EMC in Transmission and the Substation of the Future

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ABSTRACT

The future of power delivery includes a wide range of new technologies and designs. The purpose of this work is to help insure that the application of these new developments can be made with a minimum of electromagnetic interference (EMI) problems that could result in reduced reliability, significant costs, and reluctance to adopt important advances. This report examines the Substation of the Future and anticipates the impact that new technologies and practices could have on electromagnetic compatibility (EMC). Major considerations are power electronics, electronics in relaying and control, wireless technologies, and reduced spacing of equipment.

CONTENTS

1 INTRODUCTION

The future of power delivery includes a wide range of new technologies and designs. The purpose of this work is to help insure that the application of these new developments can be made with a minimum of electromagnetic interference (EMI) problems that can result in reduced reliability, significant costs, and reluctance to adopt important advances.

An EPRI paper, *Power Delivery System of the Future: Estimated Costs and Benefits*, describes a future including new technologies and systems with substantial benefits. The paper states, "A critical part of this Initiative involves the power delivery system and electricity markets of the future, which are envisioned to provide high security, quality, reliability, and availability (SQRA) of electric power; enhance economic productivity and quality of life; and minimize environmental impact while maximizing safety." One small but necessary part of this vision is to address the possibility of electromagnetic interference. Among the technologies envisioned are:

- Automation: the heart of a "smart power delivery system"
- Communication architecture: the foundation of the power delivery system of the future
- Distributed energy resources and storage development and integration
- Power electronics-based controllers
- Power market tools
- Technology innovation in electricity use

For the economic advantages of these developments to be realized, EMI problems must be avoided. The way to accomplish this is to include electromagnetic compatibility (EMC) into the initial design and development of equipment and systems.

The consequences of not designing-in EMC can be severe. Examples of new technology resulting in EMI problems in power systems include:

- 2-way radio use near electronic protective relays resulted in transmission line trips.
- EMI generated by solid-state switching devices within a FACTS system caused that system to drop off line by interfering with the control circuits.
- EMI generated by solid-state switching devices within a FACTS system coupled into a power line carrier (PLC) communication system preventing the remote substation from seeing the drop in the carrier level, resulting in loss of coordination of circuit breaker operation during a fault.

The issues described above are NOT indications of problem technologies. Quite the opposite is true. The technologies described are the solutions to many problems. The difficulty lies in the absence of advance planning regarding EMC. It is quite possible to make all the systems involved in these problems work compatibly with each other. In fact, EMI problems are the exception – not the rule.

In the past, EMI issues within substations were almost unheard of. Relays were mechanical devices that were immune to relatively high levels of interference. Sources of EMI within the substations were limited to relatively slow events like the opening of a circuit breaker. While the current or voltage being switched could be substantial, the interference generated was less than enough to affect the operation of substation equipment.

Four changes are taking place in substation design that are decreasing the margins between EMI emissions and equipment immunity:

- Faster switching of high currents and voltages with solid-state devices.
- Increased application of wireless technologies.
- More susceptible electronic relaying and control systems.
- Reduced spacing of substation equipment in compact substations.

So why do some sites have EMI problems while most do not? Sites that have EMI problems do so because inadequate attention was paid to EMC during the design and development of the components and systems of the substation. Sites without EMI problems were either designed with EMC in mind – or they were just lucky.

There is an expectation that vendors should know how to make their equipment and systems to avoid EMI problems. However, it is not that simple. Standards that limit emissions and susceptibility are not comprehensive enough to assure that all equipment will work in all systems. A piece of equipment that has operated without EMI problems in hundreds of locations may miss-operate one day in one substation. A system that has operated for years without EMI issues may begin experiencing intermittent problems because load conditions have changed over time. Complying with EMC standards does not guarantee the absence of EMI issues.

