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DIAGNOSTICS OF AN EXCHANGE PROCESSES OF ELECTRICITY IN A POWER SYSTEM

Key words

Diagnostics, power system, power quality, event, variation.

Summary

Diagnostics of the transmission of electricity in a power system requires the introduction of a new power system structure which consists of an electric power grid to which customers are connected. The technical aim of the electric power grids becomes one of allowing the transportation of electrical energy between different customers, guaranteeing acceptable voltage and allowing currents to be received by the customers. The power quality concept concerns the interaction between the grid and its clients. This publication describes a new structure of an electric power system and the principles and methods of the diagnostics of electric power grid in the light of monitoring quality parameters of energy exchanged between consumers.

1. Introduction

The diagnostics of electricity transmission in the power system requires the introduction of a new power structure. The current system is presented as a hierarchical tree structure, consisting of the following levels: generating, transmission and distribution of electric power. The basic objective of the power system is to supply electric power as a result of the process of delivery, which implies a new structure, namely a differing electric power grid, to which customers, who are participating in the power supply market, are connected. Therefore, the most crucial elements of this power system – apart from the electrical grid, which enables the exchange of energy – are the consumers and satisfying their expectations as to the parameters of supplied electricity.

The electric power grid no longer transports energy from generators to end-users instead it enables the exchange of energy between customers. It is important that these clients are also the customers of the grid (company), not only the end – users of the electricity. The technical aim of the electric power grids becomes one of allowing the transportation of electrical energy between the different customers, guaranteeing acceptable voltage and allowing currents to be received by the clients. The power quality concept concerns the interaction between the grid and its customers. This interaction takes place through voltages and currents. Various power quality disturbances, such as harmonic distortion, also may appear at any other location in the power system. However disturbances only become an issue at the interface between grid and its customers or at equipment terminals. In this case, diagnostics of the exchange process in the grid is linked to monitoring and evaluating the quality of electrical power received by the customer. Subsequently, one has to carry out an analysis to determine why approved standards are not met. In light of the present situation of electrical power market, when financial performance of enterprises is becoming increasingly important, this is an extremely crucial field in the diagnostics of electrical power systems. Monitoring the quality of energy, which includes identifying its parameters and identifying both the required standard and the procedures needed to meet the standard, has a direct effect on the efficiency of the electric power system.

2. The structure of electric power system

The overall structure of the electric power system is shown in Figure 1. The electric power is generated in large power stations at a relatively small number of locations. This power is then transmitted and distributed to end-users, typically simply referred to as “loads”. A countrywide transmission system connects the large generator stations. The transmission system enables the sharing of the resources from the various generator stations over large areas. The transmission system is an important contributing factor to the high reliability of the power supply and has led to the lower price of electricity in industrialised countries and enabled the deregulation of the market in electrical energy.

Distribution grids transport electrical energy from transmission substations to various loads. Distribution grids are typically operated radially and power transport starts from the transmission substation to the end users. This facilitates an easy methods for protection and operation. The disadvantage is that each component failure will lead to interruption for some end users.

Due to several developments during the last few years, the model in Figure 1 is no longer fully applicable. Even though technically the changes are not yet very big, a new way of thinking has emerged, which requires a novel way of looking at the power system:

The deregulation of electricity industry means that the electric power system can no longer be treated as one entity. In most countries, generation is completely deregulated or intended to be deregulated within a short time. Furthermore, transmission and distribution are often split into separate companies. Each company is economically independent, even where it is technically an integral part of a much larger system.

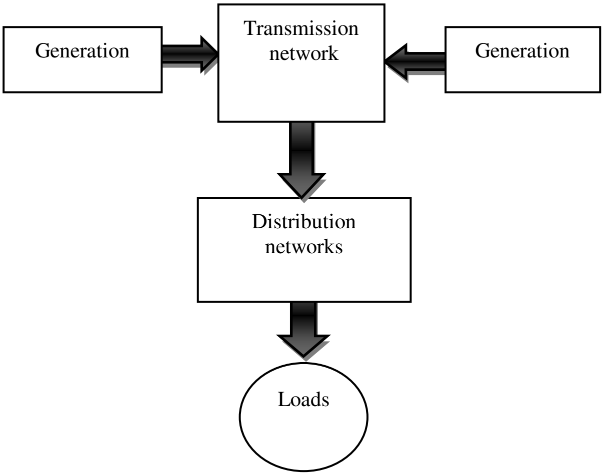

Fig. 1. Classical structure of power system

The need for environmentally friendly energy has led to the introduction of smaller generator units. This so–called “embedded generation” or “distributed generation” is no longer connected to the transmission system but only to the distribution system. In addition, economically driven forces, especially when it comes to combined heat and power stations, may cause building of smaller generation units.

Higher requirements for reliability and quality mean that the grid operator has to listen much more attentively to the demands of individual customers.

A more modern way, resulting from these developments, of looking at the power system is shown in Figure 2. The electric power grid no longer transports energy from generators to end-users but instead enables the exchange of energy between customers. These consumers are the customers of the grid (company), not only the end-users of the electricity.

