High Voltage Interfaces for Telecommunications Entering Electrical Substations and Generating Plants

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1 Summary

This technical bulletin describes the need for special protection for telecommunications entering locations that may experience high ground potential rise. Certain locations such as electrical generating plants, substations and high voltage towers contain equipment energized to extremely high voltages, so special care must be taken when installing telecommunications systems at such sites. Telecommunication systems have electrical protection systems designed for ordinary locations such as typical buildings and residences. At high voltage electrical sites, the ground grid will rise to a very high voltage during power system faults and lightning strikes. This is called ground potential rise (GPR). Ordinary telecommunication protection systems do not work when exposed to GPR. Problems such as temporary or permanent telecommunication outages, damage to equipment and wiring, and worst of all, safety hazard to people on the site or off the site can occur if protection is not properly designed. So issues ranging from minor annoyance to serious hazards can result.

The installation of a special interface, called a high voltage interface (HVI), is necessary to protect equipment and personnel from GPR. Not only is a HVI a sensible idea, it may be required by code or local practices. Most telecommunications and power companies have standards that cover the installation of HVIs. The installation of a HVI interface is required by Alberta's Electrical and Communication and Utility Code (ECUC) and the Canadian Electrical Code (CEC), and recommended by the IEEEs Std 487-2007 Recommended Practice for the Protection of Wireline Communication Facilities Serving Electric Supply Locations. Both the CEC and IEEE documents are enforced by provincial and municipal laws/codes. IEEE Std 487 recommends that high voltage isolation be installed on metallic communication circuits wherever the GPR exceeds 1000 volts peak-asymmetric, or where recommended by a protection engineer. Although a HVI is usually installed to protect against GPR due power line faults, it also provides protection against lightning induced damage.

The information given in this document is derived from IEEE Std 487-2007, IEEE 367-1997 and from practices that have been developed at major telecom service providers and power companies.

2 Why High Voltage Interfaces?

There are four main reasons to install properly designed HVIs on telecommunications circuits at GPR sites.

1. Protect people from safety hazards, both inside and outside the plant.

2. Protect communications equipment from catastrophic damage.

3. Eliminate nuisance communication outages.

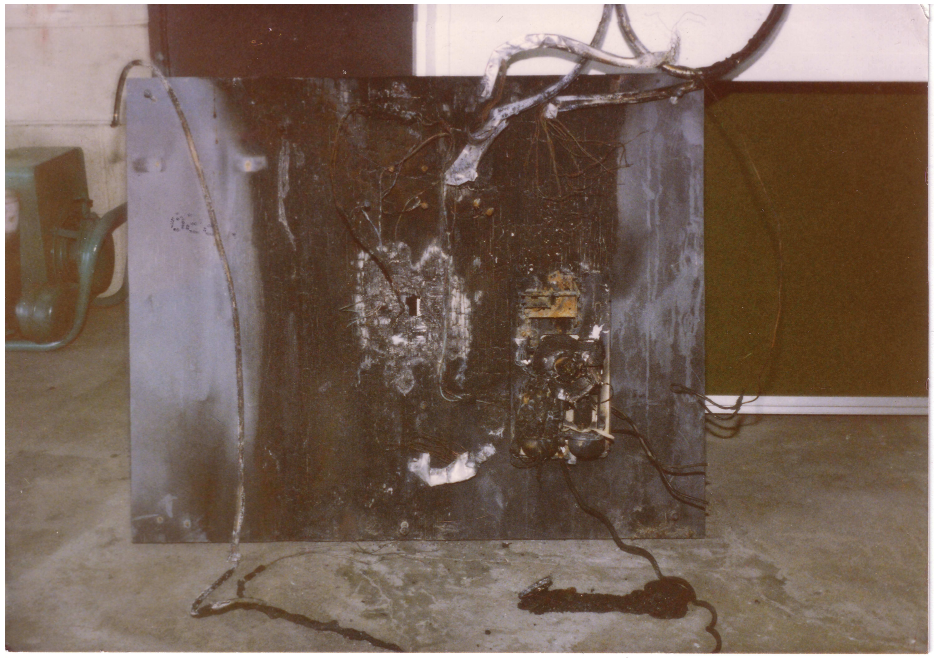


Figure 1: Equipment damaged due to ground potential rise at a substation.

