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CIGRE/CIRED/IEEE WORKING GROUP C4.24 – NEW MEASUREMENT TECHNIQUES IN THE FUTURE GRID – STATUS REPORT

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ABSTRACT

One of the issues that the joint working group CIGRÉ/CIRED/IEEE JWG C4.24 will be addressing, is the need in future networks for new measurement techniques, more complex and more accurate, which will be undergoing architecture reconfiguration (due to feeder reconfiguration) and will be witnessing old and new phenomena affecting the power quality. This paper gives a comprehensive overview and better understanding of the real challenges related to measurement techniques in future networks.

INTRODUCTION

The work of CIGRÉ/CIRED/IEEE Joint Working Group C4.24, "Power Quality and EMC Issues Associated with Future Electricity Networks", is focused on several subjects [1] and one of them, playing a crucial role in future networks, is new measurement techniques.

An important difference between the existing network and the network as we expect it to be in the future, is the huge quantity of information, acquired from the network itself, and used to manage it more efficient, less expensive and more secure in order to ensure customer's satisfaction.

The working group will be addressing the need for new measurement techniques, more complex and more accurate, capable to provide the information required in future networks, which will be undergoing, at certain moments, dynamic architecture reconfiguration and will be witnessing old and new phenomena affecting the quality of the supply. All this information will be essential to improve both the network reliability and power quality (PQ). That might possibly require new hardware and software development for assessing new indices for old types of disturbances (sags, harmonics, unbalance, etc.) and also for potentially new ones.

This paper will discuss, as it is expected to develop in the future, new measurement techniques complying with the complexity of the future network.

NEW MEASUREMENT TECHNIQUES

The development of new measurement techniques will be partly driven by necessity, partly by the availability of new technologies.

When thinking about these techniques, the following aspects should be distinguished:

- Measurement location,
- Hardware, consisting of transducers and measurement device (accuracy, sampling rate, etc.),
- Software, covering pre-processing, post-processing, data handling, PQ indices, data security.

Based on these aspects, the following sections discuss some of the new challenges and requirements resulting from the ongoing evolution of the networks and the continuous development of new devices, like EV chargers, LED lamps or PV inverters.

MEASUREMENT LOCATION

PQ monitoring (PQM) locations are strongly related to the power system architecture and infrastructure and also to monitoring goals. In existing power systems, PQM points are usually located at the frontiers between the four fundamental component segments: classic generation, transmission, distribution and customer. With large penetration of renewable generation and storage a new layer of monitoring might be added at their connection points, as these types of sources raise some concerns related to PQ.

PQM practices can differ from one system operator to another, and the choice of the practice is an individual system operator's decision to make, as long as the monitoring is in compliance with local regulations and the national and international standards. These practices include [2]:

- Traditional PQ surveys based on temporary and short-term installation of different types of PQ analyzers at random locations (e.g. at customer's PCC),
- Traditional PQM with permanently installed devices for long-term or continuous monitoring (in substations, at the PCC of large customers).

In future systems a balance should also be found between:

- PQM with traditional PQ analysers,
- PQM with non-traditional devices such as relays and controllers, which are used for daily network operation (in substations and along the feeders).
- PQM based on Advanced Metering Infrastructure (AMI) including meters with power quality features (at the PCC of large customers).

The selection of the monitoring locations is a complex task requiring a good knowledge of the power system architecture and of the PQ disturbances affecting the grid. For example, the propagation of emission in the

frequency range 2 to 150 kHz propagates differently as at lower frequencies. Emissions at higher frequencies tend to stay close to the source and therefore, most of them propagate towards neighbouring equipment. This type of measurements should hence be done as close to the customer/end-user equipment as possible [3][4].
Monitoring practices may differ between different utilities, but in the end, all of them will be relying on voltage and current transducers and acquisition devices[1].

MONITORING HARDWARE

The measurement techniques are based on a chain of acquisition including transducers, which sense voltage, current, eventually temperature and humidity, and intelligent electronic devices (IED) analyzing the signals provided by transducers.

Transducers

Classic transducers as voltage and current instrument transformers (VT/CT) are simple and robust, but only designed for high accuracy at fundamental frequency.

Figure 1. MV Instrument transformers

Voltage instrument transformers have multiple resonances, which cause measurement errors of up to 300% and even more.

