IEMI and EMC Considerations for Large Systems — Smart Grid Aspects

D. Månsson
Division of Electromagnetic Engineering, Royal Institute of Technology (KTH)
Teknikringen 33, Stockholm 100 44, Sweden

Abstract— The smart grid concept is the grid design philosophy that diversifies the power grids and the electricity markets. However a deep penetration of "prosumers" and distributed generation in urban environments could lead to significant problems from an electromagnetic compatibility (EMC) viewpoint. Traditional classification methods, used for small isolated systems, are inadequate tools to investigate, improve and evaluate mitigation measures for large distributed infrastructures such as a smart grid. Therefore, an alternative classification method, originally developed to investigate the vulnerability of large distributed systems from intentional electromagnetic interference (IEMI), is used here. The method is used to analyse the smart grid concept to investigate if the smart grid is, from an EMC and IEMI viewpoint for a large distributed system, an improvement or deterioration compared to traditional power grids (and the aspects that is attached to them).

1. INTRODUCTION

With the threat of global warming and diminished resources, the effective use of energy, on all levels of society, coupled with a low environmental impact of power generation, are vital points. Thus, to increase the effectiveness of our energy utilization, the idea of the "smart electricity grid" is internationally recognized and investigated. The key concepts of the smart grids are based around ICT[1], distributed generation of power and energy storage. Traditional concentrated large power generation will be supplemented or replaced with renewable energy sources whose production is geographically distributed. However these renewable energy sources are stochastic and, thus, the exact peak energy availability through, e.g., solar intensity or wind distribution, may not coincide with the peak energy demand. Therefore, the energy produced must be stored in an intermediary state in wait for the energy demand to increase. The stored energy can be in the form of chemical energy in batteries, potential energy of elevated water in a dam, kinetic energy in the momentum of a flywheel etc..

From this comes the concept of the "prosumer" (i.e., producer-consumer), e.g., a residential home with power generation through wind or solar power that can also store, and return to the grid, surplus energy not in demand locally. The local energy demand is obtained through so called "smart meters" and other measurements of the power consumed locally by devices and equipment. Thus, it is very important to obtain reliable measurements of voltages and currents. This information is the basis for determining the surplus or deficit of power available locally. For surplus energy that is returned to the grid, several financial procedures is discussed and tested around the globe.

All in all, this will require:

I. Complex electro-technical subsystems and power electronics for energy conversion, storage, and regulation.

II. Sophisticated ICT solutions for collecting, distributing and processing the vast amounts of information that is vital for the prosumer activities.

Therefore from this we here define and consider a smart grid to be:

"*An interconnected and interdependent non-linear system, wherein money, information and energy are flowing multidirectionally over domain boundaries wherein different limitations and demands may exist.*".

This gives the key concepts, but more importantly, that the mentioned transactions may be between different domains[2]. This is a vital observation that underlies the discussion in this paper.

[1] Information and Communications Technology.
[2] A "domain" is here considered to be a distinct part of a large distributed system; e.g., a subsection of a power grid.

2. INTRODUCTION TO ELECTROMAGNETIC COMPATIBILITY

All systems utilizing electromagnetic energy will, to some extent, emit energy in the form of electromagnetic fields and/or voltages and currents along connected cables and other conductors (if TEM mode is present as a mode of propagation). In addition, all systems utilizing electromagnetic energy can inherently, to some extent, be affected by such. It is important to remember that EMC is a desirable "state of being" that the considered systems can be in (in relation to its surroundings.

The definition of EMC is (according to the IEC [1]):

"The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment", wherein "electromagnetic environment is defined as *"the totality of EM phenomena existing at a given location."*.

