POWER PROTECTION AGAINST LIGHTNING KEEPS ELECTRONIC EQUIPMENT ON-LINE

An understanding of the degree to which lightning can affect microprocessor-controlled equipment is necessary when choosing among lightning protection alternatives.

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Although most people think of lightning's potential for damage in terms of direct and catastrophic strokes, a wide variety of more subtle problems can occur as a result of indirect strokes. Lightning is capable of inducing line voltage transients — ranging from momentary spikes or faults, to longer surges or sags — in varying degrees that will affect the performance of microprocessor-controlled equipment and computers. This article examines these problems and the alternatives for protecting against them.

The phenomenon starts with a lightning arc, either cloud-to-cloud or cloud-to-earth, which generates an intense electromagnetic field. When an overhead or underground utility line intersects the field, a voltage surge is generated on the line in much the same manner that voltage is generated from the primary to the secondary windings of a transformer. The nature and severity of this transient can vary with the duration of the stroke, the magnitude of its discharge, its proximity to the line, its distance away from the equipment, and the type and size of the other equipment served by the line.

Impulses in the power-line voltage resulting from even minor lightning strokes to the utility line can exceed normal line voltage levels by 10 times or more. These high-level impulses typically cause arcing in power distribution systems. Arcing develops when positive or negative voltages and neutral (ground) elements in the power system are close enough to one another and carry sufficient potential to allow a discharge of electrical energy or sparkover from one element to another.

It has been determined that the sparkover level of most 120 to 240V systems is approximately 6000V (Ref.: IEEE STD 587-1980). This sparkover level insures that most impulses encountered indoors are likely to have a magnitude of 6000V or less. However, voltage of this magnitude is still sufficient to damage or disrupt electronics. If they reach a computer or other sensitive piece of electronic equipment, lightning-induced transients typically create one of three possible effects. A high voltage transient can cause immediately noticeable component damage, often so high that the component cannot survive. Sharp, high-powered spikes, in other words, can destroy semiconductors and electrical devices found in sensitive electronic equipment, primarily by puncturing insulating barriers. Lesser voltage transients may not cause noticeable damage, yet they can put stress on components, causing them to degrade and then to fail a few hours, days, or weeks later. Weak transients, perhaps in the form of low energy, high frequency "noise," which are probably not capable of causing hardware damage, can be interpreted as valid digital signals and result in program errors or altered memory.

Sags — cycle-to-cycle decreases in power-line voltage — are less well known, but actually more commonly produced in electrical storms than surges or impulses. The reason is that impulse-suppression equipment used in ac distribution systems does its job by momentarily shorting the power-line (via arcing). The short circuit continues until the next zero crossing of the ac sine wave, thereby limiting the short circuit power outage duration to one-half cycle or less. While this short circuit is taking place, a portion of the downstream power continues to move toward its load. The voltage present at the load continues to decrease until soon after the arc has extinguished. This results in a sag, or short duration brownout that is usually corrected within the next few cycles. In this fashion, lightning-induced sags can travel throughout the system, whereas impulses are attenuated quickly as they travel through the system's loads and other overvoltage protection devices.

Lightning can also create blackouts, or a total loss of power, usually by damaging power transmission equipment. These can be split-second outages — where minor damage occurs and the utility responds by switching the affected loads to other intact sources in the power ground — or they can be long-term losses, resulting from major damage such as line breaks. Momentary blackouts within a building also can occur as a result of lightning-induced surges. When, as described above, the surge initiaties a short circuit at the primary distribution panel, downstream circuits throughout the building experience a brief total loss of power, rather than simply a sag in power. Even though this outage lasts no more than 1/2 cycle, a loss of this length is sufficient to disrupt some electronic equipment. Adding to the problem, the sudden return of power after the outage can appear as a secondary surge that adds another potential for damage.

CHOOSING POWER PROTECTION

Determining the best way to protect sensitive electronic equipment from lightning-induced problems will depend on the value of the function

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performed by that equipment, and which kinds of power disruptions need protection. In accordance with how the two fundamental questions are answered, one of three kinds of power protection devices can be used: those that condition incoming power to eliminate the transients and noise produced by lightning; those that provide only backup emergency power in case of blackout; or, those that provide both power conditioning and backup power.

Some engineers feel that a viable alternative for maintaining clean power is to install a dedicated line (a special circuit running directly from a primary distribution transformer to the sensitive electronic load). However, dedicated lines offer only limited protection. Although they can isolate the sensitive load from noise and transients generated along other circuits in the building, they do nothing to prevent problems such as lightning-induced power effects that originate outside the building.

