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2014 Paris Session

SC C6, PS1

Smart distribution application

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SUMMARY: (about 500 words)

Rapid and wide-spread deployment of new technologies in the electric power distribution network under the concept of smart grids has resulted in a growing need to new standards and guidelines specifically designed to address emerging technological challenges and further streamline the use of new technology. This document is prepared as part of the activities to develop the IEEE Power and Energy Society's "smart distribution application guide", to give guidance to utilities and network operators in the use of new technology in electric power distribution. The document will provide a description of the available new technology based on its application, followed by a more detailed description of the technologies and associated supporting solutions. The topics discussed in this document include improving the reliability of supply, improving the power quality, improving the efficiency of distribution-system operation, increasing hosting capacity for new production or for new consumption, and allowing market functioning and participation of all network users. This paper contains some examples of texts as they are currently being discussed within the smart distribution working group.

KEYWORDS: electric power distribution, smart grids, power quality, smart meters, hosting capacity, big data

Introduction

The Transmission and Distribution committee of the IEEE Power and Energy society started work on a guide for smart distribution applications in 2012. The guide will be issued, subject to approval under the IEEE standard balloting process, as IEEE Std. 1854 [1].

The aim of the document is to give guidance to utilities and network operators in the use of new technology in electric power distribution. The document will consist of two main parts: a description of the available new technology ("smart distribution technology") by application area; and a more detailed description of the technologies and solutions to support the new technology.

The new technology is introduced in the guide with reference to the application area, also known under the term "challenge". The following application areas are distinguished in the guide:

- ✓ Improving the reliability of supply for the network users
- ✓ Improving the power quality for the network users
- ✓ Improving the efficiency of distribution-system operation
- ✓ Increasing hosting capacity for new production or for new consumption
- ✓ Allowing market functioning and participation of all network users in those markets

The document will only discuss available technology to solve these challenges. The document will not go into a discussion on who is responsible for addressing the various challenges. This paper will present some examples of texts as they are currently being discussed within the smart distribution working group. The emphasis is on parts of the documents in which the authors themselves have been strongly involved.

Reliability

For the purpose of this paper, the term "reliability" is meant to cover short and long interruptions. The availability of new cost-effective technology allows reduction of number and duration of short and long interruptions without excessive increase in costs for network users. The application area "reliability" covers, among others, the following new technology: automatic restoration of power supply; restoration of power to affected customers with minimal switching; the use of distribution monitoring to detect incipient faults and for fault location enabling faster restoration of the supply; controlled island operation of part of the distribution grid including local energy storage.

<u>Description of the challenge</u>

The reliability of the supply, i.e. the lack of short and long interruptions, is the most important technical property of the grid for the majority of customers. The reliability of the supply can be quantified by a range of performance indices, an overview of which is given in IEEE Std. 1366. Such indices typically consider averages over all or a large group of customers and are often not of relevance for individual customers. Those indices do however play an important role in regulation and can have a significant impact on the economics of a utility or network operator. Part of the reliability challenge is therefore to improve those indices. The details of those challenges depend on the local regulatory regime, but in almost all cases is an improvement obtained by reducing the number of interruptions, the duration of interruptions, or both.

Also for individual customers what matters is duration of individual interruptions as well as number of interruptions per year. But it is no longer a matter of improving statistical indices, but making the reliability acceptable for all individual customers. Some customers have a zero-tolerance for interruptions, but most customers accept a certain number of interruptions per year with a certain duration. For example a study in Finland and Sweden concluded that rural customers accept up to three interruptions per year with duration of eight hours or less [2].

Data analytics to detect incipient failures

Numerous cable failures of Bushing Potential Devices (BPD) have been experienced at ComEd. The failures resulted in a zero secondary output of BPDs. Since the output voltage is utilized for transformer over/under voltage tripping schemes, numerous unnecessary transformer trips have been incurred. A solution to this was obtained by an analysis of large amounts of data that were available through a data analysis system called PI Historian. ComEd has been using a PI-Historian database to store SCADA data for over a decade.

