

FRAMEWORK FOR ELECTROMAGNETIC COMPATIBILITY IN ELECTRIC POWER SYSTEMS

MAGNUS OLOFSSON¹, SWEDEN, ULF GRAPE², SWEDEN

¹Swedish National Electrical Safety Board, e-mail: magnus.olofsson@elsakerhetsverket.se,

²Vattenfall Research and Development, e-mail: ulf.grape@vattenfall.com

Abstract—The aim of this paper is to propose principles on how to apportion responsibilities between grid and connected equipment with the aim to achieve electromagnetic compatibility in electric power systems. Examples of good engineering practices for grids in relation to electromagnetic compatibility are shown. Also, how to identify and characterise voltage dips is discussed. A dual approach of responsibilities for grid and connected equipment with respect to electromagnetic compatibility is proposed. In public low voltage systems where product standards are generally available, coordinated grid and product requirements will be a basis for electromagnetic compatibility. In medium and high voltage systems, in absence of comprehensive equipment emission and immunity standards, it is suggested that the grid responsible party provides relevant data such as on voltage dips to the party responsible for connecting equipment to the grid.

I. INTRODUCTION

Electromagnetic Compatibility (EMC) is a fundamental concept meaning “the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment” [1]. Applying the terminology of the EMC Directive [2], a system can be a fixed installation. The umbrella term equipment is used for apparatus and fixed installations in the EMC Directive, i.e. equipment = apparatus + fixed installation. In this paper only conducted electromagnetic disturbances are discussed.

II. THE ELECTRIC GRID AS EQUIPMENT

Annex I of the EMC Directive states: “A fixed installation shall be installed applying good engineering practices and respecting the information on the intended use of its components, with a view to meeting the protection requirements...”. Protection requirements are the fundamental properties of emission and immunity for equipment. The EMC Directive furthermore state that “Those good engineering practices shall be documented and the documentation shall be held by the person(s) responsible at the disposal of the relevant national authorities for inspection purposes for as long as the fixed installation is in operation”.

Disturbance propagation between equipment connected to an electric grid (electric network) is illustrated in Fig. 1. Disturbances can also propagate from the grid itself to connected equipment or vice versa as presented in Fig. 2 [3]. Furthermore, seen from a site in which equipment are connected to the grid it cannot always be identified if a disturbance originates from within the grid itself or from equipment(s) connected to the grid.

According to the EMC Guide [4], 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 instal-

lations”. An electric grid is thus equipment for which protection requirements apply.

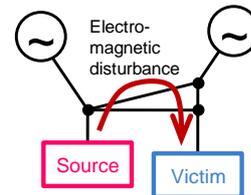


Fig. 1. Propagation of an electromagnetic disturbance between equipment connected to the grid

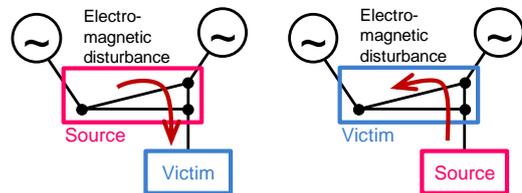


Fig. 2. Propagation of an electromagnetic disturbance between the grid and equipment connected to the grid

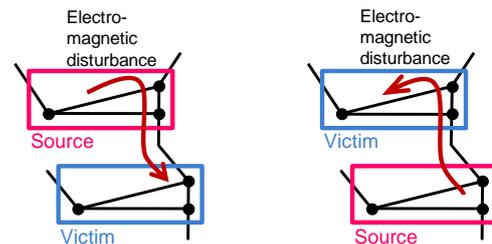


Fig. 3. Propagation of an electromagnetic disturbance between grids

Electric grid (network) is also referred to equipment in clause (18) of the EMC Directive preamble: “Fixed installations, including large machines and networks, may generate electromagnetic disturbance, or be affected by it.” Basic function of an electric grid is energy transfer with adequate Voltage Quality at connection sites, i.e. with electromagnetic disturbance levels within reasonable limits. Emission and immunity are thus most relevant also for grids. Disturbances may propagate between grids as illustrated in Fig. 3 and emission from a grid may be seen as a cumulative effect of a large number of

connected equipment. A disturbance can also originate in one grid, propagate first to another grid (possibly with a different grid responsible party) and cause interference for end-user equipment connected to this latter grid.

