Snezana Cundeva
Faculty of Electrical Engineering and Information Technologies – Skopje
Math Bollen
Electric Power Engineering Group, Luleå University of Technology, Skellefteå, Sweden

CIGRE/CIRED/IEEE WORKING GROUP C4.24 – POWER QUALITY AND EMC ISSUES ASSOCIATED WITH FUTURE ELECTRICITY NETWORKS – STATUS REPORT

ABSTRACT

The Working Group C4.24, "Power Quality and EMC Issues Associated with Future Electricity Networks", is a joint working group of CIGRE, CIRED and IEEE. This paper gives a status report of the working group C4.24. Next to an overview of the different activities started, more details are given of the work done on voltage dips, new sources of emission, feeder reconfiguration, demand side management, volt-var-control, and power quality and economics.

Keywords: power quality, Electromagnetic compatibility (EMC), voltage dips, harmonics, smart grids

1 INTRODUCTION

The Working Group C4.24, "Power Quality and EMC Issues Associated with Future Electricity Networks", is a joint working group of CIGRE, CIRED and IEEE. A collaboration has been initiated between C4.24 and IEEE WG "Power Quality and EMC Issues associated with future electricity networks", whose scope and objectives are similar.

Working group C4.24 obtained its mandate in 2012 and it should, according to its scope, address the following issues:

- 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?

2 SUBJECTS ADDRESSED

The group has currently about 40 members and held seven meetings. The work has started on several subjects, referred to as "chapters", as these subjects are likely to correspond to specific sections and parts of the final report, which should be finalised by the end of 2016. The current list of chapters is:

1) Introduction, scope of the report and terminology.
2) New developments in power electronics.

3) Overview of smart grids and power quality.
4) New emissions and voltage dips.
5) Transmission systems
6) New immunity
7) Microgrids and power quality
8) Volt-var control and power quality
9) Feeder reconfiguration and power quality
10) Demand side management and power quality
11) New measurements
12) New mitigation
13) Power quality and economics

Roughly speaking, the subjects studied within the working group, as the above list, fall into three groups:

- Subjects of introductory character (Chapters 1, 2 and 3);
- The impact of new production or consumption on the power quality in the classical grid (Chapters 4, 5 and 6)
- The impact of new technologies in the grid and the power system ("smart grids") on the power quality and EMC (Chapters 7 through 13).

The status of the work in Chapter 2 and Chapter 4, especially with reference to "supraharmonics" (emission in the frequency range 2 to 150 kHz), is presented in [1]; the status of Chapter 3 in [2]; the status of Chapter 8 in [3]; and the status of Chapter 11 in [4].

In this paper more details are given on five activities: voltage dips; feeder reconfiguration; demand side management; volt-var control; power quality and economics.

3 STATUS OF THE REPORT WRITING

The work on some chapters has proceeded further than on the others. For a few, a rather complete draft is already available, while for other chapters only the title exists. Most chapters are somewhere in between.

4 VOLTAGE DIPS

4.1 Emission

The shift from using directly-connected induction motors to adjustable-speed drive (ASD) applications is expected to continue. According to the International Energy Agency, roughly 50% of all generated electrical power is consumed by Induction Motors (IM), [5], while recent studies in [6][7], estimate that around 25% of the newly installed machines are supplied from ASDs. This means that less voltage dips due to motor starting can be expected. This will be most noticeable in industrial installations, but also in agricultural installations often connected to a weak rural network, which will experience less motor-starting dips.

Starting of drive-controlled motors is expected to lead to less severe dips than starting of induction motors, as ASDs typically allow controlled start-up conditions ("soft starting") and as a high starting current would require overrating of the ASD. However, the harmonic emission might be high during the starting of the motor, resulting in a new type of phenomenon, preliminary named "short-duration distortion due to device starting".

Improved methods for finding potential faults before they occur will result in fewer faults and therewith in fewer voltage dips.

The increased use of underground cables in distribution grids will result in more dips with a large phase-angle jump. However, as there are fewer faults in cables than in overhead lines, the total number of dips will be reduced.

4.2 Immunity

Equipment manufacturers are reasonably aware of the need to make their equipment more immune to voltage dips. However, standardization is still lacking and IEC 61000-4-11/34 still has only moderate requirements (equipment is allowed to trip, but should not be damaged). Future equipment may also be immune to other characteristics than residual voltage and duration (the ones mentioned in the standard) and equipment may actually be damaged when exposed to more severe dips than the ones in the standard. This concern is especially relevant for low-power equipment, where the power-quality knowledge of the manufacturer may be limited to what is required according to product standards.

