CHAPTER 5

ELECTROMAGNETIC PULSE (EMP) PROTECTION

5-1. Purpose of EMP protection

The purpose of the electromagnetic pulse (EMP) protection system is to protect critical electrical systems from the effect of intense electromagnetic (EM) effects caused as a result of an explosion. The frequency spectrum may extend from below 1 Hz to above 300 MHz. The high-altitude EMP produced by an exoatmospheric nuclear explosion is the form of EMP commonly of most interest because of the large area covered by a single bomb. This high-intensity EMP can disrupt or damage critical electronic facilities over an area as large as the continental United States, unless protective measures are taken in the facilities. The development of such protective measures involves grounding, bonding, and shielding.

5-2. Types of EMP

An EMP event can be subdivided into three time-based periods, each of which has distinct characteristics.

a. Early time EMP. During the early time portion of the EMP the amplitude, duration, and polarization of the wave depend on the positions of the burst and the observer, relative to the Earth’s magnetic field lines. Peak electric field strengths of over 50 kV/m with risetimes of a few nanoseconds and decay times of less than 1 µs are typical.

b. Late time EMP. During the late time portion of the EMP, currents are induced in the ground by the effects of the expanding and rising fireball constituents. These effects are called the magnetohydrodynamic EMP. As a result the currents produced induce image currents in the ground over a period of 10 to 100 seconds. Although the field strengths produced at the surface by the magnetohydrodynamic EMP are small (tens of volts per kilometer), they occur over long times. Thus, the magnetohydrodynamic EMP is a consideration for long power and communications lines and, because of its duration, for the energy it can deliver to protective devices.

c. Intermediate time EMP. Between the early-time EMP and the magnetohydrodynamic EMP, transitory phenomena produce what is called intermediate-time EMP. This EMP lasts from about 1 µs to about 0.1 s. The intermediate-time EMP observed at the Earth’s surface has a peak electric field strength of a few hundred volts per meter and is predominantly vertically polarized.

d. Surface burst EMP. When a nuclear weapon is detonated at or near the surface of the Earth, neutrons and gamma rays are ejected radially outward from the burst center. The surface-burst EMP is a more localized source than the EMP and the event may cause large currents to be induced on long conductors, such as power lines and communication cables. These currents may be propagated along the conductors for great distances from their source. Therefore, this source-region EMP may be important to systems far outside the source region if they are connected to the source region through wires, cables, or other conductors.

e. High altitude EMP. The high-altitude EMP is the most important form of EMP for communication facilities because of its large area of coverage. However, in addition to the EMP and the surface-burst EMP, a few other electrical effects could occur. System-generated EMP is produced when the high-energy particles (mostly gamma- and X-ray photons) produced by the bomb interact directly with the system structure. These interactions knock electrons out of the structure, which causes current on the structure and potential gradients between the structure and the removed electrons. The structure of interest may be system wiring or cable shielding; the current and potential differences are then on system circuits.

5-3. Effects of EMP on facility systems

EMP interaction with systems may be separated into long-line effects and local effects. Long-line effects are the currents and voltages induced on long power lines, communication cable links, or even other conductors, such as pipelines. Some of these EMP effects may be induced far away and guided to the facility along the conductor. Local effects are the currents and voltages induced directly on the facility shield, building structure, wiring, equipment cabinets, etc. These local effects are very difficult to evaluate analytically because of the complexity of the facility structure, the lack of information on the broadband electrical properties of many of the structural materials, and the extremely large number of interaction paths, facility states, and other complicating factors. On the other hand, the local interactions can be evaluated experimentally with simulated EMP fields that envelop the facility.

a. EMP induced currents. The currents induced on long straight overhead lines parallel to the Earth's surface by EMP-like events have been analyzed thoroughly. If the line is over a perfectly conducting ground plane, the current has a waveform similar to the EMP early-time waveform, except for a slightly longer risetime for lines more than a few feet high. For imperfectly conducting ground, such as soil, the imperfect reflection of the wave from the ground allows the line to be driven more strongly and for a longer time than if the ground were a good conductor.

