NEW METHODS FOR DISTRIBUTION NETWORK MONITORING WITH SMART METERS – VERIFYING DATA IN NETWORK INFORMATION SYSTEMS

Henning Taxt
NTNU/SINTEF Energy – Norway
henning.taxt@ntnu.no

Henrik Kirkeby
SINTEF Energy – Norway
henrik.kirkeby@sintef.no

Helge Seljeseth
SINTEF Energy – Norway
helge.seljeseth@sintef.no

ABSTRACT

There is an economic pressure on distribution network operators that increases the emphasis on optimizing investments and operations. A prerequisite for optimization is a correct evaluation of the status quo.

This paper presents one of several possible new methods to increase observability in the distribution network. This method, which combines voltage and power measurements at all end-user connection points, will give valuable feed-back on the quality of network documentation and measurements.

The method has been tested with promising results. However, there are limitations to its application. Further evaluations and tests should be performed to determine to what degree it can provide value to the companies in practice.

INTRODUCTION

An increase in distributed energy sources and new electric equipment, such as electric vehicles, in the distribution network is leading to more complex power flow. At the same time, pushing the utilization rate of the existing infrastructure towards its limit can be of great economic benefit. In order to increase grid utilization and limit investment needs, new methods are needed for more precise monitoring of the network and quality assurance of the network documentation. The broad implementation of smart meters can potentially bring about a new dimension of observability in distribution network.

Correct documentation of existing networks is important for network planners, operators and field workers. However, the quality of network documentation is varying greatly, from almost non-existing to fairly good. Bad quality and misleading documentation could actually be worse than no network documentation, because assuming to have correct information can lead to bad investment and operational decisions.

Several methods for enhanced distribution network observability have been suggested. One quality assurance method is simply checking the energy balance in the low voltage grid by calculating the difference between the total active energy drawn by costumers and balance measurement in the MV/LV substation [1]. This difference would indicate that something about the measurement is erroneous, be it an error in network documentation, theft or something else. With this method it would still be challenging to find the origin of this error. The time-consuming follow up of cases is a problem with the method.

Distribution state estimation (DSE) is often mentioned as a part of smart grid functionality. In its origin the state estimation was all about getting a good picture of voltages and power flows in the network from a minimum number of measurements [2]. In practice, the quality of this method relies on the network documentation, which can be of poor or uncertain quality, especially in low voltage networks.

Because of smart meters, with close-to-real-time measurements of power and voltage from all connection points, much of the extra information that the DSE could provide, is now simply measured. The approach in this paper is somewhat related to DSE. The DSE combines selected measurements with network data to estimate the distribution network state. In this paper we demonstrate that we can measure the network "state", ie. power flow and voltages (without angles), to verify or improve the network data.

In the following, the method will be explained and possible areas of use are presented. The method also has some limitations and uncertainties that will be discussed. After that, a prototype that demonstrates the method is presented, along with two examples from real networks. The paper is rounded of by suggesting a path for continued work.

METHOD

The fundamental idea is to combine two sets of connection point voltages, referred to as A and B. Both are arithmetic average values for a given time interval, e.g. one hour. Set A is the voltages resulting from a load flow calculation. The input to the load flow calculation is the measured power flows in all end user connection points, the measured voltage at one point in the network and the network admittance matrix (network impedances). The other set of voltages, set B, contains the measured voltages at all connections for the same time interval as for set A.

In the case that all data in this analysis were correct and conditions were ideal, set A and B would be identical.

Any difference between the two sets would originate from an error in the input data; the power measurement, the voltage measurement or the network documentation.

Clearly, knowing that one of the three input parameters is wrong is not sufficient to add value. To get truly valuable information, some further analysis is normally required. First, the input data confidence should be evaluated. At this stage the knowledge and experience with the specific network is of great value. Typically, voltage measurements are reliable, and if e.g. network documentation is of good quality, unmeasured power flows would be easy to spot.

Second, any voltage deviation must be analysed in the context of the network topology. That narrows down the geographic area where the error is located. Analysing the deviations in the map can also contribute in finding the most probable cause for the error, whether it is an erroneous power measurement or wrong impedances in the documentation.

