



Power Quality and EMC in Smart Grid

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Abstract — Smart Grid is increasingly seen as a means to facilitate climate friendly renewable energy sources (renewables) and to enable efficient use of electricity. For example, modern electrical networks can link wind- and solar power with electric cars. A consequence of Smart Grid is a drastic increase in use of electronics in the power system. This makes the satisfactory function of electrical and electronic equipment vital for realization of a robust Smart Grid. This paper focuses on the satisfactory function of equipment for Smart Grid with respect to electromagnetic disturbances, i.e. EMC – Electromagnetic Compatibility including Power Quality. Finally, a framework for the apportioning of responsibilities between network operators and the parties being responsible for the connection of equipment is proposed.

Keywords — Power Quality, Voltage Quality, EMC, Electromagnetic Compatibility, Smart Grid, Smart Grids, SmartGrid, SmartGrids, Renewables

I. SMART GRID – ENABLING GREEN ENERGY

A. European Union Outlook

The European Union, EU, is committed to reducing its overall carbon dioxide emissions to at least 20 % below 1990 levels by 2020. It has also set itself the target of increasing the share of renewables in energy use to 20 % by 2020 [1]. Electricity is obviously of great importance for renewables in terms of e.g. solar and wind power generation, but also for transformation of the car fleet into electrical propulsion.

The European Union SmartGrids Technology Platform vision and strategy for Europe's Electricity Networks of the Future was launched in 2006 [2]. The Smart Grid vision is aiming for “new products, processes and services, improving industrial efficiency and use of cleaner energy resources while providing a competitive edge for Europe in the global market place”. Furthermore, Smart Grid is seen as an important element for achieving the largest knowledge-based economy in

the world and also helping to improve daily life of ordinary citizen.

Clearly, the Smart Grid vision is highly important as a means to support the EU environmental as well as economical ambitions. Within Smart Grid there are a number of technologies involved: renewables such as solar and wind, electric cars, and transmission system power flow control equipment. Also it can be expected an increased use of digital communication and control including smart metering and advanced grid wide area real-time monitoring.

One example of Smart Grid application is the possibility of charging electric car batteries during hours with a surplus of low cost renewable energy. When electricity price is high, electric cars may feed energy back to the electrical network. This can be achieved using a continuous transfer of electricity price information with automatic control of the power flow to and from the electric cars. The term Smart Grid is then enabling a Smart Electrical System – the entire power system with networks as well as connected equipment converting between electrical energy and other forms of useful energy.

B. United States of America Outlook

The Obama administration recently announced availability of \$ 3,9 Billion to invest in Smart Grid technologies and electric transmission infrastructure [3]. The initiative is part of the recovery act related to the financial crisis and funding is made to create jobs and to help modernize nation's electric grid.

In an earlier Smart Grid announcement from the Obama administration [4], it was stated that “Before it can be constructed, however, there needs to be agreement on standards for the devices that will connect the grid”.

C. International Standardisation Activities

According to IEC – International Electrotechnical Commission, “Smart Grid is the concept of modernizing the

electric grid. The Smart Grid is integrating the electrical and information technologies in-between any point of Generation and any point of Consumption.” [5]. This definition was an outcome of a meeting in late April 2009 gathering experts from a broad range of countries and expertise in a strategic group for Smart Grid. The strategic group identified 19 IEC technical committees with published international standards that play a role in the Smart Grid structure. Recently IEC opened a Smart Grid web portal [6]. Standardization is indeed a vital part of realization of Smart Grid technologies.

The IEEE – Institute of Electrical and Electronics Engineers is also active in the development of Smart Grid technologies [7].

II. SMART GRID ROBUSTNESS AND VULNERABILITY

Smart Grid opens up the opportunity for an evermore sophisticated electrical system containing lots of electronic devices both controlling the power flow itself, so called power electronics, and electronics controlling the power electronics and other devices. A power system based on Smart Grid has naturally a tremendous number of computers for information exchange and control.

The electricity dependency of our society has been and is steadily increasing. Smart Grid will impose electricity even more as a fundamental of modern civilization, at least technically. Virtually no essential societal infrastructure can function properly without electricity. Considering that importance, vulnerability of Smart Grid is a most relevant concern [8].

Under the authority of the United States (U.S.) Congress, a Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack has assessed the threat of intentional electromagnetic interference – IEMI [9]. The electrical power supply system is concluded to be a highly critical infrastructure for our society, see Fig. 1.