The actual structure of the power system is still very much as in Figure 1, but many recent advances require thinking in terms of the structure presented in Figure 2. The power grid in Figure 2 could be a transmission grid, a distribution grid, an industrial grid or any other grid owned by a single company. For a transmission grid, the customers are, for example, generator stations, distribution grids or large industrial entities (which would be generating or consuming electricity at different times, based on, e.g. the price of electricity at that moment) and other transmission grids.

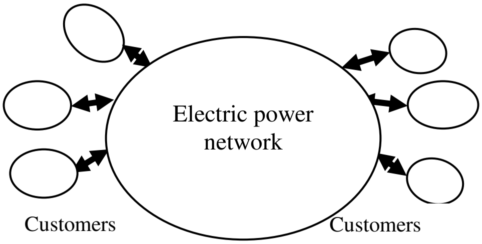

Fig. 2. Modern view of power system

For a distribution grid, the consumers are currently mainly end users that only consume electricity, but also the transmission grid and smaller generator stations can be considered as customers. All clients are equal, even though some may be producing energy while others are consuming it. The aim of the grid is only to transport the electrical energy, or in economic terms, to enable transactions between customers. An example of a transmission and a distribution grid with their customers is shown in Figure 3.

The technical aim of the electric power grids in Figure 2 and 3 becomes one of allowing the transportation of electrical energy between different consumers, guaranteeing acceptable voltage and allowing currents to be received by the customers. The power quality concerns the interaction between the grid and its clients. This interaction takes place through voltages and currents. The various power quality disturbances, such as harmonic distortion, of course also appear at any other location in the power system. However disturbances only become an issue at the interface between a grid and its customers or at the equipment terminals.

The model in Figure 2 should also be used when considering the integration of renewable or other environmentally friendly sources into the power system. The power system is no longer a boundary condition that limits, for example, the amount of wind power that can be produced at a certain location. Instead, the task of the grid is to enable the transport of the amount of wind power that is produced and to provide a voltage such that the wind farm can operate properly. The final solution will be found in the cooperation between the customer (the owner of the wind farm) and the grid operator considering various technical and economic constraints.

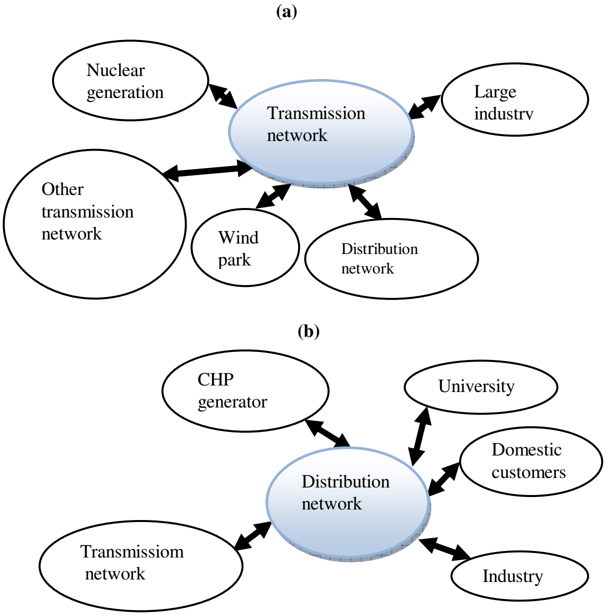

Fig. 3. Customers of a transmission grid (a) and a distribution grid (b)

Considering the electricity market, the model in Figure 2 is the obvious one: the customers (generators and consumers) trade electricity via the power grid. The term “power pool” explains rather well how electricity traders look at the power grid. The grid places constrains on the free market. A much-discussed constraint is the limited ability of the grid to transport energy, for example, between the different European countries. Under this model the lack of generation capacity is not a grid problem but a deficiency of market.

3. Power quality as the tool of diagnostics

3.1. Interest in power quality management

There are different reasons for the enormous increase in the interest in power quality management. The main reasons can be named as follows:

Equipment has become less tolerant of voltage quality disturbances, production processes have become less tolerant of incorrect operation of equipment, and companies have become less tolerant of production stoppages. All this leads to many more costs than before being associated with even a very short duration disturbance. The main perpetrators are (long and short) interruptions and voltage dips.

The deregulation of electrical power industry has led to an increased need for quality indicators. Customers are demanding and getting more information on the voltage quality that they can expect.

Embedded generation and renewable sources of energy create new power quality problems, such as voltage variations, flicker and waveform distortion. Most interfaces with renewable sources of energy are sensitive to voltage disturbances, especially voltage dips. However, such interfaces may be used to mitigate some of the existing power quality disturbances.

In addition, energy-efficient equipment is an important source of power quality disturbances. Adjustable-speed drives and energy-saving lamps are both important sources of waveform distortion and are also sensitive to certain types of power quality disturbances.