Third, several time intervals should be analysed to reveal systematic deviations and how deviations vary over time. A deviation that varies with the known load is more likely to originate from the network documentation than a deviation that is apparently random. A more random deviation is more likely to be because of missing measurements.

By applying the suggested method it is actually possible to find the location of the error, which is an advantage of this method compared to energy balance measurement on the distribution transformer that was suggested earlier.

Practical uses

The most important contribution from the method described here is the assurance of the quality of network documentation. By running this simple algorithm, the network planner, or other person that depend on the network documentation can conclude quickly whether to rely on the documentation.

If a large error is discovered, the method can be used for more specific purposes:

- Wrong impedance in network documentation (e.g. cable length or cross-section) can be discovered
- Missing or erroneous measurements (e.g. wrong placements in network documentation, theft) can be discovered
- The distribution transformer voltage ratio can be checked remotely, if not measured

Reliable network documentation is valuable in many operations that the network companies perform. The exact knowledge of network impedances can have a great impact on the way power quality is assessed, both in network planning and in problem solving, moving away from a practice where those responsible for power quality typically focus on specialized measurements, while network planners mainly focus on load flow and simulations on a higher aggregation level. Obtaining high quality documentation is an important start in the process of combining approaches.

Limitations and uncertainties

There are some obvious limitations to the proposed method. There is a long range of possible roots to the differences between measured and calculated voltages that this method is based on. If other, more random influence on the voltage become prominent, it would become harder to draw good information from the results. Some of these uncertainties are briefly mentioned here.

The actual impedance of the network is not constant and will vary slightly with temperature. A different temperature than assumed, leads to a different resistance in the calculations than in the real network, and would be an unknown root to differences.

The accuracy of length specifications in the network documentation is unknown. If these are just approximate, one can assume that there are significant deviances in the real and documented components.

Handling of missing measurements is important. They could be replaced by an estimate or they could be left out completely. In any case it should be clearly marked when measurements are missing.

PROTOTYPE TESTING

The method has been implemented as a prototype in an existing program package from Powel. The data was provided by Smart Energy Hvaler, a smart grid demonstration project. In this area about 7 000 smart meters are installed, as well as supplementary measurements in selected network nodes. The meters are configured to send hourly energy and average reactive power measurements to the central database regularly. In addition, hourly average voltage measurements are recorded and stored locally and can be collected on demand.

The energy and reactive power measurements were stored automatically in a Measurement Data Management System (MDMS). From the MDMS the data was easily accessible for the load flow application. The voltage measurements were, for practical reasons, transferred from the smart metering system to the prototype on csv file format, but should ideally be stored in and accessed from the MDMS like the other measurements. In Norway, the most common low voltage network configuration is the 230 V IT (delta) network. All values are therefore three-phase and voltages are the average of all available phase voltage measurements. In 230/400 V TN networks the calculation can be performed per phase.

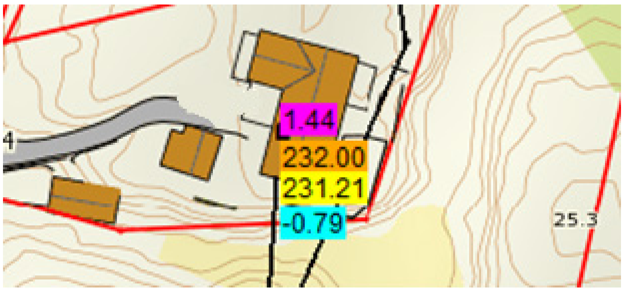

Figure 1 Screen-shot from the prototype, displaying the information available on end-user level. From the top: measured power and voltage, calculated voltage and difference with red/blue color coding.

The prototype is started by choosing a geographic area and time interval. The program then imports all relevant active and reactive power measurements and voltage measurements and runs the load flow calculations. If the voltage on the low voltage terminals of the distribution transformer is not measured, the prototype re-runs the calculation, adjusting the transformer voltage until the average deviation between the two sets of voltages is small.

Figure 1 shows how the information can be presented in a map. The most relevant information is the deviation between the two voltages, which is coloured red if the measured voltage is more than 0.5 V lower than the calculated, and blue if it is more than 0.5 V higher. As additional information the power and voltages can be presented in the map as well.
In the following two examples of use are presented.