Here, the definition of a system should not be limited to smaller equipment (e.g., computers) but can also be large distributed systems and fixed installations such as buildings, boats or even power grids. (The definition of "system" used is [2] "*system: multiple equipment or electrical units connected by cables, data links, etc."*.) All EMC problems can essentially be subdivided into five components (see Figure 1) and to increase the compatibility between two, or more, systems any of these five points can be addressed. These five components are:

1. The source of the physical disturbance (creating the electromagnetic interference (EMI)).
2. The suitability of the propagation path for the disturbance.
3. Interaction between the disturbance and system exterior (i.e., coupling to the system interior).
4. Internal coupling of the disturbance (i.e., spread of the disturbance inside the system)
5. At last, a component of the system is subjected to the disturbance, creating the EMI.

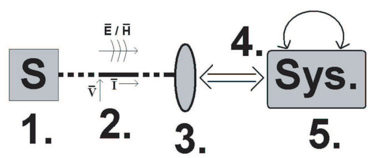

Figure 1: Decomposition of EMC problem in five components.

For many large complicated distributed systems, e.g., boats, buildings, etc. there often does not exist a particular individual responsible for the successful integration, with respect to EMC, of all subsystems and equipment during construction and overhauls. (Airplanes, however, is one exception.) Thus, different systems can be installed that may unintentionally disturb other electronic systems and, thus, decrease the overall performance of the system. In other word, there exists a severe lack of knowledge of the total system integration and behaviour (the interconnections and interdependencies between the different subsystems). (This is believed to be correlated to the relative obscurity of EMC as a discipline, even amongst most electrotechnical engineers. Fortunately, this is fundamentally a matter of information, awareness of the problem and education of the personal, which is, in part, solvable.) However, it is very important to remember that many severe, and some catastrophic, incidents due to EMI has occurred in the past [3] where the events leading up to the explosion on the USS Forestall in 1967 [4] and the sinking of the HMS Sheffield in 1982 are two of the more noticeable. A more recent incident in Sweden [5] involved problems with the radio communication at an airport. (The pilots were sometimes not able to communicate with the air traffic control and the reason was found to be two new LED advertising signs, with faulty EMC design, emitting radio frequency EMI in the communication bands of the air traffic.).

From the above, it should be clear that a large distributed system, as a whole, is inherently more prone to suffering from EMI problems than an isolated system.

3. CLASSIFICATION METHOD FOR INTENTIONAL EMI

Due to different reasons, it is not suitable to use traditional EMC classification methods (see [6]) when investigating the vulnerability of large distributed systems from intentional EMI (IEMI). The method developed (see [7]) to manage such situations is based on three main variables;

- Accessibility, the ability of gaining access to the different parts of the facility or critical components belonging to it.

- Consequence of a disturbance.
- Susceptibility of the system, which is further subdivided into.
  - Receptivity, the degree of the facility's ability to mitigate disturbances between and within electromagnetic topological zones.
  - Sensitivity, the different upset threshold levels of the equipment and subsystems inside the facility.
  - Redundancy, the availability of backup systems and ability to "degrade gracefully".

The method has successfully been used in cases with critical infrastructure installations.

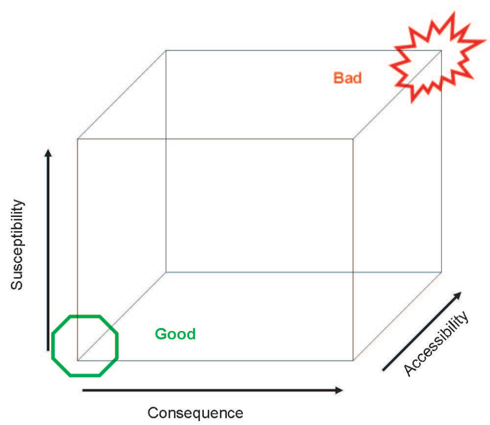

Figure 2: The IEMI cube centres on accessibility, susceptibility and the consequence of the attack to determine the vulnerability of a large distributed system against IEMI.

The advantage of this method is that it is inherently suitable to handle large distributed systems, such as a prosumer installation in a smart grid.