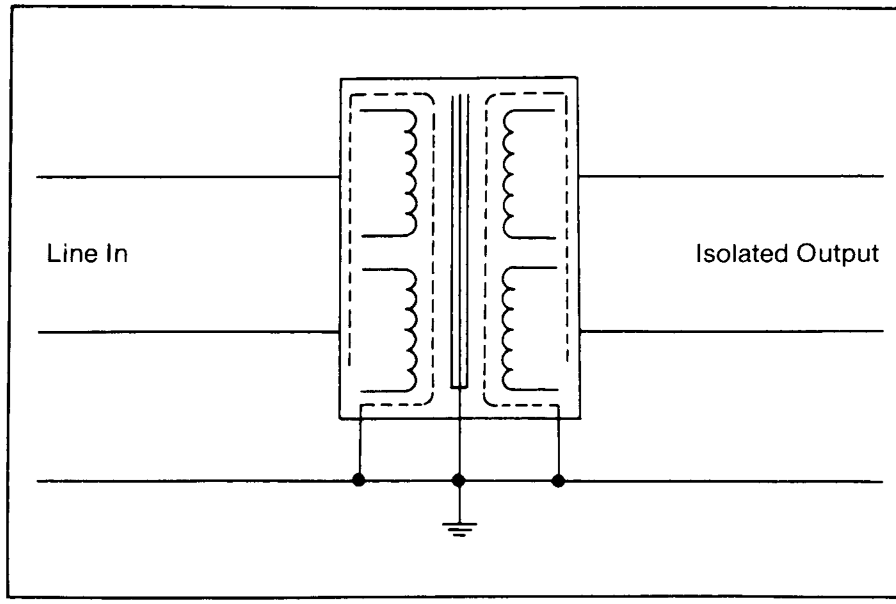

Figure 1. Ultra-Isolation Transformer.

A variety of basic power protection devices bought in hopes of providing lightning protection for electronics include surge suppressors, passive filters, ultra-isolation transformers, and electronic tap changers. While these simple devices do perform some selected power protection functions, their limitations must be considered.

Surge suppressors, for instance, can clip lightning-induced spikes at some absolute voltage level. However, these devices do not attenuate electromagnetic interference (EMI), making it possible for EMI to deteriorate sensitive electronic devices; nor do they compensate for voltage sags.

Passive filters do a better job of noise reduction (although only at certain frequencies), but they are typically incapable of attenuating low frequency, high energy transients. A sufficiently forceful lightning-induced transient can blow up the device, cutting off all power to the electronic equipment. Also, these devices do nothing to counteract surges or sags.

An isolation transformer, on the other hand, can provide reasonably good common-mode surge protection and a fair amount of normal-mode surge protection, but cannot regulate voltage sags. Figure 1.

The electronic tap changer, which is based on a multi-tapped transformer combined with electronic sensing and switching, provides voltage regulation by selective switching among taps in response to input voltage. Some of these units are relatively inexpensive, although tap changer design schemes typically provide insufficient inherent noise attenuation. Consequently, noise protection devices such as surge suppressors, line filters and filter capacitors are usually provided at additional cost. These added devices still exhibit all of the limitations described earlier. Tap changers do not provide smooth, continuous adjustments of output voltage. Instead, they respond in steps typically ranging from ±13% to ±17% of nominal output voltage. Figure 2.

