Diverting Surges to Ground: Expectations versus Reality

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Significance
Part 4 – Propagation and coupling of surges

A misconception is sometimes encountered, that surges can be eliminated by sending them on a one-way trip to "ground" in a manner similar to leftovers that disappear in the kitchen sink disposall, never to be seen again. Unfortunately, electricity travels along closed loops, and no special SPD configuration nor amount of "grounding" – be it ‘dedicated’, ‘isolated’, ‘separated’, ‘delayed’, or otherwise – can dispose of unwanted electrons. Sending them down the drain of a grounding conductor only makes them reappear within a microsecond about 200 meters away on some other conductor.

This paper presents a brief review of some of the fallacies, with illustrative measurement results, and proposes two approaches for remedy, rather than counterproductive grounding practices based on misconceptions.

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Expectations versus Reality

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Preamble — A misconception is sometimes encountered, that surges can be eliminated by sending them on a one-way trip to "ground" in a manner similar to leftovers that disappear in the kitchen sink disposall, never to be seen again. Unfortunately, electricity travels on closed loops, and no amount of "grounding" - be it dedicated, isolated, separated, or otherwise - can dispose of unwanted electrons. Sending them down the drain of a grounding conductor makes them reappear in a microsecond about 200 meters away on some other conductor. The cycle for the waste through the environment takes longer, giving the illusion of disposal (at least as seen from the point of view of the kitchen sink - from the global point of view, one should take a different view, but that is another story). This paper presents a brief review of some of the fallacies, with illustrative measurement results, and proposes two approaches for remedy, rather than counterproductive grounding practices based on misconceptions.

SURGE PROTECTION SCHEMES

The usual method of providing surge protection involves diverting the surge current into some low-impedance path, so that the voltage drop resulting from the flow of the surge current through the diverter will produce only a small fraction of the voltage that would appear if no diversion were provided. This diversion can be performed by devices acting as a "crowbar" or as a "clamp." Another method of providing surge suppression involves attempting to block propagation of the surge, for instance with a low-pass filter. This method, however, would not succeed with the filter alone because the typical surge is originating from a current source so that an attempt to prevent the current flow would mean a very high voltage across the filter input components. As a second stage, a filter will work if another means is provided for diverting the surge before it reaches the filter (Figure 1). This approach is sometimes implemented in a single packaged device; another possible implementation is the "cascade" arrangement [1], [2], [3], [4] where a high-energy surge arrester is provided at the service entrance of the building to effect diversion of the surge before it would enter the building and propagate down the branch circuits.

A surge having the capability of delivering substantial currents and propagating down the branch circuits will result in large voltages at the end of the branch. Depending upon the relative values of the time for the surge to travel the length of the branch, and the duration of the surge, the propagation can be described in terms of traveling waves (surges shorter than the travel time) or in terms of a circuit analysis with lumped L, R, and C components (surges longer than the travel time) [5]. In the absence of a diverter at the service entrance, users can protect their connected equipment by installing a readily available plug-in protective device at the end of the branch circuit, that will divert the surge from the line conductor to the neutral conductor or to the equipment grounding conductor, or both.

Figure 2 shows the configuration of the conductors of a branch circuit extending from the service entrance panel to a receptacle at the end of the branch: L and N are the two current-carrying conductors, EG is the equipment grounding conductor, and LG is the "local ground" which can be building steel, piping, ducts, or the equipment grounding conductor of another outlet connected to another branch circuit. In Figure 2a, a plug-in surge suppressor is connected between line and neutral; in Figure 2b, a generic-type filter is plugged in the receptacle. Both types of devices at the end of the branch circuit will effectively limit the surge voltage between the line and neutral conductors, the two conductors feeding the power input components of the (sensitive) equipment. However, the surge current 'returning to ground' in the neutral conductor N will produce an inductive voltage drop along this conductor. With respect to the equipment grounding conductor EG at that point, a voltage will appear that can be magnified by the traveling wave effect of the branch circuit for the short inductive spike in the neutral conductor [6]. If the surge-protective device arrangement involves a path by way of the equipment grounding conductor (most electronic equipment, even if not provided with a built-in surge protector, have an EMI filter containing capacitors connected line-to-ground), then a voltage will be developed between the end of the equipment grounding conductor EG and other local grounded points at the potential of LG.

