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Coordinating cascaded surge-protective devices: an elusive goal

By Francois D. Martzloff and Jih-Sheng Lai

Cascading two or more surge-protective devices located at the service entrance of a building and near sensitive load equipment is done to ensure that each device shares the surge stress in a manner commensurate with its rating. The ultimate purpose is to achieve reliable protection of equipment against surges impinging from the utility supply, as well as internally generated surges. Coordination may or may not be effective, depending upon the relative clamping voltages of the two devices, their separation distance, and the waveform of the impinging surge.

Recent progress in the availability of surge-protective devices (SPD), combined with increased awareness of the need to protect sensitive equipment against surges, have prompted the application of a multi-step cascade protection scheme. In this scheme, a high-energy SPD is installed at the service entrance of a building to divert the major part of the impinging surge current. Then, SPDs with lower energy-handling capability and (presumably) lower clamping voltage than that of the service entrance, are installed downstream near or at the equipment to complete the protection. Figure 1 shows a typical two-stage cascade surge protection. The arrester and the suppressor are separated by a distance *d* determined by the specific installation. To make the distinction between these two devices, we will call the service entrance device 'arrester' and the downstream device 'suppressor.' Such a scheme is described as 'coordinated' if the device with high energy handling capability does receive the largest part of the total energy involved in the surge.

This scheme was initially based on the technology of secondary surge arresters prevailing in the 1970s and early 1980s. Another basis for this scheme was the consensus concerning the waveform and current levels of lightning surges impinging on a building service entrance. With the emergence of new types of arresters for service entrance duty and the recognition of waveforms with greater duration than the classic 8/20 impulse[1], a new situation arises that may invalidate the expectations on the cascade coordination scheme.

Service entrance arresters were based on the combination of a gap with a silicon carbide varistor disc, the classic design before the advent of metal-oxide varistors (MOV) that made gapless arresters possible. With a gap plus varistor element, the service entrance arrester could easily be designed with a 175-volt Maximum Continuous Operating Voltage (MCOV) in a 120-volt (rms) system. Meanwhile, the downstream suppressors were selected with a lower MCOV, driven by the perception that sensitive equipment requires a low protective level.

The coordination scheme can work for this combination of SPDs if there is a series impedance (mostly inductance)

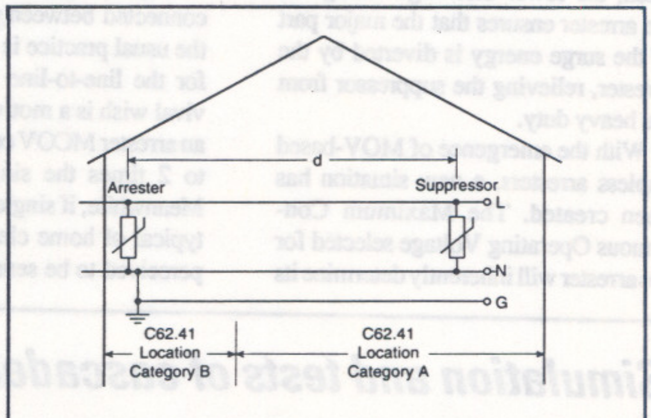

Figure 1: Typical two stage surge protection scheme for a residence

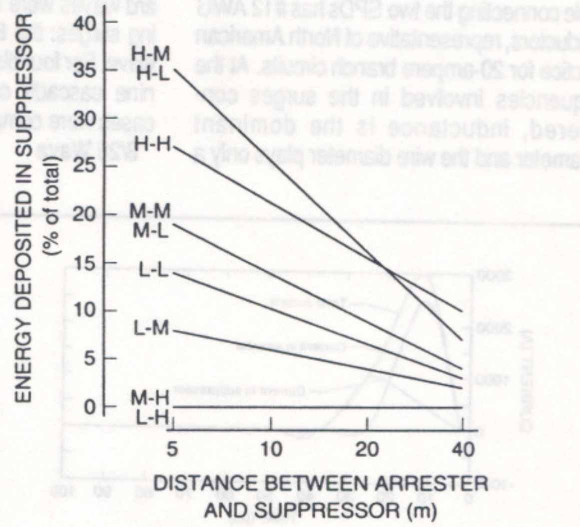

Figure 2: Percentage of total surge energy deposited in suppressor, as a function of separation distance, for cascade combinations of 250 V, 150 V, and 130 V, with an 8/20 µs impinging surge.

