SURGE RECORDINGS THAT MAKE SENSE: Shifting focus from voltage to current measurements

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Abstract - The paper proposes to establish a program for characterizing surge events according to the capability of a surge event to deliver a surge current through the power system in end-user facilities. This characterization would replace the conventional and by now misleading monitoring of surge voltages. The new approach will use a current transducer including a silicon-avalanche diode with the lowest possible voltage to "attract" surges away from other surge-protective devices connected within the facility. The voltage signal from the current transducer will then be recorded using any power quality monitoring instrument available to the individual researchers, providing complete current waveform parameters.

I. INTRODUCTION

I.1 Background

Characterizing the surge environment has been a subject of research for the last forty years, driven by the increasing concern about the vulnerability of new electronic appliances to transient overvoltages. However, practically all the recording campaigns conducted by major organizations such as ERA (Bull and Nethercott, 1964)[1], General Electric (Martzloff & Hahn, 1970)[2], IBM (Allen & Segall, 1974)[3], Bell (Goldstein and Speranza, 1982)[4], Canadian Electrical Association (Hughes & Chan, 1995)[5], National Power Laboratory (Dorr, 1995)[6] and other researchers, including Hassler & Lagadec (1979)[7], Meissen (1983)[8], Wernstrom et al. (1984)[9], Goedbloed (1987)[10], Standler (1989)[11], and Forti & Millanta (1990)[12] have been limited to the measurement of transient voltages.

We now propose a change in the protocol for the monitoring of power quality in ac power systems. This change has become necessary because end-user power systems are no longer what they were at the time the early surveys of transient overvoltages were conducted. Varistor-based surge-protective devices (SPDs) have become so ubiquitous in low-voltage ac power systems that hardly any location can be found where there is not some form of transient voltage limitation in effect. Attempting now to characterize the environment so that appropriate SPDs could then be prescribed for specific locations based on voltage measurements would be quite misleading. What such a measurement would yield today is no longer the surge characteristics of the monitored ***system***, as it was at the time of the early surveys, but the ***residual voltages*** of whatever SPDs are installed nearby.

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I.2 Making meaningful measurements

The proposed change in monitoring practices is to insert a current transducer between the low-voltage power system being monitored and the existing monitoring instruments. This transducer would consist of an SPD with the minimum tolerable voltage rating across the power line, to be connected at some point of an installation, and serve as a "magnet" for attracting the impinging surges. To use a metaphor, this SPD in effect becomes the "winning bidder" by offering to the impinging surge the path with lowest clamping voltage among all the parallel-connected SPDs of the installation.

A current transformer with the "magnet SPD" in the primary and an appropriate burden on the secondary would be used to feed the resulting voltage signal into the existing power quality monitoring instruments now used by many organizations and individual researchers. In this manner, the surge current attracted by the "magnet SPD" can be recorded to find the true character of surge events at that particular location, despite the presence in the local system of any and many unknown and uncontrolled SPDs.

II. TRANSDUCER DESIGN

II.1 Breadboard design

Preliminary results on the feasibility of such a recording system have been obtained: a suitable silicon avalanche diode has been identified and proven to act as a "magnet," even in the presence of "competing" metal-oxide varistors, and yet able to withstand the temporary overvoltages that can occur in the system. At this point, the transducer design principle is well defined, and concerns that the "magnet" effect could be effective only within a small power system have been addressed, as discussed later in the paper.

The current transducer would consist of a string of silicon avalanche diodes (SADs) in series with the primary of a current transformer with a burden connected across its secondary, an overcurrent protective fuse in series with the diodes, and an indicating light to signal a blown fuse. In the final design that would be used to deploy a number of these transducers, all of these components will be included in a package derived from the so-called "plug-in SPD" which are offered by many manufacturers. Using the external package of such a device will provide a low-cost envelope to build a few hundred transducers with no tooling costs and yet provide a package suitable for connection to wall receptacles in end-user systems.

The power system can include several branch circuits to supply the loads, some of which featuring SPDs incorporated into load equipment or installed by the end-user. At some point of this system, selected for convenience by the instrument operator, the transducer will be installed. A key point of the proposal is that pinning down the actual location of the monitor is no longer a concern because of the "magnet" effect of the low-clamping SAD string.

Figure 1 shows a schematic diagram of the transducer. Selection of an appropriate string of SADs is an exercise in brinkmanship: the SAD string must have a clamping voltage sufficiently low to make it the winning bidder, and yet not so low that the temporary overvoltages occurring in the power system would destroy it. In a preliminary experiment, a SAD string with a nominal voltage of 185 V at 1 mA dc was found to survive exposure to 130% of nominal 120 V system voltage, ensuring sufficient distance from the brink of failure.