The PI Historian revealed that some of the above-mentioned failures were immediate but others exhibited an erratic or arcing voltage signature that was present from hours to days prior to the actual failure. Much of the signature remained within the traditional alarm set point bandwidths, so the erratic activity went undetected. A new algorithm has been developed to detect these incipient failures. Within PI Asset Framework, which enables users to define and create a hierarchical model representation of assets, a standard deviation algorithm together with some additional filtering criteria is used to detect erratic BPD voltages in real-time and send a notification to engineering personnel. Figure 1 shows how the standard deviation rises up consistently once the period of arcing voltage begins. A standard deviation above 1.2 is encountered more than 3 times in minutes within a one hour period that is monitored. This system is currently deployed on over 200 transformers and has successfully prevented several transformers from tripping by detecting an impending failure.

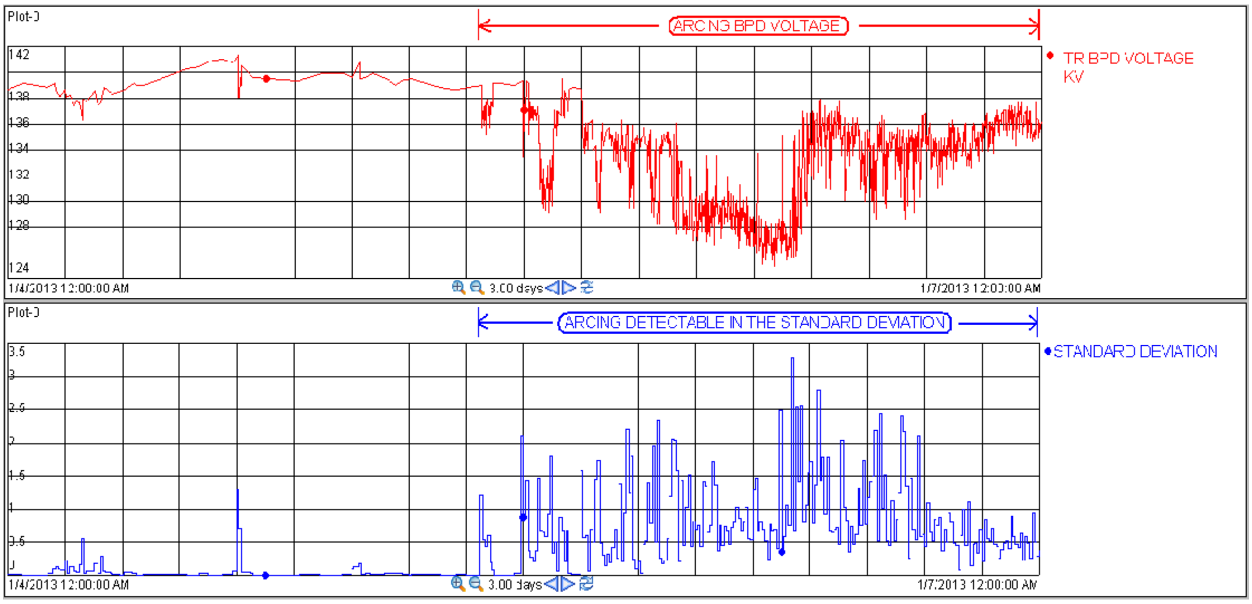

Figure 1. Standard deviation calculation and comparison for detecting erratic BPD voltages

Distribution efficiency

The application area "efficiency" covers the following new technology: optimal network reconfiguration; minimize the largest peak demand over selected feeders over a specified time period; capacitor bank management; maintenance scheduling; use of real-time monitoring data; use of hourly-metering data; optimization of transformer rating.

Description of the challenge

The efficiency of the distribution grid may be the most difficult performance aspect to quantify. It is however possible to give specific examples of what would constitute an increase in efficiency. Such examples are:

- ✓ Reduction of the losses in the grid;

- ✓ Reduction of peak load;
- ✓ Increasing the utilization of components;

Next to that also overall cost reductions for planning, operation, and maintenance, can be considered as improvement of distribution efficiency.
For integrated utilities, that also own production units, efficiency improvement may even include reduction of losses on the production sites and increasing utilization of those units. One may even go a step further and include the overall need to reduce energy consumption in this challenge.