2
FACTORS IMPACTING THE SPECTRAL CONTENT OF EMI

Many factors influence the spectral content of emissions. Some are relatively technology independent such as voltage level, current magnitude, packaging, and shielding. But, some are directly related to technological changes. Two of these are:

- Rise and falltime, and
- Ringing (overshoot and undershoot)

The factor with the greatest impact on the high-frequency content of the spectra from a pulse train is the rise/falltime of the pulses. A pulse train with faster rise/falltimes will have a greater high-frequency spectral component than a pulse train with slower (larger) rise/falltimes. Reducing rise/falltimes is a goal often quoted by producers of power electronic devices. As shown in Chapter 3, reducing rise/falltimes from 20 µs to 5 µs increased emissions at some frequencies by 10 dB. Further reducing rise/falltimes to 1 µs resulted in an additional 15 dB increase in EMI levels.

The effect of ringing is to enhance the spectral content near the frequency of the ringing. In one case evaluated, eliminating ringing on the time domain pulse train would reduce emissions by 18 dB.

3
POWER ELECTRONICS

The technologies used for power electronic devices are constantly evolving. Research is ongoing to develop solid-state devices that are cheaper, handle more power, and are faster. All of these features are needed to advance the electric power system to what we foresee as the future of power delivery. However, as we move forward, we need to consider what the shape of the pulses will be for these technologies.

An example of a measured time domain turn-off from an operational FACTS system is shown in Figure 3-1. This voltage has a risetime of about 10 μs and significant ringing. (To facilitate Fourier analysis the measured turn-off has been turned into a pulse by creating a trailing edge symmetrical to the leading edge.)

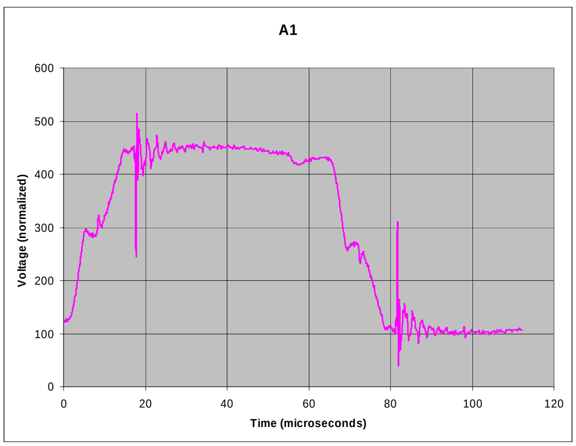


Figure 3-1
GTO Turn-off Transients

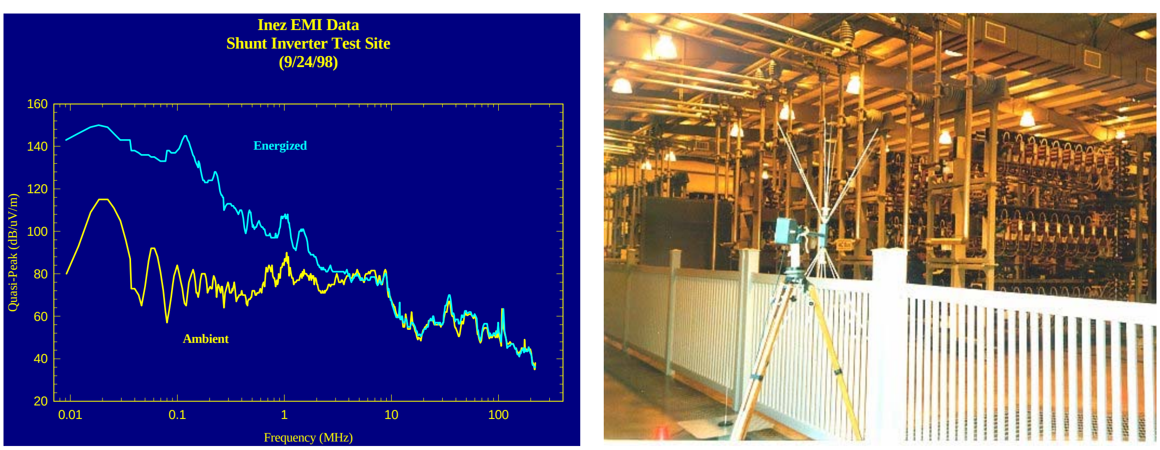


Figure 3-2
Measured Emissions Inside Inverter Hall

Figure 3-2 shows the emission measurements corresponding to the pulse in Figure 3-1. Figure 3-3 is the result of a Fourier analysis of the Figure 3-1 waveform.

