Voltage Quality in the context of EMC

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Abstract—**The aim of this paper is to define responsibilities for grid operators and network owners, as well as for those responsible for electromagnetic immunity and emission of equipments, including the standardisation community. Starting with a summary of the development of the concepts of Voltage Quality and Electromagnetic Compatibility – EMC respectively, similarities and differences in the concepts are discussed. Based on the framework of EMC, requirements for grid operators, owners and other stakeholders are proposed in terms of network strength and on how to distribute available emission levels in order to comply with defined voltage disturbance planning levels. At low voltage a standardization approach is suggested and for higher voltage a scheme to achieve the required voltage quality for electromagnetic compatibility.**

I. INTRODUCTION

Over time, to larger extent, electricity is converted into other forms of energy using electronics; both in control and in main circuits, the latter based on power electronics. As one example, European Union member states experts have agreed to phase out regular incandescent lamps by 2012 [1]. Furthermore, our society is increasingly dependent on electricity as an efficient energy carrier. This has led to an awareness of the quality of the electricity in terms of functionality when converted to useful energy. Examples of useful energy are electric light, telephone and internet communication, and electricity based industrial manufacturing processes, transport in trains etc. For the carrier of energy the qualities of the electricity beyond its continuity of supply are less important as long as the functionality for the end user is reasonably secure.

In this paper Voltage Quality is discussed in the context of EMC – Electromagnetic Compatibility as a concept to accomplish functionality in the use of electricity.

II. POWER QUALITY AND VOLTAGE QUALITY

A. *Power Quality and Quality of Electricity Supply*

Power Quality is defined as “characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters”, including also interruptions, i.e. loss of continuity of supply [2].

Council of European Energy Regulators (CEER) includes three elements in the term Quality of Electricity Supply being Commercial Quality, Continuity of Supply and Voltage Quality [3].

B. *Voltage Quality*

In a recent CEER report [4], the term Voltage Quality parameters used in [3] is replaced by the term Voltage disturbances with explicit reference to Electromagnetic Compatibility as the aim of Voltage Quality.

CEER refers to the following as Voltage disturbances [4]:

- Frequency and time deviation
- Voltage dips
- Supply voltage variations
- Harmonic voltages (including interharmonics and subharmonics)
- Mains signalling superimposed on the supply voltage
- Flicker
- Rapid voltage changes
- Voltage swells
- Voltage unbalance
- Transient overvoltages

EURELECTRIC – The Union of the Electricity Industry in Europe, states Quality of Supply is a general term which, “besides continuity of supply and voltage quality, may also include commercial aspects such as service quality” but in [5] it defines Quality of Supply as continuity of supply and commercial aspects, i.e. excluding Voltage Quality. In the following the principal set of disturbances in [4] is used as definition, i.e. Voltage Quality meaning deviations from ideal symmetrical sinusoidal voltage conditions.

As a response to a formal declaration that electricity is a product concerning liability for defective products according to European Directive 85/374/EEC [6], a European standard for voltage characteristics [7] has been developed mainly as an initiative by European grid companies. In [4] a comparison between the voltage disturbance naming in the global IEC EMC standard [2] and the European voltage characteristic standard [6] is presented. It is clear that the same phenomena are given different names in the standards with no apparent reason.

III. EMC – STANDARDS AND DIRECTIVES

A. *Structure of EMC within IEC*

Electromagnetic compatibility is defined as [8] “the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment”.

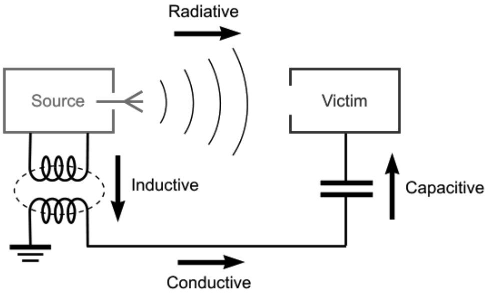

Fig. 1. Electromagnetic Interference Coupling Modes [9]

Modes of propagation of electromagnetic disturbances are shown in Fig. 1. Radiated – classical – EMC has been on the agenda for many years, e.g. in the standardization organisation CISPR – The International Special Committee on Radio Interference – which was set up in year 1934 [10].

