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Ground Systems Design Considerations for Vessels

Tanks and vessels have numerous grounded and protection systems. These include static discharge from fluid-movement bonding, lightning-protection ground, lightning-discharge halo, equipment bonding, cathodic protection, stray-current control, power and external-line protection, instrumentation connection, and instrumentation protection.

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Each system has unique requirements. In fact, grounded systems interact and, in some cases, interfere with each other. Design concerns, considerations, and requirements for each system are identified here. These procedures are appropriate for engineers who design, operate, or maintain electrical systems for vessels used in any facet of the petrochemical industry. Although this article specifically concerns tanks and vessels, the concepts can be applied to a broad range of grounding applications for structures.

In designing a ground and protection system for tanks and vessels, there are many different documents and conflicting ideas. Segments of these are useful. Unfortunately, no single guideline provides all design and installation considerations. A pragmatic design approach has been identified, categorized, and presented as a result of successful implementation at a number of different facilities. The difference in ground terminology is delineated in Table I.

Static Electricity

Problems with static electricity arise with three conditions: an explosive mixture, an electric charge accumulated in a low-conductivity material, and an electric-field discharge that causes a spark of sufficient intensity to ignite the mixture.

Static electricity is generated when two dissimilar materials are in relative motion. A static-electricity charge is developed by relative motion to a metal object, such as a tank, which is insulated from the earth. Similarly, filling an insulated container with charged material creates a static field. The third source of charge buildup is solid or liquid movement of a low-conductivity material, such as a hydrocarbon. The static effect on hydrocarbons is enhanced if dispersed water, aqueous solutions, or conductive air is present.

Splash filling, agitation, and mixing are frequent causes of static electricity inside a tank or vessel. Activities outside a tank, such as draining and taking a sample, can cause static buildup. Static electricity builds due to the motion of low-conductivity materials. In nearly all cases, water, a treating solution, or air is present to provide a somewhat conductive path. Likewise, wet steam escaping into the atmosphere can accumulate a static charge on insulated materials.

Electric fields develop proportional to the second power of velocity. Accordingly, linear-flow velocity should be kept less than 1 m/s, if possible.

Dust dispersed from surfaces may develop a charge. The effect is greater with smooth surfaces. In general, a charge will not develop if both materials are conductive.

These types of static buildup are generally limited to movement of liquids or solids. Uncontaminated gases seldom develop a charge buildup.

Table I. Types of Grounds

Type of Ground	Description	Uses
Grounding Conductors	Metal paths commonly referred to as the “ground”	Maintain minimum potential between metal and earth
Grounded Conductors	Current-carrying wires connected to ground at one point	Neutral of power systems as well as the common or negative of dc-instrumentation circuits
Shielding Conductors	Metal foil, braids, or pipe around a signal conductor	Intercept extraneous signals and noise, then conduct them to ground
Bonding Conductors	Wires that connect between metal items that may become energized	Keep the potential differenc between metal equipment to a controllable level

Preventing Static Hazards

Several steps mitigate the static hazard. The primary source of protection is an effective static ground. Any ground that is adequate for power circuits, lightning protection, or personnel safety is adequate for static grounding. Because the current is very low, an electrical path with very high resistance, on the order of 1 MΩ, is adequate [1].

Maintaining conductivity between fluid movement and metal surfaces will decrease static effects. Conductivity is achieved using a number of procedures that are specific to the system.

Fluids

Metal storage tanks should be grounded, and all metal frames and pipes should be bonded. However, external grounding cannot control sparks and ignitions inside tanks.

Any conductive objects inserted into tanks should be grounded.

- Hose nozzles should be bonded before filling starts.
- Steam jets should be grounded before cleaning.
- Drums should be grounded before steam is let out.
- Nozzles and funnels should be metal and must be grounded (Fig. 1).

Insulated tanks connected to insulated lines should have a grounded metal pipe section in the line (Fig. 1). If there are no other grounded metal objects, insulated containers should have a ground-wire insert.

Mechanical strength, not electrical current, determines the ground-wire size. The minimum self-supporting size is #4 American wire gauge (AWG). The minimum size for burial is #2 AWG. Flexible ground wire should be used for bonds that are disconnected often.

