IEEE STANDARDS ASSOCIATION

IEEE Guide for the Protection of Communication Installations from Lightning Effects

IEEE Power Engineering Society

Sponsored by the
Power Systems Communications Committee

IEEE
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New York, NY 10016-5997
USA

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IEEE Std 1692™-2011

Lincoln, Nebraska

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The objective of this Abstract is to clarify technical concepts and provide informative background for the practitioner. Whereas IEEE 1692-2011 primarily addresses theory and installation detail for wireless sites, this Abstract extends the application discussion to wire-line sites.

IEEE 1692-2011 was produced by the Power Systems Communications Committee of the IEEE Power Engineering Society and released in August, 2011. For detail information regarding IEEE 1692-2011 refer to http://ieeexplore.ieee.org

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IEEE 1692-2011

I Introduction

Background

Every year, communications equipment in the outside plant (OSP) suffers millions of dollars of damage. A severe lightning storm in rural America typically means loss of service, truck rolls, non-warranty parts replacement and insurance claims.

Most of the damage is unexplained or not investigated, and yet is preventable.

IEEE 1692 is the first industry publication that provides guidance for lightning protection of electronic communications equipment in the OSP environment. Related documents, NFPA 70 (the national electric code), NFPA 780 and NESC only address the protection of buildings and personnel safety.

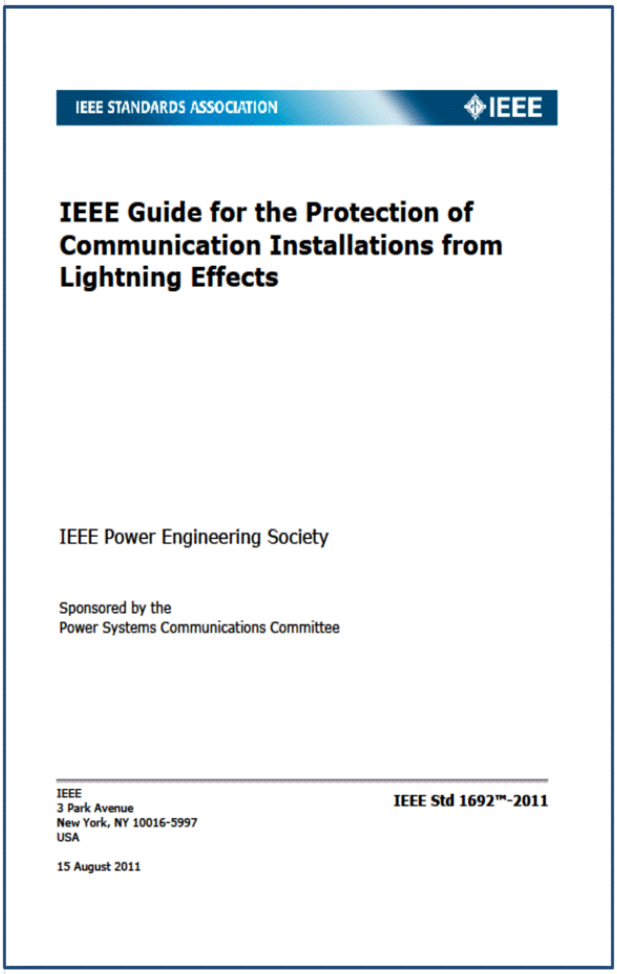
Purpose

The purpose of this IEEE 1692 Abstract is to:

1. familiarize the reader with the faults that are accountable for most of the unexplained lightning related damage, and
2. explain the advantages of blocking technologies to effectively isolate and protect communications equipment.

Action

Readers are encouraged to thoroughly review the recommendations for application to their networks.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II Basic Protection

Most lightning threats to communications equipment in urban areas can be mitigated by appropriate surge protection and grounding practices.

A. Equi-potential Ground Plane

Essential to all lightning protection strategies is keeping all ground points close to the same potential to minimize voltage differentials:

1. Connect all equipment grounds to a common ground bar,
2. Connect all power and communication structures on site to a common (single point) ground, and
3. Locate grounding ingress/egress at ground level to minimize the voltage differential with respect to ground.

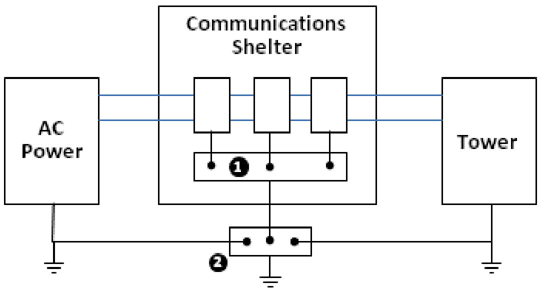

Fig 1. Simplified Equi-potential plane design

B. Grounding – Soil Resistivity

The effectiveness of a grounding system is dependent on multiple factors such as soil resistivity, grounding electrode contact with the earth, and arrangement of the grounding components (rods, wires and bars).

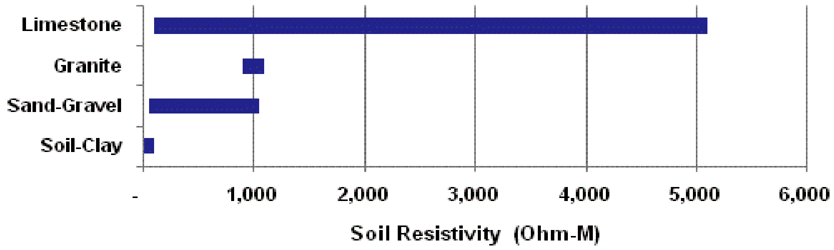

Fig 2. Soil Resistivity Values of Common Earth Compositions

However, achieving low ground resistance (5 Ohms or less) may not be practical or even possible in higher soil resistivity conditions. Referring to Figure 2, sand-gravel, limestone and granite are 20 to 100 times more resistive than surface soils and clay.[1] Sand-gravel and limestone encompass a broad range of possible soil resistivity values that may significantly vary within a given area.

