ADVANCED POWER QUALITY MEASUREMENT CAMPAIGN INTERESTING MEASUREMENT RESULTS

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ABSTRACT

Due to several new challenges and opportunities, many believe that the electricity network of the future must be a smart network (smart grid). Renewable energy production, large scale penetration of electrical vehicles and power quality requirements through international standards and national regulations are only some examples of such challenges and opportunities.

SINTEF Energy Research in cooperation with several partners is running several competence building projects (CMP) related to smart grids. Three of these projects are cooperating on a measurement campaign with advanced measurement capabilities.

This paper describes the measurement campaign in terms of measurement locations and measurement system. In addition, a few of the interesting measurement results already discovered are also presented.

INTRODUCTION

The importance of performing power quality measurements has gained increased interest in Norway since the Norwegian regulator introduced regulations relating to the quality of supply in the Norwegian power system. [1]. The introduction of distributed generation has in some locations caused challenges related to power quality and has also raised the utilities awareness of the importance of performing measurements. The Norwegian regulations (in force from 2005) requires that all Norwegian utilities from 1.January 2006 perform continuous measurements of power quality in their networks and that m are stored for at least 10 years for some parameters.

SINTEF Energy Research in cooperation with the Norwegian Research Council, the Norwegian regulator and several Norwegian utilities, power producers and industry companies is running several competence building projects (CMP) related to smart grids. Three of these projects are cooperating on a measurement campaign with advanced measurement capabilities. A total of 25 instruments are installed and they are continuously storing the sampled wave shapes of 4 voltage and 4 current channels. Many different calculated parameters (Short time flicker (Pst), Long time flicker (Plt), Total Harmonic distortion (THD), Voltage root mean square (Vrms), current root mean square (Irms), etc) are available together with the continuous wave shape of all voltages and currents. The measurements are mostly located in areas with distributed generation from either small scale hydro power or wind farms. However, some measurements are performed in areas with large industry facilities or in city networks.

The objectives of this measurement campaign are to:

- Establish a power quality database with a large amount of measurement data
- Map power quality in different types of power networks
- Analyse how disturbances spread throughout the power network
- Analyse power quality in networks with power production from fluctuating energy sources
- Analyse the influence of distributed generation on the connected power network
- Analyse how distributed generation influences reliability in power networks
- Establish new models and methods for load modelling

Phenomena observed so far include (amongst others):

- Observations of challenging interaction between different renewables (wind vs. small scale hydro)
- Load-tap changer operations and interaction with renewables
- Instability problems in a wind power plant caused by inadequate controller settings
- Saturation in measurement transformers causing “false dips” to be recorded
- Higher power production than nominal power from wind farms
- Heavily fluctuating loads at customers believed to represent relatively constant or slow varying load

MEASUREMENT LOCATIONS

The measurement locations are mainly chosen based on feedback from the project partners. Areas without representatives in these research projects are therefore not included with measurements to the same extent.

In the request for possible measurement locations the following elements were emphasised as desirable:

- Areas with large penetration of distributed generation
- Areas with planned connection of new distributed generation
- Areas with reported problems related to power quality
- Areas with power production from wind power
- Areas with heavy industry

The locations of the different measurement instruments are shown in figure 1 below.

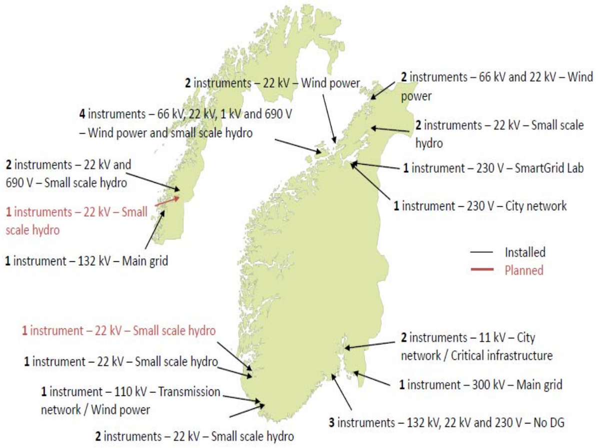

Figure 1: Measurement locations

The distribution of measurement instruments to different categories is shown in Table 1. It should be noted that several categories could apply for one instrument.

Table 1: Distribution of measurement instruments by category

Category	Number of instruments
Small scale hydro power	9
Wind power	7
Heavy industry	3
Critical infrastructure	2
Office building/Service sector	2
Rural areas (mainly overhead lines)	21
City networks (mainly power cables)	4
High voltage (22 kV < U)	6
Medium voltage level (1 kV < U ≤ 22 kV)	12
Low voltage level (U ≤ 1 kV)	6

The instruments are mostly organised in clusters of two or more instruments in the same area. This is done to get a better understanding of how disturbances spread throughout the network and how generation units respond during disturbances.