When a system is made of several pieces of equipment that are powered from such separate branch circuits, their respective chassis which are connected to their own equipment grounding conductors will be at different potentials at the instant a surge occurs on one branch circuit, but not the other. A data transmission link between the elements of the system typically has its reference connected to the equipment chassis. Thus, the data link becomes involved in attempts to equalize the potential between the two chassis, and may fail in the process. This scenario is well recognized [7]. Thus, protecting the power port of the equipment transfers the problem to the data port: the surge did not disappear!

CLAMPING OR FILTERING PROTECTION

In an attempt to overcome this problem, an alternate approach has been proposed whereby the protection would be obtained by a filter action rather than a diverter action. The expectation is that the filtering action would not involve the flow of current in the surge return path that was found to be the cause of the data link problem. However, even the filter, in order to provide the necessary closed-loop path for the surge current, has to accept the surge current at the rate which is imposed by the surge source. On the output side of the filter, the let-through voltage may well be very low, but on the input side, current will flow. If this filter is installed at the end of a branch circuit, the same effects of developing potential differences among grounded elements should be expected in the final analysis, a disappointing result in view of the hoped-for elimination of the data link problem.

The situation is illustrated by a series of simple laboratory experiments where a 30-meter length of three-conductor wire was used to simulate a branch circuit. Surges were injected at one end, and the effects of connecting surge-protective devices at the other end were observed by measuring the voltages between several combinations among the neutral conductor, the equipment grounding conductor, and the local building ground. Figure 3 shows a 0.5 μs - 100 kHz Ring Wave [8] with 3-kV peak applied at the origin of the branch circuit (Figure 3a) and the 4.2-kV surge arriving at the other end (Figure 3b).

Note that the first peak of the surge is higher at the end than at the origin, illustrating the enhancement of the traveling wave arriving at the open end of the transmission line. Figures 4 and 5 show the effects, desirable and undesirable, of connecting a clamp-type device at the end of the branch in an attempt to limit the line-to-neutral surge voltage.

Figure 4a shows the desired effect, that is, clamping of the Ring Wave at about 400 V between line and neutral conductors (L-N). Figure 4b shows the classic side-effect, a spike of 1300 V between the neutral conductor and the equipment grounding conductor (N-EG), occurring during the fast rise of the Ring Wave. Figure 5a shows the voltage between the neutral conductor and the local ground (N-LG), still a 1300-V spike. Figure 5b shows the voltage between the equipment grounding conductor and the local ground (EG-LG). The voltage of Figure 5b is a burst of 80-V oscillations that could be damaging to a data link connecting two pieces of equipment, each with its own signal reference but separated by this difference of potential.

With a filter-type device installed at the end of the branch, the voltages shown in Figure 6 and Figure 7 were observed. Figure 6a shows the voltage between the neutral conductor and the local ground (N-LG), a 1100-V spike similar to that produced by the clamp in Figure 5a. Figure 6b shows the voltage between equipment grounding conductor and the local ground (EG-LG), with a brief oscillation and peak of about 500 V, significantly higher than the 80-V burst of Figure 5b. Figure 7 shows a simultaneous recording of the initial part of the surge event: current in the line conductor, upstream from the filter (upper trace), and line-neutral voltage (L-N) at the output of the filter (lower trace), which is essentially free from significant overvoltage. Note in Figure 7 the 70-A peak current in the line conductor, with a rise time of 400 ns (about 170 A/μs) which has to be returned by way of the neutral. Figure 8, in a similar manner for the case of a clamp, shows the 120-A peak current in the line conductor, with a rise time of 700 ns (probably by happenstance, also about 170 A/μs). Thus, both approaches involve a return current path with substantial rates of current change, which are at the root of the ground differential side-effect.

