CIGRE/CIRED C4.24 – power quality in the future grid – first introduction

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***Abstract*— This paper introduces the new CIGRE/CIRED working group C4.24. The scope of the working group covers the way in which power quality is expected to change in the future grid. This paper present the way in which the work within the group is preliminary organized. The paper also gives some more details of the ongoing discussion within one part of that work: "smart grids and power quality", which gives mainly a proposal for the approach in the remainder of the report.**

***Index Terms*—power transmission and distribution, power quality, smart grid, hosting capacity, CIGRE, CIRED.**

I. Introduction

CIGRE is an international association, with headquarters in Paris, France, that is promoting collaboration with experts from all around the world by sharing knowledge and joining forces to improve electric power systems of today and tomorrow [2]. The association is best known for its biannual conferences in Paris, but it also sponsors a large number of working groups and publishes the results from those groups as technical brochures. CIRED, located in Liege, Belgium, is a similar organization [3] but directed more towards power distribution whereas CIGRE is more directed towards power transmission. The technical activities within CIGRE are organized in a number of study committees. Study committee C4 within CIGRE covers the wide area of "system technical performance" including among others power quality, electromagnetic compatibility and insulation coordination. Within each study committee a number of working groups are active, see [4] for an overview of the groups within study committee C4.

This paper is about one of those working groups, introduced in Section II. The terms "smart grid" and power quality are briefly introduced in Section III, followed by a summary of the relations between power quality and smart grids. Section IV introduces power quality as an important performance indicator for the smart grid and Section V introduces new types of power-quality disturbances that may originate from new types of equipment connected to the grid. The structure of the activities in the working group is summarized in Section VI.

II. CIGRE/CIRED JWG C4.24

Working group C4.24, "Power quality and EMC issues associated with future electricity networks", is one of the about 20 working groups that are currently active within CIGRE study committee C4. It is a joined working group between CIGRE and CIRED that obtained its three-year mandate at the end of 2013. The title of the working group is very broad, but the specific terms of reference given to the group narrow this down significantly.

The following issues will be considered and addressed in further detail by the working group [5]:

- ✓ The emissions (harmonic and unbalance) by new types of devices connected to the distribution network as production (DG) or consumption (load), especially devices with active power-electronics interface including equipment connected to low-voltage and installations connected to higher voltage levels. This might require the evaluation of new measurement techniques, including a closer look at the frequency response of existing instrument transformers and sensors. The main question is: will this require new ways of considering power quality in the design?
- ✓ The positive and negative impact of new smart distribution applications such as Volt &VAR control and feeder reconfiguration on power quality (voltage unbalance and harmonic flow) in the distribution system.
- ✓ How these power quality issues at the distribution level may impact the transmission system.

At the IEEE PES JTCM 2014, it has been initiated a discussion with the IEEE PES power quality Subcommittee for a collaboration between C4.24 and IEEE WG "Power Quality and EMC Issues associated with future electricity networks", whose scope and objectives are similar. Subsequently, the collaboration was approved by CIGRE SC4 and by the abovementioned IEEE subcommittee.

III. Power Quality and The Smart Grid

There are several definitions of the smart grid. The following one is used by the Swedish Energy regulator [1]: "*The set of technology, regulation and market rules that are required to address, in a cost-effective way, the challenges to which the electricity network is exposed*". It is close to the one used by the European Energy regulators.