Check a single low voltage network

The first example is from an analysis in one low voltage circuit. The network is 230 V delta-connected, and most customers have a three phase connection. Supposedly, all power drawn from the network is measured by smart meters, but there is no measurement on the transformer.

The result for one specific hour is presented in Figure 2. At this hour, three of the measured voltages are significantly lower than calculated (marked in red) implying that the network documentation is probably not correct here.

As a response to this finding, field personnel did an inspection of the grid in the area. The inspection revealed a bad connection with significant local heating in one of the connection points. On arrival the personnel measured a voltage in the installation of 227V. After repairing the connection, the voltage had increased to 237 V. A potentially hazardous situation was avoided. More field inspections should be performed to evaluate the results and find out how representative this first test was.

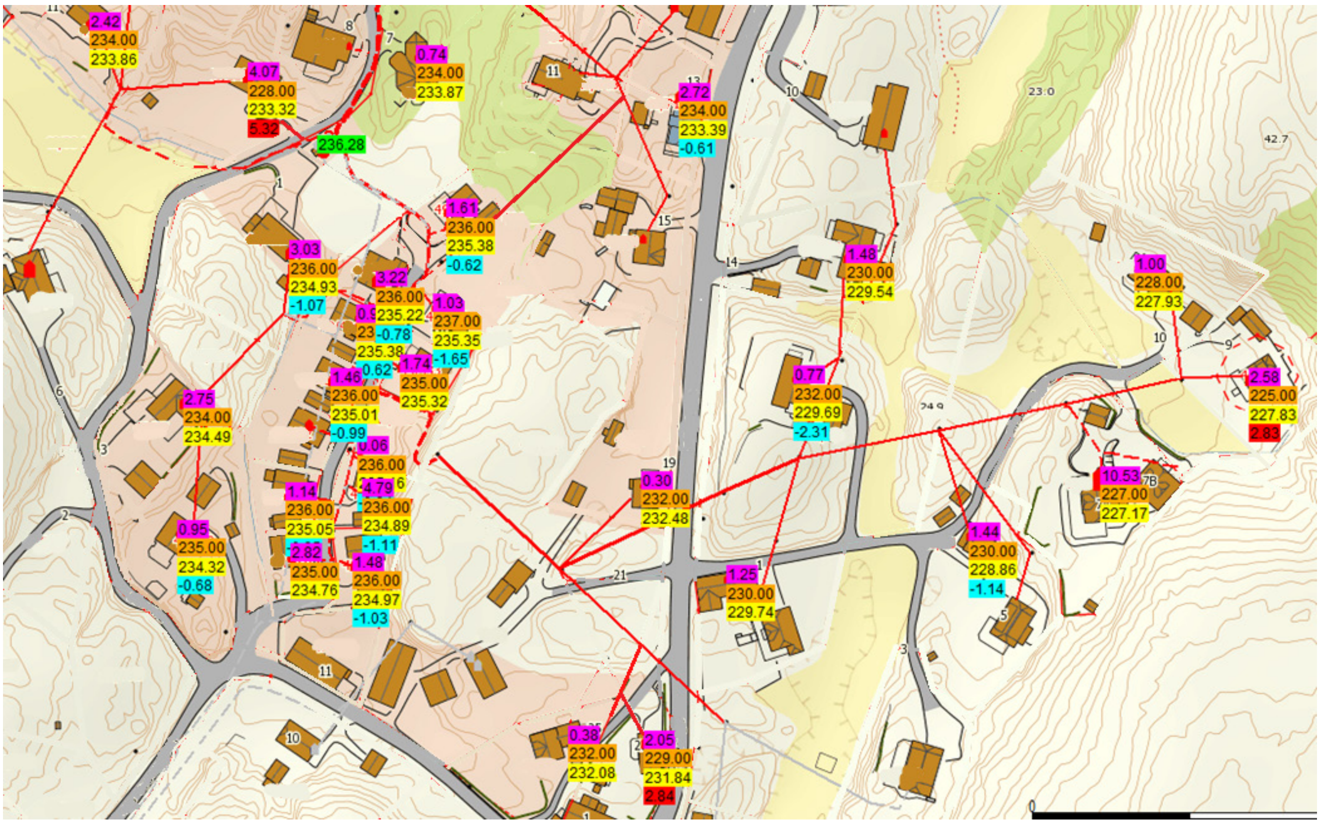

Figure 2 Example from the prototype. At three connection points (shown in red) the measured voltage is significantly lower than voltage calculated based on the power measurements.