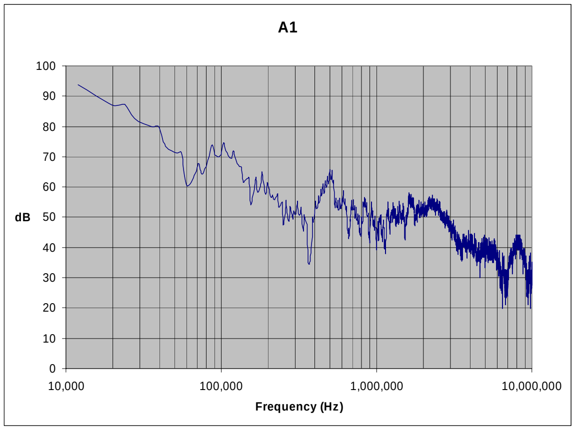
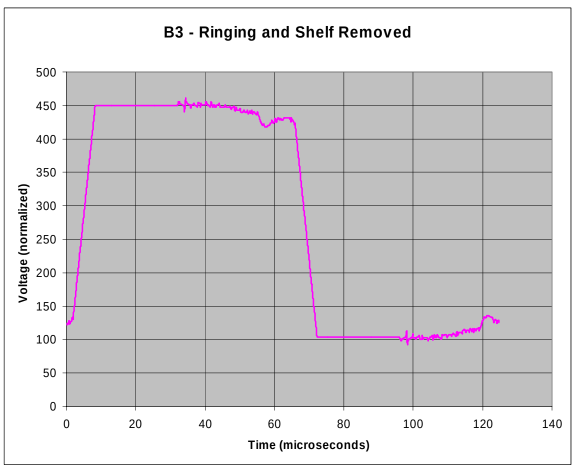


Figure 3-3
Fourier Analysis of Pulse Waveform (normalized magnitude

Note that the energized curve in Figure 3-2 has approximately the same shape as the normalized curve in Figure 3-3. This correlation between calculated and measured results is necessary to assure validity of any EMC evaluation.

For the purpose of this evaluation the pulse waveform was cleaned up. The ringing was eliminated and the irregularities reduced. The resulting pulse waveform and calculated spectral content are shown in Figure 3-4. This waveform and spectra will be used as the baseline for comparisons.



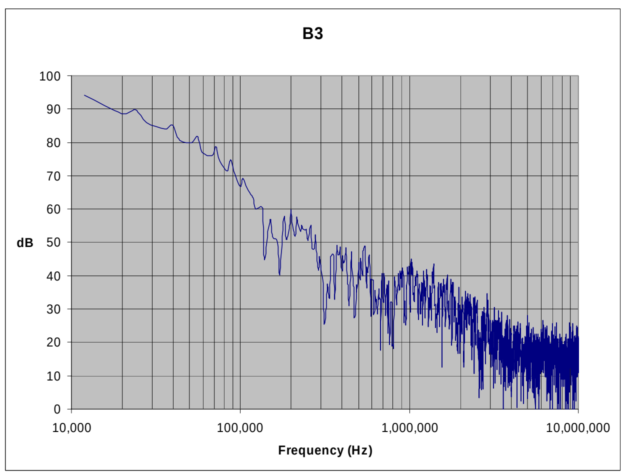


Figure 3-4
Cleaned Waveform

Rise/Falltime

As stated above, the high-frequency content of the spectra resulting from a pulse train is very dependent on the rise/falltimes of the pulses. To evaluate the impact of this design variable the pulse in Figure 3-4 was modified to have different rise/falltimes. The Fourier analysis was then repeated. The results are shown in Figures 3-5 through 3-7.