It will be prudent to include a fuse in series with the SAD string for the case where a large surge would exceed the current-handling capacity of the SAD string and cause its failure. A visible indication of a blown fuse can be added to the package, similar to the indication now routinely provided by the commercial plug-in SPDs offered for residential use.

A commercially available and low-cost current transformer* has been identified that can provide sufficient accuracy for the measurements over a sufficient frequency range. Conventional current-viewing transformers used in the laboratory are much more expensive and would not be necessary for the purposes of the recordings. Considering the wide range of surge events and the resulting statistical uncertainty in citing "representative values" of the surge events, obtaining results of current measurements within an order of magnitude is already a very large improvement over the present lack of knowledge. In the example of recording capability discussed later in the paper, there is a 50:1 difference in the cost of a laboratory-type current-viewing transformer and the low-cost current transformer required for deployment of a large number of monitors.

Matching the burden values to the voltage requirements of the monitor input circuits has not yet been done at the time of this writing, but might be reportable by the time of presentation of the paper. Tradeoff between the cost of the current transformer and its frequency response is another area where improvements to the proposal can be made to obtain meaningful recordings at a cost that will not be a deterrent to acceptance of the proposal.

** Please note that the author has no vested interest in promoting or endorsing any hardware, and that the final selection of the current transformer is still an open design tradeoff consideration. Commercial availability is cited here only in support of the concept of using readily available, low-cost components for the deployment of many transducers.*

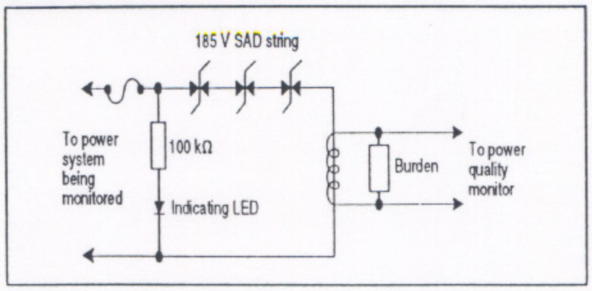

Figure 1 - Schematic of the transducer

II.2 Radius of attraction

By design, the string of diodes is intended to become the "magnet" that will attract the impinging surges. We recognize that this winning bid can be ensured only within a certain radius from the transducer. Increasing distances between the transducer and competing SPDs eventually produces a decoupling of the two devices and might allow a competing SPD connected upstream from the transducer to divert the surge first. This situation is the reverse of that sought when making studies of the coordination of cascaded SPDs, where the concern is to ensure that a heavy-duty SPD located upstream of a lower-duty SPD is sufficiently decoupled so that an impinging surge will be diverted by the upstream SPD. The parameters of cascade coordination have been addressed at length in the literature [13], [14], [15] and will not be discussed here, but serve as a useful reminder to take a careful look at possible limitation in the radius of meaningful measurements.

To ascertain that the transducer will remain the winning bidder, a simple test was performed by assembling a physical mock-up of an installation with a service panel feeding three branch circuits, with lengths of 4.5 m, 9 m, and 18 m respectively. The SAD string was connected at the end of one branch circuit while metal-oxide varistors (MOVs) with nominal 200 V at 1 mA dc were connected at each end of the other branch circuits.

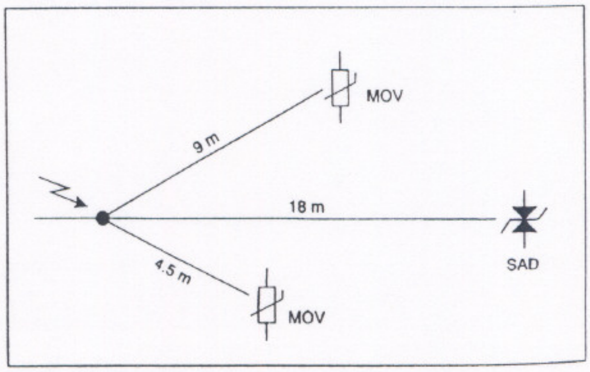

Figure 2 - Arrangement of competing SPDs

We can expect that the least favorable combination would be that of the SAD connected at the end of the longest branch circuit, with an SPD of relatively low clamping voltage installed at the end of the shortest branch circuit. A Combination Wave [16] was applied to the service panel, and the currents in the three branch circuits were monitored, with the SAD string successively connected at the end of the 4.5 m, 9 m, and 18 m branch circuits. In all three cases, the SAD attracted all the surge current, with no current detected in the MOV-terminated branch circuits.

More sophisticated analysis can be performed by applying the numerical modeling techniques developed in the referenced modeling studies [17], [18], extending the distances and combinations of competing SPDs from the simple example shown in Figure 2 to determine how extensive an installation can be and still have the transducer remain the winning bidder. In this manner, the pitfall that threatens credibility of contemporary voltage recordings (uncertainty about other unknown SPDs connected in the system that can produce misleading results of low surge activity) will be eliminated.