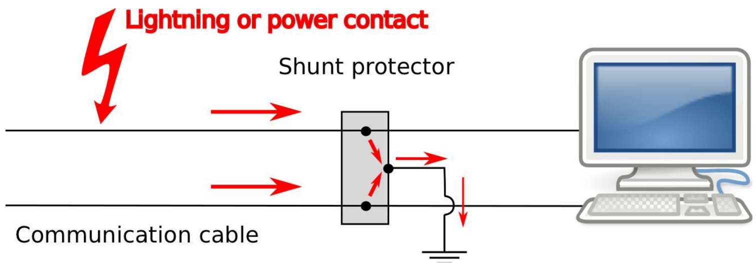
4. It is recommended by IEEE practice, it is often required by company practices, and depending on the jurisdiction, it may be required by code.

As will be explained in the following sections, GPR can be very high at electrical substations and plants, ranging from a few hundred volts to tens of thousands of volts. This GPR can be transferred to telecommunications cable at the plant, and can even appear many kilometers away from the plant location. Obviously this is a widespread human safety hazard that must be avoided. Any telecommunication equipment throughout a large area can be severely damaged as well. Fig. 1 shows damaged telecommunication equipment from a substation. Standard protection and an old style telephone were completely burnt due to high GPR at the substation. Imagine what would have happened if someone was using that phone at the time of the incident.

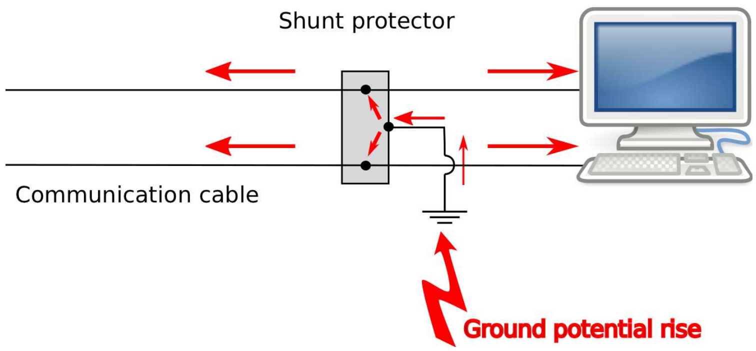
Although catastrophic events such as those described above are relatively rare, small GPR events occur frequently due to minor events such as trees falling on phase wires, lightning strikes, high winds, and insulator flash-over. This can cause small voltage bumps which can cause temporary or long-term telecommunications outages. These may result in inconvenience, additional costs due repeated repair and lost productivity, and repeated calls to the telecom service provider. Considering the financial impact of those minor but frequent events, the installation of a HVI may be sensible even at low GPR sites.

Alberta's Electrical and Communication and Utility Code (ECUC - 1999)[1] states in paragraph 179 "Communication and control circuits entering a generating station or substation shall be isolated where necessary to prevent the transfer of unsafe potentials out of the station or substation." More complete technical details are in IEEEs Std 487-2007 Recommended Practice for the Protection of Wireline Communication Facilities Serving Electric Supply Locations. Std 487-2007 describes when it is necessary to install such isolation, gives a good technical background on the principles of GPR and describes general methods of designing appropriate protection for telecommunications facilities in an near stations. HVIs are necessary at most electrical substations, generating plants, and cellular sites located on high voltage towers.

[1]This has been reissued as the Alberta Electrical Utility Code in 2007. It is available from the Safety Codes Council of Alberta for $6.95.



(a) Protector shunts current to ground at ordinary locations.



(b) At GPR sites, GPR appears on the ground and is shunted to the telecom pair and appears on any grounded equipment.

Figure 2: Shunt type telecom protection.