4. CONFORMITY TO ENVIRONMENT

To investigate the smart grid concept with this method we need first to discuss the main components of the smart grid concept. Power generated by renewable energy sources is, before eventual correction by power electronics, by nature often of highly varying power quality. Not only is the power quality inherently bad, but the power electronics (e.g., AC/AC converters) needed to acquire the 50 or 60 Hz signal can themselves, in the conversion process, be the cause of both conducted and radiated disturbances. For example, a power inverter on the market, advertised for use with photovoltaic cells, was found to have conducted disturbances of 17.6 dB over allowed limits and radiated emission of 10.3 dB over the limits [8]. In addition, a relative recent incident was reported in [9], wherein it was described how the fire department in Stockholm had communication problems at a certain location. The cause was traced to a church, where the newly installed LED lamps inside erroneously utilized pulse width modulation (PWM) that created radio frequency disturbances in the vicinity of the church. An investigation of the lamps showed that they did not comply with the EMC requirements necessary to be sold in Europe.

Such situations, might not pose a problem when power electronics are used where, and how, they were intended. However in a smart grid, the, e.g., AC/AC converters, might be situated in an electromagnetic environment for which they were originally not planned, and more importantly, designed for. Using the definition of a smart grid set forth above, we see that the quantities mentioned (e.g., power) can flow "over domain boundaries wherein different limitations and demands may exist." Using the example of a wind power plant at a prosumer's residential home, the above mentioned power electronics sits between the zone with high voltages (with large varying power quality) and the zone with low voltages and an approximate 50 or 60 Hz signal.

The issue is that these converters are usually, from an EMC point of view, designed and tested for an electromagnetic environment harsher than the residential home. It is difficult to translate the emission limits given in standards (e.g., [10]) to any general distance between transmitter and receiver so we can't say if the permissible emitted electromagnetic fields for industrial equipment are above the limits for immunity for normal residential COTS equipment. However, it is a well established fact that residential COTS equipment can be interfered with [11] and especially an industrial environment is a challenge [12]. In [11] it was seen that COTS equipment bearing CE-mark and, thus, should comply with EMC requirements, could be interfered with at electric fields levels much lower than the EMC immunity requirement limits in the particular frequency band (few tenths of V/m compared to 3 V/m). The differences in required immunity limits for radiated fields, between an industrial and residential electromagnetic environment are significant (e.g., 10 V/m compared to 3 V/m (80–1000 MHz)). Clearly the industrial environment is a harsher electromagnetic environment, as the equipment is expected to withstand higher field values. Thus, the problem is that, in a prosumer installation, it can be expected that at the interface boundaries between different electromagnetic environments (different domains) equipment will be placed where they are not commonly found and expected (by the equipment designers). If the emissions from such equipment exceed the limits for the "low level" zone they will not exist in a harmonious state with that equipment and EMC is not achieved. In other words, the integration of future power components, in a prosumer installation, can be problematic.

5. SMART GRID EVALUATION

For the smart grid the unit of evaluation is here taken to be the prosumer installation, i.e., the stability and performance of the smart grid as a whole is dependent on the behaviour of this. Using the classification method described above the smart grid concept is analysed.

The consequence of an electromagnetic interference in a smart grid is believed to be significantly less than a traditional power grid. This is due to the inherent flexibility of distributed generation and energy storage, as well as factors discussed below.

Remembering the definition of the susceptibility of the system given above, the situation changes as follows.

The receptivity[3] of the system is unchanged as a smart grid installation has not, inherently, more mitigation against electromagnetic disturbances, than a traditional power grid installation. The sensitivity[4] of the system is also unchanged as we do not expect the subsystems and equipment of a smart grid installation to be significantly different than a traditional power grid installation. (As argued above it is the placement (point of installation) of the subsystems in a prosumer installation that is dominantly different, not the actual subsystems or equipment.).

