

Best Practices for Conducting an Electromagnetic Compatibility (EMC) Assessment

An Electric Power Utility Perspective

2013 TECHNICAL REPORT

Best Practices for Conducting an Electromagnetic Compatibility (EMC) Assessment

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ABSTRACT

The concept of assessing the electromagnetic compatibility (EMC) of a complex system is illustrated in detail in this report with reference both to the case of conventional standard compliance testing and to a custom type of assessment focused on system functionality.

The process of performing an EMC assessment in systems that are part of the electric grid infrastructure is not currently supported by an official reference standard and can be developed on a case-by-case basis for specific purposes. It is shown that an EMC assessment can be used as a routine monitoring of electric power system performance characteristics to provide an alert for the onset of the early stages of malfunctions or conditions with potentially high rates of failure.

Keywords

Compliance testing
Electromagnetic compatibility
EMC assessment
System functionality

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THE ELECTROMAGNETIC COMPATIBILITY (EMC) SYSTEM

1.1 The definition of EMC

Electromagnetic Compatibility (EMC) is traditionally a well-rooted discipline in many engineering sectors and is gaining increasing relevance as telecommunication and electronics become ubiquitous in virtually every aspect of technological applications.

The power grid technology is certainly not immune from this trend; in fact the need for EMC solutions is growing, and from this perspective, efforts are in progress to make EMC part of the engineering toolkit for the electric utility industry [EPRI, 2012], [EPRI, 2013].

A formal definition of EMC is provided by the International Electrotechnical Commission (IEC) 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.” [IEC, 1990].

The term Electromagnetic Compatibility is often referred to along with *electromagnetic interference* (EMI). The two terms are often interchanged or used together although they refer essentially to opposite takes on the same issue. The IEC defines electromagnetic interference as “degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance.” [ibid.].

A more pragmatic definition may be quoted from the classic treatise by [Paul, 2006]: a system is said to be electromagnetically compatible with its environment if the following conditions are met:

- It doesn’t cause interference with other systems.
- It is not susceptible to emissions from other systems.
- It doesn’t cause interference with itself.

Thus, from an operational point of view, EMC is really a prescription for how devices/systems should interact with their “electromagnetic environment” that, following [DoD, 2007], may be defined as “*resulting from the power and time distribution, in various frequency ranges, of the radiated or conducted electromagnetic emissions*”.

Some degree of subjectivity exists in the given definitions since the terminology does not address quantitatively the terms “causing interference” and “susceptible”, nor does the terminology specify what would be the “acceptable” level of performance of a device that is subject to some interfering EM field. As it will be discussed in more detail in the following section, the resolution of these ambiguities is provided by the definitions of the test methods that are utilized as part of an EMC standard, or are devised for a customized EMC assessment process.

1.2 The Equipment under Test and EM Environment

From the previous definitions, it is clear that the two essential elements in an EMC assessment are the equipment under test (EUT) and its electromagnetic environment. The EUT is a generic term that refers either to a specific component or to a complex system. Its definition is made prior to the execution of an EMC assessment and describes the EUT's interaction with the electromagnetic environment as well as the limits applicable to the EUT's expected performances.

For example, a high-frequency electromagnetic noise could be emitted from a particular integrated circuit installed on a printed circuit board. These emissions are likely to be significantly different from the ones that are measured outside a conductive enclosure that is housing the electronic board. These two scenarios illustrate how a radiated emission test can have quite different levels of expected performance depending on the definition of the electromagnetic environment.

In the first case, the most relevant electromagnetic environment is represented by the electronic components in the immediate vicinity of the source of the noise and the EMC limits to be imposed in this case are strongly related to the type of design of the electronic board and its layout. For the second case, the applicable EMC limits are most likely related to the placement of the EUT in an environment where other RF-sensitive devices may be present.

1.3 The Fundamental EMC Measurements

There are four fundamental categories of EMC measurements; they are all directly connected with the electromagnetic environment and involve (electromagnetic) emission and susceptibility (also referred to as immunity, especially in European standards) both for conducted and radiated signals. Thus, the four areas that categorize the EMC standards are radiated emissions (RE), conducted emissions (CE), radiated susceptibility (RS), and conducted susceptibility (CS).