3.2. Definition of power quality

Various sources give different and sometimes conflicting definitions of power quality concept. According to the Institute of Electrical and Electronics Engineers (IEEE) “power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment”.

The International Electrotechnical Commission (IEC) definition of power quality is as follows: “Characteristics of the electricity at a given point on the electrical system, evaluated against a set of reference technical parameters”. This definition of power quality is related not to the performance of equipment but to the possibility of measuring and quantifying the performance of the power system.

Power quality is the combination of voltage quality and current quality. Voltage quality is concerned with deviations of the actual voltage from the ideal voltage. Current quality is the equivalent definition for the current. A simple and straightforward solution is to define the ideal voltage as a sinusoidal voltage waveform with constant amplitude and constant frequency, where both amplitude and frequency are equal to their nominal value. The ideal current is also of constant amplitude and frequency, and the current frequency and phase are the same as the frequency and the phase of the voltage. Any deviation of voltage or current from the ideal is a power quality disturbance. A disturbance can be a voltage disturbance or a current disturbance, but it is very often not possible to distinguish between the two. Voltage disturbances originate in the power grid and potentially affect the customers, whereas current disturbances originate with a customer and potentially affect the grid. Again this classification is due to fail. For example, starting a large induction motor leads to an overcurrent. Seen from the grid perspective, this is clearly a current disturbance. However, the resulting voltage dips is a voltage disturbance for the neighbouring customers. For the equipment operator, this is a current disturbance, however, for the neighbours, it is a voltage disturbance. The fact that one underlying event (the motor start in this case) leads to different disturbances for different customers or at different locations is a very common occurrence for power quality issues.

This difficulty of distinguishing between voltage and current disturbances is one of reasons the term “power quality” is generally used, even though there are many alternative definitions. In this publication, “a power quality issue” is any type of disturbance. A commonly used alternative is to distinguish between “continuity” (or reliability) and “quality”. Continuity includes interruptions, and quality covers all other disturbances. Short interruptions are sometimes seen as part of continuity, sometimes as part of quality. Following this line of reasoning, one may consider voltage dips as a reliability issue, which it is – from the consumer’s viewpoint.

The Council of European Energy Regulators uses the term “quality of service” in electricity supply. This term considers three dimensions:

Commercial quality concerns the relationship between the grid company and the customer.

Continuity of supply concerns long and short interruptions.

Current quality includes the following disturbances: “frequency, voltage magnitude and its variation, voltage dips, temporary and transient overvoltages, and harmonic distortion”.

The adverse current quality is only a concern where it affects the voltage quality.

A report by the Union of the Electricity Industry states that two primary components of supply quality are set as follows:

Continuity: freedom from interruptions,

and

Voltage quality: the degree to which the voltage is maintained at all times within a special range.

3.3. Division of power quality disturbances

An important division of power quality disturbances is between variations and events. Variation are steady state or quasi steady state disturbances that require (or allow) continuous measurement. Events are sudden disturbances with a beginning and an ending.

A typical example of a power quality variation is the variation of power system frequency. Its nominal value is 50 Hz but the actual value always differs from this by up about 1 Hz in a normal system. At any moment in time the frequency can be measured and a value will be obtained.

A typical example of a power quality event is an interruption. During an interruption the voltage at the customer interface or at a measurement location is zero. To measure an interruption, one has to wait until an interruption occurs. This is done automatically in most power quality monitors by comparing the measured voltage magnitude with a threshold. When the measured voltage magnitude is less than the threshold for longer than a certain time, the monitor has detected the start of interruption. The end of the interruption is detected when the voltage magnitude rises above the threshold again. The duration of the interruption is obtained as the time difference between the beginning and the end of the event.

The distinction between "variation" and "events" is not always easy to make. A unique way of defining events is by triggering that which is required to start their recording.

Variations do not require triggering. On the other hand, events do.

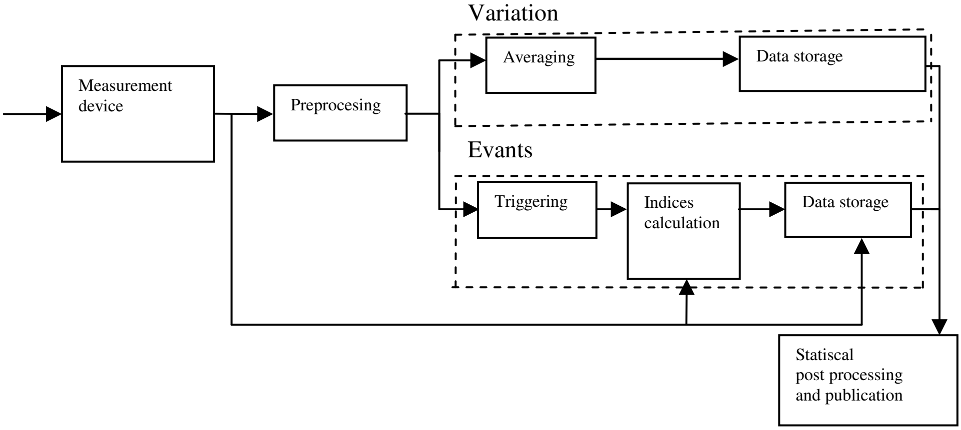

Fig. 4. General scheme of power quality measurements: (1) voltage or current in system, (2) sampled and digitised voltage or current, (3) quantity for further processing

3.4. Monitoring the power quality

From a pure measurement viewpoint there is no difference between power quality measurements and the measurement of voltage and currents, for example for protection or control purposes. The results of power quality monitoring are not used for any automatic intervention in the system.