The redundancy[5] of the systems is believed to be substantially improved as, per default, the smart grid as a whole has many backup units and alternative subsystems of operations (i.e., energy storage and distributed generation) that can continue operating if the normal operation of one particular installation is interfered with.

The accessibility term, as defined above, cannot directly be used here. The accessibility term is a measurement of how easy it is to gain access to the system and deliver an electromagnetic disturbance to a particular point in the system. I.e., how easy it is to introduce a large disturbance in the system where it, in a traditional EMC situation (normal unintentional EMI), would not be expected (due to mitigating measures installed) and pose a significant problem. Thus, the key point is that a significant disturbance is introduced in the system where it would not be expected, i.e., disturbance sources exist where they are not expected. This situation is similar to the discussion above, wherein, e.g., power electronics (producing noise/disturbances of detrimental levels) are introduced alongside relatively unprotected systems. Thus, we recognize the fact that "accessibility" can, in this non-IEMI scenario, be translated to how well subsystems and equipment conforms to their environment (as discussed above) and a "conform to environment factor" is formed. This is then related to how well the different systems of the prosumer installation adhere to regulation and standards (EMC and power quality) so that all subsystems and equipment are electromagnetically compatible with each other.

Thus, it is believed that the smart grid, as a concept with prosumers having local power generation and storage, leads to a power grid, as a whole, that is a substantial improvement over a traditional power grid structure with, more or less, centralized power generation.

ACKNOWLEDGMENT

This work was made possible through funding from the "STandUP for Energy" collaboration.

[3] Receptivity, the degree of the facility's ability to mitigate disturbances between and within electromagnetic topological zones.

[4] Sensitivity, the different upset threshold levels of the equipment and subsystems inside the facility.

[5] Redundancy, the availability of backup systems and ability to "degrade gracefully".

REFERENCES

1. http://www.iec.ch/emc/explained/environment.htm.
2. IEC Standard, 61000-6-6, "Electromagnetic compatibility (EMC) — Part 6-6: Generic standards — HEMP immunity for indoor equipment," 2003.
3. IEC Standard, 61000-1-5, "Electromagnetic compatibility (EMC) — Part 1-5: General — High power electromagnetic (HPEM) effects on civil systems," 2004.
4. Leach, R. and M. Alexander, "Electronic systems failures and anomalies attributed to electromagnetic interference," NASA Report 1374, National Aeronautics and Space Administration, Washington, CC 20546-0001, July 1995.
5. http://www.elsakerhetsverket.se/Global/PDF/Rapporter/EMC/Resultat%20fr%C3%A5n%20 EMC-tillsyn%20av%20reklamskyltar.pdf.
6. Månsson, D., R. Thottappillil, and M. Bäckström, "Intentional EMI against critical infrastructures, a discussion on mitigation philosophy," *Proc. American Electro-Magnetics Conference*, 2010.
7. Månsson, D., R. Thottappillil, and M. Bäckström, "Methodology for classifying facilities with respect to intentional EMI," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 51, No. 1, 46–52, February 2009.
8. http://www.elsakerhetsverket.se/sv/Produktsakerhet/Forsaljningsforbud/Vaxelriktare-for-solpanel-avger-storningar/.
9. http://www.elsakerhetsverket.se/Global/PDF/Aktuellt/2012/Aktuellt_2_12.pdf.
10. IEC Standard, 61000-6-4, "Electromagnetic compatibility (EMC) — Part 6-4: Generic standards — Emission standard for industrial environments," 2006.
11. Månsson, D., R. Thottappillil, T. Nilsson, O. Lundén, and M. Bäckström, "Susceptibility of civilian GPS receivers to electromagnetic radiation," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 50, No. 2, 434–437, May 2008.
12. Chilo, J., C. Karlsson, P. Ängskog, and P. Stenumgaard, "EMI disruptive effect on wireless industrial communication systems in a paper plant," *Proc. of IEEE International Symposium on Electromagnetic Compatibility*, 2009.