Two possible methods (and perhaps more, still to be developed) can overcome the problem. The first is to avoid the problem altogether by not allowing large surges to enter the building. This desirable situation can be obtained by providing a suitable surge arrester at the service entrance. While earlier proposals to recommend or even to mandate such installation by means of the National Electrical Code have not been accepted by the Code Panels, growing recognition of the benefits may eventually lead to a more general application of this method. Of course, proper coordination, as discussed in Refs [2]-[4] will have to be implemented. With the high-current surges effectively diverted before they enter the building, there is still room for an effective application of surge-protective devices at inside receptacles, to deal with the (low-energy) surges generated within the building by normal and abnormal operation of the array of diverse equipment installed in the building.

The second approach, available to users who do not have the opportunity or means to install an arrester at the service entrance, is to provide a combined surge protection that covers both the power port and the communication port of the equipment to be protected. Dubbed 'local ground window' [9], this approach consists in routing both the power cord and the communication line (telephone, cable TV, RS232 link) through a single 'window', with any protective device on either line diverting any surge through the same path.

Thus, regardless of the length of that path, both ports are kept at the same potential, correcting the root problem of potential differences. These local ground windows are now becoming available from many sources; however, no generic standards have yet been developed to evaluate their effectiveness. The electric utility industry is attempting to develop 'performance criteria' that will help in the process. The author invites comments and inquiries on the development of these criteria, an objective of this Open Forum.

CONCLUSIONS

1. Effective protection against surges unavoidably requires diversion of the surge through a closed-loop path, which can involve two or more branch circuit conductors if the surge-protective device is installed at the end of a branch circuit.

2. While the main function of the device, limiting overvoltages between line and neutral, is accomplished, the return path for the surge current will produce differences of potential among the conductive parts at the end of the branch circuit, differences that can be damaging to certain components of connected equipment.

3. A more effective protection scheme is to divert the surges at the service entrance, rather than allow them to flow in the branch circuits. This cascading of a device at the service entrance and one at the end of branch circuit (the latter still necessary for protection against internally-generated surges) needs appropriate coordination.

4. Users who do not have control over their facility to the extent of providing a service entrance arrester may obtain relief and avoid side effects by applying a combined 'local ground window' to both the power port and communication port of their equipment.

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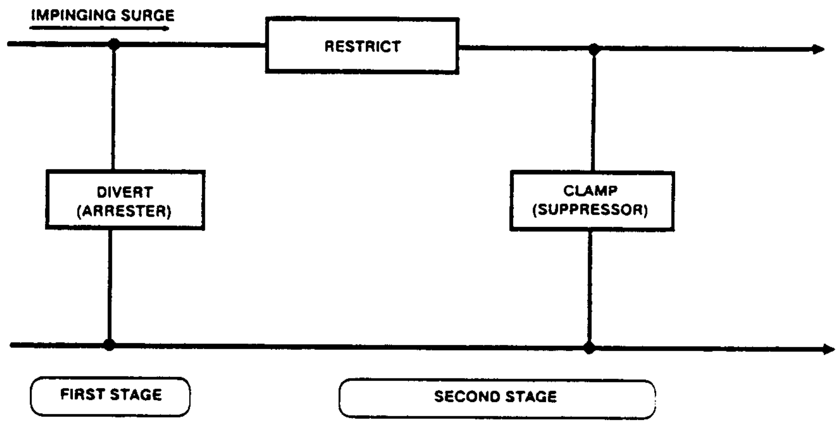
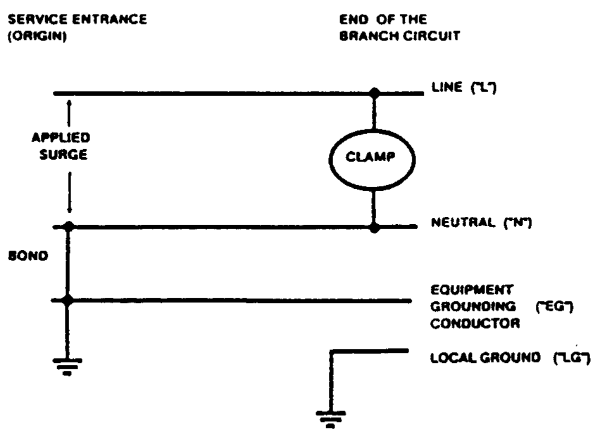
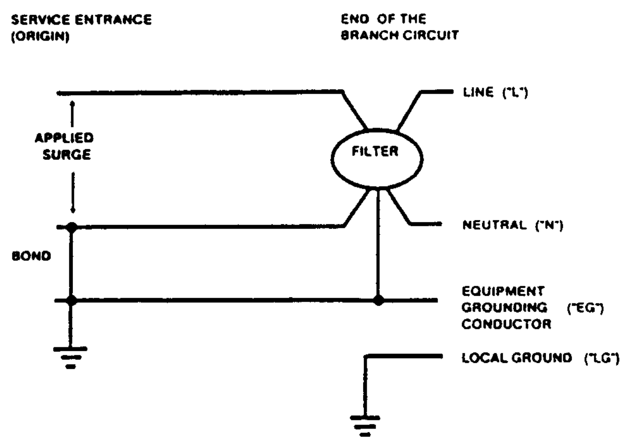