Dehydration during arid seasons dramatically increases soil resistivity.[2] L-GPR produced by "dry lightning" can be extremely damaging (refer to Pg. 7, Soil Resistivity-Ground Voltage).

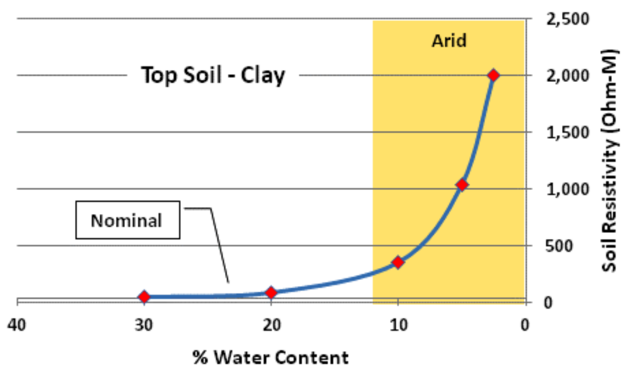

Fig 3. Surface Dehydration effect on Soil Resistivity

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[1] USDA Bulletin 1751F-670

[2] Ibid

To achieve lower 60Hz impedance in multi-electrode grounds it is necessary to assure the electrodes are as far apart as they are deep to minimize the mutual inductance between the electrodes. Mutual inductance reduces the grounding efficiency for all frequencies.[3]

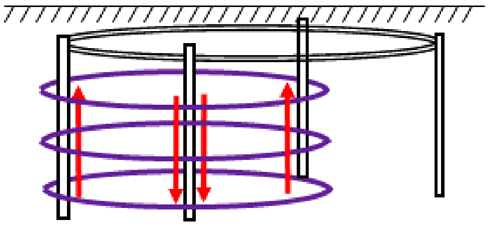


Fig 4. Mutual Inductance of Ground Rods

However, longer or additional ground electrodes do not reduce the grounding impedance behavior at the lower lightning frequencies (refer to Pg 7, Grounding-Frequency Dependent).

Grounding is subject to degradation from corrosion and other environmental factors and requires periodic maintenance and testing to maintain desired ground resistance.

C. Surge Protection – Application Considerations

Surge Protection Devices (SPDs) have proven to be an effective deterrent against most power and signal line threats. Surge protection responds to elevated voltage and redirects the energy to the return conductor or ground - the intended primary fault paths in Figure 5. SPD failure produces the destructive secondary fault paths.

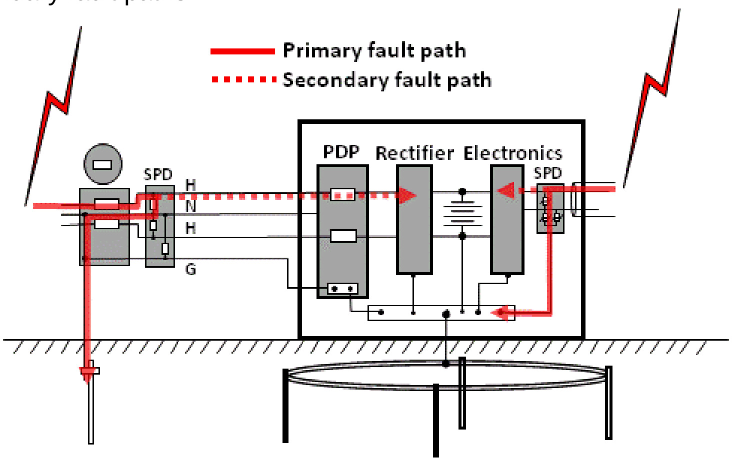
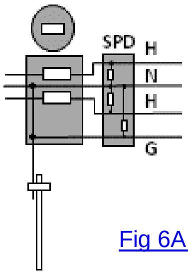


Fig 5. AC and Signal line SPD Protection



All mode protection (L-L, L-N, L-G & N-G) is necessary for primary protection of outside plant electronic sites.

NFPA 70 (NEC) permits only one neutral-ground bond at the site, located at the service disconnect. A second N-G bond after the service disconnect can circumvent circuit breaker protection.

Fig 6A. Primary SPD Modes

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The neutral ground mode on a secondary SPD at the Power Distribution Panel must be disabled, which may otherwise provide an additional fault path for elevated voltage on the master ground bar during a GPR event (refer to Pg. 9, Fault: Ground System Transients).

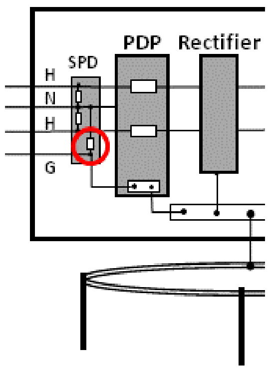

Fig 6B. Secondary SPD Modes

[3] Megger, Getting Down to Earth, 2010, P38

Surge protectors are reactive devices. The response of surge protectors allows let-through voltage that may fatigue sensitive electronic circuits over time.

Hybrid SPDs combine faster reaction and high capacity to reduce let through voltage.

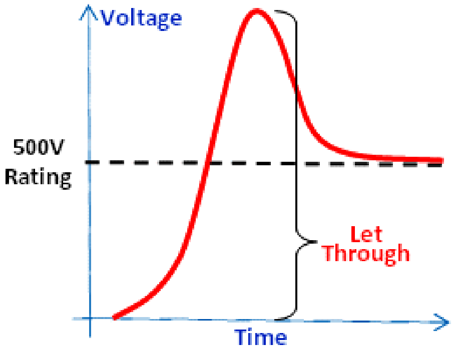

Fig 7. SPD Let-through Voltage

III Power Line Strikes & Flashovers

A direct strike to a power line or signal cable creates high voltage transients that can produce destructive current on the conductors. The extreme voltage and current produced by a lightning strike can overwhelm the best SPD.