It is essential to understand the nature of these four categories: the distinction between conducted and radiated is more of a practical nature and is related to the type of instrumentation that is required during the EMC testing.

The term “radiated” refers to the transfer of electromagnetic energy that occurs without the presence of a solid material, typically a conductor. Included in this term, are two means for energy transfer: through electromagnetic waves and through induction fields (in the near field, see for example [Balanis, 2005], [Ott, 2008]), although, these are quite different phenomena from a physical standpoint.

The term “conducted” typically refers to signals, still within a wide range of frequencies, which can be picked up by cables or other conducting structures (for example railways next to a high-voltage transmission line). “Conducted” signals in this case may also refer to guided propagation in a transmission line (like a coaxial cable), while strictly speaking, that would be a case of radiated electromagnetic waves.

The distinction between emission and susceptibility occurs at the fundamental level in the definition of the EMC concept. A common misconception may assume some kind of relationship between emission and susceptibility limits—as if, for example, with lower emission limits, a lower susceptibility threshold could also be tolerated.

In reality, emission limits have been devised for the main purpose of avoiding interference with radio communications. In other words, in EMC terminology, the emission limits are meant to control the effects of “unintentional transmitters,” that is, devices that are not emitting EM energy by design.

On the other hand, susceptibility thresholds have been devised mainly to establish an acceptable level of electromagnetic noise in the environment where typical electronic devices may be expected to operate.

All these definitions are obviously application-dependent and for this reason, different specialized EMC standards have been devised in different engineering fields—for the automotive industry, for the aerospace sector, etc.

1.4 EMC Relevance in Today’s Electric Utility Environment

Devising best practices for an EMC assessment requires the understanding of how EMC (or the lack thereof) can impact the operation of the electric power system. Typically, the investigation of a possible EMC problem results from a specific occurrence (e.g. a malfunction or a power quality issue or the detection of other-than-nominal parameters, etc.).

However, as EMC becomes fully integrated in power utility practices, an EMC assessment may also find its place as part of preventive/quality control procedures established to ensure that new components or systems will perform as planned. For a new substation, as an example, an EMC assessment could occur before starting routine operations (or before operating a new SCADA controller system, or after replacing obsolete controllers, etc.).

An EMC assessment can also be an effective monitoring tool to prevent failures by catching early stages of performance degradation of insulators, grounding connections, or shielding enclosures. For instance, corrosion in an outdoors enclosure may be sufficient to create an aperture that allows emissions from a nearby cellular telephone tower to interfere with sensitive electronics.

1.5 EMC Relevance in Near-Term Power Grid Technology Developments

A near-term, important change for the electric infrastructure is the deployment on a large scale of “smart grid” technologies. Far from being a single and a well-defined step, it will represent an ongoing evolution towards a tighter integration of data processing, telecommunication, and power infrastructures.

This process will create a new, more complex electromagnetic environment where EMC will become a necessity, rather than just a useful tool. A necessity because low-voltage, microelectronics-based systems are, in general, more vulnerable to EM interference than their older counterparts that are based on electromechanical devices or analog electronic circuitry.

The challenge of this more complex electromagnetic environment: how to retain the advantages that come from the utilization of advanced electronics while at the same time not lowering the reliability of the electric infrastructure nor creating a widespread, new level of maintenance issues (that would also carry the costly requirement of re-training some of the workforce).

Furthermore, there is a growing concern related to the increased vulnerability against intentional EM attacks that can impact the functionality of systems critical for the continuity of the grid operations.

EMC guidelines for building the new *smart grid* infrastructure can provide the required technical elements for designing a system that is both robust and resilient against EM disruptions. The definition of the proper EMC engineering best practices for the power grid will then have to take into account all the vulnerability issues just mentioned.