In later years, the concept of EMC has been applied also in relation to conducted low and high frequency electromagnetic disturbances in electrical networks. Within IEC – International Electrotechnical Commission, Technical Committee TC 77 is responsible for Basic and Generic EMC publications describing and classifying electromagnetic environments also covering emissions, immunity, test procedures, measurement techniques, etc. [11]. Low frequency is defined as frequency from 0 Hz up to and including 9 kHz, which is under the responsibility of Subcommittee SC 77A.

EMC material within IEC comprises a comprehensive and coordinated set of standards, technical reports etc. with the collective aim to achieve compatibility in between equipment.

B. *EMC in the European Union EMC Directive*

The first version of the EMC Directive of the European Union (EU) came into force on 1st January 1992. Thereafter the directive has been amended several times and after a long period of development, a new EMC Directive was published in the Official Journal of the EU on 31st December 2004 [12].

One major development of the current EMC Directive is the inclusion of fixed installations into the scope of EMC in addition to the apparatus. The common term equipment is used jointly for apparatus and fixed installations, with the same general protective requirements valid for both.

Some examples of fixed installations according to the EMC Guide [13] of the European Union are: Power plants, power supply networks, wind turbine stations, industrial plants, car assembly plants, railway infrastructures, air conditioning installations, water pumping stations, water treatment plants, airport luggage handling installations, airport runway lighting installations, and skating hall ice rink machinery installations. According to the EMC Guide, the definition of fixed installation is wide and the “definition covers all installations from the smallest residential electrical installation through to national electrical and telephone networks, including all commercial and industrial installations”.

C. *EMC and Safety – IEC and the EU*

In addition to the issue of functionality being related to EMC, TC 77 also covers safety aspects of electromagnetic compatibility [11]. This is different from the regulation in the EMC Directive of the European Union in which safety related EMC is not in the scope but covered by other directives.

IV. ACHIEVEMENT OF EMC IN AN ELECTRIC GRID

A. *EMC Phenomena*

The IEC defines the following principal electromagnetic conducted phenomena [10]:

Conducted low-frequency phenomena:

- Harmonics, interharmonics
- Signals superimposed on power lines
- Voltage fluctuations
- Voltage dips and interruptions
- Voltage unbalance
- Power frequency variations
- Induced low frequency voltages
- DC component in AC networks

Conducted high-frequency phenomena:

- Induced voltages or currents
- Unidirectional transients
- Oscillatory transients

Here the IEC is fully in line with EU and in the EMC Guide a comprehensive list with examples of electromagnetic phenomena is presented [13]. It shall be noted that both IEC and EU include interruptions as an electromagnetic phenomenon.

Comparing with the list of CEER (see subsection B in section II) the disturbances are essentially covered by the IEC and EU list of phenomena. Measurement of Power Quality is furthermore defined in an EMC standard of IEC [2].

B. *Basic Concepts to Achieve EMC in Electric Grids*

Electromagnetic compatibility in terms of voltage quality is related to immunity and emission of equipment connected to an electric grid in which electromagnetic disturbances can propagate.

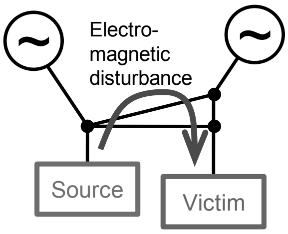

Fig. 2. Propagation of electromagnetic disturbance in an electric grid

As illustrated in Fig. 2, an electromagnetic disturbance can propagate from a source to one or several victims via the electric grid. There may be several sources from which disturbances are added thus jointly contributing to a level of disturbance at a specific site in a grid.