III. BASIC CONCEPT TO ACHIEVE ELECTROMAGNETIC COMPATIBILITY

In order to achieve electromagnetic compatibility in an electric system, immunity of equipment connected to a grid should to a reasonable extent be higher than the electromagnetic disturbance level to which it is exposed. For a device connected to a power grid, this disturbance level is the Voltage Quality. The disturbance level in a grid is generally not constant and varies with time and site location. Also the immunity of equipment may vary with time and between different equipment of the same type. As a result probability distribution of emission and immunity levels should be considered. This is shown schematically in Fig. 4.

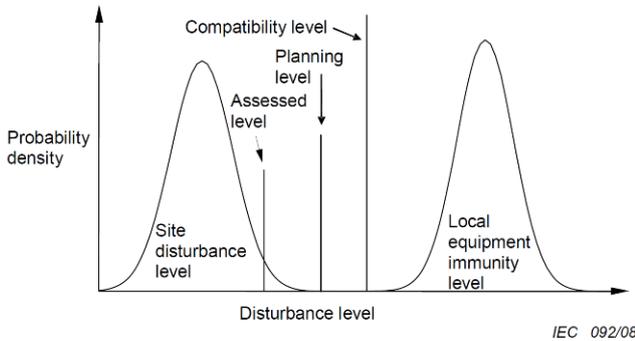


Fig. 4. Voltage Quality concepts with time statistics in a site within a grid [5]

IV. ELECTROMAGNETIC DISTURBANCES

A. Principal Electromagnetic Phenomena

The IEC – International Electrotechnical Commission defines the following principal electromagnetic conducted phenomena [6]:

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

B. Voltage Dips

Voltage dips is one type of disturbance phenomena emitted from grids which result in substantial economic costs. A common source of voltage dips is natural light-

ning causing flashover on overhead lines. During flashover one or several electrical 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 reclosing, electrical equipment connected to a meshed grid may experience a short-time reduction in voltage, which is the voltage dip. Voltage dips are discussed in detail in [7].

Studies in Sweden has estimated the cost for short duration interruptions (≤ 3 min.) and voltage dips to be 100 to 150 million € per year [8], where the main cost is related to stops in industrial processes such as paper mills. Studies for other countries have shown similar results.

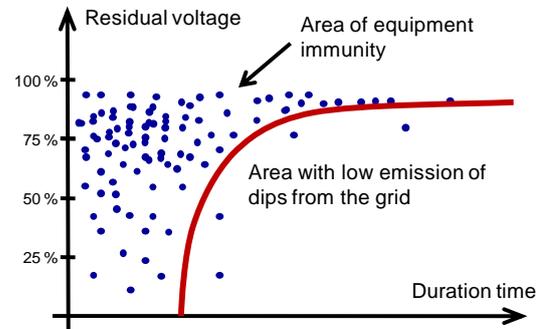


Fig. 5. Areas of equipment immunity and low emissions of voltage dips

C. Assessment of Voltage Dips

An individual voltage dip is, according to [9], characterized by two parameters; the residual voltage and the duration. Individual voltage dips during a certain time period are indicated as blue dots in Fig. 5 using the residual voltage and duration as coordinates. In order to achieve electromagnetic compatibility, immunity of connected equipment is preferably such that a reasonably share of dips are within the immunity area.

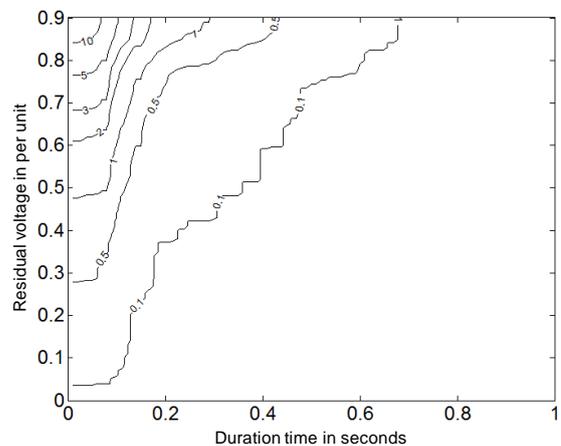


Fig. 6. Example of contour map for voltage dips [11]

The scatter plot in Fig. 5 can be made for a specific site in a grid or for a large geographic area such as a country or continent representing many sites within a given time frame, e.g. one year.

An alternative representation of voltage dips is the use of contour maps [10], [11] – see Fig. 6. Also contour maps can be made for a specific site or as a representation of many sites in a geographic area. Each contour in the map represents the same number of dips during a time interval e.g. one year. For a specific site it is normally very challenging to base the contour map on measurements due to infrequent events and related lack of statistical confidence. A more practical method is to apply engineering judgement and/or calculations.