Ground conductors may be insulated, but uninsulated wires make it easier to check for continuity. Connections may be made with pressure-type clamps or exothermic welding.

Containers must be filled slowly. Turbulence from filling operations should be minimized by using a bottom connection or filling tube extending nearly to the bottom of the tank. Grids, gauzes, and gratings in the inlet of the tank should be eliminated since these cause charge separation. Projections that can cause a discharge should be avoided.

Adding a combination of conductive salts to the flow stream can reduce potential buildup. For special considerations, a floating-roof tank will preclude the development of a hydrocarbon-air mixture that may be volatile [1]-[3].

However, floating roof tanks can have problems where flammable mixtures exist. These can be above open-top floating roofs when the roof is high, when the roof is low and there is a leak in the seal, or when there are two seals and vapors are trapped between them. This is so common that the area above the floating roof is defined as Class I, Division 1. An effective protection is to bond the upper roof to the metal tank walls with Type 302, 28-gage × 2-in-wide stainless-steel straps.

Dusts

Systems for handling dusts are very similar to any that handle other flammable material. Conductive dust clouds or layers can contribute to a static-electrical discharge. The spark occurs between an insulated conductor and ground. It does not occur within the dust itself [2]. Therefore, appropriate grounding is critical. There are two additional considerations. First, the air where dusts are moved should be ionized. This prevents the development of a capacitor with the dust as a dielectric. Next, the container must be made inert to prevent conduction.

Personnel

Personnel clothing and activity has been known to contribute to sparks, equipment damage, and injuries. Appropriate attire must be required.

Personnel filling tanks should wear conductive shoes. Rubber or synthetic soles that provide a capacitor dielectric should be avoided. Outer clothing should not be removed in the vicinity of flammable mixtures. Separation can cause static sparks. Metal hats should also be avoided.

Synthetic fabrics have a greater tendency toward static production than natural fabrics. Natural fibers and approved flame-retardant fabric should be worn to reduce personnel injury from ignition sources.

Computers or other electronics should not be used in a classified area unless they are approved for the area classification.

Lightning Currents

Lightning effects come in two forms: direct stroke and indirect currents. Lighting tends to strike protrusions, high points, and edges of structures. Lightning causes damage as a result of heat and mechanical forces when traveling along a high-impedance path.

No single guideline provides all design and installation considerations.

While it is impossible to protect against direct strokes, lightning energy can be dissipated to minimize damage. A low-impedance, metal path to ground should be of sufficient size to carry the tremendous energy from a lighting strike [4], [5].

The three components of a protection system are: air terminals, conductors, and ground terminals. Air terminals provide a contact point for the lightning discharge. Conductors (down-comers) provide a safe path for the high current produced. Ground terminals provide a location for dissipation of the lighting energy.

Nonferrous materials are preferred for each of these items in order to reduce rust or corrosion. Similarly, dissimilar metals in the circuit should be avoided as they create problems in the form of corrosion, high resistance, loose connections, and voltage drop.

The system should be constructed in the form of a cage. Since the impedance of the protection path is inversely proportional to the number of routes, use two or more down-comer paths. As lightning operates like a high-frequency source, sharp bends or narrow loops should be avoided (Fig. 2).

Down-comers on metal structures, like tanks and towers, are generally ineffective. In the case of a direct- or induced-lighting strike, the surge will arc from the down-comer to the structure. Therefore, dissipation of the energy is handled by effective bonding across joints or pins and by effective grounding of the structure.

The ground-surface contact area is more important than ground resistance in eliminating damage. Distribution of the ground system places all points at the same potential. This mitigates surge problems, even in very high-resistance soil. The ground network or a branch must be extended at least 2 ft from any buried concrete to prevent damage to the structure.

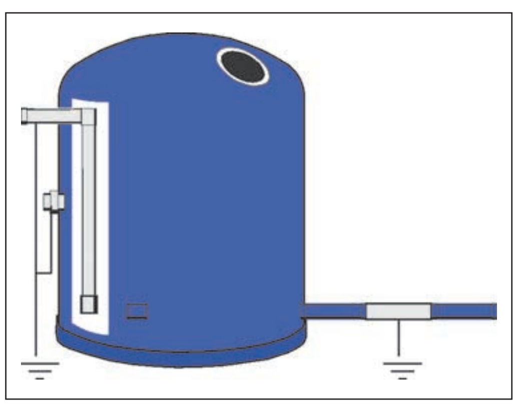

Fig. 1. Grounding for nonconductive vessels.