In addition, there may well be grid equipment itself emitting disturbances, as well as disturbances from other origins inside the grid such as natural lightning as illustrated in Fig. 3a. Here, the grid itself is an equipment emitting disturbances. Seen from the victim position, there is no difference whether the origin of the disturbance is from equipment being connected to the grid as in Fig. 2 or whether the origin is within the grid itself.

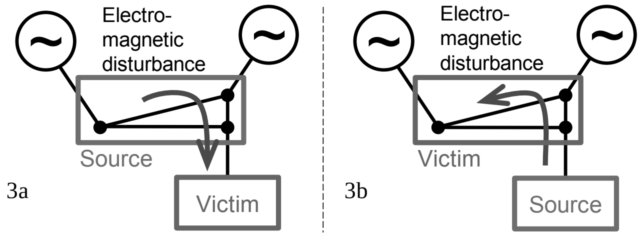

Fig. 3. Propagation of electromagnetic disturbance in an electric grid

Furthermore, especially at lower voltage levels, a disturbance level may be the common result of a vast number of sources emitting disturbances.

In principle, though rarely the case in real life, electromagnetic disturbances may propagate from a source to the grid as victim in the case where it contains sensitive equipment, see Fig. 3b. The grid itself can in this case be regarded as equipment. This is also stated in the clause (18) of the EMC Directive preamble: “Fixed installations, including large machines and networks, may generate electromagnetic disturbance, or be affected by it.”

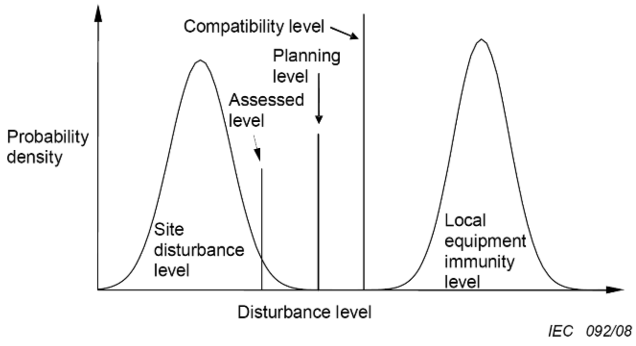

Fig. 4. Voltage quality concepts with time statistics in a site within a grid [17]

In the concept of EMC, keeping control of the electromagnetic disturbance level, the compatibility level, is just a means to achieve compatibility. Local equipment immunity levels should be higher than the site disturbance level in order to achieve EMC, see Fig. 4. To ensure a certain margin to the compatibility level, a planning level is applied by the grid operator or network owner.

C. *Examples of Electromagnetic Disturbances with Impact on Voltage Quality*

An example of electromagnetic disturbance is voltage fluctuations caused by electrical arc furnaces at steel plants. Such varying loads result in high and rapidly fluctuating power demand from the grid with changes in the order of 10 per second. This may cause fluctuations in the light from lamps, flicker, thus being an example of lack of EMC.

Another common example of disturbance is voltage dips e.g. where natural lightning causes flashover on overhead lines. During flashover one or several phases are electrically connected to each other and/or to ground through the arc in open air, thus resulting in a voltage close to zero at the location of the lightning strike. After automatic opening and reclosing of the line breaker(s), the line insulation level is mostly sufficient for normal line operation. During the process of short-circuit, breaker opening and re-closing, electrical equipment connected to a meshed grid may experience a short-time reduction in voltage, being the voltage dip.

A study in Sweden has estimated the cost for short duration interruptions (≤ 3 min.) and voltage dips to be 100 to 150 million € per year [14], where the main cost is related to stops in industrial processes such as paper mills.

D. *Network Strength*

A basic performance of a grid at a certain site (point of connection) is its strength, normally at medium and high voltage levels defined as short circuit power and at low voltage level as network impedance. At a low voltage level, minimum network strength is normally required for safety reasons in order to make fuses blow and thereby disconnect parts of electrical installations sufficiently fast in case of short-circuits. A good strength of the grid is a basic capacity especially when handling low frequency phenomena such as voltage fluctuations and lower order harmonics.