Figure 1
Basic approach for two-stage protection schemes

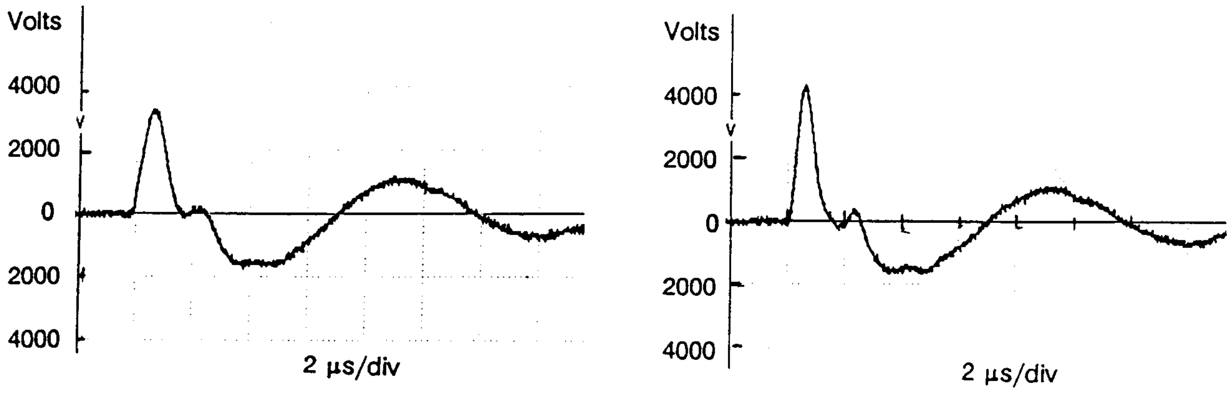


(a) Clamp-type suppressor



(b) Filter-type suppressor

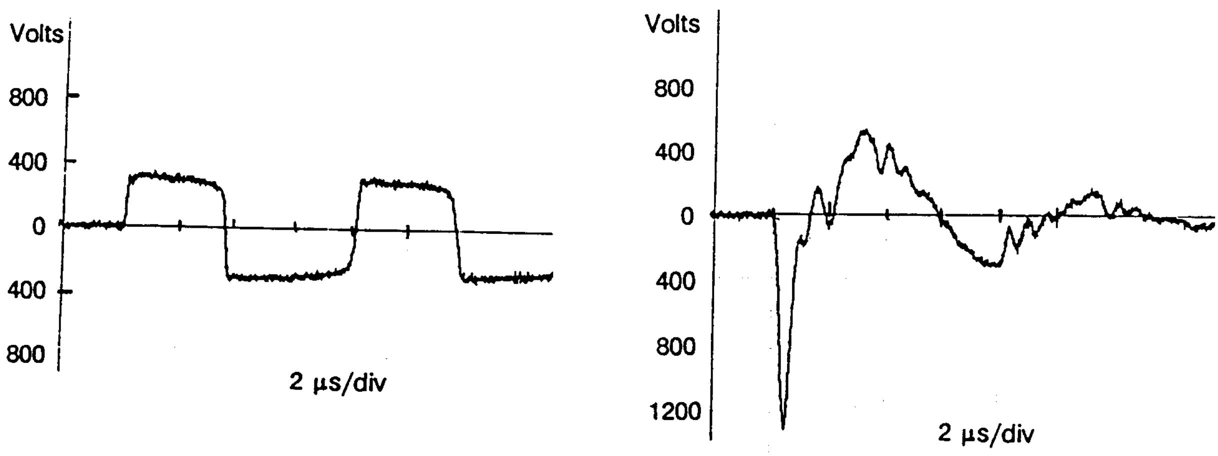
Figure 2
Configuration of branch circuit conductors and suppressors