b. Effects on long buried lines. In long buried lines imperfectly conducting soil does not completely reflect the incident field; some of the incident wave is transmitted into the soil. This field in the soil can induce current in underground cables, pipes, and other conductors. However, because the velocity of propagation of a wave is much less in soil than in air, the bow-wave effect is almost negligible on buried conductors. Furthermore, the attenuation on buried conductors is greater than on overhead lines because of the proximity of the soil to the buried conductor.

c. Effects on conductors in contact with the soil. For conductors in contact with the soil (i. e., buried bare conductor), the current at any observation point is determined primarily by coupling within one skin-depth of the observation point. Current induced at points farther away is so strongly attenuated by the soil that it adds little to the total current at the observation point.

d. Effects on vertical structures. The EMP interacts with vertical structures, such as radio towers, waveguides, and cables to overhead antennas, and downleads from power and communication lines in much the same manner as it interacts with horizontal lines, except that it is the vertical component of the electric field that drives the vertical structures.

e. Effects on closed shields. The EMP fields incident on a closed shield induces surface currents and charge displacements on the outer surfaces of the shield. If the shield is continuous metal (i. e., it has no opening or discontinuities in its surface) and about 1 mm thick, voltage is induced in circuits inside the shield by these surface currents.

f. Effects on insulated penetrating conductors. Conductors, such as power and signal wires, that pass through the shield may allow very large currents and voltages to be delivered to internal circuits. The current on the wire just inside the shield is about equal to the current just outside the shield; the wire is a hole in the shield or, in other words, a 0 decibel (dB) compromise of the shield. A major concern for

EMP interaction is the penetrating conductor that can guide EMP-induced waves through shield walls. The shield is effective in excluding the incident EM waves, but it has little effect on the waves guided through it on insulated penetrating conductors.

g. Effects on apertures in shield surfaces. Apertures in the shield surface allow the external EMP-induced fields to penetrate through the shield and interact with internal wiring or other conductors. The external electric field associated with the surface charge density can induce charge on internal cables. The external magnetic, field which has the same magnitude as the surface current density can penetrate through the aperture to link internal circuits.

h. Transient radiation effects on electronics (TREE). Another important electrical effect is known as transient radiation effects on electronics (TREE). The radiation emitted by the nuclear explosion can interact with components of electronic circuits to produce ionization or atomic displacements in the semiconductor and insulating materials. The effects range from momentary changes in conductivity to permanent changes in crystal lattices. Semi-permanent effects, such as trapped charges in insulating materials, may also occur. TREE may upset memories, produce spurious circuit responses (logic errors), drive circuits into abnormal states, or cause permanent damage. As with most other EMP forms, damage caused by TREE can also occur through secondary effects. Self-inflicted damage may be triggered by abnormal conductivity in a junction that allows stored energy to be released. In addition, one circuit may be caused to instruct another circuit or another part of the system to perform some forbidden act that destroys the circuit or even the system.

i. Effects on large networks. Protecting large networks from the EMP usually involves conservative protection of individual parts of the network in the hope that network hardness will follow from component hardness.

5-4. Grounding protection against EMP

Some form of grounding is required in any electrical or electronic system for protecting personnel from electrical shock, controlling interference, proper shunting of transient currents around sensitive electronics, and other reasons. (Grounding does not directly provide protection against EMP, but must be done properly to prevent creation of more serious EMP vulnerabilities.) Ideally, grounding would keep all system components at a common potential. In practice, because of possible inductive loops, capacitive coupling, line and bonding impedances, antenna ringing effects, and other phenomena, large potentials may exist on grounding circuits. The choice of grounding concept is therefore important in the EMP protection philosophy.

a. EMP grounding protection considerations. There are important considerations in the EMP grounding protection that affect the value that can be placed on EMP protection. The EMP protection adds cost to the facility, and the value received for the added cost is confidence that the facility will survive EMP. Since EMP would not ordinarily occur during peacetime, degradation of the protection is not evident from peacetime operation of the facility. Protecting communication facilities against the EMP typically consists of developing a closed EMP barrier about the facility. The barrier consists of a shield to exclude the incident space waves and various barrier elements on the essential penetrating conductors and in the apertures required for personnel and equipment.