The goal of ground system design is to make conflicting requirements for each type of system connected to ground compatible.

As with all electrical signals, lightning current will flow through the path of least impedance. The inductance of copper wires used for grounding is nonlinear but is approximately 0.5 μH/ft. The rapid rise time of a lightning pulse creates a frequency greater than 1 MHz. At these nominal values, the impedance of the wire exceeds 3 Ω/ft. [6], [7]

$$Z = R + jX_L$$
$$X_L = 2\pi fL$$
$$X_L = 2\pi^* 1 \text{ Mhz}^* 0.5\mu\text{H/ft} = 3.14\,\Omega/\text{ft}.$$

The nominal resistance of ground wires is 0.3 Ω/1000 ft or less. The inductance is four orders of magnitude (10,000 times) greater. Resistance of any size wire is insignificant in the calculations.

Using very conservative estimates, a surge contains in excess of 3 kA. Often it exceeds 10 to 20 kA. Thus, the voltage drop along each foot of wire is at least 9,000 V [8]

$$V_{drop} = I_{surge} Z_{wire}$$
$$V_{drop} = 3{,}000^* 3.14\,\Omega/\text{ft} = 9{,}000 \text{ V/ft}.$$

Just a few feet of interconnecting wiring will create a very large potential difference between the ends during transient conditions.

The above calculations demonstrate that there is no such thing as a common-earth potential point. Nevertheless, plant-grounding systems are connected to the earth as a point of reference. The effectiveness of the earth connection depends on the soil resistance, the amount of energy to dissipate, and the available structures. Techniques to build an effective ground system are discussed in subsequent sections.

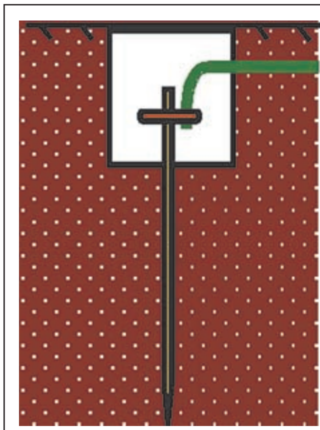

Fig. 2. Bending radius.

The Effect of Lightning on Tanks

Additional lightning protection for tanks is not required if three criteria are met: they can withstand direct strokes if they are electrically continuous, have adequate thickness, and are sealed to prevent the escape of liquids, vapor, or gas. Nevertheless, bonding remains a criterion for safety reasons.

Experience has shown that tanks that have sheet steel 3/16-in thick and are electrically continuous are not susceptible to lightning puncture. However, all vapor or gas openings must be closed or provided with flame protection [5].

An arc that would cause no damage to the tank walls itself can contain enough energy to ignite a flammable atmosphere. It is common practice in some locations to leave the thief hatch open or unsealed. This creates a potential hazard in the case of lightning discharges.

Larger tanks having adequate contact with a conducting pad or surface are self-grounding. A tank at least 20 ft in diameter and setting on earth or concrete is self-grounded. A tank at least 50 ft in diameter and setting on bituminous pavement is self-grounded. All other vessels must have an additional grounding path.

Metal piping may protect metallic tanks not resting on the ground. However, cathodic protection systems will generally result in isolation of the vessel from metal-piping systems.

Metallic tanks insulated from ground should have bonding jumpers to ground to reduce electrical potential and to prevent damage to the insulating materials. Tanks become insulated when membranes or liners are placed under the vessel to prevent soil contamination.

Tanks with outside electrical connections for motors and instrumentation also need to be bonded and maintained at a uniform potential [9].

For equilibrium bonding, use a minimum of two grounding terminals with less than 100 ft of separation around the perimeter of the vessel to be protected.