Avoiding circular currents through transformers

When transformers are paralleled, the paralleling scheme must work properly to minimize circulating current between the transformers. If the scheme is not working correctly, the transformers run inefficiently and in the worst case could actually result in failure of one or both transformers. In many cases, voltage regulation may be unaffected and thus load dispatchers may not readily detect that the paralleling is not functioning correctly. Utilizing the before-mentioned PI-AF, detection algorithms were developed to identify paralleled transformers based on transformer and bus tie circuit breaker status and then monitor the reactive power difference between paralleled transformers. When time-based reactive power difference threshold levels are exceeded, a notification is sent to the responsible engineering personnel to evaluate the situation and submit work requests for repair. Figure 2 shows that when two transformers are not paralleling correctly, there is a relatively larger difference between the transformers' reactive powers. This indicates that one transformer is supplying reactive power for load and also reactive power that circulates through the other transformer. Ideally, both transformers should have equal reactive powers flowing. The reactive power difference of transformers is monitored and a notification is provided if the difference exceeds a threshold value for one hour. More than 30 ComEd substations are currently monitored in a pilot project using this method to review its effectiveness.

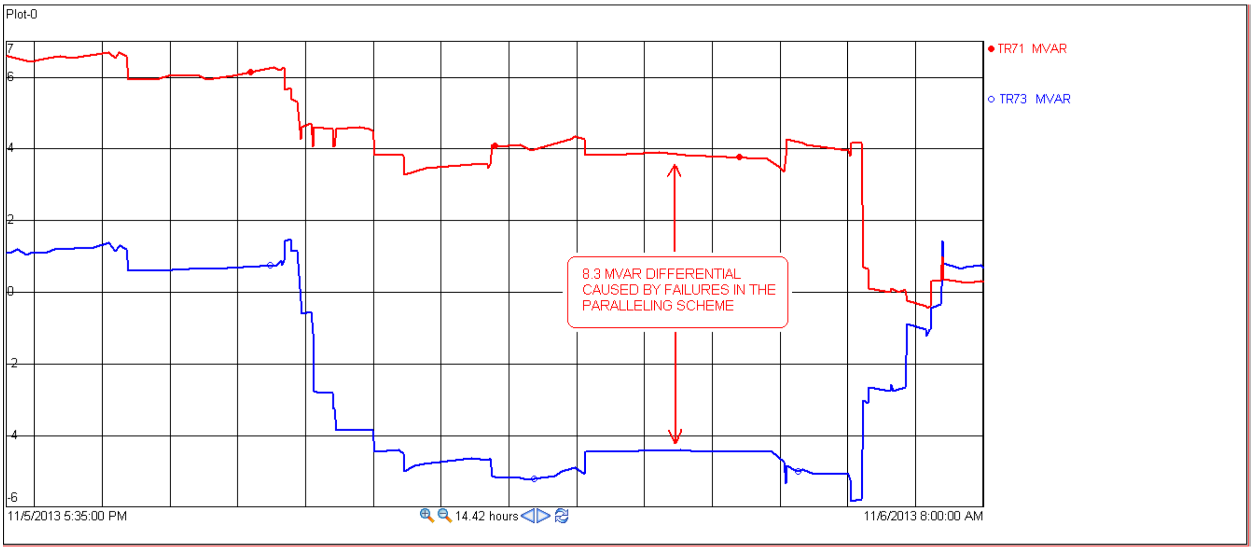

Figure 2. Transformers reactive power comparison for detecting correct paralleling

Use of hourly metering data

An increasing number of utilities equip their customers with smart meters that include the possibility to measure consumption with a high time resolution. In many cases, a resolution of one hour is used, hence the term "hourly metering". An example of hourly data is shown in Figure 3. Hourly metering allows participation of the customer in hourly pricing schemes and in demand response. Hourly data on electricity consumption gives the customer feedback on consumption patterns, which in turn can be used as an input to energy-saving measures.

The hourly consumption data can also be used as a tool in the network planning, especially when reactive power and voltage are also recorded by the smart meter.