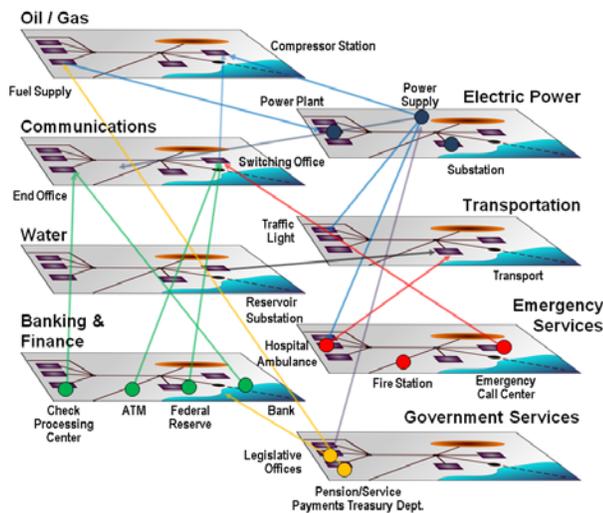


Fig. 1. A Conceptual Illustration of the Interconnectedness of Elements Contained within Each Critical Infrastructure [9]

Out of seven characteristics, the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) states that the “Modern Grid” will have the ability to

Resist Attack [10]. Another characteristic listed is that it Self-Heals:

- Self-Heals
- Motivates and Includes the Consumer
- Resists Attack
- Provides Power Quality for 21st Century Needs
- Accommodates All Generation and Storage Options
- Enables Markets
- Optimizes Assets and Operates Efficiently

Also the European Union Smart Grid Technology Platform [11] addresses security saying Europe’s electricity networks must be “Reliable: assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties”.

Example of Smart Grid on a large scale is the initiative aiming for large-scale solar electrical energy from the Sahara desert up to Europe [12]. Robustness and vulnerability are naturally to be considered for such a large system [13].

Consequently, while the importance and complexity of the electrical power system is increasing, it is reasonable to require a higher robustness in days ahead.

III. EMC AND VOLTAGE QUALITY IN SMART GRID

A. EMC – Electromagnetic Compatibility

The physical characteristic of Smart Grids technologies with an increased incorporation of potentially sensitive electronics has naturally implications with respect to Electromagnetic Compatibility – EMC. The satisfactory function of electrical and electronic equipment with respect to electromagnetic disturbances is the aim of EMC. The IEC – International Electrotechnical Commission [14] defines Electromagnetic Compatibility as “the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment”. In the European Union EMC Directive [15] “equipment and system” of IEC corresponds to the EU term equipment, where equipment is subdivided into apparatus and fixed installation. See also [16].

Electromagnetic disturbances may be radiated or conducted and electrical/electronic equipment potentially sensitive to any or to both of these types of disturbances. Disturbances are in turn subdivided into a number of low and high frequency phenomena, where IEC defines low frequency up to and including 9 kilohertz.

B. Relation between Voltage Quality and EMC

Both IEC and EU define EMC to cover electromagnetic phenomena from zero hertz. Furthermore the IEC defines the following principal electromagnetic conducted phenomena [17]:

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

Voltage Quality can be seen as an umbrella name for deviations from ideal voltage conditions at a site in a network [18]. This is equivalent to electromagnetic disturbances of the voltage at the site. With no disturbances the Voltage Quality is perfect, otherwise not. Electromagnetic disturbances are defined as electromagnetic phenomena that may degrade the performance of equipment [19].

Adequate Voltage Quality contributes to the satisfactory function of electrical and electronic equipment in terms of Electromagnetic Compatibility. Electromagnetic disturbances as imperfect Voltage Quality at a site in a network can be regarded as electromagnetic emission from the network [20]. According to the EMC Directive network is equipment. This is in line with the original name of IEC Technical Committee (TC) 77 which was “EMC between electrical equipment including networks”; now simply EMC [21].

The technical function of an electrical network is electromagnetic energy transfer with adequate Voltage Quality at its sites, i.e. at connection points. Similarly, immunity of an electrical network can be seen as the ability to absorb disturbing emissions such as distorted current with adequate Voltage Quality while transferring energy, i.e. with satisfactory function. For e.g. low order harmonics and voltage fluctuations, network strength is relevant for network immunity [22], [23]. Geomagnetically induced current caused by space weather is another example of electromagnetic immunity relevant to an electric grid [24] to keep its function satisfactory.