The number of manufacturers of small end-user equipment is increasing and there is a much higher diversity in used power-electronic interfaces than in the past, when all equipment used the same four-pulse diode rectifier. This is expected to reduce the risk of mass-tripping of end-user equipment.

Equipment manufacturers should be made aware of the voltage dip check list created by CIGRE/CIRED/UIE WG C4.110 [7]. The dip immunity tests that were done 10 to 20 years ago should be repeated for modern equipment to assess their voltage-dip immunity. Not only residual voltage and duration should be considered, but also other relevant dip characteristics.

4.3 Fault-ride-through

This is basically the same as equipment voltage-dip immunity, but applies to generators. Similar to consuming equipment (see above), an assessment should be made of the potential impact of other characteristics (beyond residual voltage and duration) on the immunity. For large synchronous machines and their auxiliary supply, the impact of dips is rather well understood. But for smaller units, especially with power-electronics interface, the impact is less well understood.

4.4 Multiple dips and short interruptions

Single-phase fault-clearing and reclosing will result in “single-phase short interruptions”. Single-phase short interruptions can have different (including more severe) impact on equipment than three-phase. IEC 61000-4-30 classifies such events as dips, but with zero residual voltage. Additional characteristics are needed to get information that may be necessary to make the link with equipment performance. Possibly, a new type of event should be defined, somewhere in between a dip and a short interruption.

Due to increased use of automatic reclosing and feeder reconfiguration schemes, multiple dips and short interruptions are expected to occur more often. There is still a lack of knowledge on how these multiple events impact end-user equipment. During an earlier WG (C4.110), the issue of possible damage due to multiple events was discussed, but did not result in any conclusion. A thorough study of this is still very much needed.

5 NEW EMISSION

Several new emission-related issues are under discussion in the working group. The list below (which is most likely not complete) summarizes some of this.

For a number of reasons, there is an increasing emission in the frequency range between 2 and 150 kHz, also known as “supraharmonics”. This is discussed among others in a companion paper [2]. Although some standards exists that cover this frequency range [21], there is general agreement that there is a serious need for more standardization here. Not only the limits but also the performance indices to be compared with the limit (like THD, harmonic and interharmonics subgroups) need to be adapted to this new frequency range. Study of the propagation of supraharmonics will also require the development of new models for power-system components. For example, the coupling between primary and secondary side of transformers has to be considered.

A related issue is the need for new measurement techniques. Already without instrument transformers, measurements in this frequency range are far from trivial. The presence of instrument transformers, i.e. measurement of supraharmonics voltage and currents superimposed on high voltages and high currents, is a serious challenge. The presence of supraharmonics, where not anticipated, can also result in erroneous measurements at lower frequencies due to aliasing.

Power-line communication (PLC) is an important source of supraharmonics and the highest levels are typically due to PLC. But end-user equipment can also adversely impact PLC: either by creating a low-impedance path for the communication signal or through emission at the frequency of this signal.

Distributed generation will form new sources of harmonics, both (classical) harmonics and supraharmonics. Where it concerns harmonics it is important to realize that often a significant amount of DG can be installed without the need to strengthen the system. The result is an increase in harmonic current without a reduction in source impedance. A related issue is that the diversity between local sources of DG is likely to be much smaller than between loads.

The replacement of overhead lines by underground cables will shift resonances to lower frequencies. This will not cause new emission but it could result in amplification of existing emission. One example is the occurrence of harmonic overvoltages when energizing a transformer in the neighbourhood of an underground cable.

The replacement of incandescent lamps with LED and CFLs will create many new small sources of emission. Related to this is the growth in the number of small devices connected to the low-voltage grid. The total emission of all these small devices may be a substantial contribution to the voltage distortion.

Larger sources of harmonic distortion that may appear in the low-voltage grids are chargers of electric vehicles and electric heat pumps. At transmission levels, HVDC and FACTS devices are potential new sources.

There is a general trend of replacement of non-electronic loads by electronic loads. This takes away a source of damping at resonance frequencies. Together with the before-mentioned shift of resonances to lower frequencies, it could result in a local or global increase in harmonic voltage levels.