1.6 The Goal of an EMC Assessment

Any EMC analysis assumes that a target, a particular system or piece of equipment (the equipment under test, EUT), and an EM environment have been defined. Beyond that, a choice must be made between two basically different approaches to an EMC assessment. One is the “conventional” standard compliance test process, designed to verify if a particular system meets the EMC standard specifications. The second is related to the “health status” or “functionality status” of the system under operation to verify its ability to function correctly for a given set of inputs and environmental scenarios.

This distinction, far from being a textbook formal classification, is of pragmatic nature: the first type of assessment is typically well-defined, following a repeatable and well-structured procedure. The second type, on the other hand, has a fairly undefined boundary and no specific procedural rules. Rather, the second type refers to situations where it is necessary to obtain a clear picture from an EMC perspective, but having no specific applicable test which applies to the problem under investigation—or an applicable, defined EMC standard (as is often the case for power utility applications).

This “functionality status” type of EMC assessment fits more naturally in the category of best engineering practices. It is more related to a particular, system-dependent type of measurement and provides the foundations for building a database that can be utilized eventually for devising a formal EMC standard applicable to a particular technology area (such as electric utility applications).

1.7 EMC Assessments for Standard Compliance

Compliance with EMC standards typically facilitates the design of an electrical system (both industrial and consumer) so that it can maintain its functionality when its different components, or subsystems, are operating and sharing the same electromagnetic environment.

A compliance assessment always refers to a particular reference standard. The standards are designed to ensure that the tests are repeatable; thus, they specify in detail the test methods, the limits against which compliance may be verified, the type of test hardware to be utilized, and the laboratory setup.

The test outcome is essentially a pass/no pass result, possibly supported by more detailed information as to the extent that the prescribed limits have been met (or not met).

A schematic view of the structure of a generic EMC standard is shown in Figure 1.1 (official EMC standard publications can be consulted for more details, for example [DoD, 2007b]). At the top level is the standard definition: this essentially prescribes the general area of applicability of the standard itself. A hypothetical example could be “EMC Standard for Smart Grid Electronic Devices.”

The second level contains the specification of the test methods (Figure 1.1 assumes only three test methods, but that is just an example). A test method is a procedure specified for the measurement of a restricted set of parameters. A more detailed description of how a possible test method can be constructed is shown in Table 1.1.

Continuing along the same line of the previous example, a particular test method could be specified for measuring conducted emissions in the frequency range from 10 Hz to 200 kHz of digital controllers for smart grid applications.

At the lowest level, a particular set of limits (just two in the example of Figure 1.1) is specified for each test method. These limits refer to the actual values of the defining EM quantities that can be measured during the test. The specification of these limits derives from the understanding of the functionality of the EUT and the constraints due to the particular EM environment. Defining these limits, in general, is not a straightforward task and should also take into account situations wherein the functionality of the EUT is close to being compromised, or wherein other devices could be affected.

Referring to the test method of the previous example, it could be estimated that the maximum tolerable level of the conducted emissions on the wiring of the digital controller could be 100 millivolts—within the specified frequency range. Beyond that level, the controller has been found to be, or can be reasonably considered, no longer reliable.