A. Lightning – Flashover Dynamics

Lightning produces an extremely high current pulse than can momentarily reach 200KA within 2uSec.[4]

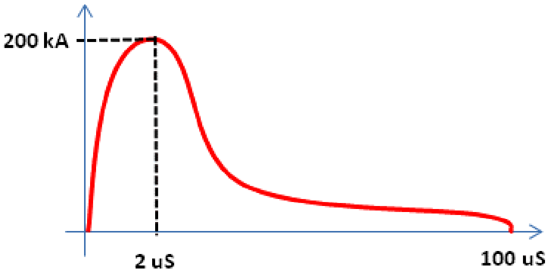

Fig 8. Simplified Lightning Discharge Profile

The familiar vulnerability to lightning is a transient. Despite the use of a protective ground wire, lightning current can flashover from the ground wire to a phase or neutral line. If the protecting ground wire exhibits a high impedance to ground, a significant voltage can develop that exceeds the air breakdown value (~3MV/m), allowing the lightning current to arc to a phase or neutral conductor, impressing severe current on the terminal circuits.[5]

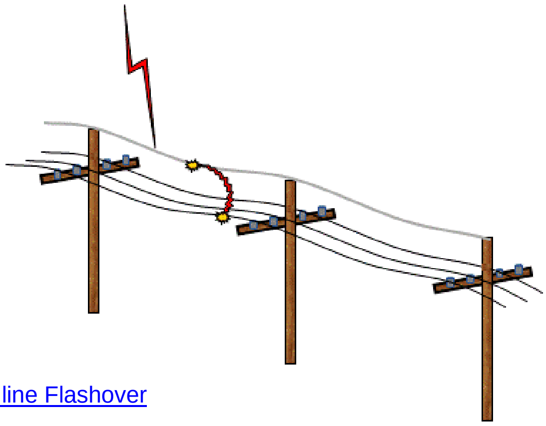

Fig 9, Power line Flashover

[4] The Lightning Discharge, Martin A. Uman, International Geophysics Series, Vol 39, 1987, Pg 341

[5] Handbook of Chemistry and Physics, Chemical Rubber Company, any recent edition

B. Surge Protection – Performance Limitations

The threshold voltage of an SPD is not an ideal constant. The actual performance of surge protection is subject to the applied voltage. Higher voltage increases the current, and higher voltage across the SPD will be let through to connected equipment.

Severe voltage produced by a direct strike or flashover may expose the electronic circuits to very high let-through voltage, potentially damaging equipment and the SPD.

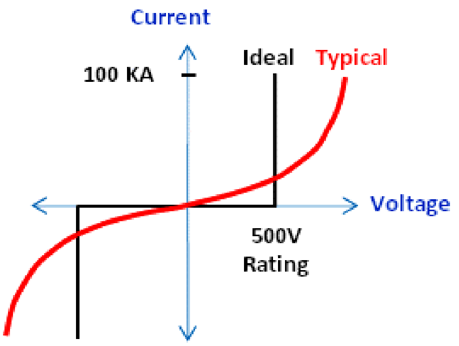

Fig 10. SPD Performance is Current Dependent

C. Recommended Solution – AC Isolation

AC Isolation provides protection from flashovers and other severe utility transients. Detection of lightning before the strike preemptively opens the AC circuit, blocking transients that may otherwise overwhelm surge protection.

During isolation from AC power, operations safely continue on resident DC power until the threat has passed, at which time AC power is automatically re-connected.

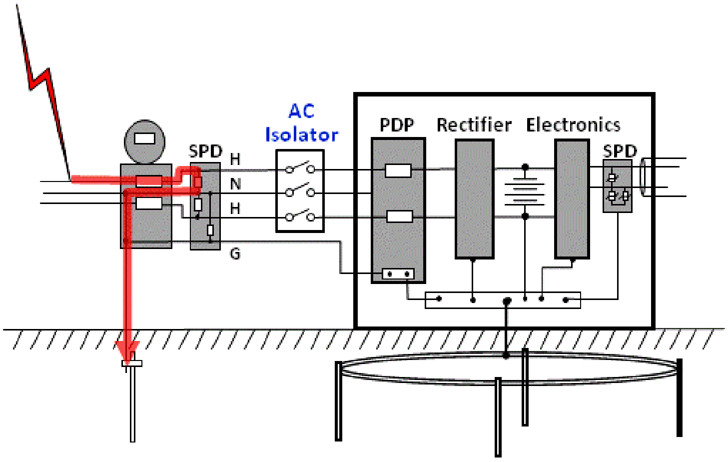

Fig 11. AC Isolation Solution of Severe Power Line Transients

IV Lightning Ground Potential Rise (L-GPR)

IEEE-1692 primarily focuses on the threat posed by L-GPR, undoubtedly the least understood and consequently, least protected lightning threat. The energy from a lightning ground strike is not immediately dissipated in local earth. The voltage of the earth rises as energy is radiated outward creating momentary voltage gradients between ground points.

A. Lightning – Discharge Dynamics

Lightning is an electrostatic discharge – a transfer of electrical charge between the cloud and ground. Prior to a strike, negative charge accumulates in the lower portion of a storm cell causing a concentration of offsetting positive charge in the earth. During this process the earth's normal electric field of 100V/m increases to over 2,000 V/m and changes from negative to positive polarity[6].