Several other definitions are being used, either similar to the one above, or such that the kind of technology is being defined. An example of such is the definition by IEC: "*electric power system that utilizes information exchange and control technologies, distributed computing and associated sensors and actuators, for purposes such as:*

- *to integrate the behaviour and actions of the network users and other stakeholders,*
- *to efficiently deliver sustainable, economic and secure electricity supplies*"

A number of relations between the transition to the smart grid and power quality can be observed. These can be summarized as follows:

- ✓ The new technology, regulation and market rules can also be used to improve power quality. The main developments have been on dedicated power-electronics controllers, once referred to by the term "custom power". But other developments, such as advanced voltage control (using data from multiple locations) and power-quality markets should not be forgotten or ruled out.
- ✓ Power quality is part of the new challenges to which the grid is exposed and for which the transition to the smart grid is needed. For example: solar panels connected to the low-voltage networks will result in overvoltages; the switching frequency of the converters in wind turbines causes high-frequency signals flowing into the grid; harmonics are generated by EV chargers; the repeated starting of heat pumps can result in visible light flicker; feeder reconfiguration can cause unbalance and short interruptions. Most important here, not only from a research viewpoint but also for practical applications, is the potential occurrence of new types of disturbances due to new types of equipment connected to the grid. Some examples will be shown in Section V.
- ✓ When smart-grid solutions remove some of the other limits, like overload or stability limits, power quality may become what sets the limits. Thus, even when power quality is not an issue now, it may become an issue later.

IV. Performance Indicators of the Grid

What matters to the users of the electricity network (the future smart grid) are the following three issues:

- ✓ The price for using the network (the network tariff),
- ✓ The reliability,
- ✓ The power quality.

For some customers also safety and environment matter and one may argue that they should be added to this list as well. We will not go into that discussion here. However, technical subjects like overload protection, operational security, power-system stability and insulation coordination are just internal technical issues that do not matter to network users.

A. The Hosting Capacity Approach

Power quality and reliability will be important when quantifying the performance of the future grid. This is one of the bases of the so-called "hosting-capacity approach" [6][7] that is illustrated in Fig. 1.

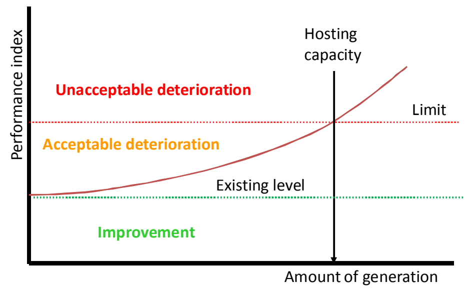

Fig. 1. The hosting-capacity approach: comparing a performance index with a predefined limit gives the hosting capacity above which the reliability and quality of the supply can no longer be guaranteed.

To determine how much new production can be connected to the grid (at a certain location, to a certain feeder or to the grid as a whole) a set of performance indicators is compared with a limit for each index. Once the first of those indices exceeds its limit, the hosting capacity is reached.

Connecting more generation than the hosting capacity will result in the grid no longer being able to provide acceptable reliability and power quality to all customers. This holds for the classical (existing) way of planning and operating the distribution grid. We will see below that there are alternatives under the smart-grid paradigm.

An overview of the development of the hosting capacity concept and its applications is given in Chapter 3 of [8].

The choice of performance index and limit can have a big impact on the hosting capacity. This has been shown by several studies [9][10][11] and an example is shown in Section IV.B.

B. Overvoltages

The occurrence of overvoltages is the main power-quality issue when connecting renewable electricity production to the distribution grid, as shown for example in Chapter 4 of [12], and in Chapter 9 of [13].

The hosting capacity approach for overvoltages is shown in Fig. 2. In this example, the performance index is the highest 10-min rms voltage for any customer at any moment in time. A range of performance indicators is possible and the choice is one of the main issues in the discussions on voltage-quality regulation in Europe [14].

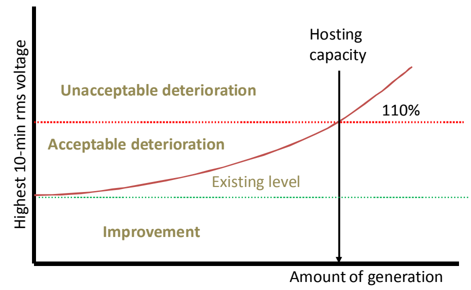

Fig. 2. Hosting capacity approach for overvoltages.