b. EMP barrier. The EMP barrier is usually a facility-level shield fabricated from welded sheet steel. The thickness is usually selected for ease of fabrication, but in areas where exceptional mechanical abuse is likely, mechanical strength, as well as workability, may be a consideration. Shield assembly is typically accomplished by continuous welding, brazing, hard soldering, or other fused-metal process to minimize the number of discontinuities in the shield (a weld or other fused-metal pint is considered continuous metal). This shield should be bonded to the earth electrode system in a number of places, typically in a grid configuration with a cable equal in size to the largest earth electrode grounding conductor. This bond should be a continuous weld to preclude any potential high resistance bonds that may develop with aging of the facility.

c. Coupling of EM energy to penetrating conductors. Many factors affect the coupling of EM energy to penetrating conductors. The EMP waveform characteristics, such as magnitude, rate of rise, duration, and frequency, are each important. Further, the observer's position with respect to the burst is a factor. Because the interaction between fields and conductors is a vector process, the direction of arrival and polarization is also important. Conductor characteristics also affect EMP coupling. These include conductor geometry (length, path, terminations, distance above or below the earth's surface), physical and electrical properties that determine series impedance per unit length (including diameter, resistivity, and configuration), and the presence and effectiveness of shielding. For overhead or buried conductors, the electrical properties of soil affect coupling. Many elements of a facility can act as efficient collectors and provide propagation paths for EMP energy. EMP can couple to structures such as power and telephone lines, antenna towers, buried conduits, and the facility grounding system. Actual antennas, non-electrical penetrators such as waterpipes, and any other conductive penetration can couple EMP energy into a structure. In addition, if the structure is not shielded or is not shielded well enough, EMP can couple to the cables between equipment inside. Penetrating conductors (plumbing, waveguides, grounding cables, electrical conduit, and cable shields) must be grounded by bonding to the shield wall at their entry point. The preferred method of bonding is by peripherally welding them to the wall. However, it is permissible to use clamps, collets, etc., that peripherally bond the penetrating conductor to the shield with little or no discontinuity.

d. Treatment of penetrating conductors. Signal and power wires that need not penetrate the shield should not penetrate the shield. Wires that must penetrate the shield must be treated with a barrier element, such as a filter or surge arrester, that closes the barrier above a voltage threshold or outside the passband required for signal or power transmission.

e. Openings in EMP barriers. Unnecessary openings or discontinuities in the shield are not typically allowed. Those openings necessary for personnel and equipment loading and for ventilation must be properly grounded to ensure continuity and a continuous path to the ground system.

5-5. Typical components and installation details

Typical components and installation details for EMP protection systems are described below.

a. Shielding. An EMP-induced event can cause a magnetic or electric field to be induced in an electrical circuit that can cause an error in the response of the circuit. As in electromagnetic interference (EMI) protection described in chapter 4, an effective means for the reduction of this interfering coupling is the use of shields around the circuits and around interconnecting lines penetrating the EMP barrier and internally within the barrier.

(1) To determine the shielding required at a facility, the equipment susceptible to such events should be surveyed. The sensitive equipment will typically be located within the shielded barrier provided for EMP protection. Shielding should be provided for the cabling servicing this equipment by installing it in rigid metal conduit that is bonded to the entry plate of the shield. Instrumentation and coaxial cable should be of shielded construction with connectors providing additional protection as the cable passes through the entry plate into the protected area.

(2) Insure that shield continuity is maintained at points of entry of signal cables, power conductors, utility lines, and ground conductors.

(3) Make sure that windows, doors, and ventilation ports are shielded along with the walls. Use well-bonded screen wire for windows, use metal doors, and apply honeycomb ducts or appropriate screening over ventilation ports.

(4) Equip all power lines supplying shielded areas with power line filters.