Prior to discharge, the voltage differential between the cloud base and earth dramatically rises to between 10M and100M volts.[7]

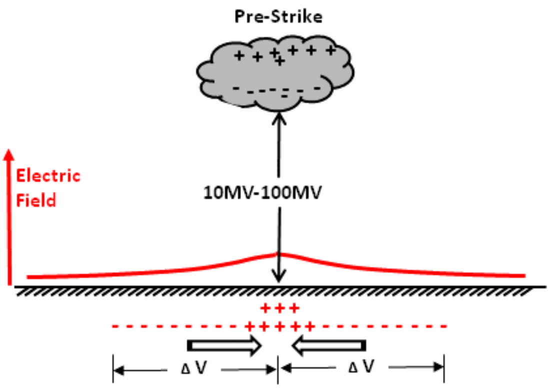

Fig 12. Pre-Strike Ground Charge Motion

The discharge produces ground current that radiates through the earth's surface in all directions. The peak current amplitude of a lightning strike ranges from 5KA to 200KA. There are typically 3 to 4 discharges per lightning channel (the visible flicker is repetitive ground strikes).[8] Consequently, successive waves of energy are radiated from the strike point.

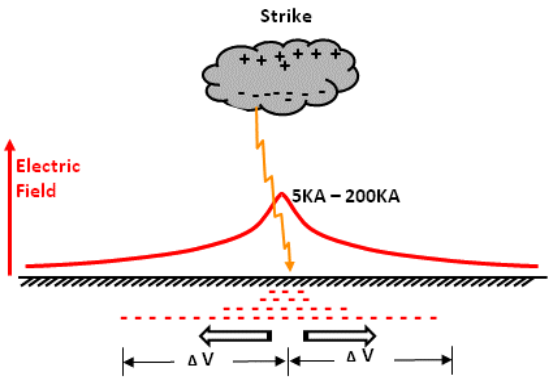

Fig 13. Post-Strike Ground Charge Motion

The discharge creates voltage gradients radiating from the strike point, comparable to the waves created by a rock striking a water surface. The 5 - 200KA lightning current converts to ground current.

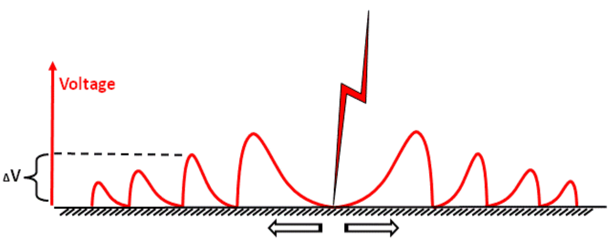

Fig 14. Ground Voltage Gradients

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[6] Lightning, Martin A. Uman, Dover Publications, ISBN 0-486-64575-4, Pg 48, 51

[7] Ibid, Pg 214-215

[8] Lightning, Martin A. Uman, Dover Publications, ISBN 0-486-64575-4, Pg 4

B. Soil Resistivity – Ground Voltage

Soil resistivity is a significant determinant of the voltage, or potential, gradient. Higher soil resistivity produces higher voltage potentials for a given current.

At a half-mile distance, an average lightning strike of 25KA produces very low voltage in a soil-clay region. However, a site with a sand-gravel composition will be exposed to potentially damaging voltage. The diagram below displays approximate ground potentials. (Referring to the dashed line in Figure 15, a 25KA strike in limestone measuring 2,000 Ohm-M produces a gradient potential of 30,000V over one half mile.)

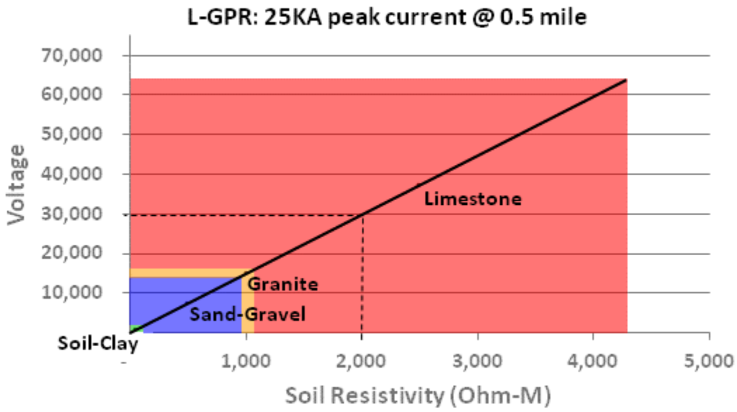


Fig 15. Soil Resistivity effect on L-GPR Voltage

Caveat: Communication sites in urban areas are relatively immune to the L-GPR threat due to the extensive underground infrastructure that is highly conductive, substantially reducing the effective soil resistivity. By contrast, rural areas characterized by elevated soil resistivity are highly vulnerable to just one near-proximity ground strike.

C. Grounding – Frequency Dependent

Grounding is designed to provide a low impedance current path to earth for both safety and equipment protection purposes. However, grounding systems behave differently at different frequencies. Grounding is a very effective conductor at very low frequencies, as demonstrated by grounding resistance tests typically conducted at 50 –150Hz. However, grounding is inductive at the lower frequencies of lightning between 5KHz and 500KHz.[9]

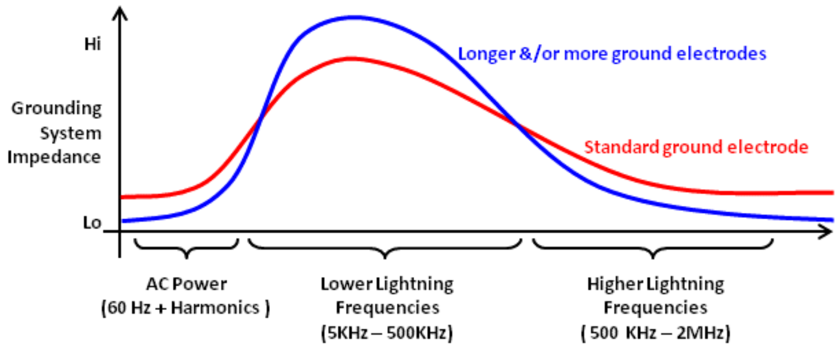


Fig 16. Grounding Effectiveness is Frequency Dependent

[9] IEEE Transaction on Power Deliver, Vol 23, No 4, October 2006, Triggered Lightning Experiments; Brian DeCarlo, Vladimir Rakov, et.al

The resulting high impedance at these frequencies significantly affects the current path. The referenced studies found that in higher resistivity earth over 50% of the lightning current impressed on the grounding system was forced onto the AC phase and neutral lines.