3 Telecommunication Protection Systems

Telecommunication systems use a great deal of copper and other metallic cable. Even modern fibre optic cable, the fibres of which are made of non-conductive glass, may contain metallic components such as an aluminum sheath for moisture barrier and even a copper pair. At each building entrance, a standards-compliant protector must be installed to prevent high voltages from entering the building. At a minimum this protector must protect for human safety, but it is also desirable to prevent system outages and equipment damage. High voltage can appear on metallic cable due to induction from power lines, contact from power lines, and lightning strikes. These usually occur outside the building, and for that reason the typical telecom protector is a shunt device. As shown in Fig. 2(a), a shunt protector is connected between the tip and ring conductors (the two conductors that make up the pair) and ground. Normally, the shunt device is inactive, and appears as a high impedance. When the voltage exceeds some threshold, usually about 350 V, the shunt device activates, and shorts the pair of wires to ground, which will short circuit the voltage and divert damaging current to ground. In some installations a series fuse-type device may be included to protect from excessive currents. Shunt devices can be carbon blocks[2], gas tubes, solid state devices, or various hybrids. In order for these protectors to work properly, they must be connected to a good ground. Also, any metallic components, such as cable sheaths, should be connected to ground at the service entrance.

Shunt protection devices work when the source of the high voltage is external to the serviced building, but they do not help when the high voltage appears on the ground of the site, which is the case at electrical substations, power generating plants and high voltage towers. The next section describes what can happen at those locations.

[2] Carbon blocks are quite out-dated, but they may still exist in older telecom plant.

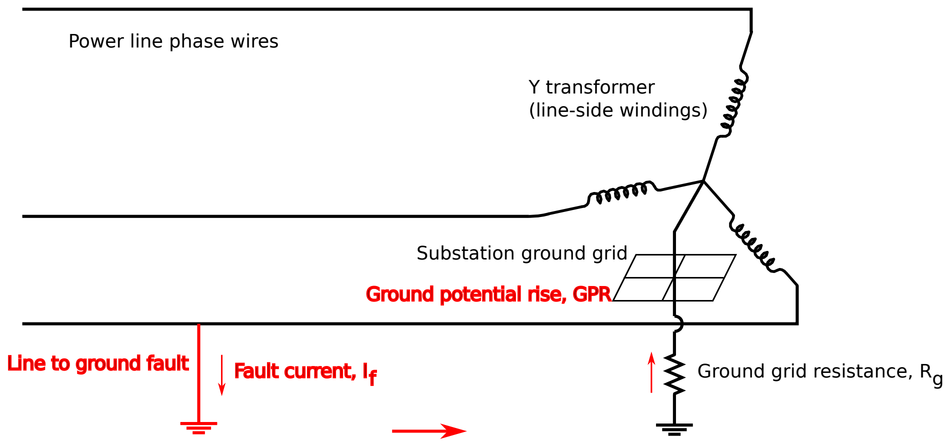


Figure 3: Line to ground fault creates ground potential rise at a substation.

4 Ground Potential Rise

Fig. 3 shows a simplified diagram of a high voltage location such as an electrical substation or power generating plant. During a power line fault, a phase wire shorts to ground or another phase wire, which can cause a very high fault current to flow back to the transformer via ground. Power companies endeavor to achieve a low ground grid resistance, R_g, but since high currents may flow, a significant voltage may still result. For example, if the ground grid resistance is $R_g = 0.5$ ohms, and the portion of fault current flowing via ground is $I_f = 2$ kA$_{rms}$, then the resulting GPR is 1000 V$_{rms}$[3].

So what happens if a standard telecom protection scheme is installed at a GPR location? That kind of scheme was designed to shunt high voltage from the telecom pairs to ground, but during GPR, the voltage appears on the ground. In the example above, the GPR was 1000 V$_{rms}$, and typical shunt devices operate at 350 V. As shown in Fig. 2(b), the shunt protector will short the voltage on the ground to the telecom pair. This will present a hazard to personnel and equipment inside the GPR locations, and will divert the high voltage out of the GPR location, presenting a safety hazard to customers and equipment over a widespread area. Likewise, any cable sheaths connected to the ground will be affected. A different protection scheme must be devised.