Power quality measurements are performed for a number of reasons:

One is finding the cause of equipment malfunction and other power problems. Finding the cause of a power quality problem is in many cases the first step in solving or mitigating the problem.

Another is permanent and semi-permanent monitoring to obtain statistical information on the performance of the supply or of the equipment. An increasing number of grid companies are installing permanent monitors to be able to provide information to their customers on the performance of their system.

Permanent and semi-permanent monitoring can be used to monitor the grid instead of only voltage and current quality at the interface with the consumer. A number of grid companies have used voltage dips recordings and statistics to assess the or a blackout. Even though transmission operators have installed disturbance recorders for this purpose, power quality monitors may have given more important additional information. This statement holds true to an even higher degree for public and industrial distribution systems. Knowledge of the

chain of events that led to an interruption or blackout is important for preventing future events.

A general scheme for carrying out power quality measurements is shown in Figure 4. Parts of the measurements take place in dedicated devices, often referred to as power quality monitors; and other parts take place in devices that perform other functions as the performance of the distribution system protected. Permanent power quality monitors can play an important role in reliability-centred maintenance (RCM).

Another important application of permanent power quality monitoring is that troubleshooting no longer requires additional measurements. The moment a problem is reported, past data can be used to examine the cause, which are the results of wide scale monitoring campaigns.

This type of distribution power quality (DPQ) survey, which is performed in the United States, can be used to define the electromagnetic environment to which end – user's equipment is subjected. The data obtained from permanent monitors can be used to analyse the system, and events that led to an interruption.

The post-processing of the data is often conducted to computers far away from the monitors. The actual measurement occurs in a measurement device, which often includes the standard instrument transformers. The whole chain from the analogue voltages and currents in power system to the statistical indices resulting from the post-processing is referred to as power quality monitor-ring.

The first step in power quality monitoring is the transformation from analogue voltages and currents in the power system to sampled digital values that can be processed automatically. The measurement device block in Figure 4 includes:

Instrument transformers,
Analogue anti-aliasing filters,
Sampling and digitising, and
Digital anti-aliasing and down sampling.

Anti-aliasing is needed to prevent frequency components above the Nyquist frequency (half the sampling) from showing up at low-frequency components. This is a standard part of any digital measurement device. Usage of special instrument transformers is a typical power system issue. Voltage and current in a power system are in many cases far too high to be measured directly. Therefore, they are transformed down to a value that can be handled. The sampled and digitised voltage or current waveforms (referred to as "waveform data") are available for processing.

The further processing of the data is completely different for variations and events. For power quality variations the first step is again the calculation of appropriate characteristics. This may be the RMS voltage, the frequency, or the spectrum. Typically average values over a certain interval are used, for example, the RMS voltage obtained over a 10-cycle window. Some monitors use different window lengths. Some monitors also give maximum and minimum values obtained during each interval. Some monitors do not take the average of the characteristic over the whole interval but a sample of the characteristic at regular intervals, for example, the spectrum obtained from one cycle of the waveform once every 5 min. Further post-processing consists of the calculation of representative statistical values (e.g., the average or the 95 percentile) over longer periods (e.g., one week) and over all monitored locations. These resulting values are referred to as site indices and system indices, respectively.

The processing of power quality events is different from processing of power quality variations. In fact, the difference between events and variations manifests itself in the method of processing, not necessarily in the difference in physical phenomena. Considering again the RMS voltage, the events considered are short and long interruptions, voltage dips and swells, and (long-duration) overvoltages and undervoltages. The standard first step in their processing is the calculation of the RMS voltage, typically over a one-cycle window. However, contrary to power quality variations, the resulting value is normally not stored or used. Only when the calculated RMS voltage exceeds a certain threshold for a certain duration does further processing start. Some typical threshold and duration values are given in Figure 5. These events are referred to as voltage magnitude events and as RMS variations.

The vertical axis of Figure 5 gives the threshold values as a percentage of a reference voltage. Typically the nominal voltage is used as a reference, but sometimes the average voltage over a shorter or longer period before the event is used a reference. The horizontal axis gives the time during which the RMS voltage should exceed the threshold before further processing of the event starts. Further processing of a voltage dip event is triggered whenever the RMS voltage drops below the voltage dip threshold (typically 90%), whereas further processing of a long interruption is triggered when the RMS voltage drops below the interruption threshold (typically 1 or 10%) for longer than 1 to 3 min. Different values are used for the border between dips and interruptions and for the border between short and long interruptions.