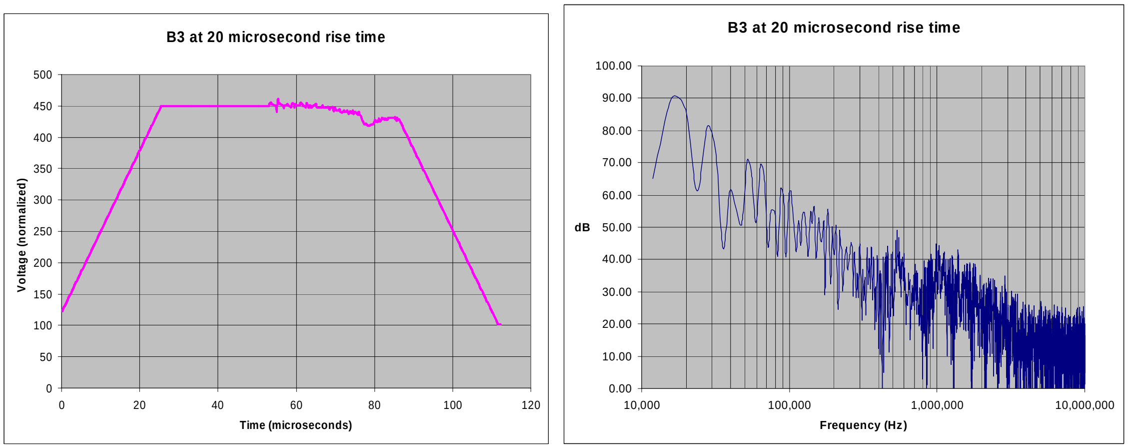


Figure 3-5
20 µs Rise/Falltime

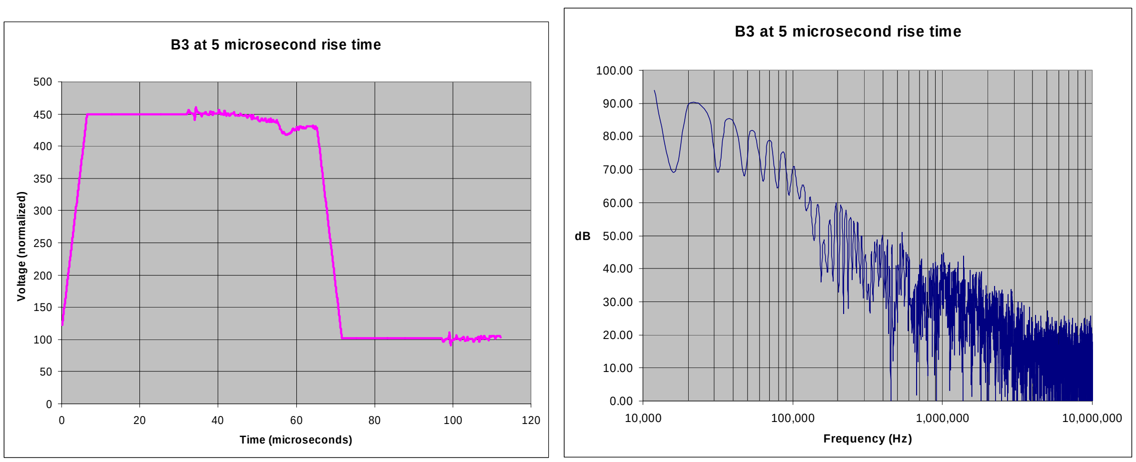


Figure 3-6
5 µs Rise/Falltime

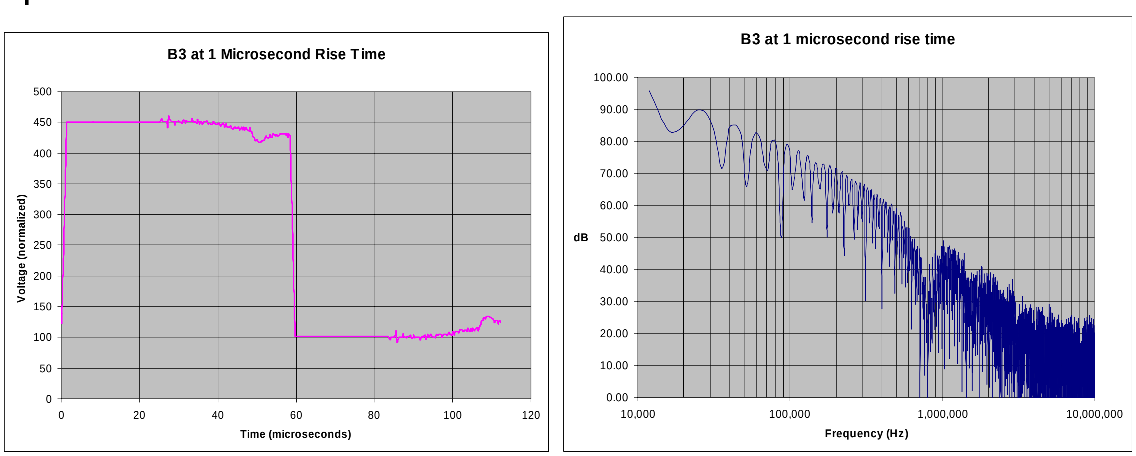


Figure 3-7
1 µs Rise/Falltime

Comparing Figure 3-5 to Figure 3-6 it can be seen that for frequencies up to 300 kHz there is an increase in emissions of 10 dB. And, comparing Figure 3-5 to Figure 3-7 it can be seen that for frequencies as high as 5 MHz there is an increase in emissions of up to 25 dB.

Clearly, rise/falltime has a significant impact on EMI emissions.

Ringing

The effect of ringing is demonstrated by comparing the cleaned waveform of Figure 3-4 with a waveform with ringing restored, Figure 3-8.

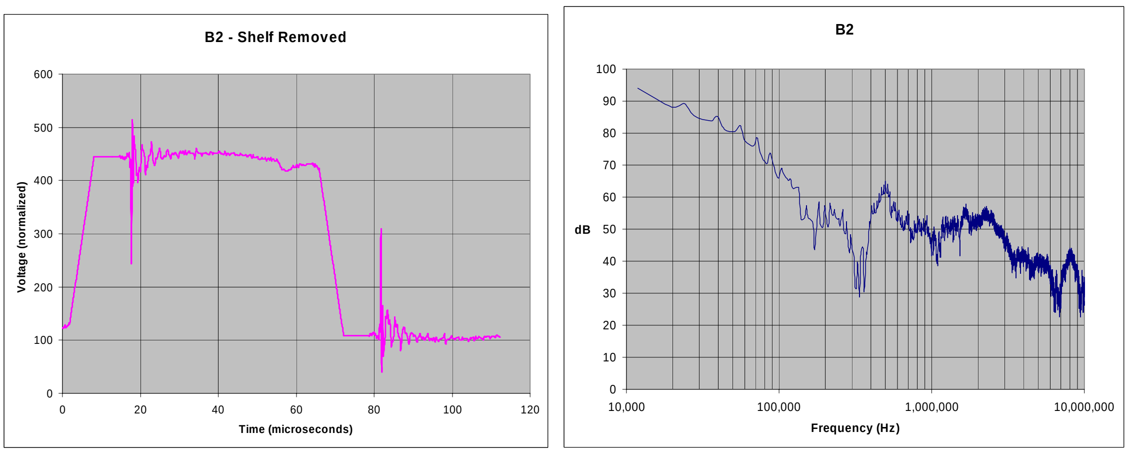


Figure 3-8
Ringing Added to Clean Waveform

The effect of ringing is to increase emission by 10 to 20 dB over a frequency range from 400 kHz to 10 MHz.

Clearly, ringing also has a significant impact on EMI.

Conclusions

Power electronics is a necessary part of the power delivery system of the future. As we work to increase performance of solid-state devices, we need to be aware of pulse waveform characteristics that tend to increase EMI emissions. Either those characteristics need to be designed out of the devices, or mitigation needs to be provided to insure that EMI problems are avoided.

4
CONTROL SYSTEMS

Substation control systems are more likely to be a victim of EMI than a source. Substation control systems include a wide range on low-voltage low-power systems involved in sensing, processing information, and operating equipment. Some examples are:

- Protective Relays (microprocessor technology)
- Computers (faster, lower operating voltage, more vulnerable)
- Dedicated controllers (microprocessor technology)
    - FACTS, etc.

Control systems also involve wiring, cables, fiber optics, and wireless connections. To varying degrees these systems can be sources or receptors of EMI. There are common wiring practices that should be followed to avoid EMI problems with wiring. For example, power and signal wiring should not be co-located. And, electromagnetic coupling is inversely proportional to distance (i.e. greater distance results in less coupling).