Although longer or additional grounding electrodes reduce AC-60Hz impedance, the higher inductance of longer ground rods may also increase the impedance for the low-range frequencies of lightning.

D. Fault Paths – Recommended Solutions

The unexplained lightning related damage to communications equipment is typically attributable to an L-GPR fault, inducing either a signal line transient or a ground system transient. A signal line transient is evident if the protectors have failed. <u>However, a ground system transient can inflict significant equipment damage without affecting the protectors.</u>

Fault: Signal Line Transients

The lightning discharge current on cable shields can induce currents on adjacent conductors, producing high voltages in cables and electrical equipment. The shield current produces a magnetic field which couples to the signal lines and produces a current in the opposite direction.

Note that a similar fault may be caused by 60Hz GPR in close proximity to a power substation or generation plant.

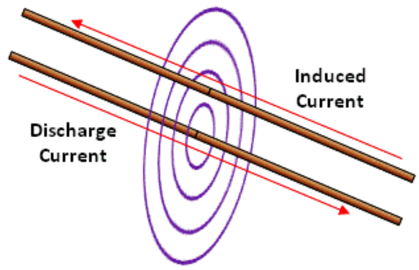


Fig 17. Magnetic Field Induced Current

Recommended Solution: Optical Isolation

Optical Isolation inserts a dielectric path for signal lines that may otherwise expose personnel or equipment to voltage transients. Applications include:

1. Service centers that potentially expose operators
2. Services to high voltage facilities - substations and power generation plants
3. Class A facilities that must continuously operate in all circumstances

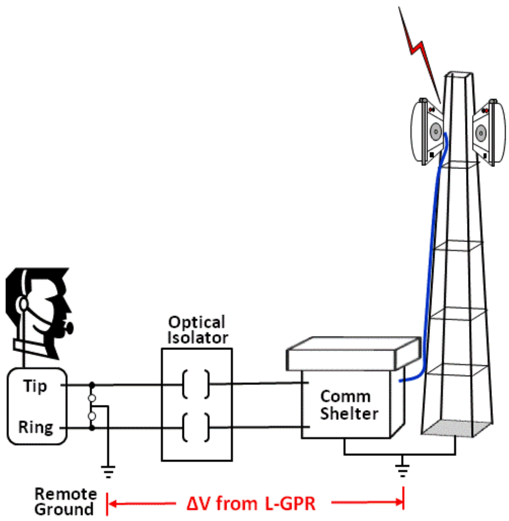


Fig 18. Optical Isolation Solution of Signal line Transients

Fault: Ground System Transients

Single point grounding of the communication's site seeks to achieve an equi-potential ground plane that assures very low voltage differentials between bonded ground circuits, and thus little threat of fault current.

However, connection to the AC power service introduces a remote, lower potential ground reference during an L-GPR event. The high potential difference between the communications ground and the AC service ground makes the power phase and neutral lines a preferred discharge path between the grounds. The safety ground is only partially effective because of the higher impedance to lightning frequencies.[10]

The grounding system near a lightning ground strike elevates in potential with respect to other grounds. The voltage impressed on the grounding system elevates the master ground bar (MGB).

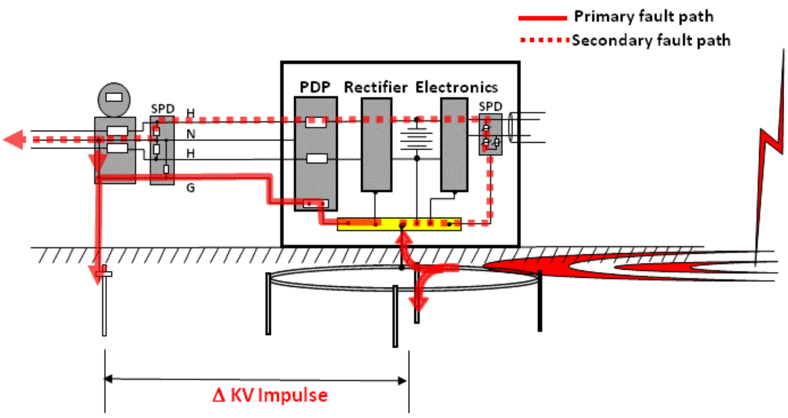
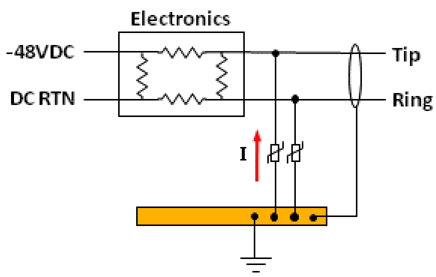


Fig 19. Ground System Fault Path

The signal line surge protectors are connected to the MGB. SPDs are bi-directional devices (to protect against positive and negative polarity transients[11]) and activate if the MGB voltage exceeds their threshold. The activated SPD provides a conductive path for the elevated MGB voltage to the Tip and Ring circuits. A fault path is created to the lower potential ground references on the signal line terminations and the remote power ground circuit for the electronics equipment.

Voltage on the subscriber circuit is substantially dissipated over the intervening distance. However, there is a significant potential difference on the adjoining power circuit, exposing the communications equipment.



Transient & Source	MOV Clip	Net Voltage Rise
Ground 1000V	250V	750V to Tip & Ring Circuit

Fig 20. SPD conduction of L-GPR

Referring to Figure 20, if the MGB experiences a LGPR of 1,000V and the SPD has a 250V threshold, about 750V is applied to the Tip and Ring line card circuits relative to remote ground.