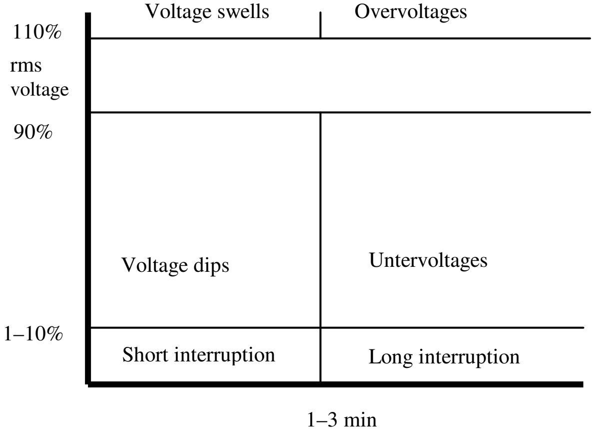

Fig. 5. Examples of threshold values triggering further processing of events based on RMS voltage

The triggering levels in Figure 5 are often referred to as "definitions" for these events. The thresholds are aimed at deciding which voltage dip events require further processing (e.g., to be included in voltage dip statistics).

The further processing of a power quality event consists of the calculation of various indices. The so-called "single-event indices" typically include a duration and some kind of magnitude. The actual processing differs for different types of events and may include the use of the sampled waveform data. Statistical processing of power quality events consists of the calculation of site indices (typically the number of events per year) and system events (typically the number of events per site per year).

4. Signal-processing tools

The processing of power quality monitoring data can be described by block diagram in Figure 6.

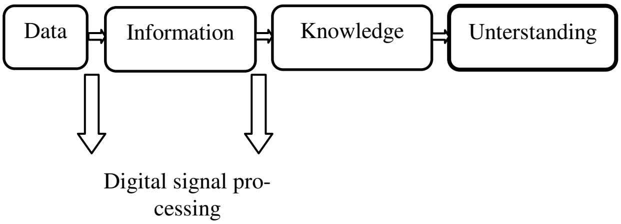

Fig. 6. Role of signal processing in extraction of information from power quality data

Data are available in the form of sampled voltage and /or current, waveforms. From these waveforms, information is extracted, for example, the retained voltage and duration of a voltage dip. Signal-processing tools play an essential role in this step. The extracted knowledge from the information (e.g., the type and location of the fault that caused the voltage dip), both signal processing tools and power system knowledge are needed. Having enough knowledge will lead to understanding, (for example, that dips occur more during the summer because of lighting storms) and to potential mitigation methods.

5. Monitoring process

The process of power quality monitoring involves a number of steps that require signal processing:

Characterising a variation is done by defining certain features. The choice of features is often very much related to the essence of the variation.

Distinguishing between a variation and an event, a triggering mechanism is needed. The most commonly used method compares a sliding-window RMS value with a threshold value.

Characterising each event through a number of parameters once an event is detected involves the extraction of one or more features. For voltage dips the event characterisation is very much related to the characterisation of voltage variations.

Classifying each event according to its underlying causes from the extracted features can often be considered as the final aim of the analysis.

As far as the signals are concerned, they can be roughly classified into two categories: stationary and non-stationary signals. The strictly stationary signals do not exist in real-life power systems; both small and large statistical changes occur in signal parameters. The presence of small and relatively slow statistical changes is addressed through so-called “block-based methods”. The signal is assumed stationary over a short duration of time (or window, a so-called “block of data”); and the signal features, characteristics or attributes are estimated over this window. Next the window is shifted in time and calculations are repeated for a new block of data. The resulting estimated features become a function of time depending on the location of the window. Apart from this block-based signal processing methods, Kalman filters offer non-block-based processing which can be directly applied to non-stationary signal processing. The knowledge of different aspects of block-based (batch processing) and non-block (iterative processing) signal processing methods are very important to monitoring the quality of a power system.

The next logical step after quantifying and characterising the data is to classify, diagnose, and mitigate the disturbances. Appropriate tools to achieve this include machine learning and automatic classification and diagnostics. Classification methods use features (or attributes, or characteristics) of data as the input and the designated class label of the data as the output. A classification process usually consists of steps such as feature extraction and optimisation, classifier design that finds a mapping function between the feature space and decision space, supervised or non-supervised machine learning, validation, and testing.

6. Electromagnetic compatibility

All communication between electrical devices is in the form of electromagnetic waves governed by Maxwell's equations. This holds for intentional as well as unintentional communication. Electromagnetic waves are responsible for power supply to the equipment communication and for the exchange of information between equipment. For a power supply, in most cases, Kirchhoff's equations are used as a low-frequency approximation of Maxell's equations. They are responsible for all kinds of disturbances that may endanger the correct operation of the equipment. These electromagnetic disturbances may reach the equipment through metallic wires (conducted disturbance) or in the form of radiation (radiated disturbances).