In Fig. 3 [12], the impact of different indicators is shown. When the highest rms value is used, the hosting capacity is equal to 1 MW. When instead the 99% value is used, the hosting capacity is increased to 2.3 MW. Thus by allowing the voltage to exceed the limit during 1% of the time, more than twice as much production can be connected. This comes however at the expense of an increased risk of damage to end-user equipment because of overvoltages.

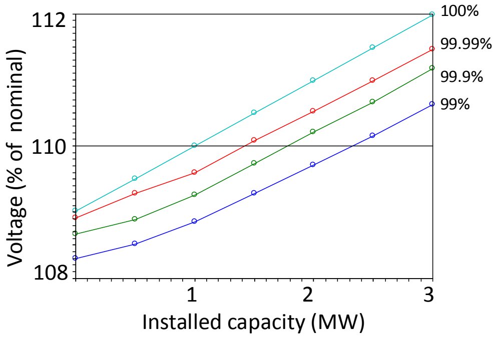

Fig. 3. Four different performance indices with the same limit.

C. *Curtailment*

Instead of allowing overvoltages to occur during a small percentage of time, the production can be curtailed whenever the voltage would otherwise exceed the limit. In this way the risk will not be carried by the network users with equipment sensitive to overvoltage, but by the owners of the production units that will be curtailed.

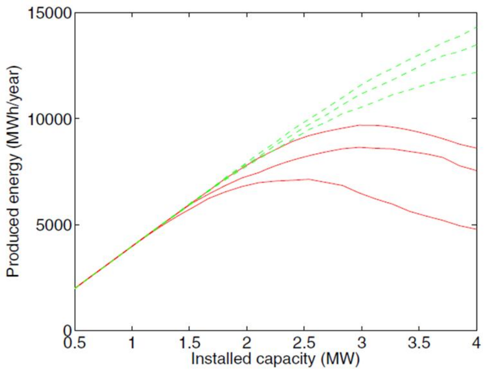

Fig. 4. Produced energy, with curtailment to avoid overvoltages, for hard curtailment (red) and soft curtailment (green) at three different locations.

With increasing amount of local production it will no longer be the risk of overvoltage that increases but the amount of energy that will be curtailed. This is illustrated in Fig. 4 for three different locations [15]. A distinction has been made between hard curtailment and soft curtailment. For hard curtailment, the production unit is disconnected whenever the voltage would otherwise exceed the limit. For soft curtailment, the production is reduced such that the voltage remains equal to the limit.

Fig. 4shows the annual electricity production as a function of the amount of installed production capacity. With hard curtailment, the annual energy production reduces after a certain amount of installed capacity. This reduction is dependent on the local voltage profile.

V. New Types of Power Quality Disturbances

New technology connected to the grid may introduce new types of power quality disturbances. What is urgently needed is a serious study of the emission from new types of equipment. This should not concentrate on the "normal emission" like harmonics 3, 5 and 7. Instead research efforts should be directed towards abnormal emission. It is not possible to decide beforehand what kind of emission will be of interest for detailed study. It is therefore important to not only measure according to standard methods as this will immediately limit the amount of new information that can be obtained.

A. *Even harmonics and interharmonics*

Modern wind turbines are equipped with power electronic converters and are therefore suspected to be a source of harmonic emission. As shown for example in [16][17], the emission at the classical harmonic frequencies (5, 7, 11 and 13) is low. The highest values are below 1% of the nominal current and much lower than emission from most other equipment connected to the grid. However, high order even harmonics (36, 38 and 40) are shown to exceed the limits set by IEEE 519.

Next to harmonics, wind turbines also emit interharmonics. This is shown in Fig. 5, for three modern turbines [16]. The interharmonic levels are clearly higher than for other equipment. Most network operators do not use any limits for interharmonics, but when limits are used they may be very low making it difficult for wind turbines to be connected without expensive filtering.

A thorough evaluation of the emission limits is needed for "abnormal frequencies" like even harmonics and interharmonics, for voltages as well for currents.