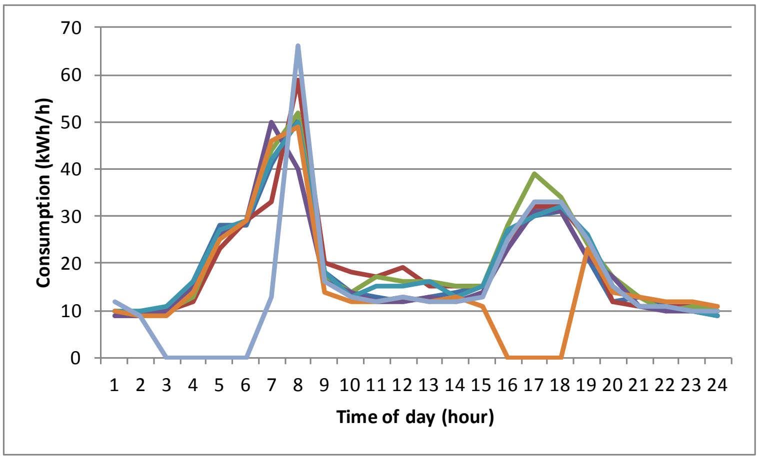

Figure 3. Hourly consumption during seven consecutive days for an agricultural customer

The sum of the consumption by customers downstream of a distribution is a good estimate for the loading of the transformer. Having accurate knowledge facilitates the replacement of the transformer at the appropriate time; i.e. neither too early, nor too late. When voltage recordings are available, this can give feedback to the network operator on the need for strengthening the network. But even without voltage recordings, the voltage drop can be estimated from the metered values by using a sufficiently detailed model of the feeder.

Power quality

The term power quality is meant to cover all disturbances in voltage and current, with the exception of long and short interruptions. This includes a whole range of disturbances, where supply voltage variations are of most concern to domestic customers, especially in rural areas. Industrial customers typically show more interest in reduction of number and severity of voltage dips. Network operators show, however, more interest in harmonic distortion of voltage and current, as it is their duty to maintain the voltage distortion within acceptable limits.

The application area “power quality” covers the following new technology: advanced methods for voltage control in distribution networks; minimize operating violations of overvoltages or undervoltages with minimum switching; use of monitoring for power-quality management; use of advanced meter reading with power quality functions; advanced protection reducing the fault-clearing time.

Description of the challenge

Power quality disturbances can be divided into so-called “events” and “variations”. Events are occasional and rare deviations of the voltage from its nominal or ideal value. Power quality events, like voltage dips, can be treated in a way very similar to short and long interruptions. At system level, average indices can be calculated, equivalent to SAIFI and MAIFI for long and short interruptions. For individual customers, there are limits to what they consider as acceptable. The challenges to the network operator are similar to those with reliability, i.e., to improve the average performance and to ensure that no customer experiences more events than what is considered acceptable (the on-going discussion on what is acceptable is not provided in this paper). The main power quality events that are of interest to customers and network operators are voltage dips. Normal switching transients are an issue that occasionally comes up with certain industrial installations. Abnormal transients like those due to current chopping and restrike with capacitor de-energizing can result in damage to end-user equipment and should be avoided. Lighting strokes to low-voltage overhead lines can result in equipment damage for end-user equipment.

Power quality variations are minor variations from the normal or ideal value, like harmonics, voltage unbalance and long-term overvoltages or undervoltages. The challenge with these is to maintain them within certain limits, for example the voltage distortion limits set by IEEE 519 in the U.S.[4] or by EN 50160 in Europe [5].

Power-quality applications of smart meters

The presence of smart meters with many customers allow for additional applications beyond the primary role of the meters, which is recording the energy flow between the customer and the grid. One such additional application is to monitor power quality. A number of applications of these data are envisaged.

- ✓ Obtaining statistics on the performance of the grid. It becomes possible to get a complete picture of the grid performance by gathering the data from all smart meters. A more likely application could be when a sample of smart meters is interrogated and statistics are obtained out of these, for example on a weekly basis.
- ✓ Each of the smart meters gathers statistics on power quality, for example over each calendar week. Only those meters for which the power quality is unacceptable report back to the network operator. This information is used in investment decisions. In this way investment will only be made when needed: there is no overinvestment due to the need to maintain margins; neither underinvestment due to unknown locations with insufficient power quality.
- ✓ Once a parameter exceeds an acceptable limit, an alarm is sent to the network operator. This information can be used to take measures during the operational stage, for example load shedding or feeder reconfiguration. A typical example, that is often discussed, concerns supply voltage variations.