The importance of Voltage Quality to achieve EMC is clearly stated in a report from CEER – Council of European Energy Regulators [25]: “Due to the nature of electricity, voltage quality is affected by all the parties connected to the power system. When voltage quality is too poor, a key question is whether the disturbance (e.g. a harmonic disturbance) from a customer’s installation in to the power system is too big or whether the power system (the short circuit power) at the point of connection is too weak. The aim should be to have an electromagnetic environment where electrical equipment and systems function satisfactorily without introducing intolerable electromagnetic disturbances to other equipment. This situation is referred to as electromagnetic compatibility (EMC).”

C. Field Experiences with Smart Grid Technology

Examples of lack of EMC in relation to evolving Smart Grid technologies have been reported in Sweden. Kilowatt-hour meters in households sending data signals on the power

lines have caused interference with e.g. dimmer controlled lamps and electrical appliances. There are also cases reported where electrical apparatuses in households have interfered with electronic kilowatt-hour meters with adverse errors in registration of energy. Power electronics in wind power plants have emitted disturbances interfering with transfer of kilowatt-hour meter readings as signals on power lines.

Power electronic based photovoltaic solar and wind energy equipment may emit disturbances causing e.g. voltage fluctuations and unbalance [26]. However, with a proper design such equipment may well improve Voltage Quality, e.g. reducing depth of voltage dips [27].

IV. EMC DIRECTIVE AND ELECTRICAL NETWORKS

The preamble (14) of the EMC Directive 2004/108/EC of European Union [15] reads: “(14) Manufacturers of equipment intended to be connected to networks should construct such equipment in a way that prevents networks from suffering unacceptable degradation of service when used under normal operating conditions. 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 standardization organizations should take due account of that objective (including the cumulative effects of the relevant types of electromagnetic phenomena) when developing harmonized standards.”

This means that both parties responsible for networks (being equipments) as well as for equipment connected to networks are supposed to contribute to EMC.

V. ELECTROMAGNETIC COMPATIBILITY IN POWER SYSTEMS

A Power System is exemplified in Fig. 2. Fixed installations are indicated with closed loops in light blue colour.

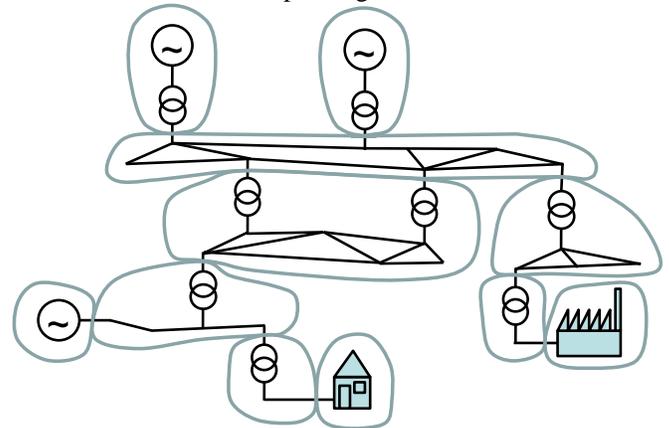


Fig. 2. Power System made up of Fixed Installations

Applying the concept of fixed installation, there is principally no difference between electrical networks or connected equipment in terms of electromagnetic disturbances. Both networks and connected equipment can emit electromagnetic disturbances and immunity is similarly relevant in this context. A network may well be connected to

other network(s) which may emit disturbances or be affected by disturbances in terms of imperfect Voltage Quality. Lack of immunity can also degrade the very basic function of the grid of energy transfer. One such case is where energy transfer is interrupted due to interference caused by geomagnetically induced currents.

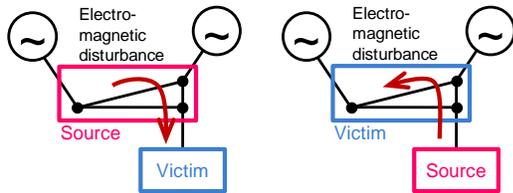


Fig. 3. Propagation of an Electromagnetic Disturbance between the Network and Equipment Connected to the Network

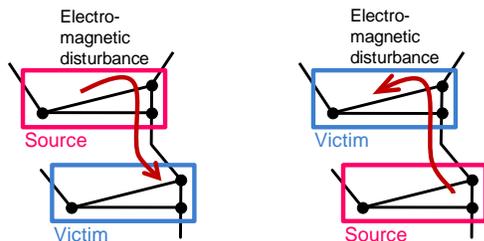


Fig. 4. Propagation of an Electromagnetic Disturbance between Networks

Disturbances can propagate from a network to connected equipment or vice versa as presented in Fig.3 [20]. Disturbances may also propagate between networks as illustrated in Fig. 4 and emission from a network may be seen as a cumulative effect of emissions from a large number of connected equipment in terms of imperfect Voltage Quality at a specific site.