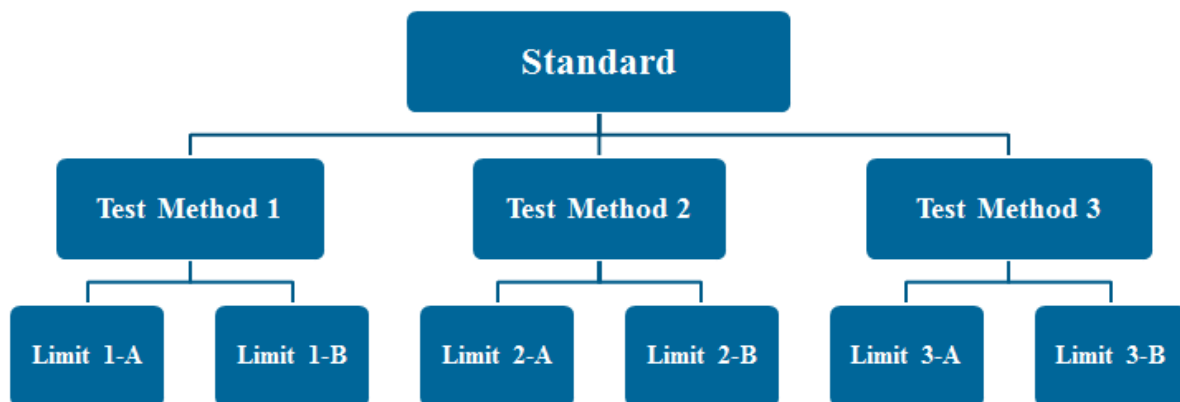


Figure 1-1
Basic Structure of an EMC Standard

Table 1-1
Generic Specifications for a Test Method for an EMC Standard

Applicability	Describe the type of devices and conditions to which the test applies
Limit	Define the quantities to be measured (typically in volts, amperes, or derived units) and their allowed range
Test procedure	
- Purpose	Describe what the procedure is used for in relation to a particular utilization of the EUT
- Equipment	List the type of test equipment and its defining set of technical specifications (e.g. Spectrum analyzer with 0.1-1000 MHz bandwidth)
- Setup	Geometry and instrumentation placement
- Procedure	Steps necessary to record the required information including preparation phase
- Data presentation	Expected output (plot, table) standardized for easy comparison

1.8 EMC Assessment of System Functionality Status

The second type of EMC assessment introduced in Section 1.6 (related to system functionality) poses a significantly different challenge compared to the standard compliance case: there being no prescribed setup with the definition of the test itself being case-dependent, often relying on the experience of the operator.

Once the general focus of the assessment has been defined, the next step is to understand the potential outcome. Assessing whether or not EMC is achieved in a particular system may require further specifications. The process is similar to that which led to the definition of EMC compliance standards and their test methods, the difference being that testing is now customized to a particular system or scenario.

This approach fits well with the current status of EMC applications to power grid problems, in that there are currently no actual EMC standards specifically defined for application to the electric utility industry.

For a given EUT, the entire structure represented in Figure 1.1 now must be defined from the bottom-up. The first step of this process begins with the definition of the electromagnetic environment. Then, the particular aspect of EMC being investigated needs to be defined; consider, for example, the problem of the placement of a high-power line and a digital communication cable in close proximity. The test method(s) may then be specified along with the appropriate test limits.

The final step consists of defining the proper test setup, both in terms of required instrumentation and environmental setup (for example, a shielded room in the laboratory, vs. open-air testing, vs. the actual environment where the device under test is located).

Based on these simple considerations, the importance of the availability of a well-defined EMC standard may be better appreciated. When testing according to a reference standard, most of the conceptual definition work has been already accomplished, and all that remains is to follow a

procedure for collecting data that may be compared with a given prescription to arrive at a pass/no- pass decision.

For the customized type of assessment, on the other hand, the number of specified variables could be quite large. Some of the required choices may not be made without a large case database and/or long experience of related EMC measurements in the field.

Clearly, the implementation of the procedure as has just been outlined may prove to be ineffective without a significant test design phase prior the execution of the test. In practice, the best approach for conducting these functionality-types of EMC assessments is to focus on very specific problems requiring a minimal amount of data collection. A few application examples will be discussed in Section 2.

2

EMC ASSESSMENT: FOCUS ON ELECTRIC UTILITY CRITICAL ASSETS

2.1 EMC Assessments for the Power Grid

The transition to an EMC-aware approach to the design and maintenance of the electric grid infrastructure does not necessarily require a long learning curve or a significant resource investment; ensuring EMC in power grid components and systems is a realistic goal for any electric utility company. A fully-integrated EMC program for the power sector will, however, have to go further to include regulatory aspects and the involvement of manufacturers.

The following subsections discuss the specifics of the implementation of EMC assessment guidelines for applications in the most relevant areas of power grid technology.

2.2 EMC for Electric Power Generation: Nuclear and Conventional Plants

Most of recent past and current EMC efforts with application to the electric utility sector have resulted from a strong interest expressed on the subject from the nuclear electric generation sector.

