Facility Grounding Challenges Resulting From End-Of-Branch Power Supply

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In the broadcasting and telecommunications world, whether for commercial radio and television, public safety, wireless data and voice, or transportation applications — transmitter and tower/uplink sites are often located on undeveloped land, generally not in close proximity to other businesses or residential areas. Hence, supplied electric power to these facilities is frequently delivered via a branch circuit which terminates at the broadcast or signal processing structure. This being the case, these facilities and operations are uniquely susceptible to electrical fault events discussed in detail below. Service anomalies of this nature frequently result in off-air episodes and/or equipment damage, and consequently serious financial and operational repercussions.

As discussed in the following paragraphs, proper attention to electrical grounding can greatly help in minimizing such losses and financial impacts. Importantly, these "fixes" are readily addressable, not expensive, and provably highly effective.

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Unfortunately, due to highly standardized and generally effective, yet less-than-optimal grounding methods widely used by electric utility companies, an end-of-circuit configuration for electric power supplied to a transmitter/telecom site can cause significant power quality issues for broadcasters and communications operators. Too often, unattenuated surges and spikes occurring anywhere upstream from the circuit end point will infect a broadcasting plant or telecom facility due simply to being at the "end of the line". The very sensitive and expensive equipment resident at the facility easily becomes a target for dissipation of fault currents, either in the form of heat or as a partial route to ground. At a minimum, these events can cause a switchover to emergency power generation, or in severe cases, equipment damage — and an off-air or site-failure event. For mission critical facilities, the latter situation of course must be anticipated and avoided.

But in addition to less-than-optimal inbound electric service grounding, strategies for earthing and grounding commonly deployed by broadcasters and telecom facility builders are now *known to be insufficient* for the protection of digital broadcasting and signal processing equipment. In fact, traditional grounding systems in place at the vast majority of broadcast and telecom facilities in North America, regardless of industry or application, are generally based on concepts and practices developed well over 50 years ago — almost exclusively for the protection of *analog* equipment from relatively low frequency transient over-currents and excess voltages. When installed at end-of-branch-circuit electric supply locations in particular, traditional grounding strategies using simple copper rods and grids, whether chemically enhanced or not, are effectively obsolete.

To understand why this is the case, a better understanding of the dynamics of power supply fault events is necessary.

Surges and spikes in electric service are frequently caused by switchgear malfunctions, or unexpectedly rapid changes in load requirements on an electric distribution system. Many of these events are sufficiently managed by traditional grounding - IF properly installed and maintained. However, an entirely different set of conditions is produced when a lightning strike causes dramatic changes in transient current frequency and voltage in a power distribution system. Importantly, lightning caused power and frequency spikes can develop from either direct strikes on electric power distribution equipment such as transformers or substations or induced by a strike in close proximity to aerial or buried lines and facilities.

For many years, lightning was considered to be strictly a direct current (DC) flow. Substantial research undertaken since the 1970s reveals, however, that lightning actually has both DC and alternating current (AC) characteristics, and with respect to AC behavior, the frequencies contained by lightning can be extremely high. More recent research has identified that the range of frequencies in lightning, in many cases, can exceed 100 MHz.[1] In fact, pulses at and above 200 MHz are possible. When these characteristics are combined with *instantaneous* current and voltage spikes greater than 30,000 amps and 250,000 volts, the current carrying ability of copper conductors in a grounding application is quickly exceeded. (Capacity of copper as a conductor begins to rapidly degrade when frequencies are greater than 60 MHz, even when expansive ‘skin depth" and surface area strategies are employed.)

The "steep wave front" seen in the common wave forms of lightning is the cause of the "overpowering" of traditional grounding systems. The highest frequencies in a discharge are found at the initiation of the event [2,3]. Hence, these frequencies are the first to reach a grounding system. But if the grounding materials and system design cannot properly dissipate this current to ground due to frequency structure (and other considerations such as impedance mismatches between copper grounding conductors and native soil), a grounding system failure occurs. Using a plumbing analogy, the "drain" becomes plugged. Current cannot flow to ground — and therefore "backs up" forcing all subsequent excess current introduced by the lightning event to "find" other locations to dissipate. Most often, when complete grounding failure occurs, the "electronically dense" circuitry and equipment throughout a broadcast or telecom facility becomes the "found" location. As the fault event progresses, energy in the strike is either converted to heat (with incumbent severe equipment damage), or in some cases may arc to nearby equipment that possibly offers some pathway to ground. Unfortunately, mechanical switches, and even MOV-based surge protectors in many cases, react too slowly to divert initial, high-frequency damaging spikes away from sensitive equipment.

With all this said, a discussion of end-of-branch-circuit challenges can continue.

When a major surge or spike enters an electric distribution line, protective equipment such as “re-closers”, “cut-outs”, and other mechanical devices along with certain forms of capacitor banks and grounding rods or buried wires are supposed to help mitigate the fault. If these preventative measures are effective, downstream equipment on the distribution system like transformers, *and more importantly customer facilities and devices*, won’t be damaged. However, as just mentioned, mechanical devices cannot react quickly enough to manage the initial impacts of a severe fault. When this condition occurs on a branch circuit, the fault will continue to flow to the end of the circuit where it must either be attenuated by grounding devices on the last pole or transformer on the branch…..or continue into a customer’s electric system.