It is important to understand the susceptibility of this equipment, and to insure emission levels do not exceed the equipment immunity.

5
COMMUNICATION SYSTEMS

Communication systems include devices within a substation passing information for the purpose of substation operation, and they include communication between devices inside the substation and devices elsewhere. These communications can be analog, digital, wired, and wireless. They can be part of the substation design, and they can be unexpected devices brought in by employees or visitors. They can even be outside the substation.

There have been multiple reports of electronic protective relays tripping when 2-way radios were used nearby. This is one simple example of the effects of EMI. The question needs to be asked as to why this is a problem. Is the 2-way radio non-compliant? That is, does it emit RF levels greater than standards allow? Is the relay non-compliant (too susceptible)? If both devices meet all applicable standards, could there still be a problem? The short answer is that all of these are possible. The ability of a device to interfere with other components and systems is not necessarily related to its compliance with standards.

The substation of the future will incorporate a level of communication between devices that is hard to imagine today. It is imperative that EMC be addressed in the design and development of these communication systems. Cross talk between communication circuits could result in miscommunication between devices. The resulting data errors might be inconsequential, or disastrous, depending on the systems and signals involved. Properly designed and installed systems will not suffer from crosstalk or other EMI problems.

6
COMPACT SUBSTATION DESIGNS

One of the changes that have been taking place in recent years is the development of compact substations. In these facilities everything is closer to everything else. Control rooms are smaller. Digital equipment replaces larger analog equipment. Solid-state devices replace mechanical devices. The potential EMI issue resulting from these trends, as mentioned above, is that electromagnetic coupling increases when devices are moved closer together. A device that works properly in an older substation might have EMI problems in a compact substation. This could happen because it is closer to a source of EMI, or because its emissions are too great for a nearby component or system.

The substation of the future will incorporate technology that will allow it to use less land. These same technologies will facilitate factory assembly of major systems, reducing construction time and costs. The tendency will be for components to be smaller and closer together. These systems can be more reliable than conventional systems. One of the reasons they can be more reliable is that we have the ability to design in electromagnetic compatibility at all levels of component and system design.

7

SUBSTATION EQUIPMENT VS. DISTRIBUTED EQUIPMENT

One of the changes taking place on electric power systems is that equipment that only existed in substations in the past is now being installed out on the lines. One example of a distributed installation is a solid-state device installed on a distribution pole to control the flow of power in the feeder. While these installations are not yet commonplace, they are indicative of a trend made possible by new technologies and advances in communications. The EMI issue raised by these installations is that we are taking devices that work well in the substation environment, where their emissions are not a problem, and moving them into the neighborhoods where more susceptible electronic systems are common. Care must be taken to insure that emissions from distributed equipment do not cause EMI problems for commercial and residential neighbors.

8
STANDARDS

At the present time EMC standards are undergoing changes – particularly in Europe. However, it must be understood that conforming to standards does not guarantee problem free operation. It is still necessary to design for EMC. Applying good design practices regarding EMI must be explicitly addressed in the procurement of equipment and systems. Further information on substation EMC standards can be found in the following EPRI publications:

- *Substation EMC Standards*, 1008707, 2004
- *Measuring & Managing Substation EMC*, 1008709, 2004

9
CONCLUSIONS

To successfully realize the vision of the Substation of the Future it will be necessary to consider EMC in the design and development of components and systems. Engineers specifying and procuring new substations and equipment will need to specify compliance with relevant EMC standards. And, when standards are insufficient, they will need to specify additional requirements.

This work has shown in a qualitative way some of the characteristics of new technologies that have the potential to increase EMI issues. Further work will address specific technologies with qualitative evaluation and testing. By understanding EMI and its causes we will move one step closer to realizing the goal of achieving electromagnetic compatibility in the Substation of the Future.

10
FURTHER READING

Power Delivery System of the Future: Estimated Costs and Benefits, EPRI, Palo Alto, CA: 2004

Introduction to Electromagnetic Compatibility, Clayton R. Paul, Wiley, 1992. ISBN 0-471-54927-4

Substation EMC Standards, EPRI, Palo Alto, CA: 2004. 1008707

Measuring & Managing Substation EMC, EPRI, Palo Alto, CA: 2004. 1008709

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