Ground Ring Protection

Clouds and lightning can create different potentials between locations in a large plant area. In addition, differences in soil resistivity can contribute to potential differences. Another problem can arise from currents caused by faults in the electrical power system. Moreover, instrumentation signals with ground loops and leakage current can also contribute to potential problems. To mitigate these conditions, it is imperative that a reference ground be maintained at equilibrium throughout the facility [6], [10].

If the facility occupies a surface area greater than 500 ft^2, a ground-loop conductor should be installed completely around the equipment (as illustrated in Fig. 3) that creates a grid with cross-connection conductors. A maximum spacing of 50 ft should exist between the conductors.

The ring electrode should be buried a depth of not less than 30 in. The ring needs to be kept a minimum of 2 ft from the foundation or exterior footings. Alternately, the ring electrode may be encased in the concrete footing or in at least 2 in of concrete over 20 ft long. The conductor should be at least #2 AWG bare copper.

Lightning down-comers, ground rods, and other grounding systems need to be bonded to the loop and to any noncurrent-carrying metal that is within 8 ft vertically or 6 ft horizontally of the loop. All structural steel must be bonded to the grid. Wires and conductors bonded to the protection system should not be painted. The resistance of any bonded object should be less than 1 Ω.

Bends in conductors must be maintained to an included angle of less than 90° and a radius of at least 8 in. Suspended conductors should be supported at least every 3 ft.

Exothermic welding or listed devices, such as lugs or clamps, are preferred for connections. Connections not observable must be compression-type or welded.

Inspection wells should be placed at points where the ground rod connects to the grid (Fig. 2). The well should be at least 6 in diameter and encased in pipe or concrete. A cover should be placed over the well.

Fences should be bonded to the ground loop if they cross or are within side-flash distance of 6 ft. The fence should have bonding across gates and other discontinuities, such as end or corner posts.

Implementation of these steps will provide an effective earth connection.

Incoming Lines

External lines often come into an equipment rack or building that is protected by a grounding grid. These lines include power, data, communication, telephone, and antenna cables [11].

Incoming cables should be bonded to a local, single-point, common bus. This bus may be a separate rat-race ring or a common-connection point. Ultimately, it will be bonded to the ground ring.

Lightning protectors installed on electric- and telephone-service entrances and on radio- and television-antenna lead-ins provide protection for the structure as well as the equipment. If possible, these are mounted and grounded at the local common bus at the entrance. These lines should also be protected again before distribution in cable trays. Where data lines are exposed to transients, using fiber-optic segments can effectively isolate the noise.

Lightning protection for power lines depends on the load. The voltage, number of phases, and configuration describe the type protection. Nonelectronics can generally be protected with shunt-type protectors. The protection devices may be