III. BREADBOARD TEST

A simple breadboard was assembled with the 185 V SAD string connected to the output of an 8/20 μs surge generator and a 100 Ω resistance inserted in series to limit the current delivered by the low-impedance generator. The resulting current (longer than 8/20 μs because of the inserted resistance) was applied to the one-turn primaries of a laboratory-grade current-viewing transformer and of the low-cost current transformer, with a 2 kΩ burden across its secondary. Their secondary output voltage was recorded by a laboratory-grade digital signal analyzer. Figure 3 shows the recorded voltage across the SAD string and the two current signals.

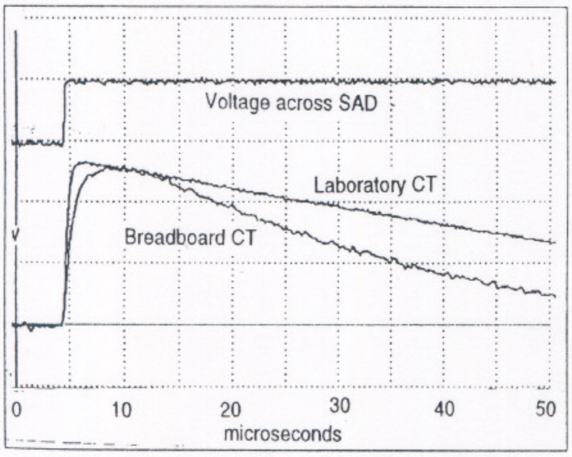

Figure 3 - Voltage across the SAD string and corresponding current signals delivered by the laboratory-grade transformer and the breadboard current transducer

To make the comparison easier, the signal analyzer input sensitivity of the two current-displaying channels was adjusted so that the two current signals would coincide near their peaks. The point to be made here is not the actual numerical values, but the quality of the frequency response of the low-cost transducer, illustrated by a time-domain representation of an impulse.

Inspection of the two current traces shows a loss of signal at the front as well as in the tail, symptomatic of a limited frequency response. While such a loss would be absolutely intolerable in a laboratory environment, we must place it in its proper perspective. As outlined in the introduction, we are now facing a new situation, brought about by the proliferation of SPDs, where surge voltage measurements no longer have the significance they once had, so that we have no knowledge on the real surge threat existing in the system. The current-delivery capability of the surge event, as recorded by the imperfect current transducer is an immense improvement over the present total lack of knowledge.

Given the wide range of possible surge events, the relatively small loss of information represented by the two areas separating the two current signal traces is small compared to the common area that represents a good estimate of the order of magnitude of the current-delivery capability of the recorded surge event. In contrast to laboratory measurement researchers, operators and users of field surveys are already content to have the surge events characterized within one order of magnitude when the alternative is no meaningful information at all. As discussed earlier, tradeoff between transducer cost and quality of the frequency response is still an open consideration, for which comments from interested parties are earnestly invited before implementation of the proposal is initiated.

IV. PROGRAM IMPLEMENTATION

The next step in making the change from surge voltage recording to surge current recording would be to recruit enough participants willing to acquire the transducer and use their existing commercial monitor(s) to record the occurrences of surge currents attracted by the transducer. This transducer could be produced in cooperation with some manufacturer of a plug-in SPD, so that a readily adaptable outside package could contain the transducer components and provide a simple and safe way of connecting it to a receptacle.

Within the IEEE, a new Task Force of the Standards Coordinating Committee on Power Quality is developing protocols for reporting monitoring results; hopefully, the concepts presented in this paper will be taken into consideration by that Task Force and by other organizations interested in making surveys for characterizing the electromagnetic environment. The IEC is also considering the development of guidance documents on measurement methods in the area of power quality, where this shift of focus should be taken into consideration.

The author is volunteering to collect and compile the statistics of the recordings that would be made with the new transducer. Individual researchers and organizations are invited to contact the author with comments, suggestions of alternate approaches, and ideas for implementing this change in characterizing the surge environment that will make sense in the new environment of proliferating surge-protective devices.

V. CONCLUSIONS

1. Given the proliferation of SPDs, the need to replace the recording of surge voltage events by the recording of the capability of surge events to deliver a current into load equipment, in particular SPDs has been identified.
2. Tests made on a breadboard design using readily available components show that meaningful surge current recordings can be obtained, even with a very low-cost design. Improvements in the frequency response could be obtained by a tradeoff in component costs and refinements of the design.
3. Implementation of a program may be possible if sufficient interest is aroused by the proposed change in conducting field surveys of surge events.
4. Standards-writing bodies concerned with characterizing the electromagnetic environment in low-voltage power systems could make an important contribution by giving recognition to the new situation and shifting focus from surge voltage measurements to surge current measurements.

VI. ACKNOWLEDGMENTS

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