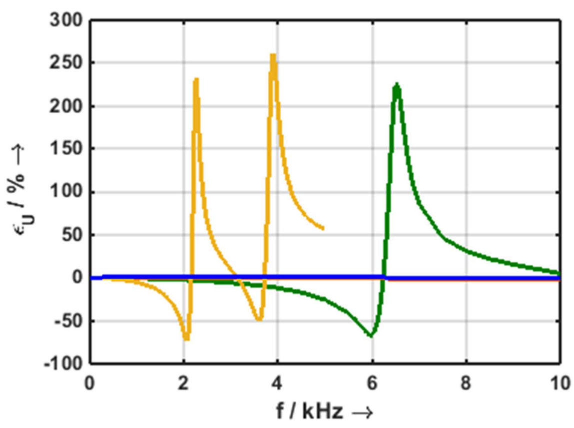

Figure 2. Frequency responses of different voltage transducers (green: inductive VT 20 kV, red: inductive VT 20 kV with extended frequency range, orange: inductive VT 110 kV; blue: RC divider 110 kV)

The "bandwidth" of voltage instrument transformers for harmonic measurements mainly depends on VT design and voltage level. While inductive 20-kV-VTs can usually measure with sufficient accuracy up to 2 kHz (green plot in Figure 2), inductive VTs for 110 kV can only be used for measurements up to about 600 Hz (orange plot in Figure 2). More details can be found in [5][6]. Some manufacturers face this challenge by developing VTs with extended frequency range (red plot in Figure 2).
Sensors represent a new solution for current and voltage measurement in power systems, providing information required for protection, fault location, PQM, network monitoring and operation.

Figure 3. MV Sensors

Their extensive dynamic range allows with only a few types to cover the whole current and voltage range for measuring and protection purposes. Because no ferromagnetic cores are used, they are non-saturable and linear over the whole measuring range. The sensor burden is only a fraction of a VA comparing to the typical burden of a conventional transformer of 15 VA and more. They are much smaller in volume and weight compared to conventional instrument transformers.
The sensors can be divided in three categories:

- Current Sensors – for current measurement with high linearity and wide dynamic range;
- Voltage Sensors – allowing non-saturable, linear, ferro resonance free measurement,
- Combined Sensors – current and voltage elements are integrated in the same compact cast resin and used for current & voltage measurements.

The sensors are used for measuring, protection, tariff billing and other applications. A special version of these sensors, with a wider bandwidth, is suitable for power quality monitoring and fast transients detection. According to the phenomenon or effect used to measure voltage and current, the sensors can be classified in:

- Optic (voltage & current),
- Impedance (resistive or capacitive) voltage dividers (blue line in in Figure 2),
- Rogowski-coil (current),
- Proprietary electrical field sensing technologies.

Measurement Device

The traditional power quality analysers still are the most powerful and equally expensive devices used for PQM. There is a consensus that in future network, the PQM features available on some IEDs, already connected to the network (relays, controllers, meters), to be advantageously exploited. This trend will significantly

1 For more detailed information please read the CIGRÉ technical brochure produced by CIGRÉ/CIRED JWG C4.112 "GUIDELINES FOR POWER QUALITY MONITORING".

impact the further development of these devices and characteristics such as measurement accuracy and data analysis capacity will be greatly improved.

Adding PQ functionalities to IED's firmware, raises questions about the compatibility of measurement data between different IED models, and in order to minimize discrepancies any PQ related implementation should follow the international standards guidance (e.g. IEC 61000-4-30). If the compliance with class A or S is too costly, the introduction of an additional accuracy class in the standard could be discussed. Moreover, interoperability between devices of different brands is an important issue that is not yet sufficiently addressed by the manufacturers.

There is no need that each IED connected to the network provides the full set of PQ indices. Priority should be given to those at strategic locations. A modular concept, allowing the stepwise increase of PQM functionality, like that discussed in [7] for smart meters, would give certain flexibility at reasonable costs.

PQ indices related to supraharmonics and phase angle of harmonics, are not yet implemented in PQ analyzers or IEDs, and to make that possible it may require higher computation performance and sampling frequency, also additional signal filtering, which represent major hardware revisions by manufacturers.

Combination of transducer and IED (Line monitor)

Sometimes a combination of transducer and IED, such as line monitors, could be a better solution than separate devices. Line monitors (see Figure 4) are capable to monitor the current, the electric field, the voltage when a connection to neutral/ground is provided or not (some models), to perform local signal treatment and to communicate wirelessly the information acquired.