V. RESPONSIBILITIES OF A GRID OPERATOR OR NETWORK OWNER

A. *Network Strength*

EMC standards use certain reference impedances when defining emission limits for low voltage equipment. For that purpose it is therefore sensible to define maximum levels of the network strength, i.e. impedance, for low voltage grids.

For medium and high voltage grids it is reasonable to require minimum network strength at a certain connection point in a grid. The rationale is as stated in clause (14) in the preamble of the EMC Directive: “Network operators should construct their networks in such a way that manufacturers of equipment liable to be connected to networks do not suffer a disproportionate burden in order to prevent networks from suffering an unacceptable degradation of service”.

Grid companies are introducing network strength as planning criterion in the EMC context [15] and an example of similar views from a national authority is given in [16]. A simple criterion for network strength is the maximum step change when a certain load instantaneously is connected or disconnected, such as a maximum voltage step of 3 % for connection or disconnection of the full contracted power demand [15].

B. *Emission Levels to Achieve Planning Levels*

For **low voltage** domestic equipment there are a comprehensive set of standards for emission and immunity, mainly for low frequency phenomena assuming a certain level of network strength – impedance. Combining a proper selection of network strength and emission and immunity levels, electromagnetic compatibility will be achieved with a reasonable probability in a low voltage public grid over time and space. Given that the EMC standardisation work is functioning adequately, manufacturers of equipment, grid operators and owners etc. are complying with the standards; there should normally be no difficulty to comply with reasonable planning levels of public low voltage grids with sufficient network strength. If electromagnetic incompatibility would occur to a significant extent, the EMC standardisation community would ideally take actions in order to again achieve compatibility. One possible such case can be requirements when incandescent lamps on a large scale are being replaced by low energy lamps using electronics.

At **medium and high voltage** levels, with a lack of comprehensive standards for emissions and immunity, the grid operator or owner should take the responsibility to distribute the available emission levels to its grid customers in order to keep the disturbance levels within planning levels. Useful documents in this context are e.g. [17] and [18]. It shall be noted that the grid operator or owner has an important role to provide all necessary information to its grid customer, such as emission limits and network strength to facilitate the work of the customer to fulfil emission requirements on his equipment.

A challenge for the responsibility is to fairly distribute available emission levels to the existing as well as future grid customers.

C. *Technical Requirements*

In addition to the above responsibilities of the grid, it may e.g. well be reasonable to have amended specific technical requirements such as maximum time of breaker operations for clearing faults at medium and high voltage levels, which have an influence on the duration of voltage dips, i.e. emissions from the grid. Also electrical safety is related to fault clearing.

D. *Voltage Quality as a Means to Achieve EMC*

With voltage quality seen as a means to achieve EMC the function of electrical equipment is in focus. As a concrete example, imagine an industry causing annoying light variations, flicker, for neighbouring residents. Using the EMC approach, in principle, one possible solution would be that the industry provides low energy lamps which have good immunity to voltage variations, i.e. with stable light even with severe voltage conditions. Then voltage quality would be outside normal acceptable limits but EMC prevail. With EMC function (including performance) of electrical equipment is in focus rather than quality of voltage. Voltage quality is just a means to achieve EMC.

VI. CONCLUSION

Over time, the concept of electromagnetic compatibility has evolved to also encompass the area of voltage quality in electrical grids. With the basic idea of electromagnetic compatibility being equipment not disturbing and not being disturbed, the quality of the voltage is essentially a means in order to achieve a proper function of equipment.

Based on the framework of EMC, it is proposed here that requirements are set on grids in terms of network strength and the distribution of emission levels in order to comply with defined planning levels. At low voltage a standardization approach is suggested and for higher voltage a scheme for distributing available emission limits to achieve required voltage quality needed for electromagnetic compatibility.

The approach presented here is intended to be a basis for a practical sharing of responsibilities between grid owners or operators and other parties in the joint work to achieve EMC.

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