VI. VOLTAGE QUALITY PLANNING LEVELS

In public low voltage networks within the European Union it can be assumed that an increasingly large portion of connected equipment has CE marking. This means that equipments shall be in conformity of protection requirements on emission and immunity as of the EMC Directive. So called harmonized standards are generally available and applied by manufacturers with the benefit of presumption of conformity with the EMC Directive among others.

The objective of protection requirements for equipment, including fixed installations such as electrical networks and connected equipment, is for the achievement of EMC.

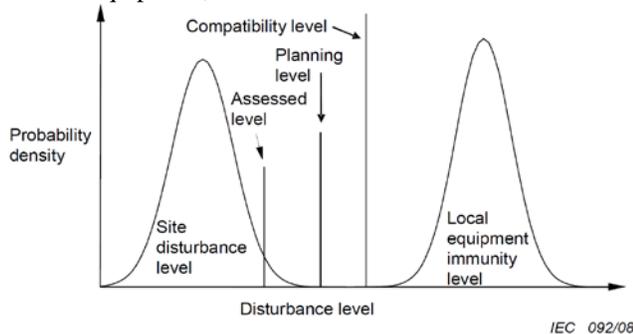


Fig. 5. Voltage Quality Concepts with Time Statistics in a Site within a Network [28]

When aiming at EMC in electrical power systems it is reasonable to apply the same reference for Voltage Quality in electrical networks as for limits on emission and immunity of connected equipment. This is schematically indicated in Fig. 5 where a common level is applied for Voltage Quality as well as for immunity of connected equipment. This common disturbance level is the so called compatibility level. Electromagnetic compatibility levels are defined in the IEC 61000-2-series for use as references for emission and immunity of equipment.

Voltage Quality planning levels are defined with a margin in relation to compatibility levels, indicated in Fig. 5.

For continuous phenomena such as voltage harmonics, the probability of not achieving compatibility is normally very small at a certain site in an electrical network [28].

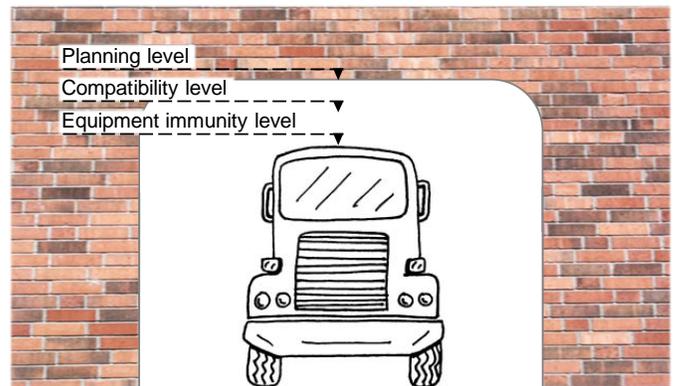


Fig. 6. Mechanical Compatibility – Viaduct Clearance and Vehicle Height

A mechanical analogy of compatibility is illustrated in Fig. 6; here in terms of infrastructure clearance and vehicle height above road. The defined compatibility level may be e.g. 4,5 meter. With this as a reference, the party responsible for the infrastructure will design the viaduct with a certain margin considering variation in the road surface, ice and snow and possibly future pavement renewals. Similarly, the truck manufacturer would consider variations in wheel diameter, suspension and vehicle manufacturing precision.

VII. APPORTIONING OF RESPONSIBILITIES BETWEEN NETWORK AND CONNECTED EQUIPMENT

A. Allocation of Available Emission Limits

In electrical networks other than public low voltage networks within the European Union, there are normally no harmonized standards for emission and immunity of connected equipment, including fixed installations. In the context of Electromagnetic Compatibility, this makes apportioning of responsibilities between parties accountable for electrical networks and parties connecting equipment to the network essential. A key task is the allocation of available emission levels in order to comply with Voltage Quality planning levels within the electrical network. Such apportionment is discussed in [20] and [18] and an important subject in IEC documents [28], [29] and [30].