6 FEEDER RECONFIGURATION

Automatic feeder reconfiguration is a feature for improved service to the customers following a fault or a system disturbance. Reconfiguration of feeders, automatic or manual, is also required during other situations like load balancing and load isolation. While automatic feeder reconfiguration has a larger impact on PQ parameters like short interruptions, manual reconfiguration can also affect long interruptions. It is always desirable that PQ is preserved during feeder reconfiguration situation other than faults. However, following a fault, some network operators and regulators may allow PQ parameters to deviate for a short period of time.

The report will present a range of scenarios under which PQ parameters will be affected. The scenarios include feeder reconfigurations as a consequence of network faults as well as normal network operation. A distinction will be made between feeder reconfiguration following a fault and feeder reconfiguration not associated with a fault. For feeder reconfigurations following a fault, the period during the fault or the way in which the operation of the protection impact the PQ are not considered. Feeder reconfigurations i) to enable maximum penetration of DG resources and ii) for preventive maintenance are considered as scenarios for normal network operation.

7 DEMAND SIDE MANAGEMENT

Two types of Demand Side Management (DSM) are distinguished:

- Energy Efficiency and Energy Conservation DSM programmes, when less-efficient types of equipment are being replaced by more energy-efficient equipment (e.g. replacement of incandescent lamps with CFLs and LED lamps); this includes technology improvement of equipment, typically occurring over longer time-scales (e.g. replacement of CRT TVs with LED TVs);

- Direct DSM control of equipment aimed at reducing system peak load, as a part of system balancing, to provide different types of system reserve, or to improve the network performance.

7.1 Network-related effects

Connecting and disconnecting specific types of loads will change network characteristics and impact grid performance. This is manifested by, e.g. changes in harmonic emissions, or dynamic characteristics of the aggregate loads, and their further interactions with the network and system impedance.

More frequent switching of groups of loads in various DSM scenarios will lead to deeper and/or more frequent system voltage variations, which might then require fundamental changes in voltage control. This could be a closer coordination of the DSM scheme with the reactive power compensation, as well as active or passive filtering in the network.

7.2 Customer-related effects

Increased energy-efficiency of equipment is often made possible through the use of active power-electronic converters, forming a part of the grid interface of the equipment. A drawback of the use of power-electronic interfaces is the possible increase of harmonic distortion levels and introduction of new electromagnetic interference. Although it is possible to make power electronic loads to tolerate a wide range of disturbances, they are in practice often more sensitive to PQ disturbances than classical equipment. The tripping or malfunctioning of the devices may have a further negative impact on the grid or on nearby equipment.

Replacement of resistive and linear loads with non-linear power electronic loads (e.g. incandescent lamps with CFLs, LED lamps and directly-connected motors with ASD-controlled ones) will influence dynamic system behaviour and responses to faults. Where it concerns harmonic distortion, the capacitors often present on grid-side of the converter will introduce new resonances. The reduced amount of resistive load will result in a higher amplification at existing and new resonance frequencies.

Anticipated near-future electrification of the road transportation sector will introduce a large-scale deployment of electric vehicle battery chargers, which are also non-linear power electronic loads with possible negative impact on PQ and also one of the possible targets of DSM actions and schemes.

7.3 Special considerations for reactive schemes

Considerations should be given to the assessment of DSM on PQ regarding “reactive” vs. “preventive” DSM schemes. Reactive schemes might be needed to “save the system” and during their activation PQ requirements may become secondary. Care should be taken to avoid damage to end-user equipment or wide-scale equipment mal-operation, especially when reactive schemes will be activated more often than is the case currently.

7.4 EMI issues

It is anticipated that a large number of communication, monitoring and metering systems will be applied in future electricity networks. Consequently, there will be an increased possibility for electromagnetic interference (e.g. with power line carrier signals, but also other communication systems), delays in two-way communication, as well as possible problems in sharing communication infrastructures. It is already reported that specific PQ disturbances (e.g. harmonics coming from customer loads) may interact with the DSM control signals (e.g. interference with power line carrier signals) [12][13].

Research has shown that disturbances originating in the LV network can travel to the MV network through the transformer's parasitic couplings [14]. As these disturbances can cause interference in remote locations, their origin can be difficult to find. Techniques to shield wires from EMI have been developed over the years for locations such as substations, but they might not be enough to prevent the harmful effects of EMIs caused by transients [15]. In addition, EMI caused by radio frequency phenomena, as well as harmonics, needs to be further evaluated.