[1] In this notation, used by arrester designers, the number 8 represents the rise time (front) of the current surge, and the number 20 represents the duration of the surge, measured at the level of 50% of the peak, both using microseconds as a unit of time.

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between the arrester and the suppressor. The inductive drop in the series impedance, added to the clamping voltage of the suppressor, becomes high enough to spark over the arrester gap. Then, the lower discharge voltage of the arrester ensures that the major part of the surge energy is diverted by the arrester, relieving the suppressor from the heavy duty.

With the emergence of MOV-based gapless arresters, a new situation has been created. The Maximum Continuous Operating Voltage selected for the arrester will inherently determine its clamping level. Some utilities wish to ensure survival of the arrester under the condition of a lost neutral — twice the normal voltage for a single-phase, three-wire service connection. For three-phase systems in which SPDs are connected between phase and ground, the usual practice is to rate these SPDs for the line-to-line voltage. This survival wish is a motivation for selecting an arrester MCOV corresponding to 1.7 to 2 times the single-phase voltage. Meanwhile, if single-phase equipment, typical of home electronic systems, is perceived to be sensitive, there will be a tendency to protect it with the lowest possible clamping voltage.

This situation leads to a 'High-Low' combination of SPD ratings where the arrester clamping voltage is higher than that of the suppressor. Let us now examine the implications of such a High-Low combination for the coordination of the resulting cascade. During the ascending portion of a steep surge such as the 8/20, the inductive drop may still be sufficient to develop enough voltage across the terminals of the arrester and force it to absorb much of the impinging energy. However, during the tail of the

Simulation and tests of cascaded SPDs in a low-voltage system

For the configuration shown in Figure 1, four different values of *d* were used in the simulation: 5, 10, 20, and 40 meters. The cable connecting the two SPDs has #12 AWG conductors, representative of North American practice for 20-ampere branch circuits. At the frequencies involved in the surges considered, inductance is the dominant parameter and the wire diameter plays only a minor role. For three SPD voltage ratings, there is a total of nine possible cascade combinations as shown in Figure B1. Two standard waves were chosen as assumed impinging surges: the 8/20 wave, and the 10/1000 wave. For four distances, two waveforms, and nine cascade combinations, a total of 72 cases were computed.

8/20 Wave

As one example of the combinations that were simulated, we describe the results for a cascade with 250-volt and 130-volt SPDs separated by 10 meters. The simulation results of the currents flowing in the two SPDs are plotted in Figure B1, showing total current injected into the cascade by the surge source of the model, current in the arrester, and current in the suppressor. Figure B2 shows in-

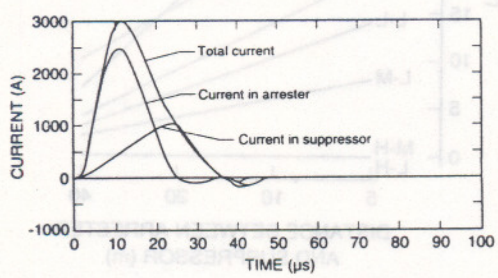

Figure B1: Computed current distribution between arrester and suppressor for a 250 V–130 V cascade, separation of 10 m, and 8/20 μs impinging surge.