The reasons are related to the necessity of upgrading decades-old technology for sensors, actuators, and control room hardware, while preserving the highest degree of reliability. In the nuclear sector, as well as in other “mission critical” industrial areas, “old” technology is often synonymous for “reliable” technology (aerospace is a classic example). Upgrades tend to be difficult to implement and they must pass a strict level of scrutiny and relevant certifications.

In the specific case of nuclear power generation, a typical example involves changes from analog to digital electronics. While the benefits are undeniable, there are several issues related to reliability and resilience of the digital technology in the power station environment. The trend in digital electronics has been consistently towards reduced voltage levels and higher input impedance components (e.g. MOSFET vs. Bipolar transistor technology). This higher impedance makes the electronics more susceptible to external disturbances—both conducted and radiated in nature.

An EMC assessment in this case should be focused on the wide-band characterization of the EM environment and the susceptibility of the different components and systems (or, at least, of the subsets that are considered critical). The introduction of filters and shielding for selected components or devices should be considered as well.

The conventional power plant scenario presents many similarities with nuclear plants from the electronic monitoring and control perspective. Besides obvious differences related to the components operating in a high-radiation environment, many other tasks are similar in nature. In practice, the introduction of modern electronic system upgrades in conventional plants has been easier since the regulatory structure is not as strict as that of the nuclear sector.

However, the criticality of several systems (e.g. high-pressure or high fire-hazard environments) calls for extreme caution in the deployment of new components with a short history of operation (or none) that can support reliability estimates. For these reasons, both nuclear and conventional plants are considered together in this discussion.

The EMC task of guaranteeing the reliability of the electronic equipment must also consider a constantly changing EM environment due to the proliferation of wireless portable communication devices. The numbers of transmitting radios present in a particular area can provide a hard-to-predict variable (unless specific restrictions are set in place, such as “exclusion zones” for wireless communications in nuclear plants), and so as well is the peak field RF level that can be reached, its location and time.

While wireless communications, typically digital, utilize efficient protocols that operate in short pulses (as opposed to a continuous RF carrier signal) verified instances have occurred of interference caused by cellular phones in close proximity of electronics in a nuclear plant control room.

2.3 EMC for Grid Operations: Supervisory Control and Data Acquisition (SCADA) Systems

The introduction of automatic controls in industrial processes is practically ubiquitous at all levels. The electric power industry is undergoing a transition towards more sophisticated SCADA systems allowing remote control of large power loads and distributed real-time data processing.

This new system will rely on an increasingly large flow of information towards centralized control nodes. In this environment, the occurrence of an “EMC event” may be difficult to detect as the majority of the monitoring data and related control actions, done in automatic mode with minimal or no human supervision, often occur on a time scale too short for operator interaction or intervention.

The prevention of EM interference and testing of SCADA system susceptibility then becomes a primary concern. For systems placed in outdoor locations (sensors and data acquisition, processing, or communication devices), even basic, “classic” EMC concerns, such as the quality of grounding, bonding, and shielding become an important factor. These should be part of routine inspections since environmental factors can alter those parameters over time.

Another important aspect of an EMC assessment, in the particular case of SCADA systems, refers to the evaluation of the shielding effectiveness of the enclosures for outdoor applications: in this case, factory data from a new installation can easily be compared with that from a unit already installed and functioning properly in the field to determine potential or ongoing problems.

2.4 Telecommunication Channels for Remote Sensor Networks

The telecommunication industry has been the cradle of the EMC discipline. Thus, it may provide the electric power sector well-tested engineering practices for the implementation of dedicated or shared communication channels in support of monitoring of grid operations.

As a general trend, a data communication channel for power grid applications will be carrying less information (requiring a smaller data throughput) as compared to, for example, a broadband, consumer cable TV or internet system. Thus, it will be able, in principle, to provide more easily a highly-redundant, error-correcting transmission protocol—increasing its reliability.