(a) At origin

(b) At end of branch

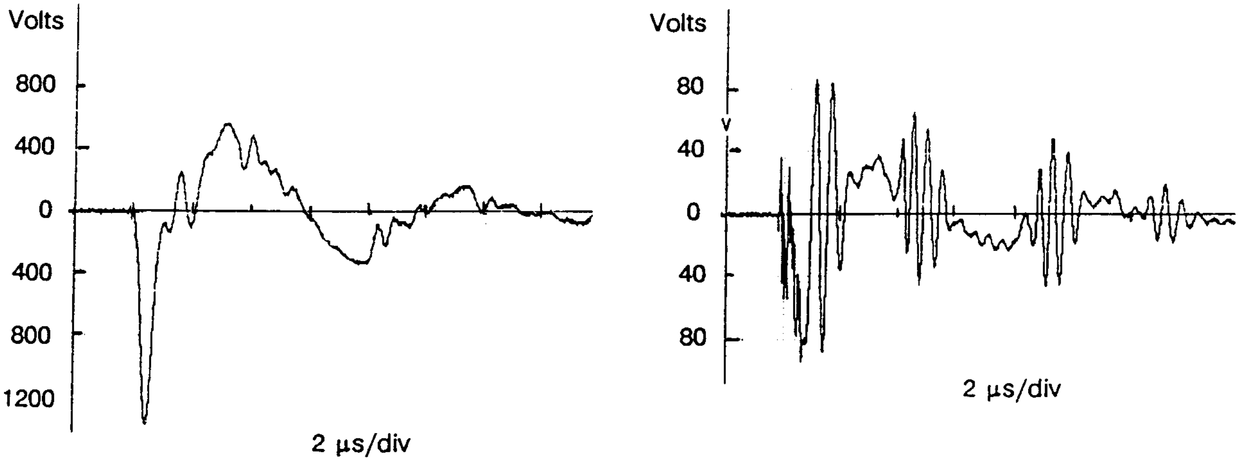
Figure 3
Voltages at origin and at end of 30-m branch circuit,
with a 3-kV Ring Wave applied between the line and neutral conductors



(a) L-N Voltage

(b) N-EG Voltage

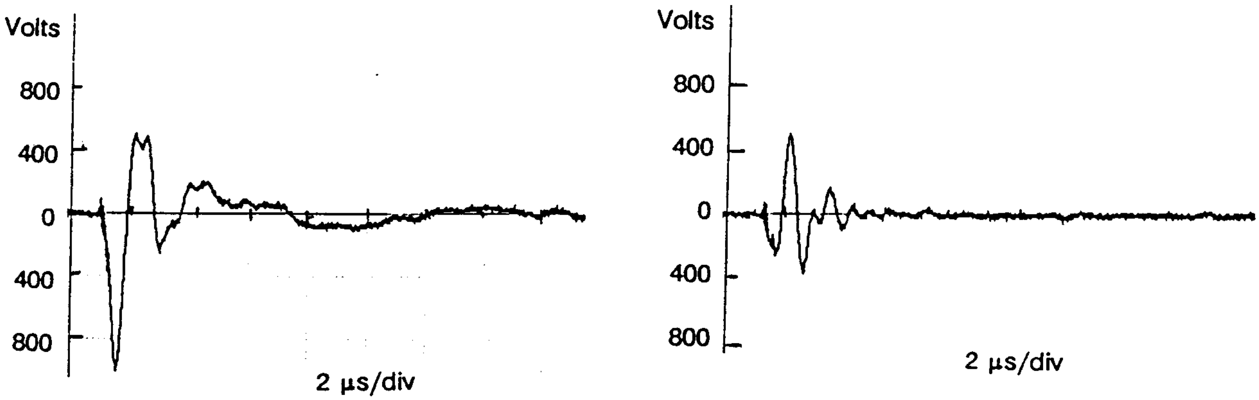
Figure 4
Voltages between line and neutral conductors (L-N)
and between neutral and equipment grounding conductors (N-EG)
at end of branch, with single varistor connected between line and neutral conductors