Figure 4. Line monitors

MONITORING SOFTWARE

Regarding the monitoring software it has to be distinguished between the pre-processing of data (sampling, time aggregation, calculation of indices, etc.), which is usually done by the measurement device and the post-processing (calculation of weekly percentiles and compliance assessment), which is normally achieved by the analysis software. Furthermore, the handling and storage of data are other important aspects, particularly because of the continuous increase of the quantity of data acquired.

PQ Indices

The PQ indices we use today have been around for more than twenty years. As the network evolves, the PQ indices should evolve with it. Since the distributed generation becomes more prolific, so do the challenges associated with it. To better understand the unbalance caused by e.g. the shading in PV we have now a new set of indices [8]. As we have more and more measuring points, the data gathered becomes ubiquitous and we need methods to further refine it. One idea is to aggregate PQ indices in order to find sections of the network with the worst PQ issues [9].

Updating old indices and developing new ones will demand new software development but they will provide first time comprehensive information that will eliminate the need for additional monitoring.

New indices capable to provide additional information are required for:

- Harmonics,
- Supraharmonics (2-150 kHz)
- Unbalance,
- Voltage dips,
- Flicker with non-incandescent lamps.

Supraharmonics, 2-150 kHz

Emission in the supraharmonic range (2-150 kHz) has different characteristics than emission below 2 kHz. When analyzing measured data in this higher frequency range a different approach is therefore needed. The supraharmonic spectra are often of broadband character. Spectra at lower-frequencies contain mainly discrete or narrowband components at integer multiples of the power-system frequency.

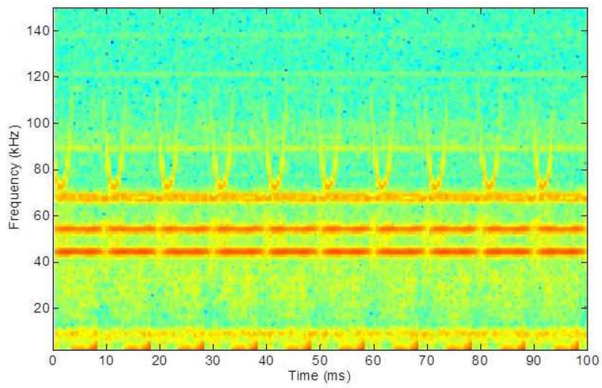

Figure 5. Spectrogram of the current drawn by a LCD TV

Narrowband components in the supraharmonics range are often not stationary and change amplitude over time in the millisecond range. The emission can also have other features like time-frequency varying which are not common in the harmonic range [10][11]. One method used for analyzing supraharmonics is the Short Time Fourier Transform (STFT). A sampled signal is divided into smaller windows and a Discrete Fourier Transform (DFT) is applied to each window. The outcome is typically represented as a spectrogram. The spectrogram will show changes in the spectrum over time thus giving information on the characteristics of supraharmonics not given by traditional harmonic emission analyzing techniques. An example of the outcome of a STFT is shown in Figure 5.

In order to quantify supraharmonic emissions, a comprehensive set of indices has to be developed, which should include time domain and frequency domain parameters. Time-domain parameters like maximum value or point on wave of maximum can be easily obtained from the filtered waveform (see Figure 6).

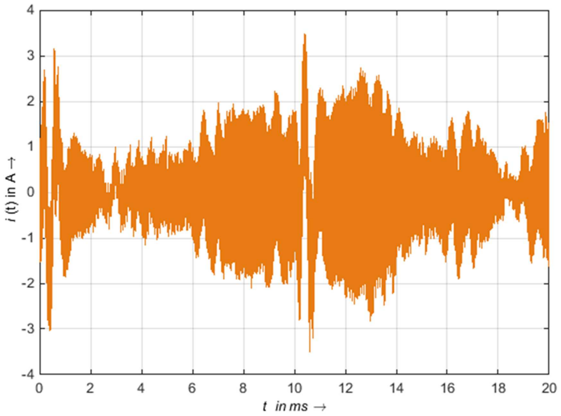

Figure 6. Highpass filtered current waveform of a DC charging station (Chademo) for electrical vehicles (maximum value: 3.5 A; POW of maximum: 10.5ms/190°)

Frequency domain parameters could be the magnitude of a certain emission band or the total supraharmonic distortion (TSD). In order to ensure the comparability of results, some calculation parameters, like a specific bandwidth has to be defined in advance. The signal in Figure 6 has a maximum of 120dBμA (RMS) which corresponds to 1 A at 45 kHz. Compared to the maximum value of 3.5A the averaging effect of classical FFT approach is clearly to see.