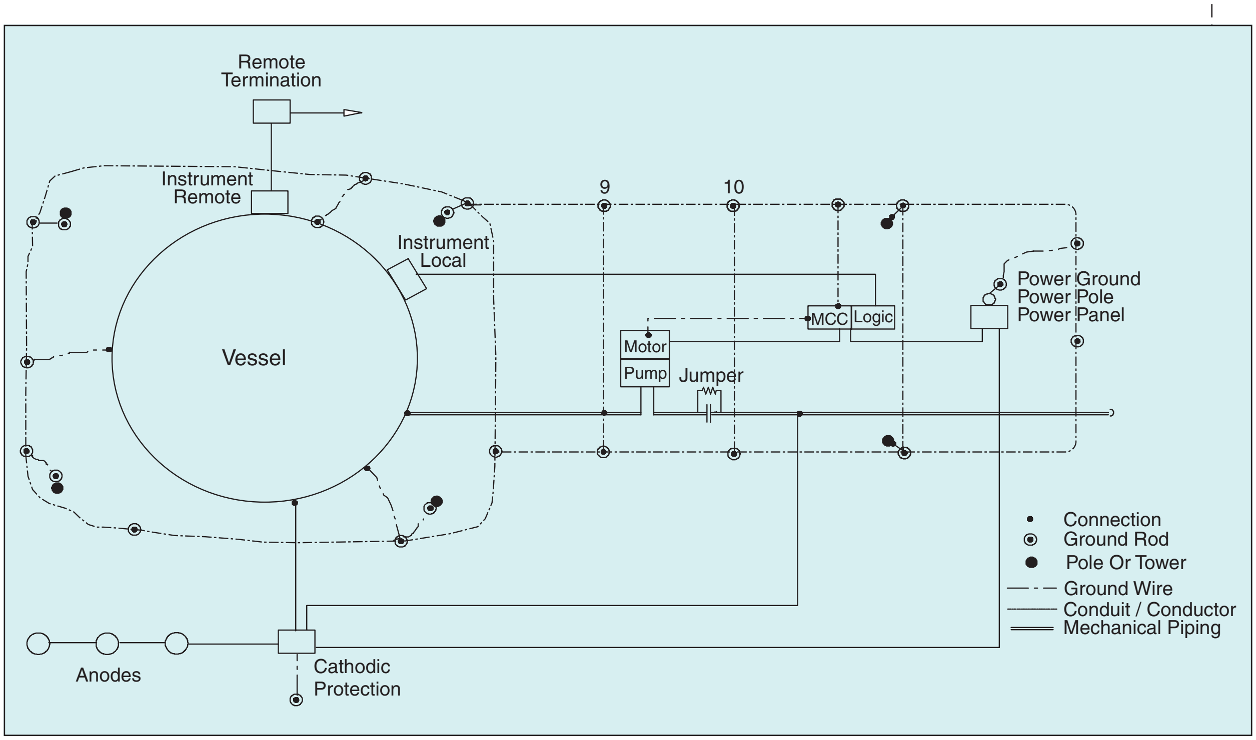

Fig. 3. Ground systems.

transient voltage-surge suppression systems (TVSS) or isolation transformers.

Ground Rods

Ground rods should be 8 ft long and have a diameter of 0.5 in. The material can be solid copper, copper-clad steel, or stainless steel. They should be separated to minimize interference. Greater separation will reduce (improve) the contact resistance with the earth. There are extensive calculations for determining the most effective distance between ground rods. For most conditions, a minimum distance of 2.2 times the length of the electrode should separate the rods.

A grid and ground ring will maintain equilibrium potential. When installed in conjunction with a system grid, ground rods should be less than 50 ft apart. Where soil resistance is greater than 5,000 Ω/cm, an alternative should be evaluated. Lowering the contact resistance by concrete or additional rods is recommended. The rods must be bonded together, preferably using a ring arrangement [12].

Where an isolated electrical device is installed, an alternative grounding electrode system is viable. Instead of constructing a ground ring and grid, a triad of concrete-encased rods should be used.

Electrical-system grounding can not be used in lieu of lightning ground rods. Nevertheless, the systems must be bonded together.

Ground Resistance

Traditionally, ground-circuit resistance has been measured with a three- or four-point method. Test electrodes were installed to permit measurement of the resistance range with an ac instrument. However, a clamp-on instrument now allows direct reading of the resistance by inducing a signal on the conductor [13].

Variations in temperature and moisture will affect the measured ground resistance. Dryer soil will have greater resistance. Similarly, cooler soil will have higher resistance. To ensure protection, designs should be based on the average or higher resistivity conditions.

The grounding system should be tested visually every seven months for corrosion or broken wires and electrically every 14 months. Over time, this cycle assures tests in all seasons and weather conditions.

The resistance of the ground system depends on the application. The goal for power grounding systems is a 25-Ω ground resistance. If this is not met, the only requirement to satisfy the National Electrical Code (NEC) is to add a second ground rod [14].

For a 120-V circuit that is faulted and touching earth, 25 Ω allows a current of 4.8 A. That is an inadequate amount of current to trip a 15- or 20-A circuit breaker. In order to trip a 20-A breaker, the total ground-path circuit resistance must be less than 6 Ω.

$$
\begin{aligned}
I_{\text{trip}} &= V_{\text{fault}}/R_{\text{gnd}} \\
&= 120/25 = 4.8\ \text{A}, \therefore < 20\ \text{A}.
\end{aligned}
$$

Electronic circuits are particularly susceptible to transients and shifts in current levels. For these devices, a ground resistance of less than 1 Ω is desired.

Concrete Resistivity

In an attempt to improve soil resistivity, designers have added various chemicals. Chemical electrodes are often proposed to accomplish reduced resistance. However, maintenance requirements and expenses make this a less-than-preferred option.