(a) N-LG

(b) EG-LG

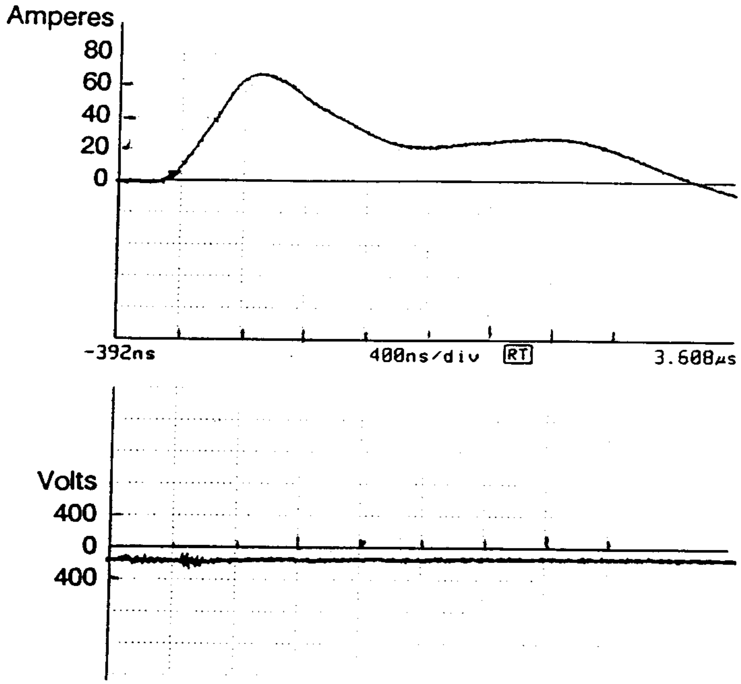
Figure 5
Voltages between neutral and local ground (N-LG)
and between equipment grounding conductor and local ground (EG-LG)
at end of branch, with single varistor connected between line and neutral conductors



(a) N-LG

(b) EG-LG

Figure 6
Voltages between neutral and local ground (N-LG)
and between equipment grounding conductor and local ground (EG-LG)
at end of branch, with filter-type suppressor connected at end of branch



(a) Line current

(b) Output voltage

Figure 7
Current in line conductor upstream of filter
and voltage output of the filter (synchronous traces)
with filter-type suppressor connected at end of 30-m branch

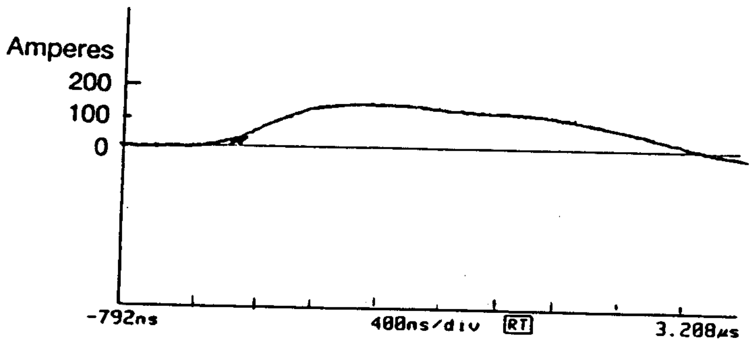


Figure 8
Current in line conductor upstream of varistor,
with varistor connected between line and neutral at end of 30-m branch