4.1 Root-Mean-Square vs Peak Asymmetric Voltage

In the example above, we calculated a GPR of 1000 V$_{rms}$. *Root-mean-square* (RMS) is an average measure used when comparing the average energy in time-varying voltages to direct current (DC) voltages. With protection systems, it is really necessary to consider the maximum voltage that equipment or personnel will be exposed to. If we have 1000 V$_{rms}$, the peak steady state voltage will be $\sqrt{2} \times 1000 = 1414$ V$_{peak}$. We also must consider that there is energy stored in the power system. A fault is a sudden change in the state of the system, so an even larger over-voltage will occur for a short period of time. The amount of this overshoot depends on the reactance in the system. Typical overshoot factors range from about 1.4 to over 2. So we now must consider a quantity called *peak asymmetric voltage*. In our example, the equipment and personnel will be exposed to a total voltage of $1.4 \times 1414 = 2000$ V$_{peak-asymmetric}$ to over $2 \times 1414 = 2828$ V$_{peak-asymmetric}$. So even with this fairly conservative example, the hazard can be quite significant. If the reactance in the system is not known, then a good rule of thumb is to double or triple V$_{rms}$ to estimate the V$_{peak-asymmetric}$.

[3]Recall Ohm's law: voltage is equal to current times resistance.

Table 1: GPR voltage levels from IEEE Std 487-2007.

Level	Range ($V_{peak-asymmetric}$)	Note
I	0 to 300	Minimal impact
II	300 to 1000	Possible impact, telephone protectors survive safely.
III	over 1000	High voltage protection is recommended.

Table 2: Service classes from IEEE Std 487-2007.

Service Class	Required Reliability	General Recommendation
A	Cannot tolerate service interruption, before, during, or after power system fault	Install HVI for all voltage levels
B	Can tolerate service outage during fault, must self-restore	Install HVI for voltage levels II and III
C	Can tolerate service outage during fault, can tolerate outage until service personnel called to restore	Install HVI for voltage level III

4.2 Voltage Levels and Classes of Service

IEEE Std 487-2007 describes three voltage levels, and typical ranges are given in Table 1. It also discusses three different service classes, Table 2, that describe the reliability required.

At voltage level I, the GPR is low enough that special protection may not be required[4]. However, if Class A service is required, then a HVI interface is recommended and special considerations must be made during circuit installation. At voltage level II, ordinary telephone shunt protectors will not be permanently damaged and should restore after the power system fault clears, but service will be interrupted and GPR can be transferred outside the substation during a fault. It has been found that some systems, such as private branch exchanges, may lock up after a fault and may not restore themselves. For that reason, it may be recommended to install HVI on both Class A and B services at voltage level II. At voltage level III, it is recommended to install HVI on all three classes of services to prevent safety hazards and permanent equipment damage.

4.3 In-Plant Potential Differences

Within properly designed plants, all grounding systems and metallic components are bonded together in order to eliminate dangerous voltages appearing between equipment. However, there will be some resistance between grounding systems in a large plant site, and fault current flowing on the grounding conductors. As a result, there may be a significant difference in voltage between different buildings on the same plant site. This may be very difficult to predict in a large facility. If in-plant communications experience outages or damage during lightning storms or power system faults, it may be necessary to install HVI on communications between buildings, and some protection engineers recommend the placement of bonding conductors along inter-building cable runs in order to equalize the potential and minimize induced voltages.

5 Zone of Influence

The GPR voltage calculated above occurs on the ground grid of the substation or plant using a remote (unaffected) ground as a zero volt reference. The GPR appears on the whole ground grid and everything bonded to it. The ground grid usually extends 1 metre beyond the fence in order to eliminate touch potential for people outside the substation or plant. Since the earth is resistive, the GPR does not fall to 0 V (referenced to remote ground) immediately off the ground grid. Instead, the voltage drops off gradually. The distance from the ground grid where the voltage falls below 300 $V_{peak-asymmetric}$ is called the *zone of influence* (ZoI). This distance can be only a few metres, but can be as large as a few kilometres.

[4] Higher values are sometimes used depending on dielectric breakdown of cable and site specifics.