B. Emission Allocation between Networks

Allocation of available emission levels is also relevant between networks. As an example, planning levels for low order harmonics should normally be stricter at higher voltages in comparison with at lower voltage levels. Thus, for certain low frequency phenomena a network at a higher voltage level should be normally planned with higher Voltage Quality than at lower voltage levels. It is desirable to apply standards for compatibility based planning levels for all voltage levels, i.e. from low voltage up to the highest transmission voltages.

VIII. TOWARDS CONVERGENCE OF POWER QUALITY AND EMC

As expressed in [31], in 1990s, 10 national committees of IEC initiated standardization actions in the direction towards convergence of Power Quality and EMC. The fruits of these efforts are e.g. the EMC standard on Power Quality measurements [32], from where Power Quality principally can be seen as including Voltage Quality and Current Quality.

The innovative and sensible approach of the EMC Directive in which electrical networks are considered equipment is a basis for a holistic and fruitful application of EMC within power systems.

IX. SMART GRID, EMC AND POWER QUALITY

EMC including Power Quality is one of several components needed to realize Smart Grid, which is illustrated in Fig. 7.

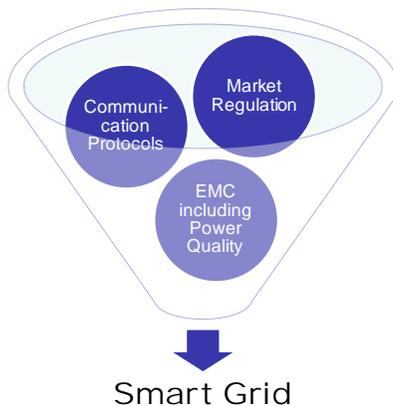


Fig. 7. Some Components Needed to Realize Smart Grid

It is desirable to consider EMC including Power Quality a prerequisite for power systems, i.e. being a fundamental technical requirement prior to any market regulations etc. As a consequence, the regulatory system for parties responsible for electrical networks should be designed accordingly. As for electrical safety, EMC should be a minimum performance level to be considered in the design of power systems. Network regulatory systems should consequently make it possible to pass on costs for EMC including Power Quality to users of networks as is done for electrical safety.

X. PROPOSAL ON ACTIONS WITHIN STANDARDISATION

The following actions of the standardisation communities are suggested to support EMC including Power Quality for Smart Grid:

1. Standardise electromagnetic compatibility levels for disturbances in terms of Voltage Quality for all standard voltage levels of public electrical power networks. This means extending the IEC 61000-2-series to coverage of voltage levels from 230 V up to the highest transmission voltages of public national electrical networks.
2. Standardise how to define planning levels, i.e. limits of electromagnetic disturbances in terms of Voltage Quality at sites in electrical networks, based on compatibility levels.
3. Standardise how to apportion available immunity of electrical networks in order to meet planning levels, i.e. explain how to fairly allocate the ability of networks to absorb distorting current emissions among present and possibly forthcoming connected equipment at sites in networks. Connected equipment may well be other network(s). The work is recommended to take origin in documents IEC TR 61000-3-6 [28], IEC TR 61000-3-7 [29] and IEC TR 61000-3-13 [30].
4. Produce a technical document facilitating the work of network operators to fulfil the EU EMC Directive requirements on protection requirements with respect to emission and immunity of networks being fixed installations.

XI. CONCLUSION

Smart Grid can enable more renewables and efficient use of electricity. Smart Grid is expected to boost an increased use of electronically based equipment in the electrical power system.

To realize Smart Grid the following issues are important to consider:

1. EMC is essential for a robust Smart Grid; both with respect to radiated and to conducted disturbances.
2. Power Quality is a means to achieve EMC between the Smart Grid and connected equipment.
3. Electrical networks including Smart Grids are equipment.
4. Protection requirements, i.e. on emission and immunity, are valid also for electrical networks.
5. Protection requirements on networks and connected equipment should be economically fairly balanced.
6. The standardisation community is recommended to develop a complete set of standards for EMC in power systems including Power Quality.
7. With a view of EMC as a technical issue where cost optimisation to a large extent is made in the standardisation community, regulatory frameworks should be designed without links to market mechanisms, i.e. similar to handling of electrical safety.

ACKNOWLEDGMENTS

The author wishes to acknowledge the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) for the use of Fig. 1 and IEC for the extract used in Fig. 5.

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