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10 The Self and Mutual inductance of linear conductors, Edward B. Rosa, Bulletin of the Bureau of Standards, Vol 4, No. 2, 1908 Pg 301-344

11 IEEE Std C62.45-1992

Recommended Solutions

Radial Grounding (for tower sites) **-** recognizes the frequency limitations of vertical grounding. Since current from a lightning ground strike radiates near the surface[12], radials off the vertical grounding reduce the grounding impedance to the low-range frequencies of lightning.

1. The combination of vertical and horizontal electrodes provides lower impedance grounding.
2. The radials increase the capacitive coupling between the grounding system and the earth.
3. However, the effectiveness of the radial grounding diminishes in soil resistivity over 500 Ohm-M.[13]

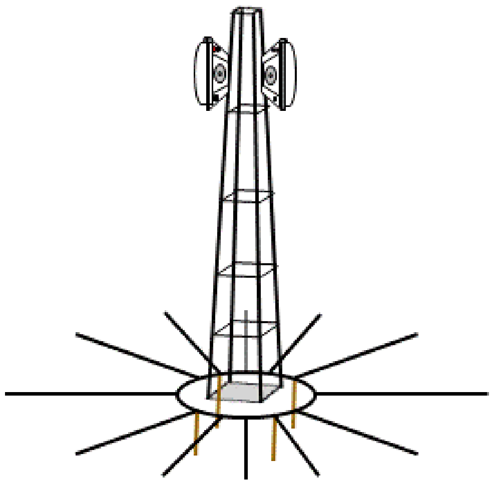

Fig 21. Radial Grounding for Towers

AC Isolation - detects lightning before the strike and preemptively disconnects the utility power phase and neutral circuit. Opening the power circuit creates a single point ground condition, effectively isolating the communications equipment and blocking the fault path. Absent a secondary path, the lightning energy is forced to dissipate through the grounding system. Communications are continuously maintained on battery or generator power during the isolation period. Utility power is automatically restored after the threat has passed.

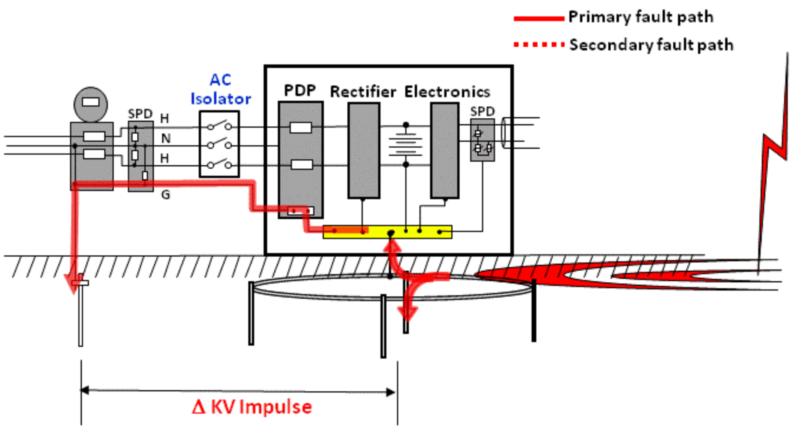

Fig 22. AC Isolation of Ground System Transients

AC Isolation requirements:

1. Standby power is required to maintain operations during the isolation period.
2. The AC Isolator also includes an AC voltage monitor that responds to AC surges and sags within 3 cycles. However, the AC Isolator must be installed on the line side of the primary SPD to provide an initial fast response to AC transients caused by non-lightning events (e.g. capacitor bank switching and inductive motor switching).

[12] An Examination of Lightning Strike Grounding Physics: C.B. More, G.D. Aulich and William Rison; Langmuir Laboratory for Atmospheric Research

[13] IEEE 1692-2011, 8.1 Note 3

V Summary

Lightning energy radiates outward through the atmosphere, the earth's surface and all conductors over a wide frequency range. Rural and remote communication's installations are particularly vulnerable to lightning. New protection technologies have evolved to augment traditional protection practices and effectively mitigate the lightning threat.

Critical to a solution is correct diagnosis of the problem. Sites with good grounding and surge protection practices are still vulnerable to severe power line faults and lightning ground potential rise (L-GPR). <u>In fact, both grounding and better surge protection actually facilitate the L-GPR fault path.</u>

Effective protection against lightning damage requires a combination of technologies to address unique circumstances. The recommended protection strategies are:

1. All exposures:

   Optimize the equi-potential ground plane, within the limitations of local soil resistivity

2. AC Transients:

   Primary all-mode surge protection

   AC Isolation for power line strikes and flash-over exposure

3. Lightning Ground Potential Rise (L-GPR):

   Optical Isolation for signal line transients

   AC Isolation for grounding system transients

   Radial grounding for towers with available real estate and low soil resistivity

Note: The effectiveness of the blocking technologies - Optical Isolation and AC Isolation, is not subject to soil resistivity or the resistance of the grounding system. A high resistance ground will just take a little longer to dissipate the blocked energy.

Augmenting traditional protection practices with the appropriate blocking technology affords the best protection strategy to minimize lightning related damage.

AC Isolation

I Technology

If L-GPR is the least understood lightning phenomenon, then AC Isolation is the least recognized solution. AC Isolation is:

1. A blocking technology – open circuits the potential fault path to the communications equipment
2. Pre-emptive – disconnects the fault path before the threatening ground strike occurs
3. Intelligent – discriminates lightning ground strikes from other electric field phenomenon

The AC Isolation technology is comprised of three components: a Lightning Detector, a Contactor to disconnect/re-connect AC power and a Controller that manages the detection and isolation functions and provides connection to remote communications. The Contactor is an electro-mechanical device with a response time of about 15mSec – too slow to react to a nearby lightning event. Consequently, the AC Isolator must discriminate the potential lightning threat before the ground strike occurs to provide sufficient time for the Contactor to isolate the communications equipment.

