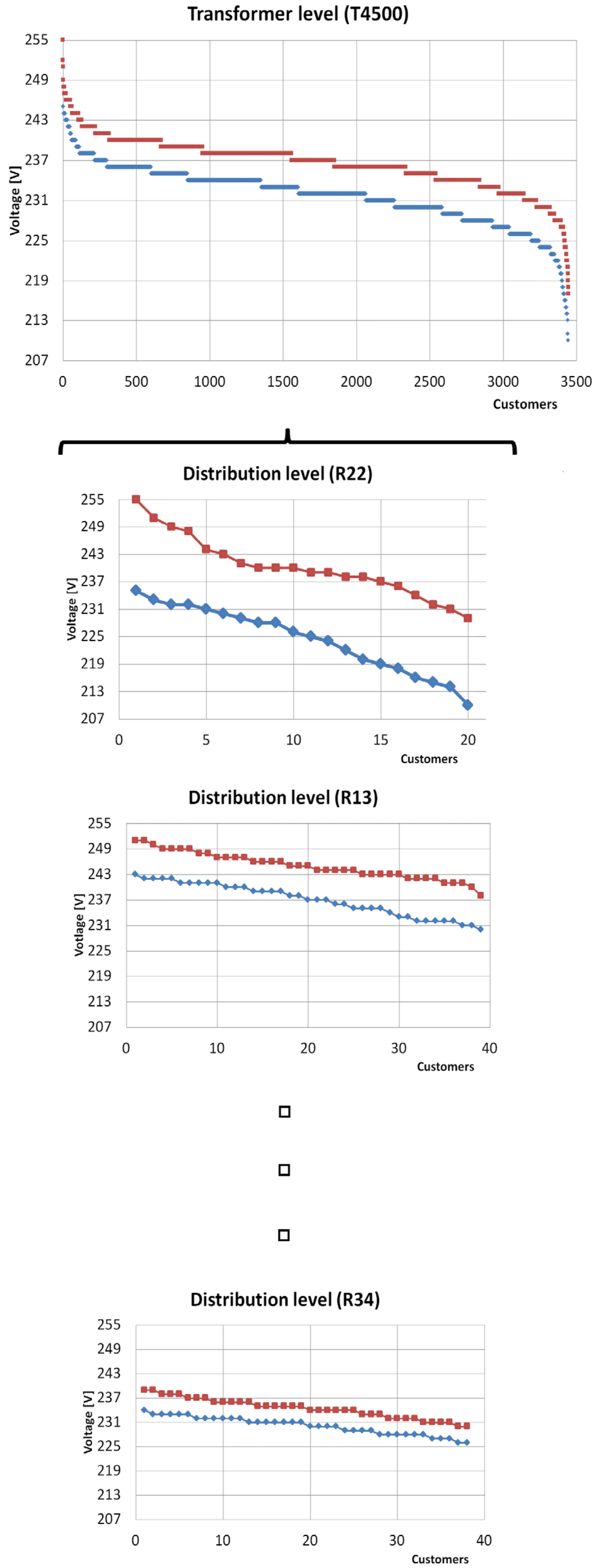

Figure 3. Highest (red) and lowest (blue) voltages at all customers under a transformer station in shown the upper diagram. The conditions in the different low voltage feeders are shown in the other diagrams.

In figure 3 there is data for one year for almost 3500 customers. The transformer overview show the + 10 % limit being exceeded. Additionally there are clear indications that voltage margins need to be checked on individual LV feeder level. For the individual LV circuits it can be seen that one feeder (R22) needs reinforcements since there are no margins left for a simple correction action like tap changing. For the second LV circuit (R13) it is actually possible to correct a little bit high voltage by tap changing. In the rest of the LV feeders the conditions are good and even "very good" (R34).

If DSO personnel can get such an overview by simply clicking on the different MV/LV transformers on the user interface and then obtain the voltage quality statistics, they will have a really efficient evaluation of the network conditions.

EFFICIENT NETWORK OPERATION

Voltage quality monitoring (and event detection) by smart meters can dramatically improve low voltage observability and make it easier and more efficient to handle customer complaint cases, network faults due to extreme weather conditions and more.

Handling customer complaints

Up until today SINTEF Energy Research has time after time seen customer complaint cases were DSOs perform only post-problem measurements for typically 1 to 4 weeks and do not find anything wrong with the voltage quality. Customers are angry and are not comforted by the DSO not having "evidence" (measurements) at the time when the problems occurred. There have of course been several cases where there actually is no problem with the customers supply voltage. SINTEF Energy Research has however also seen cases where there clearly has been found (measured voltages) an explanation to the customer's complaint by a second measurement weeks or even months later. With smart meter voltage quality monitoring the DSO may have enough documentation in many of the customer complaint cases, so further measurements with portable instruments is unnecessary.

Network recovery (after i.e. extreme weather)

Large scale power quality monitoring with smart meters can also be a valuable aid in network restoration after storms/hurricanes. A Norwegian DSO claimed after the Hurricane Dagmar (Western Norway December 26th 2011) that with a smart meter system as described in this paper, they would have been able to restore the network in less than half the time. This would be not only due to information about where there still are interruptions, but also due to information about missing phases, phase to ground faults etc.

CONCLUSIONS

A well designed system with smart meters and necessary back office software can greatly improve the LV network observability and both save costs and make the DSOs network operation and planning more efficient. Benefits from choosing smart enough meters can be:

1. Health and safety
2. More efficient cost saving network planning
3. More efficient cost saving network operation
4. Better overview and control of voltage quality
5. DSOs getting better publicity

The DSOs have to decide what level of smart grid benefits they will implement. When they invest in smart meters, they make a long term investment, and they should consider benefits they wish to realize both in long term and not at least in the not so far future. For a relatively small increase in cost that result in little extra stress on databases, communication programs and software, they can gain quite large benefits through better observability and control in the low voltage grid. This can be achieved by simple voltage quality measurements, and transfer and storage of a low amount of data compared to energy measurements.

It is important for DSOs to carefully consider not locking themselves into a system only capable of energy measurements for many years to come by selecting the simplest and cheapest hardware. Selecting user friendly software with the right analysis and data viewing tools are also very important.

Acknowledgments

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