7.5 Power-Quality-driven DSM

Frequency control is a prime example of DSM of the second type (see above). By aggregating a large number of energy rather than power-reliant loads [16] it is feasible to support the grid frequency by controlling the usage cycle of especially heating and cooling loads. More recent research [17] also incorporates wind farms.

Frequency control is in general not aimed at improving the power quality, but at maintaining the global balance between production and consumption. Similar methods may however be developed for improving other PQ performance characteristics. Examples include methods to optimize the voltage profile of the network, whilst simultaneously taking into account the load priority [18], or smoothing the power consumption curve [19]. Similar methods are developed incorporating battery energy storage systems, which are capable of feeding both active and reactive power to the grid [20].

8 VOLT-VAR-CONTROL

Volt-var control will likely be different in the future from what it is today. This will be partly driven by necessity, partly by the availability of new technology. Whereas overall this will have a positive impact on the voltage variations in the distribution network, there are also a number of potential negative impacts.

Some of the potential negative impacts include:

- Increased number of short-duration undervoltages including shallow voltage dips.
- An increased number of (individual) rapid voltage changes and the associated increase in flicker severity.
- Additional resonances with the risk of high levels of harmonic distortion.
- The emission of harmonics and supraharmonics by some of the devices used for VVC.
- A higher number of switching transients, including higher frequencies due to back-to-back switching and higher overvoltages due to multiple resonance frequencies being excited.
- The actual impact will depend strongly on the aim and implementation of the VVC.

9 POWER QUALITY AND ECONOMICS

The transition to a sustainable society has changed the types and amount of equipment connected to distribution grid. New energy efficient lighting, increasing number of photovoltaic panels (PVs), electric vehicles (EVs) and electric heat pumps cause more voltage variations and emit more harmonics than before.

There is a trend to evaluate the cost and value of power quality in the electricity market environment. The devices that cause voltage variations or emit harmonics should be responsible to the quality issue. Currently, distribution companies invest in devices to regulate voltages and absorb harmonics. The investment is done centrally without identifying the sources that cause the power quality disturbance. The investment is considered as a distribution service to maintain power quality, and the cost is recovered from customers' electricity bills. However, some equipment that generates more power quality disturbances is not identified for their negative impacts on the grid. A recurring question is whether the owners of equipment generating power quality disturbances should pay more for connecting to the grid than equipment not generating such disturbances. There is still no obvious answer to this question.

Voltage support service in transmission grid has been considered as one of the ancillary services, which can be valued and purchased from generators. This is an example for distribution network to have economic evaluations for voltage variations caused by newly installed DGs and equipment. Harmonic emissions can be evaluated using sensitivity analysis.

Market mechanisms can form the basis for control and communication involving PVs, EVs, electric heating, and other network users. Such market mechanism can also form the basis for future regulation on voltage quality and as a base for future network markets.

10 CONCLUSIONS

The work within this working group is on-going, but the discussions are far from reaching their conclusions. With two more years to go towards the final report (at the time of writing of this paper) a lot more contributions can be included.

Anybody willing to comment or contribute to the material presented in this paper is therefore encouraged to contact the authors of this paper or the members of the working group.

11 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.

12 LITERATURE

[1] A-Moreno-Munoz, S. Rönnberg, A. Gil de Castro, M. Bollen, E. Romero-Cadaval, “Ongoing work in CIGRE working groups on supraharmonics from power-electronic converters”, *CIRED*, June 2015.

[2] M. Bollen, S. Rönnberg, F. Zavoda. ”CIGRE/CIRED C4.24 – power quality in the future grid – first introduction”, *Great Lakes Symposium on Smart Grids*, September 2014.

[3] M. Bollen, S. Bahramirad, A. Khodaei, J. Meyer, R. Langella, J.P. Hasler, F. Zavoda, J. Liu, “Volt-var control and power quality (CIGRE/CIRED/IEEE C4.24)”, *CIRED*, June 2015.

[4] F. Zavoda, J. Meyer, M. Bollen, S. Rönnberg, J. Desmet, “CIGRE/CIRED/IEEE working group C4.24 – New measurement techniques in the future grid”, *CIRED*, June 2015.

[5] P. Waide and C. Brunner, “Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems,” p. 132, *International Energy Agency*, 2011.