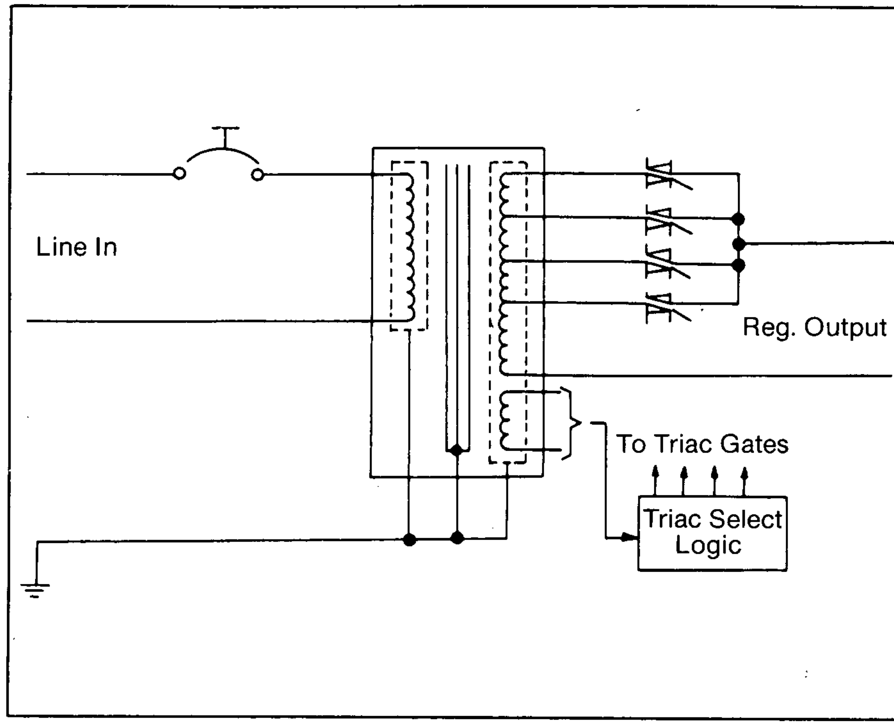

Figure 2. Electronic Tap Changer.

As lightning protection devices, none of the above four designs is equipped to sufficiently protect against the full range of lightning-induced power-line problems. For broader protection, users should consider more sophisticated regulators, power conditioners and uninterruptible power systems (UPS).

The ferroresonant regulator, also known as the constant voltage transformer, provides regulation for loads ranging from 15VA to 15,000VA. A complete static regulator, the ferroresonant regulator offers continuous readjustment of output voltage and correction of sudden voltage changes. Input line voltage fluctuations of ±15% are reduced to ±1/2% at the output. Ferroresonant regulators also provide current limiting for overloads or short-circuits, and they inherently maintain output for brief power outages of up to 3ms. The ferroresonant regulator (Figure 3) protects against transients, as well as the sags, brownouts and micro-faults typically caused by lightning strokes.

The electromagnetic regulator is a fast response static device for protecting larger systems with higher power loads. The correction of sudden voltage changes starts immediately, and is completed in less than 0.1 second. Input line voltage fluctuations of +10% to −20% are reduced to ±0.05% at the output. This design is available in power ratings up to 300kVA, in single-phase or three-phase configuration. It should be noted that, like electronic tap changers, these regulators typically provide little inherent noise protection. Surge suppressors and line filters can be added for power-line noise attenuation.

Power conditioners are an evolutionary advance above voltage regulators, providing excellent noise attenuation capabilities to computers, as well as voltage regulation. The portable micro/minicomputer regulator (MMR) represents a modification in ferroresonant regulator design to provide state-of-the-art noise rejection of 120dB in common mode and 60dB in transverse mode. There is a nominal trade-off in voltage regulation capabilities, however, as the MMR regulates input line variations of as much as ±15% to within ±13%. Additionally, the MMR will provide a minimum of 90% of nominal output voltage at 65% of rated input voltage.

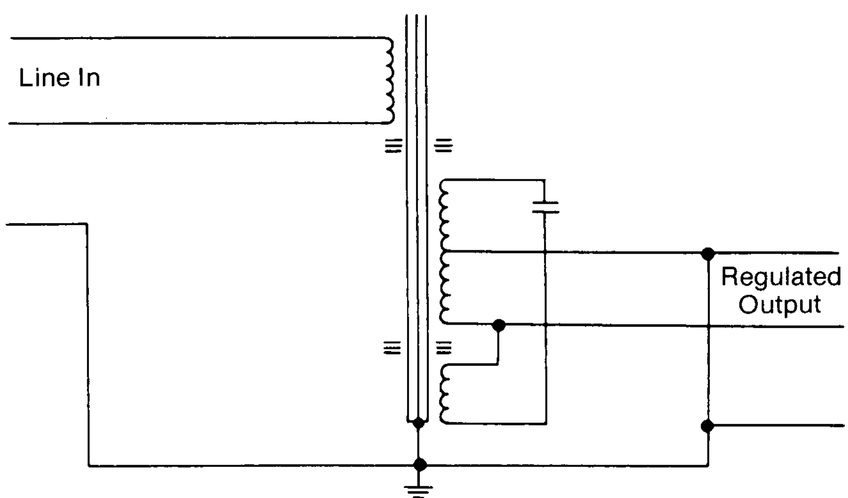

Figure 3. Constant Voltage Transformer.