On the other hand, the co-existence of large power systems with sensors and/or communication hardware creates an EM environment requiring a higher level of susceptibility thresholds against disturbances both on the mains and radiated (typically in the near field). It will be the responsibility of specific, case-by-case assessments to determine if the data network as designed is capable of supporting grid operations in the most challenging scenarios.

2.5 Advanced Metering Interface (AMI)

The introduction of “smart meters” is probably the best known and more common aspect of the ongoing transformation of the electric infrastructure. Few EMC requirements exist regarding advanced metering infrastructure (smart meters)—one of the main issues being related to the radiofrequency emissions in the high-frequency band close to the cellular phone frequency range that smart meters also use to communicate with the receiving nodes.

While smart meters are not typically critical assets from the perspective of overall power grid functionality, they are certainly an important element in the implementation of the smart grid as they are the closest interface with the end-users.

Interference produced by smart meters in a local area network and/or with customer electronics would certainly be a nuisance—perhaps even impeding the large-scale implementation of smart grid technologies. Furthermore, there have been several instances where consumers and organizations raised concerns about the safety of the smart meters radiofrequency emissions regarding possible negative health effects of EM fields on human beings.

A typical EMC assessment for these situations would consist of an electromagnetic survey of the surroundings of the smart meter (in particular near and inside residential dwellings) followed by comparison with published EM exposure safety standards.

3

CHOOSING THE ENVIRONMENT FOR AN EMC ASSESSMENT

3.1 EMC Measurements on Systems under Operation

An important aspect of EMC assessments, especially from the perspective of power grid applications, is the necessity of performing a test with the actual system under operation (a “live” system). This requires instrumentation that is portable, meets all the safety requirements, and that has the capability of recording the required amount of data required for a particular type of measurement.

From this perspective, the EMC assessments for power grid applications are somewhat unique in that, in principle—for safety reasons, and simplicity of operations—it could be desirable to perform EMC assessments on systems that are de-energized with respect to connections to high-power lines.

A “live” measurement setup is, in most cases, the only way of obtaining data under typical operational conditions, and, therefore, of characterizing the system in the most realistic scenarios. Furthermore, performing the test on a “live” system often has an economic advantage in that normal operations are not impacted (assuming that the test does not introduce significant perturbations).

In some cases, the EMC test requires only a simple set up and can be conducted in a straightforward manner without requiring any interaction with the power system. A typical example of this scenario is that of the characterization of the RF emissions performed simply with a receiving antenna connected to a spectrum analyzer: this will show the actual emission spectrum in realistic conditions and the actual environment of operation without any impact on system functionality.

3.2 Laboratory and Off-line Testing

In many instances, laboratory testing provides an ideal environment for EMC compliance and certification due to the availability of specialized instrumentation. It also provides the option of testing the equipment to its limit conditions—normally not attained in the actual operating environment. The obvious drawback of laboratory measurement is the requirement of taking the EUT away from its working environment, which in some cases, may be impossible or extremely expensive. For these situations, a transportable subset of the critical system could be separately tested in the laboratory, with the remaining connections to the grid being simulated. In the case of the SCADA system connected to a large transformer, the system by itself could be tested in the laboratory under simulated load conditions thus avoiding interfering with the normal operations of the transformer.

A different example concerns the susceptibility of a SCADA system while it operates in its own environment. For this purpose, perturbing signals are injected into the system under consideration.

The only way to determine the actual susceptibility level of the system is to gauge the impact of the perturbing signals on the system that is being controlled. Clearly, this would be impractical for a SCADA system connected to the real power line environment.

In this case, it is necessary to replace the live connection with the simulated system. The resulting susceptibility level will be then automatically taking into account in the simulated environment. An advantage of the described environment is the ability to utilize a simulator with a built-in instrumented system allowing measurements of the effects of the injected perturbations.

The described approach can be implemented both in the laboratory and at the actual location where the equipment operates (*in situ* measurement). The second option may be more costly and may be justified only if the EUT has been customized for a particular application, or is not readily available.