Concrete is an effective medium for fill around ground conductors for several reasons. Concrete is quite conductive because of the retained moisture and the alkalinity which provides free ions [15], [16]. Buried concrete has a resistivity of about 3,000 Ω/cm, which is considerably less than the average earth resistivity of 6,500 Ω/cm.

A 5/8-in × 8-ft ground rod in average soil will have a resistance of 23 Ω. This satisfies the NEC requirement. If rock is encountered the soil resistivity goes to 50,000 Ω/cm and the contact resistance is 177 Ω. The same rod placed in concrete will lower the circuit resistance to 10.6 Ω according to Dwight's formula [17].

$$
\begin{aligned}
R &= \left[\rho/191.5L\right]\left[\ln\left(48\,L/a\right)-1\right] \\
R &= \left[3{,}000/191.5^{*}8\right]\left[\ln\left(48^{*}8/0.625\right)-1\right] \\
&= 10.6\ \Omega.
\end{aligned}
$$

Construction of a concrete electrode is simple. Drill 12-in holes and backfill with concrete. Place a ground rod in the center of each concrete hole (Fig. 4).

Fig. 4. Concrete-encased electrode.

To verify the suitability of the ground, calculate the effective resistance of multiple ground rods using the empirical-relationship example. The terms are R for resistance of one electrode, n for number of electrodes, and R_n for resistance of number of electrodes. The net resistance is calculated by this relationship.

For three electrodes in concrete, the contact resistance would be reduced to 4.6 Ω [12]

$$R_{\text{net}} = \left[R_{\text{one}}/n\right]^{*}\left[2 - e^{-0.17(n-1)}\right]$$
$$R_{\text{net}} = \left[10.6/3\right]^{*}\left[2 - e^{-0.17(3-1)}\right]$$
$$= 4.6\ \Omega.$$

Although this is not an unusually low value, it is considerably better than the 177-Ω resistance in the native soil.

Halo Systems

Structures that protrude above the surrounding structures are more prone to lightning damage. Additional protection can be provided by halo systems. However, the key ingredient that makes these protection schemes appear to work is an excellent ground network. It is more important that the grounding system extend under the entire structure than that the ground is a low resistance [12], [18].

We have observed lightning striking a halo system and the flash traveling along the down-comer on multiple occasions. There was extensive damage to the electrical equipment because of an inadequate low-potential ground grid.

The zone of protection of an overhead shield is beneath a 100-ft radius arc from the overhead ground conductor. Conductors can be on a single pole or mast. Alternately, wires can be strung across the protected area.

Wood masts should have an air terminal extending at least 2 ft above the pole. An overhead ground wire or down conductor extending above or across the pole acts as an air terminal.

Insulated structures should have air terminals within 2 ft of the outermost projection of the roof or vessel edge. The terminals should be greater than 1 ft above the structure. The separation between terminals should be less than 20 ft. Terminals greater than 24-in high may be placed no more than 25 ft apart [5].

Conductors should interconnect all air terminals and provide at least two paths. One path may be used if the terminals are at a lower elevation than the top roof terminals. Down-comer wires should be #2 AWG or larger, and the down connectors must be connected to the grid.

Side flashes can be prevented by bonding between metallic surfaces or by adequate separation. Greater than 6 ft of separation is required in air. Only 3 ft of separation is required through solid materials, such as concrete, brick, or wood.

Cathodic Protection

Cathodic protection is designed to protect metal from corrosion. This is accomplished by selecting a material to sacrifice. A connection is made between the sacrificial anode (positive) and the metal to be protected that becomes the cathode (negative). Then the protected metal is made more negative. Often the connection between the anode and cathode is through a rectifier or power source to create a greater potential difference.

The cathodic source should be connected to the power system in the same way any other electrical power device would be connected. Equipment grounding and a neutral ground must be provided. Lightning arresters of the appropriate voltage should be connected to all incoming power leads. Low-voltage arresters must be connected on the dc side if the rectifier is outside a ground ring.

The positive lead of the rectifier or source should be connected to the anode. This circuit must be protected from any contact with soil, metal, or other grounded elements.