Where critical electronic equip-

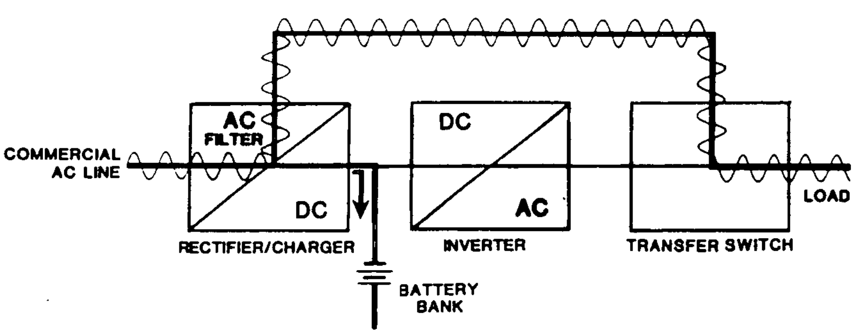

Figure 4A. SPS, under Normal AC Line Conditioning.

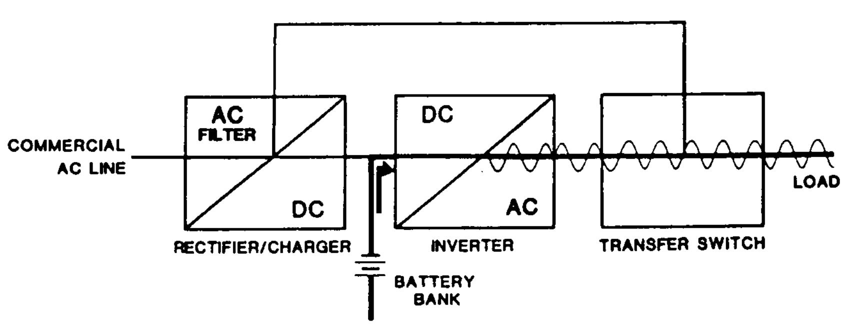

Figure 4B. SPS, during AC Voltage Droop or Failure.

ment must be protected against deep brownouts, emergency backup power may be necessary. This can be provided by either a UPS or a standby power source (SPS), although the range of other protective functions varies considerably between the two. A review of the SPS and UPS design characteristics will help clarify their capabilities.

The SPS — sometimes called an off-line UPS — consists of an inverter, battery, battery-charger and a high-speed transfer switch. Under normal ac line conditions, the inverter is at rest and the primary ac power feeds the critical load directly, or through optional filtering provided by the SPS. In the event of an ac voltage drop below a present transfer point (usually −15% of nominal), the load is transferred to the inverter, which will switch on the supply ac power converted from the battery. Figure 4.

The choice of an SPS depends largely on how much switching time the equipment to be protected will tolerate. Some highly sensitive electronics cannot tolerate the power lapses that occur during these

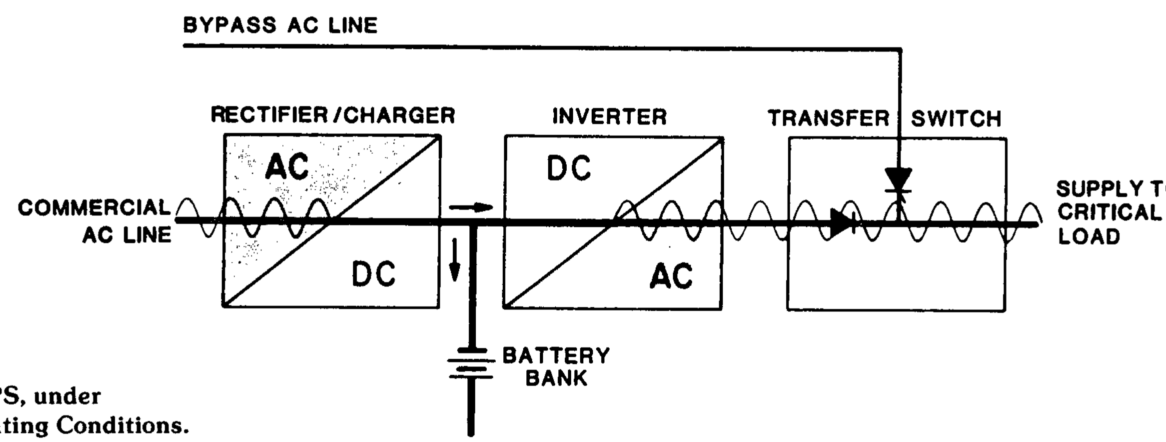

Figure 5A. UPS, under Normal Operating Conditions.