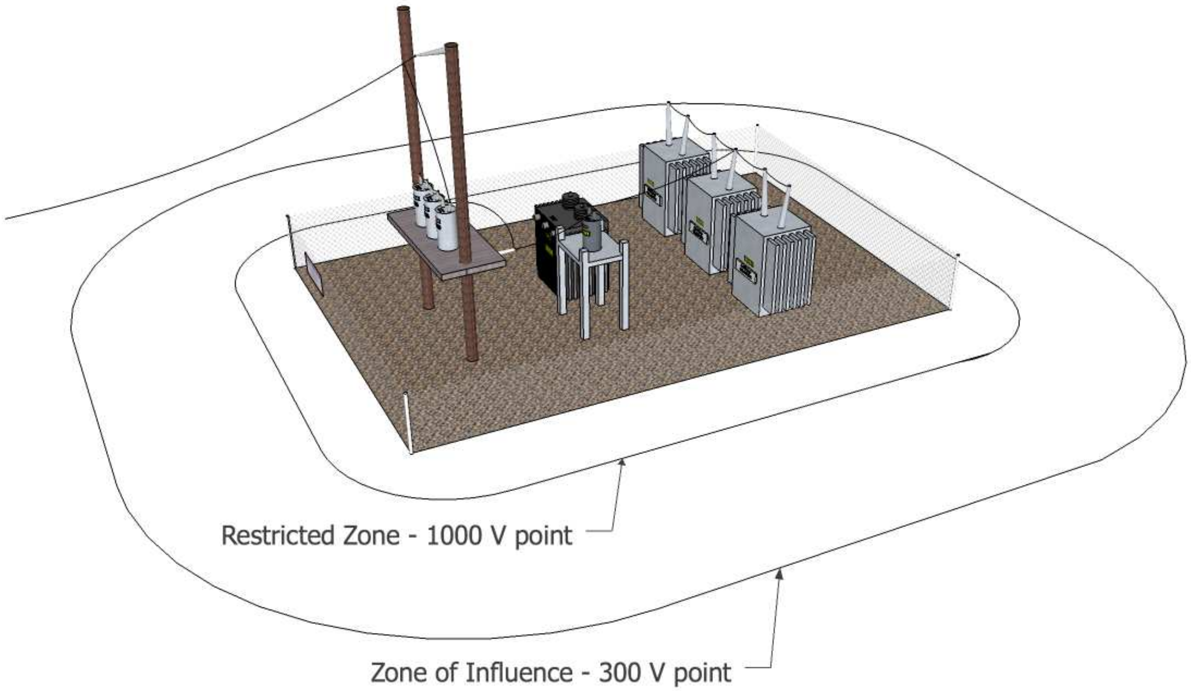


Figure 4: Zone of influence and restricted zone.

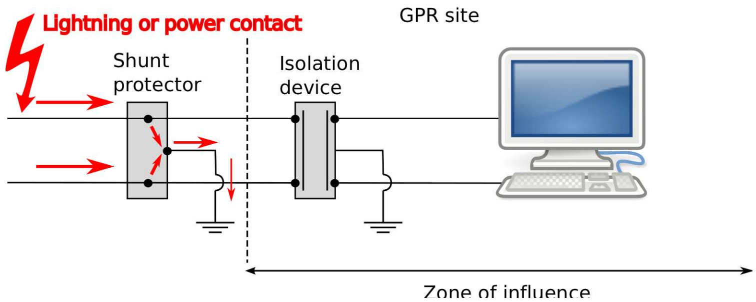
Protection engineers often calculate another quantity called *restricted zone* (RZ). It is calculated with the same formula, but using the Voltage Level III threshold of 1000 $V_{peak-asymmetric}$. The zone of influence and restricted zone of a substation are shown in Fig. 4.