3.3 Probe Setup for Data Collection

The data collection is the core of the EMC assessment. The choice and the placement of the probes (sensors or antennas) may be fairly critical in the sense that the quantities required to be measured could be either perturbed by the presence of the sensor or could go completely undetected if the location is not chosen properly.

Although a distinction could be made between passive and active probes, from a practical standpoint, the only relevant difference is the actual performance of the probe itself. Other relevant factors are the size, the power requirements, and the specifications of the connecting cables. In some situations, a wireless probe could be utilized, particularly when the transmission frequency is not of any concern.

3.4 Safety Procedures

Safety procedures are a prerequisite for a proper EMC assessment—especially with the EUT energized. The placement of the instrumentation shall be considered before starting the measurements as a conflict may exist between the requirement for a particular measurement and safety conditions. In this case, a specific procedure may be devised to obtain the required data while, at the same time, maintaining safety as required.

In general, for the majority of assessments involving power grid devices, the main concern is a 60 Hz line high voltage. On the other hand, the analysis of the EMC environment is most likely related to radiofrequency emissions or frequencies that are significantly higher than the power frequency, and typically at a much lower voltage.

Special attention should be paid to a situation where interference measurements are being conducted; it is possible that, as a result of interference, a high-voltage circuit may be activated, or some other sensors will produce a response that is potentially dangerous. In practice, the safety analysis of the situation shall consider all possible elements that would produce an energized condition in some potentially dangerous equipment.

In general, while doing an EMC assessment on power grid assets, most of the safety procedures are the same as those for normal maintenance or repair operations. The only caveat is that the EMC equipment (sensors, probes) may require placement in locations that are potentially dangerous for the operator.

4

EMC ASSESSMENT PROCEDURAL GUIDE

4.1 Preparing the Data Recording

The proper execution of an EMC assessment requires a procedural design prior to the execution. The first focus is the object of the assessment itself: the data to be measured and why.

Once the objective on the assessment is made, the proper procedures can be devised for collecting of data. In some situations, the instrumentation itself shall be selected based on the potential amount of data that will become available, and/or the time duration of the recording.

In traditional EMC compliance assessments, a particular EUT is being tested against a specific standard. This typically requires the collection of large amount of data by stepping through a range of frequencies combined with a careful observation of system behavior to determine whether compliance is demonstrated or the test has failed.

An important piece of information to be considered (and stored) is the level of discrepancy between the reference standard and the actual value measured in conditions of noncompliance. For example, an initial level slightly above the standard for a small range of frequencies may not be a concern and an exception can be granted. On the other hand, an emission peak that is 20 dB above the standard reference may be considered a potentially dangerous situation and shall be rejected as far as compliance is concerned.

More complex situations may occur where systems of components are analyzed over a long period of time to identify occasional occurrences of EMC events that are potentially dangerous for the functionality of the system. In this case, proper setup of the diagnostic environment is required: typically, a threshold should be set to provide high time resolution should an event occur. The scenario is very similar to a typical power quality measurement, where the occurrence of a predefined set of events can switch on a high-resolution mode of operation.

Finally, the scenario with the highest level of data load is one where statistics are to be derived from a large database. In this case, it is preferable to utilize equipment having onboard data processing ability. With the proper data analytics algorithm, a large data set can be reduced to a more manageable set of information that may be easily post-processed remotely.

4.2 Assessing Potential EMC Issues Based on System Specifications

A particular EMC assessment could be performed, not based on an observed malfunction, but to build a database that functions as a tool for prevention and quality control.

For example, the introduction of a SCADA system into a known radio-frequency environment will prompt an EMC assessment focused on the susceptibility of the SCADA system itself to a set of particular frequencies. The assessment will also require the characterization of the electromagnetic environment in its particular frequency range.

A key element of an EMC assessment is the determination of the EMC events of interest. Some level of subjectivity is associated with the definition of a malfunction or mis-operation. Therefore, it is important to have a good knowledge of the nominal performance characteristics of the system under analysis prior to the EMC test. A well-trained operator will be able to identify quickly conditions that are considered anomalous. These conditions should also be known to the person performing the EMC test.