Hosting capacity

The hosting capacity is defined as the amount of new production or new consumption that can be connected to the grid without endangering the reliability or power quality for other customers. The high costs and long lead times associated with increasing the hosting capacity for wind and solar power is in some cases a serious barrier against renewable electricity production. Cost-effective and more time-efficient methods based on new technology can remove this barrier. Similar hosting capacity issues are expected in the future with the electrification of the transport and with a shift to electric heating.

The application area “hosting capacity” covers the following new technology: advanced protection preventing incorrect operation of the protection due to distributed generation; advanced voltage control preventing overvoltage due to excessive net production and undervoltages due to excessive net consumption; the use of grid-size energy storage systems; dynamic line rating; global and local supervisory systems controlling curtailment of production and/or consumption to avoid grid overloading; the use of network markets for avoiding overloading and overvoltages.

Description of the challenge

The hosting capacity of the grid is the amount of new production or new consumption that can be connected without endangering the reliability or voltage quality for other network users. The hosting capacity can be calculated for individual locations but also for a larger area or even for a large interconnected system as a whole [3].
When calculating the hosting capacity, an approach is to consider different phenomena that might limit the amount of production or consumption. For each of these phenomena, a performance index and an acceptable limit for this performance index is calculated. The value of the performance index is calculated as a function of (for example) the amount of installed solar power capacity. When the performance index exceeds the acceptable limit, the hosting capacity for this phenomenon is exceeded. The principle of this approach is shown in Figure 4.

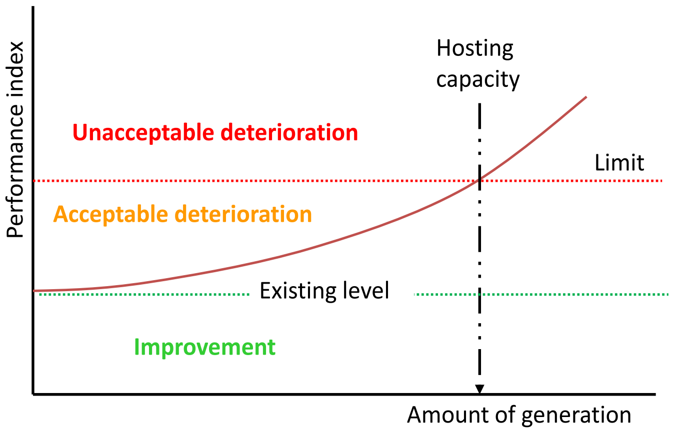

Figure 4. Illustration of the method for calculating the hosting capacity for a given performance index

When multiple phenomena are considered, the hosting capacity is the lowest of the values found for the different phenomena.
In application guide we only consider the hosting capacity for new production based on renewable energy (wind and solar power) and more efficient ways of production (combined heat and power), where the production is connected to the distribution network.

This hosting capacity is limited by a number of phenomena, where the one that puts the strictest limitation is strongly dependent on the location where the production unit is connected, on the properties of the distribution network, and on the type of production. The main limitations to the amount of production that can be connected to the distribution network are set by the following phenomena:

- ✓ Thermal overload: for small amount of production the loading of the network will reduce because the production compensates the local consumption. However, when the maximum amount of production exceeds the sum of minimum consumption and maximum consumption, the loading will increase. For high amount of production overloads may occur when the distribution network is no longer able to transport the surplus production to a higher voltage level.
- ✓ Overvoltage: the injection of active power by a production unit connected to a remote location on a distribution feeder will result in an increase in voltage magnitude and with higher amounts of production unacceptable overvoltage may occur. This could occur for rural distribution networks with rather small levels of production. What should count as an unacceptable overvoltage depends on local regulation, planning levels used by the local utility and immunity of end-user equipment.
- ✓ Protection failure: Contribution of a production unit to the fault current could result in relays tripping during a fault outside of its zone, and also in relays not tripping when needed. Another, much discussed, impact is the risk of uncontrolled island operation, with several unwanted consequences as a result.
- ✓ Unacceptable voltage quality: the presence of production units can have a negative impact on a number of aspects of the voltage quality: starting of the units may result in voltage dips or rapid voltage changes; fast fluctuations in production may result in voltage flicker, emission by power-electronic converters, and resonances associated with capacitor banks may result in higher levels of harmonic distortion.