A. Lightning Detector

Reliable detection of lightning ground strikes requires discrimination of the electric field orientation. Cloud to ground lightning is primarily a vertical electric field, whereas cloud to cloud lightning and electromagnetic transmission are primarily horizontal fields.

Prior to a stroke discharge, the development of a lightning channel rapidly changes the electric field strength at ground level. L-GPR produced by a remote ground strike causes a significant ground potential increase that also produces an electric field change.

The Lightning Detector is responsive to both events. The electric field change is detected, converted to voltage and compared to the Lightning Detector threshold. If it exceeds the threshold, isolation is initiated.

Figure 23 depicts the increasing L-GPR amplitude from an approaching storm. Low soil resistivity areas (T) that readily dissipate L-GPR energy produce a weaker electric field change, requiring a more sensitive detection threshold.

For the same lightning strike, high resistivity soil (S) dissipates less L-GPR energy, producing a stronger field change. A less sensitive detection threshold is necessary to ignore distant lightning activity that is not threatening.

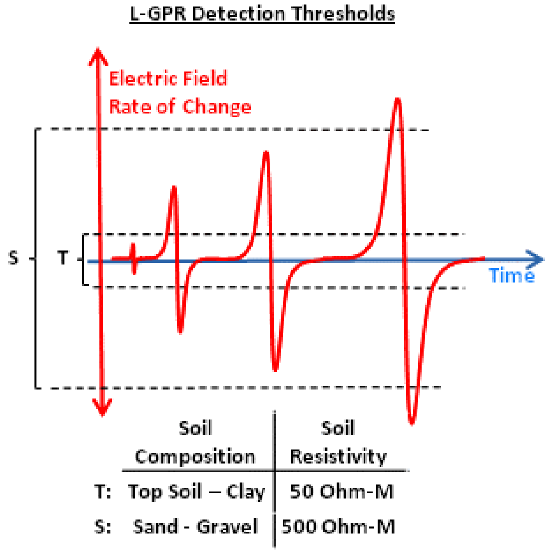

Fig 23. Detection Sensitivity based on Soil Resistivity

The Lightning Detector circuitry provides:

1. Sensitivity adjustment for user specification of the detection range based on the local soil conditions,
2. A voltage comparator to evaluate the differential voltage caused by the changing electric fields near the earth,
3. Communication with the Controller to open/close the Contactor controlling the AC service, and
4. User test of the detection and communication circuits

B. Controller

The Controller opens the Contactor in response to a signal from the Lightning Detector or an internal AC voltage monitor, based on the user specified thresholds.

1. The AC detector monitors the AC power service with two voltage comparators to detect fast transients and slower surge/sag activity.
2. Adjustable count-down timers determine the initial isolation period for L-GPR and AC power threats. Subsequent threat detection during an isolation period restarts the respective timer.
3. AC power is re-connected after it stabilizes within the user defined thresholds. Consequently, the communications equipment is protected from power recovery transients.
4. The Controller targets re-connection of AC power at the zero voltage cross-over to mitigate local switching transients and minimize in-rush currents.
5. Alarm relays are provided for connection to the site alarm panel.

A Remote Controller provides several additional features:

1. Remote communications on an Ethernet or POTS connection,
2. Remote monitoring of threat activity and adjustment of protection settings (detection thresholds and isolation timers),
3. Event logging and remote download of threat activity and the corresponding protection response; the log may be correlated with 3rd party lightning data,
4. Remote monitoring of the battery plant or test of the stand-by generator, and
5. Remote test of the AC Isolator.

C. Contactor

The Contactor disconnects the phase and neutral lines; the safety ground is not disconnected.

The Contactor is sized equal to or greater than the amperage of the AC service. For example, equipment wired off a 200A service disconnect requires a 200A contactor; equipment wired off the load center may only require a 60A contactor, or less.

Contactors for this application are rated for several million cycles.

II Installation

Installation typically requires the services of a commercial electrician.

The Controller is installed:

A. off the service disconnect, on the load side of primary AC SPD, and before the transfer switch,

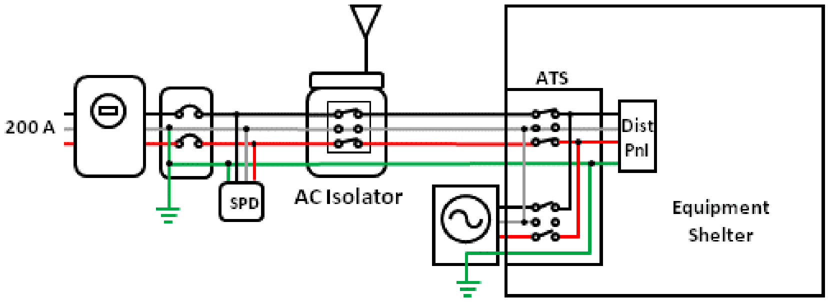

Fig 24. Typical Wireless Site (Cell Tower) Installation

B. or, off the load center and before the cabinet power distribution panel

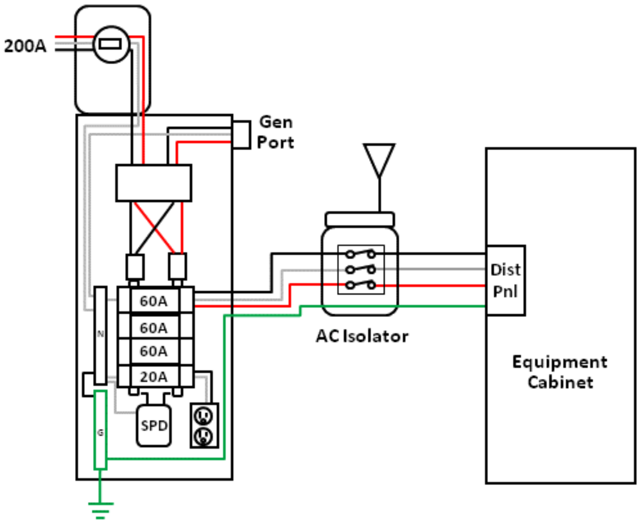

Fig 25. Typical Wire-line Site (Remote Terminal) Installation

The Controller may be mounted externally on a power pedestal, an adjoining frame, or on the interior wall of a shelter. The Lightning Detector must be mounted externally with a 360^{o} view that is unobstructed for a minimum 8 feet.

