VISION OF POWER QUALITY MONITORING AND MANAGEMENT IN FUTURE DISTRIBUTION NETWORKS

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ABSTRACT

The economic effects of power quality problems are increasing all the time. Solving those problems as fast as possible will produce savings and increase customer satisfaction. In this paper present and futures importance of two power quality quantities are considered. These quantities are flicker and harmonics. Paper will also show one vision of how current measurement via AMI could improve detection of origin of power quality problems when AMI meters are able to perform accurate power quality measurements. This consideration is done for above mentioned quantities. Improved power quality monitoring will not produce benefits itself. To achieve business benefits the business process of power quality management needs to be developed. This paper introduces one vision of the power quality management process in the future distribution networks.

INTRODUCTION

The distribution network environment is facing big challenges in the next few decades. Concerns about the global warming and rising energy price are forcing customers to use electricity in an environment friendly way. In addition, manufacturing costs of devices are decreasing due to technology development, which makes it possible for majority of customers to plug in new kinds of devices to a distribution network. With these devices it is possible to save electrical energy (e.g. compact fluorescent lamps and heat pumps), save costs compared with the use of other energy source (electric vehicle), store electrical energy (electrical storage), even produce electrical energy (distributed generation) and overall decrease CO_2 emissions. Earlier distribution networks have been designed to fulfill different kind of electricity usage needs so it is possible that power quality problems may occur when the mass penetration of these new devices starts. For example, heat pumps are pointed out to increase flicker level especially if there are several heat pumps in the same low voltage (LV) network [1].

Historically, utilities have had very little, or not at all, control or measurements beyond primary substations except the energy consumption measurement of customers. Power quality problems have been detected by customer complaints and case specific power quality measurements. This method is both expensive and time consuming and it will not answer the needs of the smart grid, because it is a reactive not proactive method of solving power quality problems. To fulfill proactive power quality management requirements continuous and extensive power quality monitoring is mandatory everywhere in the whole distribution network. One way to implement this is to add power quality measurement functions to AMI.

IMPORTANCE OF FEW POWER QUALITY QUANTITIES

The importance of power quality problems can be reviewed by its economic impacts. In the USA economical losses due to interruptions are estimated to be between 104-164*10^9 dollar annually. Other power quality problems are estimated to have 15-24*10^9 dollar economic lost impact annually. The most commonly reported symptoms of power quality phenomena are light flickering, circuit breakers tripping and computers locking up or restarting. Also some damages are reported due to voltage quality problems [2].

In this chapter, we are focusing on two quantities of power quality flicker and harmonics. We focus on these because flicker is very common reason for power quality complaints as shown in Figure 1 and harmonics are coming more common due to increasing numbers of power electronics. Interruptions represent only 5% share of power quality complaints in Figure 1 because most interruptions take place in medium voltage (MV) level and those are detected by relays in primary substation so those are not considered as power quality complaints. In other words interruptions in Figure 1 mostly mean interruptions in LV level [3].

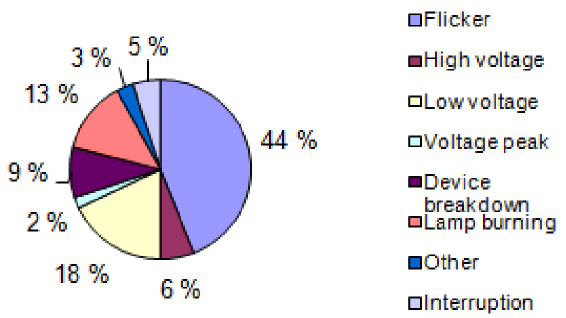

Figure 1. Power quality complaints distribution in one rural area distribution utility in Finland during 2003-2005 [3].