5.1 Effect of the Zone of Influence

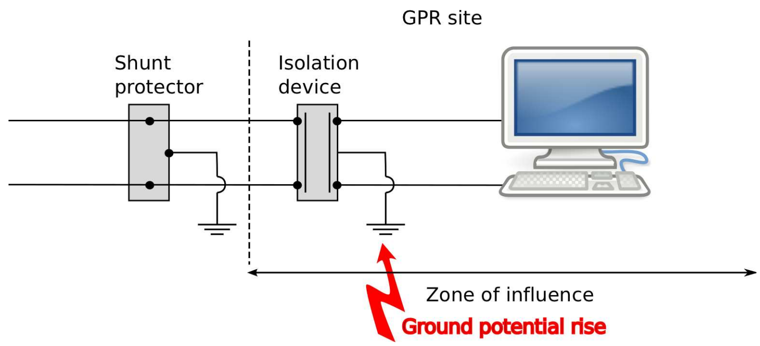
During a power system fault, any equipment, buildings or people inside the ZoI experience a voltage between 300 $V_{peak-asymmetric}$ and the full GPR of the substation or plant. Likewise, equipment, buildings or people inside the RZ experience a voltage between 1000 $V_{peak-asymmetric}$ and the full GPR of the substation or plant. So the same considerations apply within the ZoI or RZ as if they were inside a plant. Locations within the RZ must be treated as Voltage Level III sites, while locations outside the RZ and within the ZoI must be treated as Voltage Level II sites.

5.2 Zone of Influence Calculation

The ZoI can be estimated using a simple formula given in IEEE 367-1997, using ground grid area, soil resistivity and GPR figures. For simple substation geometries and uniform soil conditions this can give fairly good results, but for large, complex facilities with complex ground shapes and non-uniform soil conditions, the result may be just a ballpark guess. More precise results can be obtained using computer simulations. However, the simple formula is still very useful to get an idea of the order of magnitude of the ZoI. Calculating the ZoI in densely populated urban areas is particularly difficult, since the substation ground is connected to many grounds via the system neutral. Experience shows that few ZoI issues occur within more densely populated areas.



(a) External event: protector shunts current to ground outside zone of influence.



(b) GPR event: voltage safely blocked from exiting the GPR site.

Figure 5: High voltage interface using an isolation device in the GPR Site, and a shunt device outside the zone of influence.

6 Protection at GPR Locations

Since ordinary telco shunt protection is unsuitable for GPR sites, a different method must be designed. Instead of shunting, a high voltage interface (HVI) provides metallic isolation from high voltages. As illustrated in Fig. 5(b), the isolation device presents a very high (or infinite) impedance to voltages appearing across it, from the station side to the telco-facing side, preventing any GPR from exiting the site. A HVI must have a high enough breakdown voltage to withstand the worst-case GPR (peak-asymmetric) expected at the site. As long as correct grounding is done within the site, all parts of the communication system within the site rise to the same voltage. This poses little or no problem for equipment or personnel within small substations, but step and touch potential may occur between equipment in larger plant sites. Ordinary shunt protectors may be used outside the zone of influence of the GPR site in order to shunt external surges, due lightning or power contact, safely to ground.

Several methods may be used to provide this isolation: radio link (cellular or point to point), fibre optic cable, isolation transformers, neutralizing transformers, or a combination of these. The method to use will depend on the specific location, type of service required, availability of various services, and budget.

Although a HVI is installed primarily to protect against GPR due power line faults, it also provides superior protection against lightning induced damage. For critical telecom services, an HVI may be a suitable in any location, especially in severe lightning zones.

It is important to think of the HVI as having a high voltage side (GPR zone, station side or customer side) and a low voltage side (telco central office - CO - side or remote ground). The high voltage side experiences high GPR during a line fault while the low voltage side remains at remote ground potential (zero volts). Equipment or personnel bridging across these two sides are at risk. The high voltage side includes all equipment within the site: grounding conductors, coax, metallic conduit, cable trays, equipment bays, AC wiring, termination blocks, etc. The low voltage side includes telco equipment outside the zone of influence, the copper entrance cable and terminations on the telco side of the HVI inside the GPR site.