Unfortunately, grounding found in the vast majority of broadcast and telecom facilities is nearly always a simple collection of copper strapping and/or grid and radial conductors attached to an array of copper (solid or clad) grounding rods. At smaller sites, one or more deeply driven ground rod may constitute the entire grounding system. Any of these arrangements retain the frequency management limitations of copper, regardless of configuration and number of rods or depth of installation. Additionally, an extremely large impedance mismatch with native soil exists (resistivity differences as great as 10^{12} Ohm-Meters[4]), which significantly restricts dissipation of a fault current.[4,5] (This second topic is discussed in another paper which can be found on GroundLinx Technologies ’website.)

A severe fault current on a branch circuit, therefore, is a big problem for end-of-the-line customers for two reasons:

- Utility company grounding is rarely sufficiently robust to minimize the impact of such a surge as it travels along and to the end of a branch line. Hence, it is highly probable the fault will infect the customer's electric network.
- When the power consumer's electrical system is insufficiently grounded, a damaging event, or at least a interruption in operations is unacceptably likely.

Empirical evidence supports this position. In the case of broadcasters and telecommunications operators (again, regardless of application or industry), when recurring power quality issues or damaging currents introduced to a structure via inbound electric service (as opposed to a tower or other structure strike) are reported, in a significantly great amount of cases, the affected site is located at the end of a branch circuit. With "no place to go" to get to ground, a high energy fault on a branch conductor "sees" the electronics density of a broadcasting/telecom facility as a "target rich environment" — with highly predictable outcomes.

Prevention of these events requires a more advanced approach to grounding strategies.

The distribution networks of electric utilities are very complex, expansive, and designed for extremely high overall reliability. Techniques used in construction and maintenance of these systems are "tried and true" for the conveyance of electric power — at nominal voltages and stable frequencies generally between 50 Hz and 60 Hz. *Stability of electric service is the goal.* Happily, this goal is routinely reached across most of the world — 24/7/365.

Unexpected or extreme voltage and frequency events do occur, however…..and they are not managed as well by electric distribution networks. Importantly, the steps necessary to bring near-100% fault current mitigation and prevention measures to an entire network would be excessively expensive. Hence, there should be little expectation of electric utilities making grounding improvements toward the goal of improved severe fault mitigation (although they should be strongly encouraged to pay greater attention to end-of-branch circuits).

Assuming proper protection of facilities *dependent* on expensive, sensitive and complex electronic devices is desired, and given that traditional grounding has demonstrable limitations with respect to contemporary electronic equipment, it is entirely prudent for broadcasters and telecom operators (as well as many other industries) to carefully assess the capabilities of their existing grounding systems and strategies. More critically, when a facility or site is located at, and receives its electric power from the end of a branch circuit, it is nearly essential to aggressively consider upgrading the grounding strategy in place at that structure to a much higher performance standard. The improvements must take into account the necessity of dissipating the extreme frequencies of lightning strikes, and the massive difference in impedance between copper in traditional grounding devices and any native soil. Simple conductive rings around structures with multiple ground rods attached to each ring aren't sufficient, nor is a targeted very low "resistance-to-ground" measurement of the grounding system: Lightning-level fault currents and voltages in a grounding system behave radically different than 50 Hz -250 Hz current introduced into a grounding system by 6 -or 12-volt test meters.

Instead, the use of more resilient materials in grounding system design other than copper, or chemically enhanced copper pipe, is called for. These materials, in combination, must be able to perform three critical tasks:

- Accept and immediately dissipate a full range of inbound frequencies, `from 50 Hz up to 200 MHz.

- Create a gradient of impedance levels within the grounding device to provide “incentive” for charge to move towards ground and away from the facility electric system and its equipment.
- Remain stable throughout the entire duration of the fault event.

Traditional copper based grounding does not have these abilities. Neither does copper combined with “conductive concrete”, or code-compliant “Ufer” grounding where concrete-encased rebar serves as a type of grounding electrode.

Given the near certainty of damaging fault current at reaching a facility served by a branch-end circuit at some point in the future (or possibly on a regular basis), upgraded grounding strategies utilizing advanced materials and aggressive fault-current interception techniques are strongly recommended. Greatly improved continuity of operations (including probable elimination of off-air events for broadcasters) and prevention of equipment damage in any type of facility are the likely results. Financial benefits accruing to upgraded grounding are also quickly realized.

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As manufacturers of cutting-edge grounding systems and designers of high performance grounding networks, GroundLinx Technologies welcomes the opportunity to create extremely efficient solutions for any electrical grounding concern faced by broadcasters and telecommunications engineers. With respect to end-of-branch-circuit power quality issues, we have installed corrective/protective grounding systems at a variety of mission critical facilities nationwide. Testimonials are available from these customers.

References

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