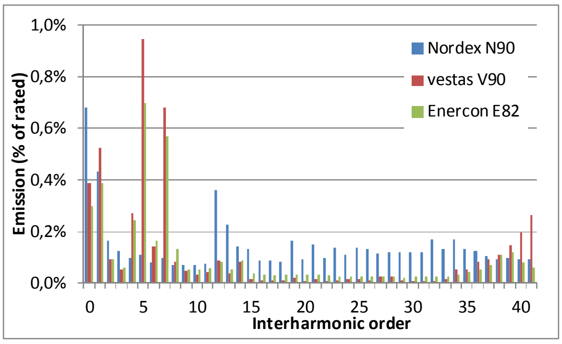

Fig. 5. Interharmonics from three modern wind turbines.

B. *Medium-time-scale voltage variations*

A new disturbance for which there is no index that quantifies its severity, is shown in Fig. 6 [12][18]: the fast variations in production for solar panels due to passing clouds.

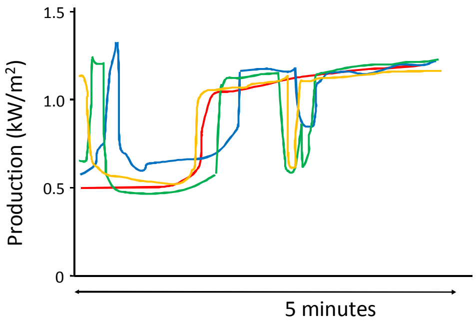

Fig. 6. Variation in production of four PV panels in the same street due to passing clouds.

When using standard methods for quantifying power quality, this disturbance will not be noticed. It is too fast to impact the 10-minute rms value; it is too slow to impact the flicker severity. New indices are needed to quantify how variations in voltage magnitude at this time scale are impacted by renewable electricity production.

C. Supraharmonics

The term supraharmonics has recently been introduced to refer to distortion of voltage or current in the frequency range 2 to 150 kHz [20]. Such frequencies originate from the active power-electronic converters that are present in more and more grid-connected equipment [20][21][22]. There are some indications that a reduction in emission at the "normal harmonics" (lower-order odd harmonics) goes together with increased emission of supraharmonics. This would make sense as active converters are a commonly-used method to reduce the level of harmonic emission at lower frequencies.

An example is shown in Fig. 7 [21]: the remnants of the switching frequency from the inverter of a solar panel. A 16-kHz signal is injected by the inverter rather independent of the produced power. Only when the panel is switched off (rms current close to zero) the 16-kHz signal disappears.

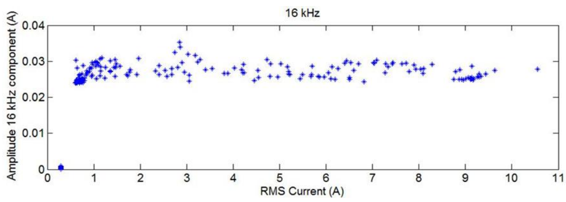

Fig. 7. Supraharmonics from a 2.5 kW PV installation, as a function of the current magnitude.

Another example is shown in Fig. 8 [20]: the current measured at the interface of a modern television (40" LCD screen; HD ready, build-in digital box, active power about 170 W). Its emission is low at the frequencies that have traditionally been a concern: harmonic three is highest at about 40 % of the fundamental whereas harmonics 5 and 7 are below 10 %. Instead the device emits frequencies that have traditionally been absent from the grid, in this case damped oscillations around 5 kHz and narrow band signals between 60 and 100 kHz.

Work has started towards further understanding of this frequency range, but more studies are needed among others to find suitable ways of quantifying the emission in this frequency range. Also the spread of emission and the impact on other devices should be studied.