The general approach is to achieve electromagnetic compatibility between equipment. Electromagnetic compatibility is defined as "the ability of a device, equipment or system to function satisfactorily in its electromagnetic compatibility without introducing intolerable electromagnetic disturbances to anything in that environment" An electromagnetic disturbance is any unwanted signal that may lead to a degradation of the performance of a device. This degradation is referred to as electromagnetic interference. Thus the disturbance is the cause, and the interference the effect. The compatibility level for electromagnetic disturbance is a reference value used to compare equipment emission and immunity. From the compatibility level, an emission limit and an immunity level are defined. The immunity limit is higher than or equal to the compatibility level. The emission limit, on the over hand, is lower than or equal to the compatibility level. The disturbances due to events in power system (faults, lighting strokes, switching actions) are treated like this in the EMC standards even though it is possible to affect the source of the disturbance. This way of treating the power system as something that cannot be affected is again related to the fact that EMC standards apply to equipment only. An often – used argument is that voltage dips cannot be prevented because lighting strokes (leading to faults, leading to dips) are part of nature. Even though is not possible to prevent lighting strokes, it is technically very possible to limit the number of faults due to lighting strokes to overhead lines. Shielding wires higher insulation levels, and underground cables are possible options. The prohibiting costs associated with some of these improvements would be a more valid argument.

Finally there are disturbances for which it is not possible (or not practical) to affect the immunity of the equipment. Therefore, the compatibility level is determined by the immunity limit.

7. Compatibility between equipment and supply

The interest in power quality started from incompatibility issues between equipment and power supply. The distinction between voltage and current quality originates from these compatibility issues. Voltage quality, from a compatibility viewpoint, concerns the performance of equipment during normal and abnormal operation of the system. The introduced distinction between variation and events is also important for compatibility between equipment and supply. Events are divided into "normal events" and "abnormal events". It is thereby very important to realise that ensuring compatibility is a joint responsibility of the grid and the customer.

The voltage as experienced by equipment during normal operation corresponds to voltage variation. Voltage variations will lead to performance deterioration and/or accelerated ageing of the equipment. Three levels of voltage variation can be distinguished as follows:

Voltage variation that has no noticeable impact on equipment, voltage variation that has a noticeable but acceptable impact on equipment and voltage variations that has an unacceptable impact on equipment, which includes malfunction and damage of the equipment.

The design of the system and the design of the equipment should be coordinated in such a way that the third level is never reached during normal operation and the time spent at the second level is limited. In practice this means that the design of equipment should be coordinated with the existing level of voltage variations.

The responsibility of the grid operator is to ensure that the voltage quality does not deteriorate beyond a mutually agreed-upon level.

8. Normal and abnormal events

It is useful to divide power quality events into normal events and abnormal events. Normal events are switching events that are part of the normal operation of the system. Examples are tap changing, capacitor switching, and transformer energising, and load switching. If the resulting voltage events are too severe, this will lead to equipment damage or malfunction. If there are many events, this will cause unacceptable ageing of equipment. The same approach may be used as for normal operation: Equipment design should be coordinated with the existing voltage quality. There are, however, two important differences. The first difference is in the type of limits. For events limits are in the form of a maximum severity for individual events and in a maximum number of events. The second difference in normal operation is that there is no documentations providing existing levels. Fortunately, normal events rarely lead to problems with the equipment. The main recent exceptions are capacitor-energising transients. These have caused erroneous trips for many adjustable-speed drivers. The problem is solved by a combination of system improvements (synchronised switching) and improved immunity of equipment. In terms of responsibility sharing the grid operator should keep the severity and frequency of normal events below mutually agreed-upon limits; the customer should ensure that the equipment can cope with normal events within those limits.

Abnormal events are faults and other failures in the system. These are events that are not part of normal operation and in the most case also unwanted by the grid operator. Voltage dips and interruption are examples of voltage disturbances due to abnormal events in the system. It is not possible to limit the severity of abnormal events; therefore, it not possible to ensure that equipment can tolerant any abnormal event. A different design approach is needed here.

When the performance of the supply is know, an economic optimisation can be made to determinate an appropriate immunity of the equipment. A higher immunity requirement leads to increased equipment costs but reduced costs associated with the downtime of the production. The total cost can be minimised by choosing the appropriate immunity level. Such an optimisation is possible when detailed information is available on system performance and is therefore difficult to apply for domestic and commercial customers.

An alternative approach is to define minimum equipment immunity. The requirements placed by normal operation and normal events already place a lower limit on equipment immunity. This lower limit is extended to include common abnormal events. An example of such a curve is the curve for voltage dips and swells. Although the origins of these curve are different, they may all be used as a minimum immunity curve. The practical use of such a curve only makes sense when the number of events exceeding the curve is limited. This is where the responsibility of grid operators comes in. The responsibility sharing for abnormal events such as voltage dips is as follows: The grid operator should ensure a limited number of events exceeding a predefined severity; and the customer should ensure that all equipment will operate as intended for events not exceeding this predefined severity. In the current situation a large compatibility gap is present between immunity requirements placed on equipment and regulatory requirements placed on the grid operator. Regulatory requirements are available in some countries for long interruptions, typically starting at a duration between 1 and 5 min.