Flicker has a very big share of power quality complaints as shown in Figure 1. One reason for this is that it is a very easy power quality problem to detect by customers. Flicker is caused by rapid voltage changes in a distribution network. Rapid voltage changes are consequences of changes in load current as shown in Figure 2 and Equation 1. Typical reasons for flicker are big motor start ups and use of arc furnaces. The importance of flicker definition is coming to be outdated at least in EU region. The European Commission Regulation number 244/2009 states that incandescent bulbs will be gradually phased out from the market [4]. Flicker response due to voltage variation in compact fluorescent lamps and LEDs is different comparing to incandescent bulbs for which the standard of flicker has designed. Acceptable limits for flicker have defined in standard EN 50160 [5, 6].

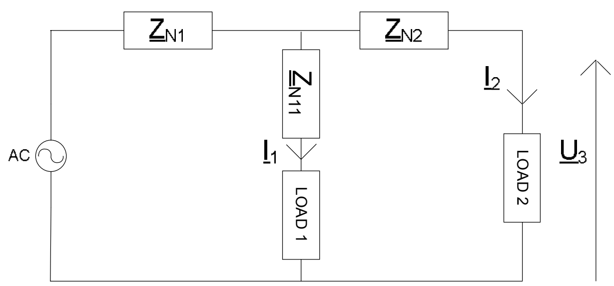

Figure 2. Single phase equivalent circuit of voltage drop due to load currents.

$$\Delta\underline{U}_3 = \Delta\underline{U}_s - \underline{Z}_{N1}\left(\Delta\underline{I}_1 + \Delta\underline{I}_2\right) - \underline{Z}_{N2}\Delta\underline{I}_2 \qquad (1)$$

where $\Delta\underline{U}_3$ = vector of voltage change at Load 2

$\Delta\underline{U}_S$ = vector of source voltage change

$\underline{Z}_{N1}$ = vector of distribution network impedance at common coupling point (CPP) of Load 1 and 2

$\underline{Z}_{N11}$ = vector of distribution network impedance from CPP of Load 1 and 2 to Load 1

$\underline{Z}_{N2}$ = vector of distribution network impedance from CPP of Load 1 and 2 to Load 2

$\Delta\underline{I}_1$ = vector of change in Load 1 current

$\Delta\underline{I}_2$ = vector of change in Load 2 current

One power quality quantity which importance is increasing is harmonic voltage. Harmonics are mostly generated in non-linear loads. The numbers of non-linear loads have increased because power electronics have become more common. It is impossible to detect harmonics without proper measurements. Symptoms of harmonics are interference in ripple control systems, increased transformer losses, flicker and overloading in zero conductors. In the standard EN 50160 there are limits for harmonic voltage, but no limits for interharmonic voltage [6].

VISION OF CURRENT MEASUREMENT UTILIZATION IN POWER QUALITY MONITORING VIA AMI

From a utility point of view there are two questions that are interesting when a power quality problem is detected. One is who is responsible for a power quality problem and the other is how to affect power quality problems.

The reason and cause for other power quality problems than interruptions are interesting from a utility point of view because causes for power quality problems are mainly loads connected to the network. Also damaged loads, poorly designed devices and damaged network components can be causes for power quality problems. In general power quality problems are considered as the events of voltage deviation. First to identify power quality problem standardized power quality measurements are needed. To point out the origin of a power quality problem some sort of information about current is also needed.

One way to describe this situation is to consider flicker in a LV network shown in Figure 3. In Figure 3 a LV network of ten customers named from C1 to C10 is outlined. Customer C2 has a large induction motor that needs to be started up a couple of times in one hour during day and evening time. The starting current is so high that voltage drop is remarkable and the short term flicker severity index (Pst) of that specific 10 minutes is above 1 at customer C2 premises. Pst value of that specific 10 minutes is also above 1 in C3, C4, C5, C6 and C7 premises because the customer connection point of C2 is close to line. This means that network impedance Z_{N1} at CPP of Figure 2 is almost the same as the network impedance at customer C2 connection point. Now every voltage change in the CPP caused by the large motor start up is close to voltage change in customer C2 premises. This voltage change will also be seen in customers from C3 to C7 premises. If these customers have their own loads that are switched on and off in day and evening time, then Pst values are higher than in customer C2 premises. The Pst value of customer C1 is lower than 1 because the impedance of the CPP with customer C2 is smaller than a network impedance of customer C2 so the voltage change caused by the large motor start up is not as remarkable in customer C1 premises than in customer C2 premises. Also Pst of customers from C8 to C10 is lower than

1 because the CPP with customer C2 is practically at the transformer and the voltage change due to the large motor start up is not remarkable at all.