The negative lead needs to be connected to the vessel being protected. Other dc negative leads should be connected to ancillary pipe to be protected.

In an effort to control cathodic protection, the metal being protected should be insulated from other metal by pipe or connections. Any metal in contact with the vessel or the negative lead will draw current. This draw may be so excessive that the vessel is not protected and develops holes.

The pipeline is commonly isolated from the vessel. Furthermore, the pipe and vessel may each have their own cathodic protection from two different sources. This creates a real challenge when both systems must be bonded to the electrical grounding network.

The systems are bonded together through a controlled-resistance jumper. However, the electrical system should not be bonded directly to a line isolated for cathodic protection. A bonding resistance of a few ohms is adequate to restrict the stray current. Moreover, the resistance must be low enough that fault current will trip protective devices. This implies the maximum resistance should be about 1-5 Ω for 120-V circuits.

Stray Currents

Stray current is any current flowing in paths other than those deliberately provided for it. These can be the result of faults or from ground return paths of other circuits. They can also arise from cathodic protection as well as the galvanic currents resulting from corrosion of metals. Seldom are measurements made to determine the existence of stray currents unless corrosion or sparks are observed.

Cathodic protection can create stray current problems, but the input voltage is comparatively low. Therefore, the incendiary or shock risks are low. In addition, galvanic potential may be present but does not exceed 1.5 V because of the battery action. Therefore, these risks for ignition are low. However, both effects can cause corrosion to any metal exposed to the currents.

Stray currents from faults and ground returns can create serious problems if the path carrying the unknown current is broken. For dry air, the dielectric strength is about 30,000 V/cm. For the shortest measurable air gap, the arcing voltage is about 350 V. This level is not generally available on broken or separated lines.

Nevertheless, intermittent connections can create arcs. The arc may ignite flammable mixtures if the potential exceeds 35 V. Above 50 V there is also increased risk of personnel electrical shock.

It is preferable to isolate the source of the stray current, if it is known. The fix for remaining stray-current problems is to bond the systems together in a known format. The accepted permanent connection is a #4 AWG conductor or a bonding resistor.

Stray current arises from multiple connections to earth. The offending grounding electrode should be isolated from the earth and the grounding connection ascertained through the grounding conductor.

Stray current can also create disturbances of instrumentation signals. In addition to the other sources, instrumentation stray currents can arise from shield conductors and conduits being grounded at more than one location. In one installation, we found 14-A leakage current flowing to the grounding electrode.

Shield conductors are normally terminated only on the source end. These must never make contact with metal or the earth at any other location.

Shields are grounded at one end only to prevent circulating currents. A contrasting consideration is to keep the potential on a shield to less than 25 Ω. On long runs, this may require multiple connections to ground.

Similarly, a conduit that is used to carry logic-level signals should not provide a continuous metallic path. A polyvinal chloride (PVC) conduit stub or a cable run can isolate one end of the conduit. Nevertheless, one end of the conduit is still bonded to the grounding network.

Instrumentation Wiring

Transients and other extraneous signals create noise. In order to cancel induced noise, twisted-pair cables are used. The same noise will be induced on both wires, but the twisting will cancel the effect at the end. For analog and higher frequency discrete signals, shielding is used. For low-level, high-frequency signals, coaxial cables are preferred [19], [20].

Twisted-pair cable bundles will mutually couple the total available surge energy to all the pairs in a cable bundle. More pairs share the energy and permit less to be imposed on one piece of electronics. Regardless of the number of pairs, all unused pairs are grounded to the local, common, single-point bus. Any surge energy induced on these lines will then be directed to the earth.

For more than six pairs in a bundle, shunt-type protectors are usually adequate to dissipate the energy. For less than six pairs, more energy is present on each pair, so inline protectors are required. The inline protectors include filters as well as shunt protectors.

Instrumentation and communication cables run more than 5 ft from high-voltage and high-power cables eliminate the majority of the induced noise. If it is necessary to cross power cables, the cables are run at right angles to avoid induction.

To provide a more complete shielding of the terminations and to protect the equipment in dirty environments, the complete electronics could be placed in a National Electric Manufacturing Association (NEMA) 12 enclosure. If this is done, sufficient air circulation must be provided for cooling.