Naturally, in a three-phase electrical system there are a number of different types of voltage dips due to e.g. various combinations of faults and transformer connections between the fault and the observation point in the grid [7]. A classification of dips in three phase-systems is used by CIGRE/CIREU/UIE working group C4.110 [12]. Voltage dips can be characterised to facilitate immunity requirements on equipment, individual or groups of equipment in industrial processes such as a paper machines [12].

V. FRAMEWORK FOR ELECTROMAGNETIC COMPATIBILITY IN POWER SYSTEMS

A. Protection Requirements for Grids

To achieve EMC in power systems, coordinated requirements for grid and equipment connected to the grid are essential. Examples of good engineering practices for a grid to fulfil protection requirements of equipment (emission and immunity) are:

- Reasonable network strength [13], [14]
- Proper frequency control (for system operators)
- Appropriate voltage control, e.g. transformer tap changer settings and reactive power control
- Selection of right-of-ways for new lines considering geographical natural lightning density
- Proper line maintenance and inspections including right-of-ways tree trimming
- Adequate lightning protection
- Effective earthing and bonding
- Application of bird deterrent to avoid insulator flashover from bird droppings when needed
- Regular substation inspections and maintenance
- Fast relay protection and circuit-breaker operations for the benefit of short duration time of voltage dips
- Synchronized switching applied for energizing of capacitor banks and reactors when appropriate to avoid inrush transients

Adequate network strength is mainly relevant with respect to low frequency phenomena such as low order harmonics and flicker. Reasonable network strength can be expressed as a maximum voltage step of e.g. 3 % for connection or disconnection of the contracted power demand as in [13]. Good network strength increases the

grid ability to absorb low frequency emissions from disturbing equipment, i.e. supporting immunity against deficient Voltage Quality. For the severance and occurrence rate of voltage dips and interruptions being emitted from a grid, maintenance and design including relay protection speed combined with circuit-breaker operating times are essential. Emissions of voltage transients originating from switching and to some extent also natural lightning can be mitigated using modern switchgear technology. It can be repeated that for fixed installations, such as grids, the EMC Directive states that application of good engineering practises shall be documented.

B. Grid Planning Levels and Allocation of Emission Levels

Having a grid designed according to good engineering practices, planning levels can be defined to apply a margin to a compatibility level as illustrated in Fig. 4. In **medium and high voltage** systems, with a lack of comprehensive equipment emission and immunity standards, the grid responsible party is proposed to take the responsibility to allocate available emission levels to connected equipment in order to keep disturbances within planning levels.

C. Protection Requirements on Connected Equipment

For public **low voltage** systems, product standards harmonized to EMC Directive are generally available. These product standards are linked with compatibility levels defined in electromagnetic environment standards. Here work within the standardisation community is vital as expressed 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. The European standardisation organisations should take due account of that objective (including the cumulative effects of the relevant types of electromagnetic phenomena) when developing harmonised standards.”

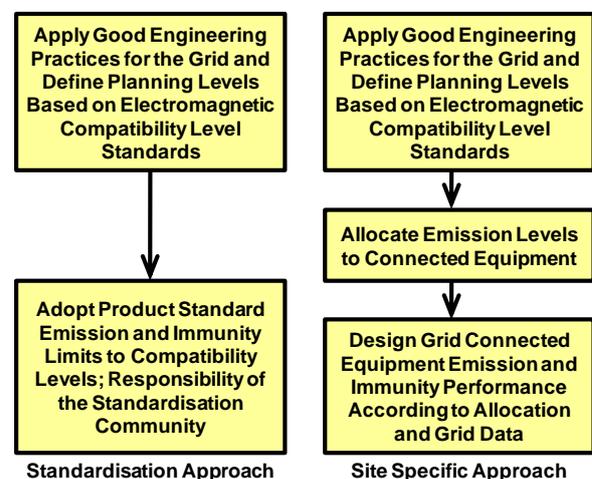


Fig. 7. Dual approach to achieve electromagnetic compatibility

With this as a basis, corresponding product [equipment] standards will be based on compatibility levels from which also grid planning levels can be defined. Proposed grid and product responsibilities are given in Fig. 7 where the left part summarizes the standardization approach applicable to e.g. low voltage public systems. The standardization approach is a coordinated holistic basis to achieve electromagnetic compatibility.