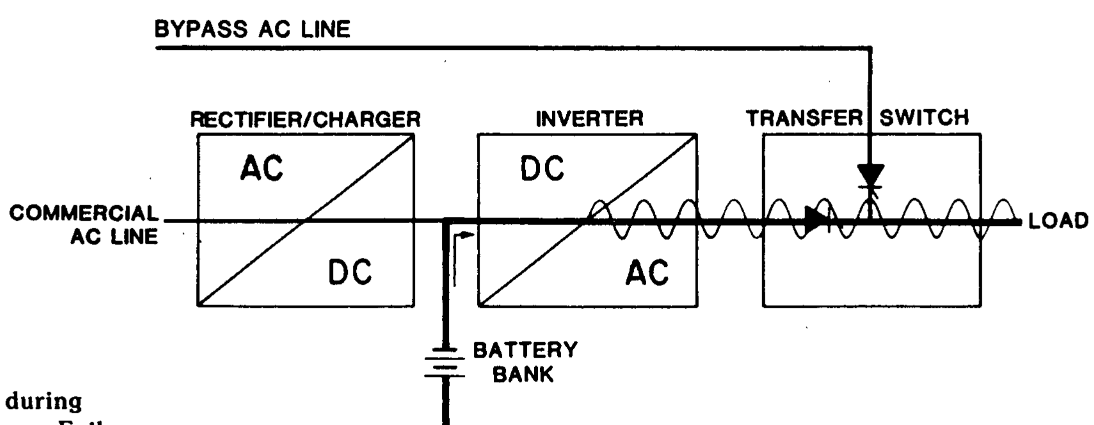

Figure 5B. UPS, during AC Voltage Droop or Failure.

switches. Some SPS designs, however, incorporate high-speed transfer switches to help reduce these power lapses. These units offer switching times ranging between 4 and 10ms, which is an acceptable transfer time for most electronic devices.

Like the electronic tap changer, the SPS provides only limited protection from lightning-induced transients or noise. To gain these capabilities, the SPS would need an additional line filter and a surge arrestor, which may be offered as options with the SPS.

For critical applications that will not tolerate the switching time of the SPS, and for those that need protection against the full range of lightning-induced power problems, including blackouts, a "true" on-line UPS is the only alternative. Serving continuously as a power conditioner, the true UPS maintains output voltage within ±13% of nominal despite line fluctuations of ±15%, providing continuous protection against overvoltage conditions and brownouts. The on-line UPS also protects against both common- and transverse-mode noise, with attenuation of at least 140dB over a broad frequency range.

Consisting of three major components — a rectifier/charger, a battery, and an inverter — the standard on-line UPS, under normal operating conditions, converts commercial ac power to dc by use of the rectifier/charger. The dc power charges the battery which runs the inverter section. The inverter then reshapes the dc power into ac, which supplies the critical load. Figure 5.

When a drop in the ac line power causes output from the rectifier/charger to decrease, the batteries automatically compensate for this drop and continue to provide dc power to the inverter. Since dc voltage is always present at the inverter input, neither a time delay nor switching is involved in maintaining the constant supply of clean, uninterrupted power. UPS operation continues with no break, and the critical load experiences no loss of power. When line power is restored, the UPS returns to normal operations, and the battery is automatically recharged by the rectifier/charger.

An economical alternative for obtaining backup power plus the benefits of conditioned power is to combine an SPS with a micro/minicomputer regulator, placing the MMR downstream of the SPS. While the SPS/MMR combination does not offer the no-break power transfer provided by a true UPS, the SPS/MMR combination can provide a cost savings (as much as $350) for protecting equipment that can tolerate the SPS switch-over delay time. However, the SPS/MMR combination has a longer recharge time than the UPS (from 8 to 16 hours for the SPS compared to 90 minutes to 3 hours for the UPS, depending on the model) and requires manual restart. (The UPS restarts automatically.)

Power protection equipment is available to provide a range of functions from simple filtering to total protection against lightning. Ultimately, the selection will depend as much on the importance of the equipment as on the user's budget. In cases where backup power is not required, but broad range power conditioning is imperative, the micro/minicomputer regulator is recommended for providing both voltage regulation and isolation from disturbances. If protection against power failure is the only function needed, an off-line SPS can provide backup power economically to maintain continuous operation. But, if the equipment is performing a critical function and must remain on-line continuously, the extra cost of providing maximum protection with an on-line UPS should be weighed against all the expenses and liabilities that will be incurred if the unit is completely shut down or damaged by power problems. ■

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