Glossary

AC Isolation. The physical disconnection of the AC utility power from electronic systems to protect against power transients and lightning ground potential rise. Typically an automatic process based on detection sensor(s).

All Mode (ref SPD). An AC surge protector that provides all modes of power protection, Typically referenced to 240V split phase and 3 phase power systems. The modes are: Line-Neutral (L-N), Line-Line (L-L), Line-Ground (L-G) and Neutral-Ground (N-G)

Capacitance. The property of parallel conductive surfaces to store energy in an electrical field between the surfaces. The degree of capacitance varies directly with the area of the parallel plates and inversely to the distance of separation between the plates. A property of a capacitor is to pass AC signals and block DC signals. The AC impedance will vary inversely with frequency.

Contactor. A relay that is designed to control power in AC power systems. A contactor is frequently used in electric motor starters and electrical power panels.

Equi-potential. Pertaining to equal electrical potential; where all points on the grounding system (sometimes referred to as a plane) strive to be at the same potential to mitigate ground current loops.

Flashover. A current arc from one conductor to another when struck by lightning. A typical example is a lightning strike to the ground protection wire on an aerial power line that arcs to the phase or neutral line below. In the first several uSec of lightning contact the immediate voltage can exceed 100KV while the impedance to ground can be very high. The phase lines are at a moderate voltage with respect to ground and provide another path to ground, as does the neutral line.

GPR (Ground Potential Rise). The increase of electrical potential in the earth with respect to another location. This may result from a downed power line or a power distribution fault, referred to as 60Hz GPR; or a lightning ground strike (L-GPR). GPR is typically a momentary condition and magnitudes can vary between mV and KV.

Ground. A direct physical connection to the earth, or a reference point in an electrical circuit from which other voltages are measured.

Ground Resistance. Ground resistance is the resistance of the grounding system to current flow. However, ground impedance is a more complete characterization of grounding conductivity that includes capacitive and inductive reactance. Grounding impedance is primarily a function of soil resistivity, surface area contact with grounding electrodes and the physical dimensions of the conductors.

Ground Ring. A series of buried grounding electrodes connected by a conductor such as a wire or cable, in direct contact with the earth encircling the grounded structure.

Grounding Electrode. More commonly called a ground rod which is driven into the earth for the purpose of providing an electrical connection to the earth.

Impedance. The total opposition to current including resistance, inductive reactance and capacitive reactance. In DC circuits there is no reactance and the impedance is just the resistance. (Refer to Reactance)

Inductance. The property of a conductor that provides a direct opposition to AC current from a self induced magnetic field caused by a change in current.

L-GPR (Lightning Ground Potential Rise). Ground potential rise created by a lightning ground strike. L-GPR radiates in all directions and is typically more severe than 60Hz GPR which returns to the distribution source. L-GPR creates extreme potential differentials across the earth surface. The differential voltages decrease with distance based on soil conditions.

MGB (Master Ground Bar). A metal bar used as a common grounding point in communication systems. The MGB contributes to providing a single point ground.

Neutral-Ground Bond. The point where the power neutral line and ground are bonded together at the power transformer and the power service disconnect. NEC requires an N-G bond at the service disconnect location; no other N-G bonds are permitted after that point.

Neutral-Ground Mode (SPD). The protection mode in a surge protector that limits voltages between the neutral and ground lines. Other modes are line to neutral and line to line. Not all surge protectors have a N-G mode.

Optical Isolation. Use of a di-electric plastic fiber to transmit signals and concurrently isolate the electronics on either side of the fiber from each other electrically.

Potential (Electric Potential or Voltage). A description of the difference in potential energy (per unit charge) between points in an electric field. The concept is exemplified by the voltage between two battery terminals. The magnitude of potential is an indicator of the ability to move charge. In Ohms Law the voltage determines how much current will flow through a given resistor.

Reactance. The opposition to alternating current due to capacitance (capacitive reactance) or inductance (inductive reactance). Reactance plus resistance equals impedance.

Resistance. The property of a material to oppose the flow of electrical current. Resistance is comparable to friction in mechanical systems. In Ohms Law a given resistance will allow a specific current for a given voltage.

Rise Time. The measure of time for an electrical signal to go from the lowest to the highest level. Typically measured between the 10% and 90% levels.

Service Disconnect. A switch at the AC utility service entrance that allows disconnection of the service from the load circuits. A circuit breaker is typically used as both overload protection and switch. The circuit breaker rating defines the current limit of the service.

Single Point Ground. A grounding system design that ensures all ground conductors from the electronics equipment are connected to a single point on the grounding electrode or ground ring. A single point ground mitigates ground current loops and ground potential differences.

Soil Resistivity. A measure of soil's ability to oppose conductance of electrical current. Soil resistivity is measured in units of Ohm-meters or Ohm-centimeters. Soil resistivity values can vary significantly from 2 to 10,000 ohm-meters. Moisture content can significantly affect soil resistivity, particularly during prolonged seasonal changes.

SPD. A surge protection device is used to mitigate transients and surges on power and signal lines by limiting the voltage between the SPD terminals. An SPD has a high resistance in a normal voltage range and low resistance in higher than normal voltages. The conduction voltage level is referred to as the threshold level. There are various technologies used in SPD's that offer tradeoffs between speed of operation, protection voltage threshold and energy carrying capacity.

Transient. Transient describes short term excess voltage on power or signal lines. The time duration can vary from a few milliseconds to nanoseconds. Excess voltages can exceed several thousand volts. The cause of a voltage transient can be lightning or power switching equipment.