At **medium and high voltage** levels, it is reasonable that the grid responsible party provides relevant information to the party connecting equipment to the grid in order to ensure proper design of the equipment – right part of Fig. 7. Examples of such information are planning levels relevant to immunity of connected equipment and allocated emission levels possibly along with network strength. For voltage dips, planning levels may be given as site contour maps as of Fig. 6. With this information, proper investment decisions can be made for equipment to be connected to the grid using e.g. dip immunity classes in standards [15], [16]. It is recognised that setting appropriate immunity requirements is a trade-off between investment cost and the cost of interruptions in e.g. an industrial process.

VI. CONCLUSION

It is proposed that the electrical grid is regarded as equipment and good engineering practices for electromagnetic compatibility protection requirements are to be considered and documented. A number of such technical considerations can be included in the design, maintenance and operation of the grid. In public low voltage systems where product standards are generally available, coordinated grid and product requirements will be a basis for electromagnetic compatibility. In medium and high voltage systems, in absence of comprehensive equipment emission and immunity standards, it is suggested that the grid responsible party provides relevant data such as on voltage dips to the party responsible for connecting equipment to the grid.

ACKNOWLEDGMENTS

The authors acknowledge the IEC – International Electrotechnical Commission for the extract used in Fig. 4. Also thanks to the authors of [11] for the use of the contour graph in Fig. 6.

REFERENCES

- [1] *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*, IEC 600 50-161 Std., Available: <http://www.electropedia.org>.
- [2] *Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC*, L 390/24, Official Journal of the European Union, 31st Dec. 2004.
- [3] Magnus Olofsson, Ulf Grape, “Voltage Quality in the context of EMC”, paper accepted for publication at 2009 International Symposium on Electromagnetic Compatibility, Kyoto, Japan in July 2009.
- [4] Guide for the EMC Directive 2004/108/EC, 21st May 2008, Available:

- http://ec.europa.eu/enterprise/electr_equipment/emc/guides/emc_guide_may2007.pdf.
- [5] *Electromagnetic Compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*, IEC/TR 61000-3-6, Ed. 2.0, Feb. 2008.
- [6] *IEC Guide 107 Edition 3: Electromagnetic Compatibility – Guide to the drafting of electromagnetic compatibility publications*, IEC, February 2009.
- [7] *Understanding power quality problems – Voltage dips and interruptions*, M.H.J. Bollen, IEEE Press, 2000.
- [8] J. Åkerlund, *Utveckling Elkvalitet Slutrapport* (in Swedish), Elforsk report 04:46, March 2004.
- [9] *Electromagnetic Compatibility (EMC) – Part 4:30: Testing and measurement techniques – Power quality measurement methods*, IEC 61000-4-30 Std.
- [10] *Handbook of Power Quality*, Angelo Baglioni, John Wiley and Sons, 2008, ISBN 0470065613, 9780470065617.
- [11] *Signal processing of power quality disturbances*, M. H. J. Bollen, I. Y. H. Gu, Wiley – IEEE Press, 2006.
- [12] M. Bollen, I. McMichael, M. Stephens, K. Stockman, S. Djokic, F. Zavoda, B. Franciso, Bill; A. McEachern, J. R. Gordon, G. Ethier, R. Neumann, “CIGRE/CIREC/UIE JWG C4.110 – Voltage Dip Immunity of Equipment in Installations – Status April 2008”, *Harmonics and Quality of Power: 13th International Conference on Harmonics and Quality of Power. ICHQP 2008*. IEEE, 2008.
- [13] P. Norberg, A. Larsson, M. Sundell, U. Grape, “Introducing Network Strength to Handle Power Quality in System Planning”, *Cigré General Session, Paris 2008*, paper C4-118.
- [14] L. Lo Schiavo, M. Delfanti, M. Merlo, M.S. Pasquadieisceglie, M. Pozzi, “Relating Power Quality and Short Circuit Power: A Detailed Analysis of Italian MV Networks”, *CIREC, 19th International Conference on Electricity Distribution Vienna, 21-24 May 2007*, paper 0898.
- [15] *Electromagnetic Compatibility (EMC) – Part 4-11: Testing and measurement techniques – Power Voltage dips, short interruptions and voltage variation immunity tests*, IEC 61000-4-11 Std.
- [16] *Electromagnetic Compatibility (EMC) – Part 4-34: Testing and measurement techniques – Power Voltage dips, short interruptions and voltage variation immunity test for equipments with input current more than 16 A per phase*, IEC 61000-4-34 Std.