MEASUREMENT SYSTEM

All measurements described in this paper are performed with the Elspec G44xx Blackbox system [2]. The measurement instruments used have a sampling rate of 512 or 1024 samples per fundamental frequency and they continuously store the sampled wave shape for all phases of voltage and current. This is an advantage when performing simultaneous measurements with several instruments compared to the more traditional trigging concept. When storing the wave shape for every fundamental frequency you ensure that you have measurement data not only from the measurement instrument located closest to a disturbance but also from more remote instruments where voltage variations do not exceed trigger levels in classic PQ instruments. The downside of this solution is that it creates larger amounts of measurement data. The Elspec G44xx Blackbox (without I/O module and GPS antenna) is shown figure 2.

Figure 2: Elspec G44xx Blackbox

The internal clocks in the measurement instruments are synchronised with Global Positioning System (GPS) signal or, in some cases, a Network Time Protocol (NTP) server. The latter is only used at locations with a fast broadband connection.

MEASUREMENT RESULTS

<u>Saturation of measurement transformers during earth faults</u>

Figure 3 presents the rms values and waveforms for the phase-to-phase and phase-to-ground voltages at a transformer between the distribution (22 kV) and transmission (132 kV) network. The waveforms of the phase currents are also included. The values for rms phase to ground voltages show that a one phase to earth fault occurs at the measurement location. The time span shown in the figure is approximately 600 ms.

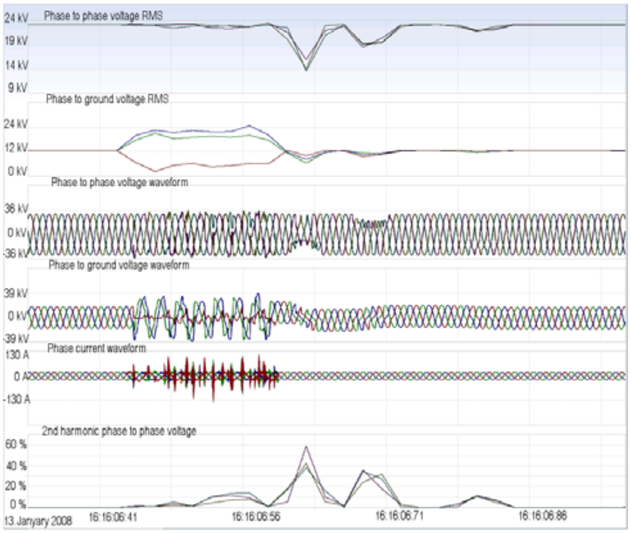

Figure 3: Potential transformer saturation causing "false voltage dip" in line voltage

When the earth fault is cleared and the phase-to-ground voltages are restored, two short voltage dips in phase-to-phase voltages are measured. The voltage dips occur due to saturation effects in the measurement transformers. This is a phenomenon that can occur in networks operated with isolated neutral, as is the case at this measurement location. The saturation of voltage measurement transformers due to earth faults in networks with isolated neutral is described in detail in [3] which presents a study performed through the results from the Italian power quality monitoring system QuEEN. A phase to phase waveform signature similar to the measured phase to phase voltages shown in figure 3 is presented as a typical dip due to voltage transformer (VT) saturation in this study. Several voltage dips due to saturation of VTs are observed both at this measurement site and other sites.

The authors of [3] suggest analysing the 2nd harmonic distortion to separate real voltage dips from "false" dips. The threshold which classifies a "false" voltage dip is a 2nd harmonic level of more than 10 % for more than 30 ms. The line voltage drops in figure 3 have a 2nd harmonic level of more than 10 % for more than 40 ms and thereby fall within the category "false" voltage dip due to saturation.

In the study presented in [3], 28 % of a total of 10775 voltage dips was classified as "false" and 12 % as "undefined". The measurement period was 7 weeks. There is no reason to expect that the distribution between "real" and "false" voltage dips are very much different in the Norwegian power system compared to the Italian power system even though "false voltage dips" so far only are studied in a few measurement locations in Norway. The "false" voltage dip presented in figure3 was discovered since both phase to phase and phase to ground voltages were measured. This shows the importance of either performing measurements in such a configuration and/or to measure the 2nd harmonic component in networks with isolated neutral. Else it will be difficult to identify "false voltage dips" due to saturation in measurement transformers. Preferable additional analyses of the measured signal should be performed since measurement results from this measurement campaign have shown several events with earth to ground faults with saturation and high 2nd harmonics when real voltage dips (short circuit) occur.

Production signature from wind farm with induction generators

Figure 4 and 5 presents measurement results performed in a wind farm with induction generators. The wind farm consists of 24 wind turbines, each with a rating of 2.3 MW. The reactive power consumption of the induction generators are locally compensated through the use of 24 capacitor banks with a rating of 1.35 MVAr each. Measurements are performed in one of the wind turbines (690 V) and in the connection point of the wind farm (66 kV). At the wind turbine, the reactive power flow is measured after the consumption of the induction generator is compensated.

In figure 4 the phase to phase voltages and total active and reactive power is shown during a period with high power production. The rated active power of the generator is indicated by a red line. The figure shows that the production reaches up to 3.68 MW (1.6 pu) for a short period. The total time span of the figure is 35 seconds. The increase in active power production results in an increase in reactive power consumption by the generator. The generator is fully compensated at rated active power production. However, during this peak in active production, a total of 0.84 MVAr is drawn from the grid. This results in a voltage drop of almost 3 % at the measurement location.