7 Correct HVI Design, Installation, Documentation and Education

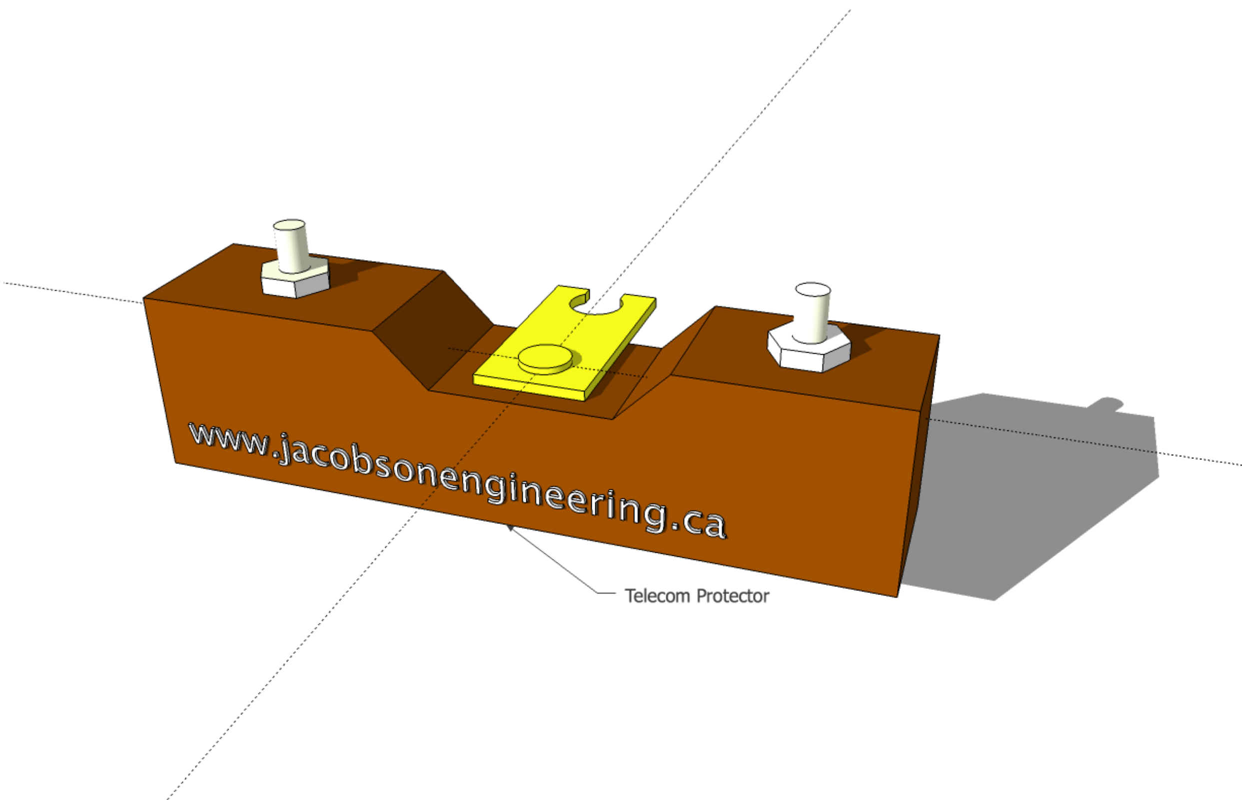
The design of a HVI is not particularly difficult, but it does require knowledge of both telecom and power systems, how GPR works, different types of telecom services and the various options available for isolation. As a result, HVI design and installation should be done by qualified and experienced personnel. HVI design can be difficult when communication systems and power grounding systems are more complex. There are a number of guidelines and rules that must be followed during design, installation and maintenance of the HVI, otherwise the HVI may be rendered useless. This author has personally inspected many substation and generating plants, and has found many incorrectly (and dangerously!) installed HVIs. There is no point spending money on a HVI installation if it is done incorrectly.

These are two goals from IEEE Std 487-2007:

"a) Educating personnel regarding the special hazards of working on communication facilities serving electric supply locations

b) Minimizing the possibility of simultaneous contact with both remote and local grounds and reducing the length of time that personnel are required to work under conditions that may expose them to danger"

Just like other safety issues, documentation and training is key. In many cases, a HVI has been bypassed, or the efficacy compromised because incorrect wiring has been installed many years after the initial installation. Working on the HVI requires special procedures to protect maintenance personnel. As a result, personnel must have access to complete on-site documentation for the HVI, and there must be clear signage. Additionally, it is recommended that personnel receive specific training on GPR and HVIs.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