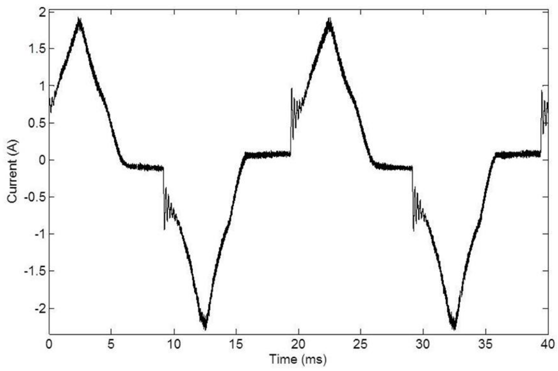

Fig. 8. Current waveform for a modern television.

D. Transmission Systems

The developments that go under the name "smart grids" will also impact the power quality at transmission level. A possible source of new types of emission at transmission level is formed by HVDC links. The number of HVDC links in use is increasing fast.

HVDC is a known source of harmonics and many of the important studies on harmonics were in fact triggered by the introduction of HVDC. As HVDC links are standard equipped with harmonic filters, they also have the ability to filter harmonics from other sources. But those filters could also give resonances at other frequencies.

The shift has been from classical HVDC to VSC-based HVDC. The new type of HVDC will introduce new types of harmonics, but nobody knows yet which ones. Supraharmonics due to the switching of the valves are the first suspect. The active converters that are part of VSC-HVDC make that there is no longer a need for harmonic filtering. That also means that no new resonance frequencies will be introduced. The converters can even be used to filter low-order harmonics from other sources.

Another new type of transmission of power, ac cables, also have an important impact on the harmonic distortion levels by shifting resonances to lower frequencies [12][23]. This might be made worse by the shift from large production units to renewable electricity production like wind and solar power that do not contribute to the short-circuit capacity. The impact of this is not fully studied yet, but an early indication is that it will result in higher distortion at lower frequencies and lower distortion at higher frequencies [12].

E. Hosting Capacity for new Types of Disturbances

Calculating the hosting capacity for such new types of disturbances is going to be difficult (Fig. 9): development is needed for the performance index, for the selection of suitable limits and for methods to calculate the value of the index as a function of the amount of new production. The knowledge to be gained from the working group will contribute to this development.

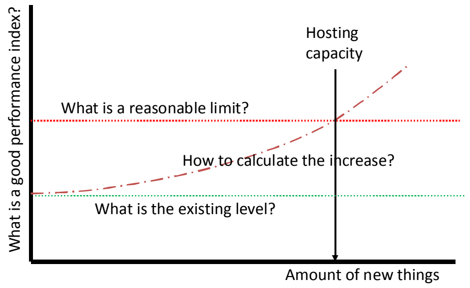

Fig. 9. Uncertainties in calculating the hosting capacity for new types of disturbances.

VI. Structure of the Work

The work within the working group is split into a number of subjects, conveniently referred to as "chapters". Typically each activity will become a chapter in the final report of the working group. Currently, the following chapters have been defined:

1. Introduction
2. New developments
3. Changes in power quality
4. New types of emission
5. Impacts at transmission level
6. New types of immunity
7. Microgrids and power quality
8. Volt-var control, optimization and power quality
9. Feeder reconfiguration and power quality
10. Demand side management and power quality
11. New measurements
12. New mitigation
13. Conclusions and future work

Here it should be noted that the work on some chapters has proceeded further than that on other chapters. For some chapter a rather complete draft exists already, for other chapters only the chapter title exists. Most chapters are somewhere in between.

VII. Conclusions

Working group C4.24 will address a number of aspects of power quality in relation to the changes that are expected to take place in the power grid. This includes new types of emission, new types of immunity and the way in which new solutions (known under the term "smart grids") will impact the power quality.

VIII. Acknowledgements

The working group C4.24 consists at the moment of about 40 members. Their contribution to the discussions is gratefully acknowledged.

This paper is not a CIGRE, nor a CIRED publication, but merely gives the authors' interpretation of the state of the discussions in the working group.

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