Check transformer voltage ratio

An adjustable and significant parameter when simulation power flows in the distribution network is the tap changer position of the MV/LV transformer. Without knowledge about this voltage ratio, a load flow calculation becomes irrelevant in the low voltage grid. On the other hand, knowing this ratio and thus being able to calculate the complete load flow of the medium and low voltage grid, would be a powerful tool in network planning and power quality work.

Figure 3 shows how the method presented in this paper can be used to determine the voltage ratio remotely, without direct monitoring of the substation. In this case the voltage is set correctly at the HV/MV transformer and the load flow of the whole feeder including low voltage network is calculated. The upper snap-shot shows the deviation between calculated and measured voltage before any adjustment where done. In this case the different low voltage circuits are clearly clustered as blue or red, meaning that the input voltage to the low voltage circuit is wrong. The voltage ratio in the network documentation can then be adjusted for better agreement between measured and calculated values.

The lower snap-shot shows the voltage deviations after the voltage ratio was adjusted. On the leftmost low voltage circuit the voltage deviation was about 10 volts before adjustment and quite well in agreement afterwards.

There are clearly more precise ways of determining the tap changer position, but they also require more effort or investment, either by measuring the voltage ratio on site, or investing in permanent remote substation monitoring.

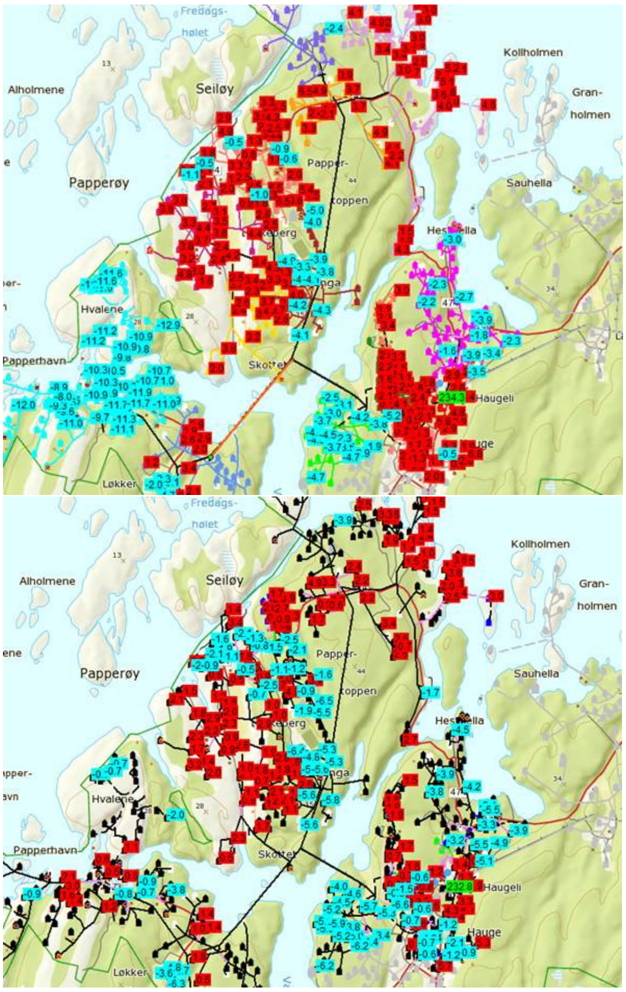

Figure 3 Procedure for remotely checking transformer voltage ratio. Upper view: before updating network documentation, lower: after adjusting tap changer position in network documentation

CONCLUSION

The described method has been tested in a Norwegian distribution network with promising results. These tests reveal a significant potential for this method. The tests also reveal the limitations to what can be achieved. The method requires a certain confidence in at least some of the input data. The errors must be of a certain magnitude to be discovered, depending on the over-all accuracy of the input data. Further testing in other types of networks is required before the method could be applied commercially.

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