The determination of anomalous conditions is actually a critical aspect of all EMC testing especially when assessing compliance against a specific standard. In many cases, tests can be performed in automatic mode without human intervention. However, there are conditions where the anomalies are difficult to define or the behavior of the system cannot be predicted based on previous experience. In this case, direct observation is required for the entire duration of the test.

4.3 Basic EMC Testing for Systems and Components

A typical example of EMC testing is the characterization of both emissions and susceptibility of particular components or systems. This characterization can be performed without referring to a particular standard. Assuming that the system performs nominally, the results of the EMC test may constitute a reference itself for determining future anomalies. This approach is extremely sensitive and effective as a continuous monitoring of the health of the system since it is based on relative changes of descriptive variables.

A recommended practice consists of building a database containing the characterization of the EMC behavior of the most critical systems operating in nominal conditions. In this way, a simple, routine, periodic check will identify anomalies before they become a serious problem. This approach would preferably be implemented by utilizing a compact data storage format and specialized EMC hardware and software to perform EMC assessments in an automatic mode.

4.4 Seeking Hidden Problems: Exercising the System to its Limits

A well-defined EMC assessment will include a departure from nominal conditions for system operations. It is important to be able to exercise the system to its limit: in this way, a database of operational ranges may be effectively determined. A monitoring system may then be set in place that will alert an operator of potential anomalies. A system may be operating within nominal parameters and, therefore, standard current and voltage (I-V) monitoring might not identify anomalies. However, deteriorating conditions could be occurring that might eventually lead to a malfunction: proper EMC monitoring would be able to identify these conditions more easily than standard I-V detection.

For example, an insulator may begin to manifest cracks in its interior and partial discharges may be occurring during normal operations. As long as the insulator is not significantly degraded, the system will perform nominally; however, a wideband radio frequency monitor in the vicinity of the insulator will easily register the presence of partial discharge occurring in insulator's interior, thus identifying the need for proper maintenance.

4.5 Customized Checklist Example

Based on the previous discussion, a “functionality” type of EMC assessment may be characterized by a widely variable range of parameters. In the following example, a checklist to be used in the EMC assessment is presented in Table 4.1. This could be easily customized depending on the circumstances.

Table 4-1
EMC Assessment Checklist

Step	Example
Define the assessment scope	“Interference of substation switchgear with wireless temperature sensors”
Define the equipment under test	RX and TX modules of the wireless temperature monitoring system
Define the test location	A substation of choice with high-voltage switchgear. Open-air testing, in situ measurements.
Define the electromagnetic environment	Wideband EM noise. Emissions in the 100 kHz-1 GHz range Transient pulse-train waveform.
Establish a figure-of-merit for the pass/fail criteria (e.g. quantify the degradation of performance)	De-modulated receiver output S/N less than 3 dB
Derive test limits	Placement of the TX sensor module at different distances from the offending source (switchgear hardware) until performance degrades. Collect EM spectrum corresponding to that location
Establish the required diagnostic	Wideband spectrum analyzer with probes covering the required frequency range
Define a test method	See example in Table 1.1

The checklist calls for the definition of a “test method,” as detailed in Section 1, although this is typically required for compliance-type EMC assessments. The example developed in Table 1.1, or a simplified version of that, could be utilized for this purpose.

5

CONCLUSIONS

The establishment of a figure-of-merit for assessing the EUT performances during an EMC testing session has been shown to be of critical importance. This is possibly the most subjective aspect of an EMC assessment, although it may become straightforward in time given sufficient knowledge of the EUT functionality.

A “good” EMC assessment will rely on proven, effective test methods and limits specifications based on demonstrably large statistical information, or sound technical argument to predict the acceptable ranges of all the quantities being measured.

As an EMC problem is found, different approaches may identify the solution: timeliness and cost, in this case, become the drivers for establishing the course of action.

Finally, EMC assessment techniques can provide an effective first line of defense against performance degradations due to component aging and environmental factors that could cause temporary disruption of EUT functionality.

6

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