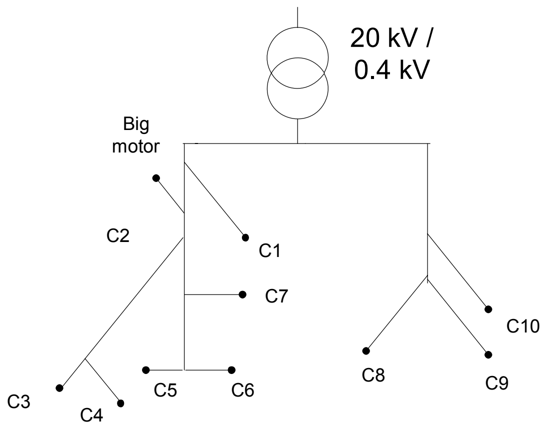

Figure 3. Outline of low voltage network.

If voltage quality quantities are only considered, the origin of flicker cannot be detected. The biggest Pst and long term flicker severity index (Plt) values are in customer C3, C4, C5, C6 or C7 premises. Assume that the biggest Pst and Plt value is in customer C6 premises. If AMI provide information about flicker, the only thing that can be said from power quality measurements is that specific customers are suffering flicker. If information about a couple of the biggest RMS current changes during 1-10 cycles time of each 10 minutes and the RMS voltage change during the biggest current changes can be provided with time stamp via AMI from every customer premises and stored to a power quality database, it could be possible to identify the origin of flicker. In addition if a couple of the biggest RMS voltage changes during 1-10 cycles time of each 10 minute and the RMS current change during biggest voltage changes is provided with time stamp from every customer premises and stored to a power quality database it could ensure the origin of flicker. This is possible because the load and customer whose current has changed most during voltage change is the reason for that voltage change as shown in Equation 1. If the voltage change is on MV side, changes in load currents are small and it can be deduced that reason for voltage change is not in that specific LV network. With this information it is possible to deduce that loads at customer C2 might be the origin of flicker in this LV network. If no crossing of flicker threshold is detected in a specific LV network during one day, all current and voltage change information from that LV network during that specific day can be deleted from a database.

For harmonic voltage, the reason is mainly non-linear loads of customers connected to network [6]. These customers can be detected also via AMI measurements if every AMI meter could provide information about total harmonic distortion (THD) of voltage and current. THD information should be provided so that a couple of the biggest THD of voltage and current during 10 cycle time of each 10 minutes and THD of voltage and current during 10 minute time of each day are generated. These are done to identify sources for short and long term harmonic voltages. The current measurement is done to identify which customers have the biggest impact on harmonic voltage. As in flicker detection, assuming that customer C2 has large non-linear load and THD of voltage, both short and long term, is high in customer premises from C2 to C7. Assume that customer C6 has the biggest THD voltage values because non-linear loads of its own and other customers are increasing THD. When THD values of current are considered it can be detected that customer C2 has clearly the biggest THD values of current and it has the biggest effect on harmonic voltage in that LV network.

The vision of power quality monitoring is that every AMI meter could produce accurate power quality measurements in the future. In addition RMS voltage and current change measurements are needed to deduce the origin of flicker. THD measurement of current is also needed to deduce the origin of harmonic voltage.