Next to these impacts at distribution level, large amounts of production connected to the distribution network also have adverse impacts on the transmission system, like increased risk of stability problems and a reduction in the amount of available ancillary services. Several of the before-mentioned solutions, for example to improve voltage quality, can also be used to increase the hosting capacity when voltage quality is the limiting phenomenon.

Market functioning

In the smart distribution application guide market operations are seen as a challenge as well as a solution. In this section it is treated solely as a challenge, with demand-response used as an example to illustrate the challenges. Market-based schemes can be solutions to most, if not all, of the challenges, including the challenges introduced by other markets.

The application area "market functioning" covers the following new technology: incentive-based demand response programs; time-based rates; smart meters; power quality markets.

<u>Demand response as a challenge</u>

The participation of small customers in hourly electricity markets (also known as "demand response") is aimed at reducing consumption peaks. Because of three different mechanisms, such market participation could however result in an increase in loading at distribution level, with overload or undervoltage as an ultimate result.

i) Opposite local and global consumption patterns.
A high hourly electricity price is an incentive to reduce consumption; in the same way, a low electricity price could be an incentive to increase consumption, for example by charging electric cars or starting warm-water boilers during low-price hours.
Consumption patterns may be different locally and globally. If such a low-price hour corresponds with a high consumption locally, it will result in an even higher local consumption.

Figure 5. Relation between local consumption and electricity price. The risk of overload increases in the bottom-right part of the diagram.

ii) Local production surplus during high electricity price
In an area where production surpluses can occur, those production surpluses may occur also during periods with high electricity prices. The incentive to reduce consumption will further increase the production surplus. The earlier case, with an incentive to further increase consumption during a high-consumption period, could also occur here.

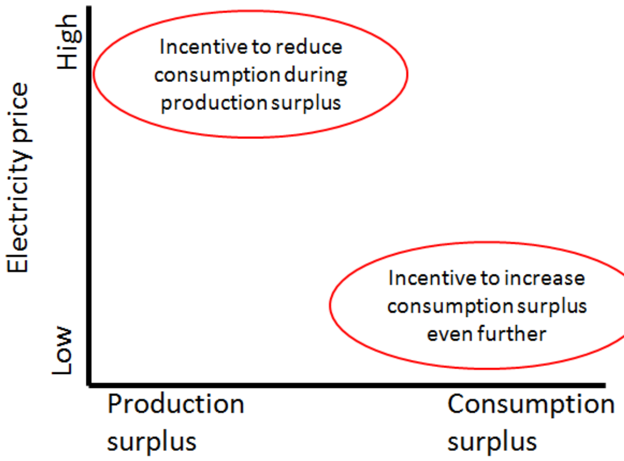

Figure 6. Relation between local production, consumption and electricity price. The risk of overload increases in the bottom-right and top-left parts of the diagram.

iii) Load-recovery
Most forms of demand response do not reduce energy consumption, but merely move it to later instant in time. The energy not consumed during a high-price hour, typically will be recovered somewhere in the near future. Especially with manual demand response, based for example on day-ahead prices, this post-demand-response recovery could result in overloads in the distribution network.

Acknowledgements

This paper is partly the results of discussions within the IEEE Smart Distribution Grids working group. This paper shall however not be referred to an IEEE standard, neither as a draft IEEE standard, nor as an IEEE working group document.
Currently the following members are contributing to the draft standard document: Djordje Atanackovic, Shay Bahramirad, Math Bollen, Larry Clark, Valentina Dabic, Vincent. J. Forte Jr., Yasuhiro Hayashi, Amin Khodaei, Jason Lombardo, Sarma Nuthalapati, Masood Parvania, Georges Simard, Veera Raju Vinnakota, Jun Yoshinaga, and Francisc Zavoda. Next to that the contributions from several unnamed individuals during working-group meetings should also be acknowledged.

The text of this paper contains the opinion of the authors. These are not necessarily the same as the opinions of the IEEE smart distribution working group or the formulations that will be part of a future IEEE Std. 1854.

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