Power quality also has a current quality site, which requires design rules in same way as voltage quality. There are two reasons for limiting the severity and frequency of current disturbances. Current disturbances should not lead to damage, malfunction, or accelerated ageing of equipment in power system. The design rules should be the same as for normal operation and normal events. The only difference is that the grid operator is now on the receiving end of the disturbance. The second reason for limiting current disturbances is that they cause voltage disturbances, which are in turn limited. The limits placed by the grid operator on the current quality for customers should correspond with the responsibility of the grid operator to limit voltage disturbances.

9. Distributed generation

Power quality is defined as the electrical interaction between the electricity grid and its customers. These clients may be consumers or generators of electrical energy. The interaction is divided into voltage quality and current quality, referring to the way in which the grid impacts the customer and the way in which the customer impacts the grid, respectively. When considering systems with large amounts of distributed generation, power quality becomes an important issue. Three different power quality aspects are considered as follows:

Distributed generation is affected by the voltage quality in the same way as all other equipment is affected. An important difference between distributed generation and most industrial installations is that erroneous tripping of the generator may pose safety risk. The energy flow is interrupted, potentially leading to excessive speed of the machine and large over voltages with electronic equipment. This should be taken into consideration when setting immunity requirements for the installations.

Distributed generation affects the current quality and through the gird, the voltage quality as experienced by other customers. The special character of distributed generation and its possible wide-scale penetration require a detailed assessment of this aspect.

A third and more indirect aspect of the relation between distributed generation and power quality is that the tripping of a generator may have adverse consequences on the system, especially when a large number of generators trip simultaneously. This can have an adverse impact on the reliability and security of the system.

10. Impact of distributed generation on power quality

The impact of distributed generation on power quality depends to a large extent on the criteria that are considered in the design of the unit. When the design is optimised for selling electricity only, massive deployment of distributed generation will probably adversely impact quality, reliability, and security. However, several types of interfaces are capable of improving the power quality. In a deregulated system these require economic incentives, for example, in the form of a well-functioning ancillary services market.

To quantify the impact of increasing penetration of distributed generation on the power system the hosting capacity approach is used. This basis of this approach is a clear understanding of the technical requirements that the customer place on the system (i.e., quality and reliability) and the requirements that the system operator may place on individual customers to guarantee a reliable and secure operation of the system. The hosting capacity is the maximum amount of distributed generation for which the power system operates satisfactorily. It is determined by comparing a performance index with its limit. The performance index is calculated as a function of the penetration level. The hosting capacity is the penetration level for which the performance index becomes less than the limit.

The calculation of the hosting capacity should be repeated for each different phenomenon in the power system operation and design: The hosting capacity for voltage variations is different from hosting capacity for frequency variations. Even for one phenomenon the hosting capacity is not a fixed value, because it will depend on many system parameters, such as the structure of the grid, the type of distributed generation (e.g., with or without storage; voltage/power control capability), the kind of load, and even climate parameters (e.g., in case of wind or solar power). Indices should be used for studying the impact of distributed generation on power quality phenomena. The "ideal value of many of those indices is zero", so that the hosting capacity is reached when the index value exceeds the limit.

By using the hosting capacity approach, the issues of power quality and distributed generation have been reduced to the acceptable performance of a power system. Obviously what is acceptable to one customer may not be acceptable to another customer and here same decision may have to be made.

Figure 7 gives an example of how to implement this method for the over voltages due to injection of active power by distributed generation units. In the figure, two different indices are used, and both are based on the RMS voltage. One index uses 95 percentile of the 10-min RMS values, whereas the other one uses 99 percentile of the 3-s RMS values. The figure also shows two different limits: 106 and 110% of the normal voltage. The choice of two limits and two indices results in four values for the hosting capacity. The hosting capacity depends strongly on the choice of index and the choice of limit. The amount of distributed generation that can be accepted by the system depends on the performance requirements placed on the system. By quantifying the responsibility of the grid operator for voltage quality, the hosting capacity for distributed generation is also determined.

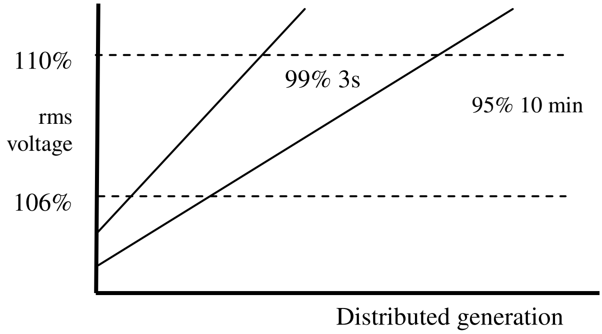

Fig. 7. Example of hosting capacity approach as applied to voltage variations; two different limits and two different indices result in four different values for hosting capacity

Distributed generation may have an adverse influence on several power quality variations. The injection of active power may lead to overvoltages in the distribution system. In addition, increased levels of harmonics and flicker are mentioned as potential adverse impacts of distributed generation. However, distributed generation can also be used to mitigate power quality variations. This especially holds for power-electronic interfaces that can be used to compensate voltage variations, flicker, unbalance, and low-frequency harmonics being injected into the system. However, the use of power-electronic interfaces will lead to high-frequency harmonics being injection into the system. These could pose a new power quality problem in the future.