VISION OF POWER QUALITY PROBLEM MANAGEMENT PROCESS AND ITS BENEFITS

To have business benefits from the better power quality monitoring the power quality management process needs to be changed too. Nowadays the power quality management process is like shown in Figure 4. In Figure 4 arrows mean time and plots mean events. First power quality problem occurs. It will take time when a customer is disturbed and when a customer complains. Utility receives complaints and decides whether case specific power quality measurements are needed. If measurements are needed, after data analysis utility informs customers and decides about further actions. Sometimes time between a problem occurring and measurements can be so long that problem has disappeared or it is so random in time that no problem is detected after data analysis. In these cases, if a problem is renewed, distribution utility may receive more complaints about the same problem and utility may even need to perform new measurements.

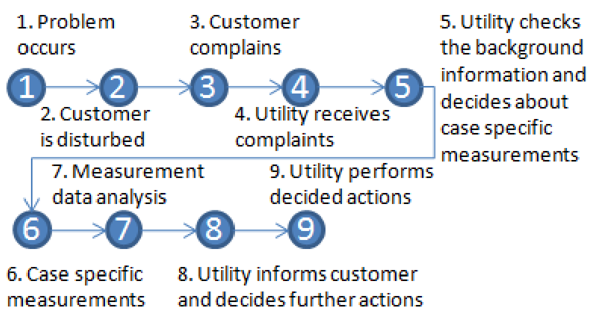

Figure 4. Today's power quality management process

In future distribution networks where there are more accurate power quality measurements the management process needs to be more straightforward and automated than today. Otherwise advantages from better power quality monitoring are lost due to an inefficient management process. One vision of a power quality management process is shown in Figure 5. Continuous measurements are checking power quality. When a power quality limit is exceeded, the data analysis will produce information about in which area problem occurred and which customer or what was the origin of power quality problem, for example, with a help of current measurement via AMI. Data analysis also informs the utility. Utility informs customers and decides further actions how to affect power quality. If there are remote controlled loads, generation and devices in a network, data analysis could also provide information about how to improve power quality with those equipment and can perform automatically all possible actions. Data analysis could also predict from LV networks power quality history in which time power quality problems may occur and perform all possible actions to improve power quality even before power quality problems occurs. It is obvious that new algorithms need to be developed for data analysis to perform all required operations. This way power quality management process could be more like a proactive process.

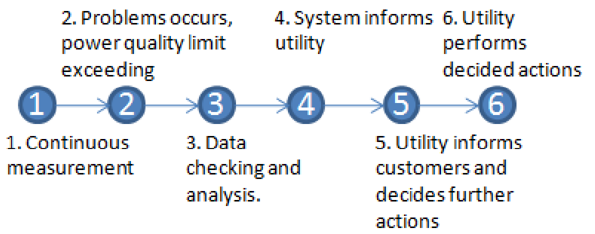

Figure 5. Power quality management process futures networks

In cases where no power quality problem is detected by data analysis and a customer is still complaining about bad power quality utility can check from a power quality database what was the situation when a customer experienced bad power quality. Now utility has information about power quality and can show to a customer that no power quality thresholds were exceeded during that specific time.

The biggest benefit using power quality monitoring and a proactive business process shown in Figure 5 is that the time between the occurrence of a power quality problem and the detection of it is much shorter than nowadays. Detection and power quality improvement can happen much before than a customer even complains about bad power quality. This increases customer satisfaction and utilities awareness about a state of power quality in LV networks. It also decreases the need for case specific measurements dramatically because utilities are assumed to have much more power quality measurements than today from every customer premises. The biggest costs consist of investments for AMI meters, which are able to perform power quality measurements, for management systems and for development of algorithms. Technical development is decreasing those costs and enabling extensive power quality management systems in the future.

CONCLUSIONS

This paper discussed importance of two power quality quantities flicker and harmonics. Flicker is the most common reason for power quality complaints and harmonics are coming more common due to increasing of power electronics. To deduce the origin of flicker and harmonics in the future, this paper proposes a vision of accurate power quality measurements in addition of current measurements via AMI. These measurements could provide enough relevant information for deduction and need for case specific power quality measurements dramatically decreases. To have business benefits from better power quality monitoring also power quality management process needs to be developed to a more straightforward direction than today. Paper also shows one vision about a proactive power quality management process in the future distribution networks.

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