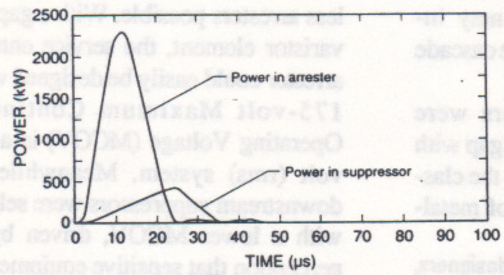

Figure B2: Computed power distribution between arrester and suppressor for a 250 V–130 V cascade, separation of 10 m, and 8/20 μs impinging surge.

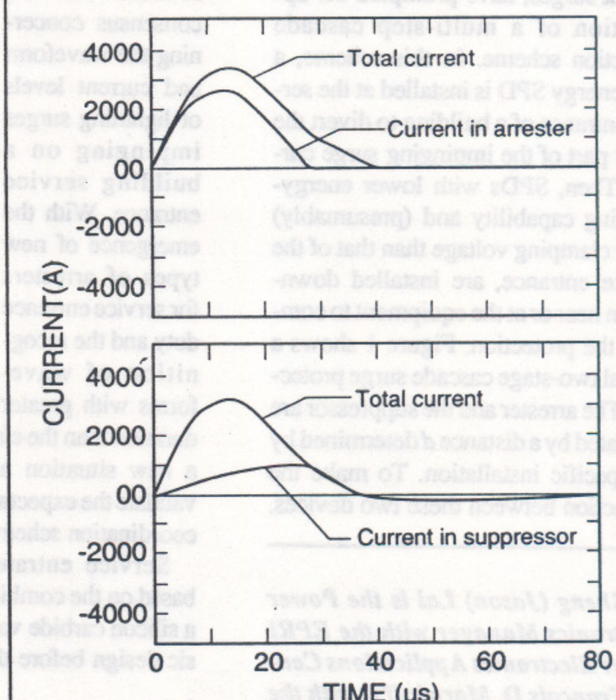

Figure B3: measured current distribution between arrester and suppressor for a 250 V–130 V cascade, separation of 10 m, and 8/20 μs impinging surge.

surge, the situation is reversed: the inductive drop is now negative and thus the suppressor with lower voltage, rather than the arrester, will divert the current.

For the new waveforms proposed in recent standards, this situation occurs for the 10/1000 surge where the tail contains most of the energy. Consequently, the expected relief provided by the arrester might not last past the front part of the surge. In response to this situation an alternate approach has been proposed — 'Low-High'— where the arrester clamping voltage is lower than that of the suppressor. Thus, a disagreement has emerged among the recommendations for coordinated cascade schemes: the 1970-1980 perception suggesting 'High-Low' and the new proposal of 'Low-High'.

The authors have presented several technical papers reporting the results of modelling the situation created by the emergence of gapless arresters and longer waveforms, with the necessary experimental validation of the model. These results cover a range of parameters, to explore the limits of a successful cascade coordination. They will serve as input to the surge protective device application guides now under development. Below is a summary of the simulation and tests conducted on different cascade combinations. The results of the simulation computations are shown in the two plots of Figures 2 (p. 15) and 3 (p. 17), where the lines represent the energy deposited in the suppressor, in percentage of the total surge energy, as a function of relative clamping voltages and separation distance. The first letter (H, M, or L) identifying the lines corresponds to the arrester, the second to the suppressor.

For an 8/20 impinging wave (Figure 2) and High-Low condition, the energy deposition in the suppressor decreases rapidly when the separation distance increases. This result explains how the High-Low configuration can achieve a good coordination with the 8/20 wave, provided that there is sufficient distance between the two SPDs, which was the assumption of the 1970-1980 studies. For Medium-High or Low-High configurations such as 150-250 and 130-250 cases, the higher voltage suppressor receives almost zero energy. The use of the suppressor is nearly redundant in this case, except for its application to mitigate surges that might be generated within the building. With closely rated SPDs (130-150 volts), the 150-volt voltage suppressor also receives much less energy than the 130-volt arrester.