Harmonics

The measurement and assessment of the harmonic phase angle for assessing possible harmonic cancellation effects by new equipment connected to the network could become important in the future. It should be noted that this phase angle is different to the one required for harmonic power calculations. Despite the fact that the harmonic phase angle might be available in an IEC 61000-4-7 complying instrument, often it is not stored by the PQ device. Also at this time, there are no clear specifications for how to aggregate them. One proposal calculates the phase angle of the vector summation of all complex 10-period-values for a certain time interval and its magnitude as the RMS value of the 10-period-values. Figure 7 shows the individual measurement values of 5^{th} harmonic (colored clouds) for two weeks monitoring in a public LV grid with about 150 households and the resulting vector for phase L3. If new equipment with a phase angle in the second quadrant (like compact fluorescent lamps) is connected, an efficient cancellation can be achieved, assuming the number of new equipments does not exceed a certain amount and the mix of the existing equipment does not change significantly [12].

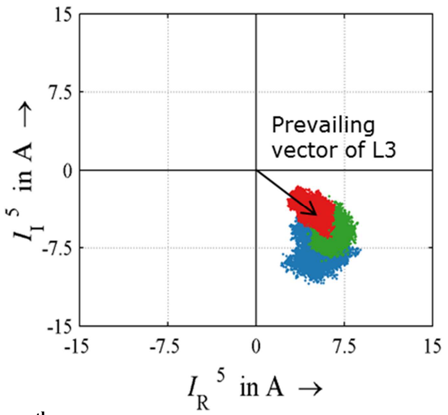

Figure 7. 5^{th} harmonic current emission of a public LV grid.

DATA VOLUMES

A power quality monitor, like many other devices in the grid, continuously measures three voltages and three currents with a sampling rate of 256 samples per cycle in a 50-Hz system. Such a device samples a total of 2.4 TB (terabyte, 1012 byte) per year. It is obvious that not all of this data is stored and that some processing of data is needed. The common approach is to calculate characteristics and indices from these data, e.g. 10-minute values or weekly 95-percentile values. For one location, the 10-minute values for 40 harmonics would give 2 million values per year. But for a system with 5.2 million monitors, this would give 270 GB per year.

With more and more measuring points, the data gathered becomes ubiquitous and methods are needed to further refine it and extract useful information in an automatic way. One idea is to aggregate the PQ indices at different levels and performing a top-down analysis starting with a single value (network index). At a lower level the PQ indices can help to find regions of the network with the worst PQ performance and which one of the PQ parameters is responsible for it [13].

Scanning such huge amounts of data manually is virtually impossible. In the future, so-called agents could continuously screen the data for specific events (like the steep change in a harmonic level) and send an alert to the user. In a second step, these agents could be furthermore developed to give assistance to the system, providing to the user not only the information related to the event, but also the possible causes and suggestions for mitigation. In case of millions of monitors, it could be beneficial to move from a central storage and post-processing of data to a distributed approach. In terms of smart meters this could mean that e.g. only daily or weekly percentile values are transmitted to the central center and most of the data will remain in smart meters, in ring buffers of different time resolution. In case of a pre-defined event occurs or if the user needs the information, the "raw data" is transmitted.

CONCLUSIONS

Findings

In future systems a balance should be found between PQM with traditional PQ analyzers and with non-traditional devices such as relays and controllers, which are used for daily network, and Advanced Metering Infrastructure (AMI) including meters with power quality.
The shifting to higher frequency, up to 150 kHz, will require new types of transducers, namely new sensors, which will replace the traditional instrument transformers.
New indices are needed for harmonic phase angles with respect to the fundamental voltage and also for supraharmonics.

On-going discussions

New types of disturbances, or types of disturbances occurring more often than in the past, may require additional indices, to be properly tracked and studied. There is on the other hand a need for simplified reporting on power quality, where a small number of indices is the desired situation. A discussion is on-going within the group on this dilemma.
There might also be a need for new indices for unbalance, flicker, and voltage dips. A discussion on this subject has not yet started within the working group

Contributions

Like with all international working groups, contributions are very welcome. Readers having opinions and contributions that may be of interest to the working group are strongly encouraged to contact the authors of this paper.

ACKNOWLEDGEMENTS

Although the authors have tried to describe the state of the discussions within the working group as accurate as possible, this paper is not a working group paper. The opinions expressed in this paper may deviate from the ones of the working group, from CIGRE, from CIRED and from IEEE.
The contribution from other members of the working group to the discussions that resulted in this paper is gratefully acknowledged.

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