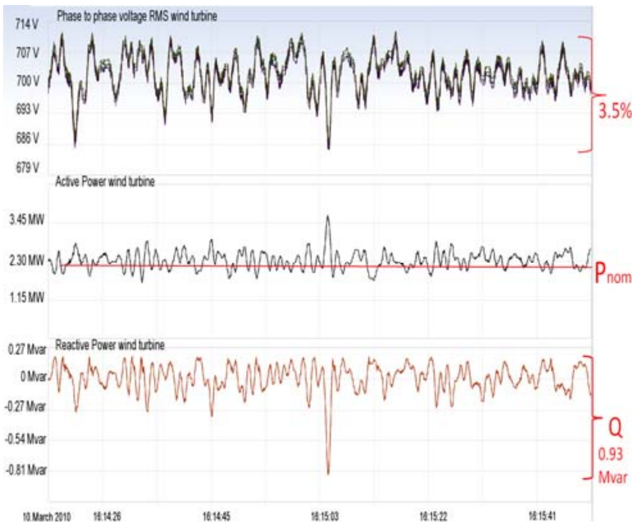

Figure 4: Phase to phase voltages and total active and reactive power from wind turbine

Looking at the entire wind farm, Figure 5 shows that the coincidence factor reduces the variations and the peak power production compared to a single wind turbine. Even so, there are power peaks which are significantly higher than the rated power of the total wind farm. The maximum power production shown in figure 5 is 59.1 MW (1.07 pu). During this peak, 6.0 MVar is drawn from the transmission network and this result in a voltage drop of 2.6 % in the connection point of the wind farm.

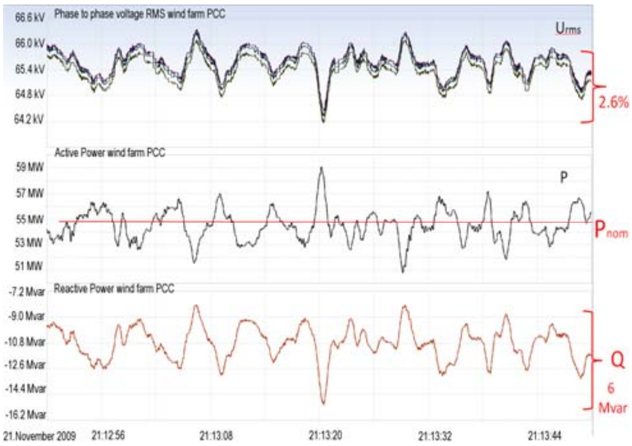

Figure 5: Phase to phase voltages and total active and reactive power measured in wind farm connection point

Wind farm production interfering the operation of small scale hydro plant

Another example of the challenges with distributed generation is a case where one of the Norwegian wind farms caused many shutdown events in a small scale hydro power plant [4]. During a 10 month period the hydro plant tripped 181 times. The vast majority of trips was caused by the hydro power generator reactive power consumption (voltage regulation) reaching the protection limit.

Thanks to the continuous data measured it was soon discovered a complex interaction between the wind farm and the tap changers in one of the transformers in the area. This tap changer operation was unnecessarily causing the voltage to increase at the connection point of the small scale hydro power plant.

The tap changer settings were adjusted according to table 2 and resulted in the number of trips of the hydro power plant to decrease to only 13 the following 10 months.

Table 2: Settings for tap changer controller

Parameter	Original setting	New setting	Comment
Us [%]	101	100	
t [s]	30	30	Definite time
ΔU [%]	1.8	1.2	

CONCLUSIONS

New challenges and opportunities on the road to smart grids will be better handled and administered with an increased level of advanced power quality measurements. Renewable energy production, distributed generation, new challenging loads etc may cause complex situations that is easier to comprehend and solve with more advanced measurements.

The problem with “false voltage dips” caused by saturation in voltage measurement transformers may be difficult to discover in measurements where only phase to phase voltages and not phase to ground voltages are measured. Such measurements are amongst others very common among Norwegian Distribution System Operators (DSOs). Using the 2nd harmonic component in the phase to phase voltage as an indicator of “false voltage dips” is a quite efficient way to filter “false voltage dips” but such a filter should preferably be made even smarter to avoid for example real voltage dips to be excluded due to high 2nd harmonics. SINTEF Energy Research is currently working with such improvements in one of the competence building projects.

REFERENCES

[1] Reg. No. 1557 of 30 November 2004: Regulations relating to the quality of supply in the Norwegian power system, Norwegian Water Resources and Energy Directorate 2004

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[3] R. Chiumeo, M. de Nigris, L. Garbero, C. Gandolfi, L. Tenti, E. Carpaneto “Implementation of a New Method for an Improved Voltage Dips Evaluation by the Italian Power Quality Monitoring System in Presence of VT Saturation Effects.” *ICREPQ 2010*

[4] T. Toftevaag, T. Solvang, “Operating experiences and voltage control issues in distribution network with large scale integration of both wind and small-scale hydro power generation”, *Cigré 2010*