For a 10/1000 impinging wave, Figure 3 shows the results of the 36 computations for this waveform. Unlike the case of the 8/20 wave, coordination for the 10/1000 wave can only be achieved by Low-High, Medium-High, or Low-Medium. Equally rated SPDs (250-250, 150-150, and 130-130 volts) result in 50 % of the surge energy being deposited in the suppressor, not a very good coordination, but at least some sharing. Note that with two SPDs of equal nominal value, but random tolerance levels, it is possible that the relative tolerances might in fact produce a situation which would not achieve good coordination: for instance, an effective 150-130 combination can result from tolerance shifts in

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stantaneous powers respectively for the arrester and the suppressor. By integrating the instantaneous power, the energies deposited in the arrester and the suppressor were calculated as 30 joules and 9 joules respectively.

Thus, the energy deposited in the suppressor, 9 joules, is about one quarter to the total (39 joules) and we have a well-coordinated cascade. Similar computations were made for all the other 35 combinations using this waveform.

Now turning to measurements, the same cascade configuration, 250 volts–130 volts with a separation of 10 meters, was set up in the laboratory with real wires and SPDs, a surge generator, and a high-speed oscilloscope. The currents recorded during the surge are shown in Figure B3. The surge generator delivers a close approximation of the standard waveform, but not the absolute equivalent. Consequently, the waveforms obtained from the experiment are not exactly the same as the simulated waveforms, but the appearance is the same. Detailed computations (not reported here) of the power distribution between the two SPDs did show good agreement between the simulation and the experiment.

10/1000 Wave

Compared to the 8/20 wave, the 10/1000 wave has a slower and longer drooping tail that contains most of the surge energy. During the long tail period, the inductive voltage drop between the arrester and the suppressor is low, and the voltage appearing across the arrester is reduced by the effect of the suppressor even with long distances between the two SPDs. Thus, the High-Low configuration cannot be coordinated as the high-voltage arrester will not absorb any impinging energy, but the suppressor does. Figure B4 shows the computed current for the arrester and for the suppressor under a High-Low (250-130) simulation for a 200-ampere peak surge current. The high-voltage arrester clamps the voltage during the impulse rising period and draws a small amount of the current pulse, I_1, which is almost invisible in the computer-generated plot. Thus, the low-voltage suppressor will absorb all the impinging energy in this High-Low configuration, defeating the intended coordination. □

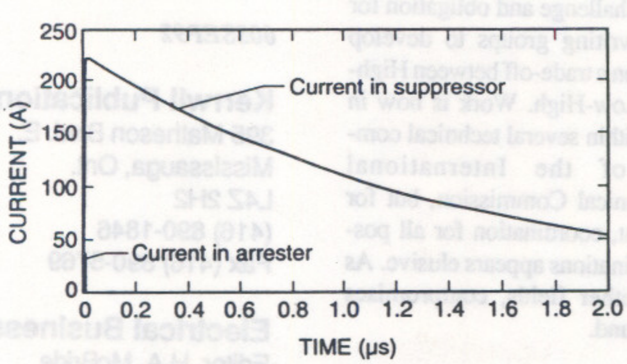

Figure B4: Computed current distribution between arrester and suppressor for a 250 V–130 V cascade, separation of 10 m, and 10/1000 µs impinging surge.

an intended 150-150 or 130-130 pair.

Discussion

The benefit of a coordinated approach is the ability to allow a single SPD at the service entrance to perform the high-energy duty, while several smaller SPDs within the premises can perform local suppression. This arrangement avoids the flow of large surge currents in the branch circuits of the installation, a situation known to produce undesirable side effects (raising the ground potentials). On the other hand, the situation exists where millions of small suppressors have been installed within equipment or as plug-in SPDs, with only sporadic and anecdotal reports of problems. Thus, it is possible to obtain protection with suppressors alone, while a coordinated scheme would provide additional benefits and eliminate side effects.