[6] P. Zwanziger, L. Trevisol, and T. Hornung, “Plenairy discussion- CEMEP: Catching-up to pass,” Proc. of the 8th conference on *Energy Efficiency in Motor Drives Systems* (EEMODS), Rio de Janeiro, 2013, p. 11.

[7] Almeida, F. Ferreirra, J. Fong, and P. Fonseca, “European Ecodesign Directive on Energy- Using Products (EUP’s), Project LOT 11 Motors,” Coimbra, p. 2008.CIGRE/CIRED/UIE C4.110, Voltage dip immunity of equipment and installations, *CIGRE TB 412*.

[8] P. Pakonen, S. Vehmasvaara, M. Pikkarainen, B.A. Siddiqui,, P. Verho, "Interference of touch dimmer lamps due to PLC and other high frequency signals," *Electric Power Quality and Supply Reliability Conference (PQ), 2012*, June 2012.

[9] IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents, *IEEE Std.* C57.110-2008.

[10] C.Y. Lee; W.J. Lee, "Effects of Nonsinusoidal Voltage on the Operation Performance of a Three-phase Induction Motor," *Energy Conversion, IEEE Transactions on* , vol. 14, no. 2, pp. 193-201, June 1999.

[11] P. Pakonen, S. Vehmasvaara, M. Pikkarainen, B.A. Siddiqui,, P. Verho, "Experiences on narrowband powerline communication of automated meter reading systems in Finland," *Electric Power Quality and Supply Reliability Conference (PQ), 2012* , pp.1-6, 11-13 June 2012.

[12] G.A. Franklin, “A Practical Guide to Harmonic Frequency Interference Affecting High-Voltage Power-Line Carrier Coupling Systems”, *IEEE Transactions on Power Delivery*, Vol. 24 No 2 pp. 630 – 641, 2009.

[13] S.K. Rönnberg, M.H.J. Bollen, M. Wahlberg, “Interaction between narrowband power-line communication and end-user equipment”, *IEEE Transactions on Power Delivery*, Vol.26, No.3 (July 2011), pp.2034-2039.

[14] R. Smolenski, M. Jarnut, A. Kempski, and G. Benysek, “Compensation of CM voltage in interfaces for LV distributed generation”, *Electromagnetic Compatibility (EMC)*, 2011 IEEE International Symposium on, 2011, pp. 351–356.

[15] C. de Abreu Silveira, C. A. da Costa, R. da Costa e Silva, L. R. Soares, and J. C. P. Guimarães, “Electromagnetic environment measurement under steady-state conditions in utility substations,” in *Transmission & Distribution Conference and Exposition: Latin America*, 2006. TDC’06. IEEE/PES, 2006, pp. 1–6.

[16] P. J. Douglass, R. Garcia-Valle, P. Nyeng, J. Ostergaard, and M. Togeby, “Demand as frequency controlled reserve: implementation and practical demonstration,” *Innovative Smart Grid Technologies (ISGT Europe)*, 2011 2nd IEEE PES International Conference and Exhibition on, 2011, pp. 1–7.

[17] Molina-Garcia, I. Munoz-Benavente, A. D. Hansen, and E. Gomez-Lazaro, “Demand-Side Contribution to Primary Frequency Control With Wind Farm Auxiliary Control,” *IEEE Trans. Power Syst.*, vol. 29, no. 5, pp. 2391–2399, Sep. 2014.

[18] J. Agneessens, T. Vandoorn, B. Meersman, and L. Vandevelde, “The use of binary particle swarm optimization to obtain a demand side management system,” *Renewable Power Generation* (RPG 2011), IET Conference on, 2011, pp. 1–6.

[19] S. Iacovella, F. Geth, F. Ruelens, N. Leemput, P. Vingerhoets, G. Deconinck, and B. Claessens, "Double-layered control methodology combining price objective and grid constraints," *Smart Grid Communications (SmartGridComm)*, 2013 IEEE International Conference on, 2013, pp. 25–30.

[20] V. P. Sinha, B. Comblin, S. Massin, S. Rasov, and P. Rosenfeld, "Application of LV active filter in battery energy storage system," *Harmonics and Quality of Power (ICHQP)*, 2012 IEEE 15th International Conference on, 2012, pp. 220–225.

[21] M.H.J. Bollen, E.O.A. Larsson, "Emission and Immunity of Equipment in the Frequency Range 2 to 150 kHz", *Bucharest Power Tech*, July 2009.