(5) Securely ground all metal shields.

b. Bonding. The bonding requirements for EMP protection necessary to ensure a mechanically strong, low impedance interconnection between metal objects and to prevent the path thus established from subsequent deterioration through corrosion or mechanical looseness are the same as those for EMI protection as established in chapter 4.

c. Entry plates. All metallic penetrations entering the protected area should enter at a common location, and all shielded cables, conduits, and pipes should be bonded to an entry plate. This plate should be designed and installed as described for EMI protection in chapter 4.

d. Filters. The majority of the interfering signals will be conductively coupled into the susceptible circuit. The proper application of filters to both the signal and power lines to reduce this coupling is the same for EMP protection as it is for EMI protection discussed in chapter 4.

5-6. Interfaces with other grounding and bonding subsystems

The grounding required for EMP protection is a part of the total facility grounding network. The ultimate path to ground is the earth electrode subsystem. Protection against EMP is imperative for sensitive electronic equipment to ensure a workable and secure system. Grounding for this protection interfaces with each of the major subsystems. Since the influence of EMP-induced interference is similar to that seen by lightning discharges, the lightning subsystem and the earth electrode subsystem are the main interfaces with the EMP protection system. It is, therefore, imperative that these systems be properly designed and constructed to ensure the most direct and lowest possible impedance to the earth ground.

5-7. Inspections and testing

Thorough inspection and testing programs are imperative to assess the effectiveness of the EMP protection measures utilized.

a. Inspections. Inspect the facility for the following.

(1) Verify that the EMP survey at the facility has been properly performed and documented.

(2) Verify that shielding provided is sufficient to meet system needs (both known and predicted).

(3) Verify that shield continuity is maintained at points of entry of signal cables, power conductors, utility lines, and ground conductors.

(4) Verify that windows, doors, and ventilation ports are shielded along with the walls.

(5) Verify that all power lines supplying the shielded areas are protected with power line filters.

(6) Verify that all electrical conduit is steel inside the shielded areas.

(7) Verify that any wiring ducts are totally enclosed.

(8) Verify that all metal shields are grounded.

(9) Verify that all seams and joints are well bonded by welding, solder, or knitted wire gaskets.

(10) Verify that all metallic utility lines are bonded to the shield at the point of entrance.

(11) Verify that all openings required for visual access are covered with wire screen or conductive glass and that the screen or glass is carefully bonded to the enclosure around the perimeter of the opening.

(12) Verify that all doors are metal with solid, uniform contact around the edges.

(13) Verify that all bonds are of the type that will provide the least resistance possible for the application, preferably direct bonding with no intervening conductor.

(14) Verify that the bonding surfaces are cleaned of all such solid materials and moisture.

(15) After bonding, verify that the completed bond is sealed against the entrance of moisture into the mating region.

(16) Verify that all metallic penetrations and shielded cables through the facility shield are bonded to the entry plate.

(17) Verify that each RF coaxial cable is bonded to the entry plate with a metal bulkhead connector, which is bonded to the building entry plate and grounded to the earth electrode subsystem.

(18) Verify that the shields of all telephone cables entering the shielded facility must be bonded to each other and to the earth electrode subsystem through the steel entry plate.

(19) Verify that filters specified in the design are installed as shown on the engineering drawings.

(20) Verify that all power line filter cases are directly bonded to the equipment case or enclosure.

(21) Verify that filters are bonded to any subassembly enclosure used to maintain shield effectiveness.

(22) Verify that filters on power, control, and signal lines are installed in a manner that maintains the integrity of the shield.

(23) Verify that the power line filters are completely shielded with the filter case.

(24) Verify that filters on power control and signal lines are placed as close as possible to the point of penetration of the case.

b. Testing. Measure the bonding resistance of each bond. One milliohm or less should be the acceptable value of the resistance measured.

c. Inspection and test records. Inspection and test records shall be maintained for the facility with the periodic maintenance records and shall be used as the baseline for determining any corrective actions that be necessary as a result of unacceptable conditions found during normal routine maintenance activities.

5-8. Baseline configuration documentation

Baseline documentation shall be maintained as part of the facility records for the life of the facility. Changes to the baseline configuration shall be documented and approved by the responsible engineer. Modifications and additions to the facility shall have the same requirements for maintaining an acceptable EMP grounding configuration as the original design configuration.