Some U.S. utilities wish to provide a service-entrance arrester capable of withstanding the 240-volt overvoltage that can occur on the 120-volt branches when the neutral is lost. This desire will force the coordination scheme into a High-Low situation because of the uncontrolled installation of low clamping voltage suppressors by the occupant of the premises. The results of the simulation and experimental measurements show that the objective of coordination could still be achieved with a 250-130 combination, if some distance is provided between the two SPDs, and if long waves such as the 10/1000 are not occurring with high peak values.

This restriction provides an incentive for obtaining better statistics on the occurrence of long waves. New standards recommend considering these long waves as an additional, not a standard waveform. Thus, the determination of a successful coordination depends for the moment on the perception of what the prevailing high-energy waveforms can be for specific environments. If most surges are of the short type, then we can expect successful coordination.

Conclusions

1. Significant parameters in achieving successful coordination of cascaded SPDs involve three factors, over which the occupant of the premises has no control. They are the relative clamping voltages of the two SPDs, their separation distance, and the waveforms of impinging surges.

2. Coordination of cascaded SPDs can be achieved under various combinations of parameters. However, some combinations will result in having a suppressor with low energy-handling capability called upon to divert the largest part of the surge energy. This uncoordinated situation can create adverse side effects when high current surges occur.

3. Coordinated schemes can be proposed by utilities to their customers, including a service entrance arrester and one or more plug-in suppressors to be installed for the dedicated protection of sensitive appliances. However, even such an engineered, coordinated arrangement could be defeated by the addition of a suppressor with a very low clamping voltage. Such an addition is quite likely in the context of the present competition for lower clamping voltages.

4. This uncontrolled situation presents a challenge and obligation for standards-writing groups to develop consensus on a trade-off between High-Low and Low-High. Work is now in progress within several technical committees of the International Electrotechnical Commission, but for the moment, coordination for all possible combinations appears elusive. As in many other fields, compromises must be found.

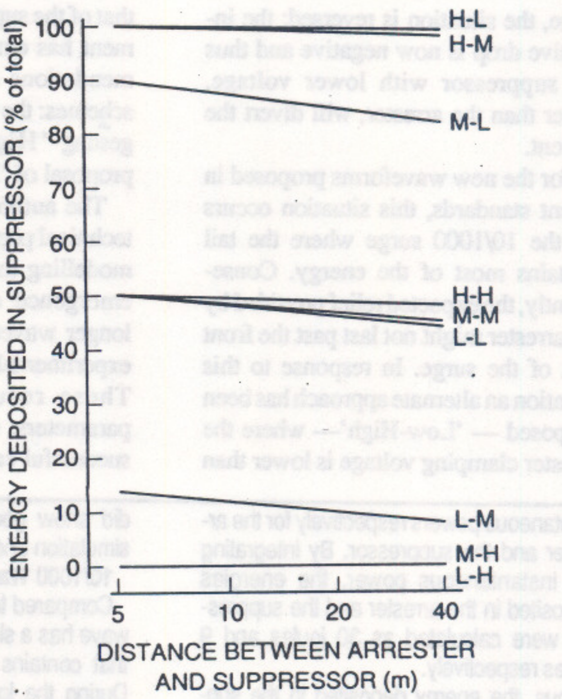

Figure 3: Percentage of total surge energy deposited in suppressor, as a function of separation distance, for cascade combinations of 250 V, 150 V, and 130 V, with a 10/1000 μs impinging surge.

For Further Reading

A recent bibliography compiled for a committee study of cascade coordination lists 32 papers published on this subject over the last fifteen years. Among these, the authors have contributed two recent North American conference papers, on which this article is based: Lai, J.S. and Martzloff, F.D. – Coordinating Cascaded Surge-Protective Devices, in *Proceedings, IEEE/IAS Annual Meeting*, Dearborn, October 1991, and Martzloff, F.D. and Lai, J.S. – Cascading Surge-Protective Devices: Options for Effective Implementations, in *Proceedings, PQA'92 Conference*, Atlanta, September 1992. □

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