Protection Devices

Protection devices are often added to the electrical system to aid in managing surges. The devices may shunt current, block energy from traveling down the wire, filter certain frequencies, clamp voltage levels, or perform a combination of these tasks.

Regardless of the function, only a few basic components are available to economically build the protectors (Fig. 5). Protection devices are selected based on the voltage, frequency, and ground system of the circuit.

The simplest arrangement is physical separation. Gaps may be used to provide arc paths above a certain level. These may be air gaps or spaces between conductors in a dielectric material. Classical lightning arresters fit in this category. Often the devices are built so that the path will become low impedance once breakdown occurs. Silicon carbide is often used in high-energy devices. Gas tubes and other breakover materials also fit in this category. This is the slowest class of protection equipment, but the energy handling capability is very large for

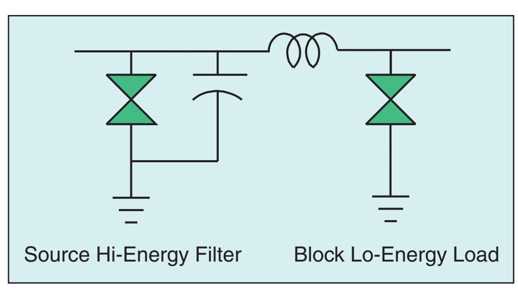

Fig. 5. Protection scheme.

the cost. Properly designed gas tubes can work to the limits of lightning levels [6].

The next common arrangement uses passive electrical elements. Capacitors and inductors are applied to the circuit. Bypass or bandpass filters can be constructed. Inline filtering uses inductors. Air core is preferred to ferrite-core inductors. The air core has less attenuation, a higher cutoff frequency, and is larger. However, it is preferred because the ferrite-core characteristics change with the magnitude and frequency of the current to be dissipated.

Semiconductor devices are the most advanced arrangement. These devices are faster, but they generally handle less energy than comparably priced alternatives. Because of the limited range of operation, these devices must be more precisely specified. Silicon devices fit into two groups; voltage or current-protective elements.

Metal-oxide devices are primarily voltage triggered and are manufactured to handle very precise quantities of energy (joules or watts per second). The device is selected for a turnon voltage that is greater than the peak expected voltage from the power supply. The energy dissipation is based on a standard waveform. Each metal-oxide varistor (MOV) will have a resulting surge-current rating. The device has an inherent capacitance.

Higher energy units tend to have a higher capacitance. However, this creates a problem with high-frequency signals. The high capacitance at high frequency will increase the impedance and attenuate the signal.

Zener, avalanche, or silicon-junction diodes are much faster devices than varistors but can not sustain as much energy. Since the unit has essentially no energy-dissipation rating, it is coupled with a primary arrester, such as a gas tube. The diode will trigger first, then the high energy will be dissipated through the gas tube.

More surge protection is provided from devices with the lowest throughput energy at a particular frequency. The throughput energy is the amount of energy that gets past the protector onto the equipment being protected. Most lightning energy can be restricted with devices designed for less than 1 MHz. Above that frequency, there is less throughput energy

For high-energy power systems, all the components in Fig. 5 may be used. Often, the capacitor can be removed from the circuit with little impact since it is difficult to match the frequency. The grounds are intentionally isolated to dissipate the energy. For typical systems, the ground terminals are tied together. Only one connection is made to ground.

Summary

There are numerous different considerations for each type of system connected to ground. Nevertheless, there is a key concern for each. The goal is to make these seemingly conflicting requirements compatible.

For lightning protection, a uniform ground grid is desired under the entire area covered by the tank or vessel and all its connected equipment. A static-lightning shield will protect the area under a 100-ft arc. If used, it should be inside the grid network.

For personnel protection, the vessel, all other metal, and the electrical equipment must be bonded together. For power grounding, the connection to earth must be a low resistance. For instrumentation signals with protection to ground, there must be no shift in the level between the source and the instrument. This is accomplished with a single connection to the grounding system. For cathodic protection, current is applied to metal that is connected to the ground system. Isolation and controlled bonding prevent stray currents.

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