With a large penetration of distributed generation, their tripping is an issue for the generator owner and for the system operator and other customers. The tripping of one individual unit should not be a concern to the system, but the simultaneous tripping of a large number of units is a serious concern. Seen from the grid this is a sudden large increase in load. Simultaneous tripping occurs due to system events that exceed the immunity of generator units. Distributed generator units will not trip for normal events such as transformer or capacitor energising. Their behaviour for abnormal events such as faults (voltage dips) and the loss of a large generator unit (frequency swings) is at first a matter of economic optimisation of the unit.

A schematic diagram linking a fault at the transmission level with a large-scale blackout is shown in Figure 8. The occurrence of a fault will lead to a voltage dip at the terminals of distributed generation units. When the dip exceeds the immunity level of the units, and they will disconnect, leading to a weakening of the system. The safety concerns and the loss of revenue are a matter for the unit operator, and they will be taken care of in a local economic optimisation.

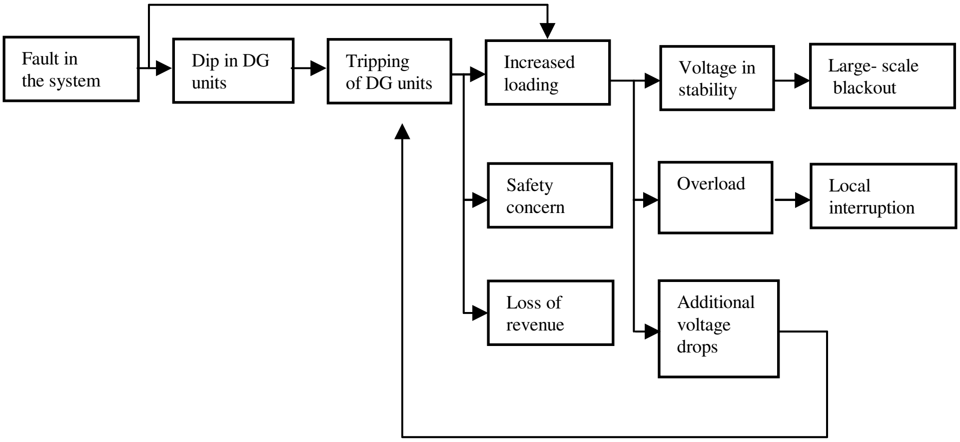

Fig. 8. Potential consequences of fault or loss of generation in system with large penetration of distributed generation

Conclusions

Diagnostics of the transmission process of electricity in the electric power grid should allow customers connected to the electric power grid to evaluate the mutual links between a single customer and the entire system of power transmission. These links can be shown as the utilisation of parameters, which characterises the quality of electricity. It should be considered that the quality of supplied electricity is a result of the technical state of all components of the electric power system and the equipment (receivers) attached to it. The occurrences of interference in the functioning of the system are the consequences of many varied factors, which directly influence the parameters of electricity. Therefore the evaluation of the quality of electricity is one of the crucial questions associated with the diagnostic process of the exchange of electrical power amongst participants of the energy market. Based on the monitoring of the values of the parameters of the quality of the electricity of each customer, the identification of the causes of deviation from the standard and its source can be located. The evaluation of the quality of electricity is also the basis for financial settlement between customers in the electric power grid. This article presents the diagnostic process in the transmission of electricity within the electric power grid in the aspect of the utilisation of methods associated with the evaluation of the quality of electricity.

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Diagnostyka procesów wymiany energii elektrycznej w systemie elektroenergetycznym

Słowa kluczowe

Diagnostyka, system elektroenergetyczny, jakość energii, zdarzenia, odchylenia.

Streszczenie

Diagnostyka przesyłu energii elektrycznej w systemie energetycznym wymaga wprowadzenia nowego modelu struktury systemu elektroenergetycznego, składającego się z sieci elektroenergetycznych, do których są podłączeni klienci, uczestniczący w wymianie energii elektrycznej między sobą (np.: wytwórcy, spółki dystrybucyjne, odbiorcy itp.). Celem technicznym sieci elektroenergetycznych jest przesył energii elektrycznej o odpowiedniej jakości, czyli o odpowiednim napięciu i prądzie. Jakość energii elektrycznej zależy bezpośrednio od wzajemnych oddziaływań na proces wymiany energii między siecią elektroenergetyczną i jej klientami. W publikacji zaproponowano nowe ujęcie diagnostyki stanów systemu elektroenergetycznego w aspekcie zmian parametrów jakości energii elektrycznej.