Keeping up with the Reality of Today's Surge Environment

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Significance
Part 5 – Monitoring instruments, laboratory measurements, and test methods
Part 6 – Textbooks and tutorial reviews

Based on the proliferation of surge-protective devices in low-voltage end-user installations, the paper draws attention to the need for changing focus from surge voltage measurements to surge current measurements. One proposed approach was to develop a simple transducer measuring the surge current that would be drawn in an SPD with low clamping voltage connected to the circuit to be monitored. A second approach, perhaps idealistic, would be to gather from SPD manufacturers data on field failures and attempt to replicate these failures in the laboratory, thereby giving some explanation on what went on in the real-world surge environment.

This need for changing from voltage to surge current monitoring was addressed in several other papers presented on both sides of the Atlantic (See in Part 5 "No joules," 1996; Make sense," 1996; "Joules Yes-No," 1997; "Novel transducer," 2000; and "Galore," 1999 in Part 2), in persistent but unsuccessful attempts to persuade manufacturers and users of power quality monitors, and standards-developing groups concerned with power quality measurements to address the fallacy of continuing to monitor surge voltages in post-1980 power distribution systems As it turned out, the response has been polite interest but no decisive action.

The proposal to gather field failure data also met with little enthusiasm at the time, however more recent standard-development activities indicate a possibility that the idea might not be completely abandoned.

KEEPING UP WITH THE REALITY OF TODAY'S SURGE ENVIRONMENT

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Abstract - The paper proposes to establish a program for characterizing surge events by the capability of a surge event to deliver a surge current through the power system in end-user facilities. This characterization would complement or even supersede the conventional monitoring of surge voltages. Two approaches are suggested: (1) Using a metal-oxide varistor with the lowest possible voltage to "attract" surges away from other SPDs connected in the facility, and then recording the surge current waveform in the varistor; (2) Gathering data on field failures attributable to surges or swells for all types of electrical appliances, then attempting to replicate the failure mode in the laboratory.

HISTORY

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 Bell (Goldstein and Speranza, 1992)[1], Canadian Electrical Association (Hughes and Chan, 1995)[2], General Electric (Martzloff and Hahn, 1970)[3], IBM (Allen & Segall, 1974)[4], National Power Laboratory (Dorr, 1995)[5] and other researchers, including Forti and Millanta, 1990 [6], Goedbloed, 1987 [7], Hassler and Lagadec, 1979 [8], Meissen, 1983 [9], and Standler, 1989 [10] have been limited to the measurements of transient ***voltages***. This focus on transient voltages was initially justified for two reasons: (1) the emphasis was on concerns of equipment failure subjected to overvoltages in the absence of adequate protection, and (2) shunt-connecting a voltage sensor to a power circuit is easier than inserting a current sensor in series with the lines.

The idea of recording surge ***currents*** that could be "attracted" by a surge-protective device (SPD) with the lowest clamping voltage in an installation was suggested in the discussion of a paper describing a digital instrument with current-recording capability (Odenberg and Braskich, 1985)[11]. A recording system with capability of recording both current and voltage, using oscilloscopes and digitizers, was developed and described in (Standler, 1987)[12]. These two recording systems were developed before the explosion, in the mid-eighties, of power quality monitoring projects made possible by the commercial availability of portable monitors with graphics capability. An ongoing project for monitoring power quality in the medium-voltage distribution systems (not low-voltage end-user systems), sponsored by the Electric Power Research Institute, is based on an instrument which has a limited response at the frequency range associated with surge voltages.

With the benefit of hindsight, this paper proposes a change in the way power quality monitoring projects are conducted. The emphasis would be shifted from recording transient voltages, or surge voltages, to the determination of what surge currents may be delivered by a surge event to a surge-protective device. This shift is necessary because a new situation has arisen in the surge environment.

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THE NEW SURGE ENVIRONMENT

In spite of the proposals cited above for recording surge ***currents*** that could be delivered to a candidate SPD, the idea has not caught on and recording surge ***voltages*** still seems to be the order of the day. In the last few years, following the advent of the metal-oxide varistor protective devices, the actual situation concerning observation of transient overvoltages has become quite different. These devices are now so ubiquitous (an estimated number of installed varistors in the United States is two billion) that hardly any location can be found where there is not some form of transient voltage limitation in effect*. Nonetheless, proposals are still being made, and in some cases implemented, to continue monitoring transient ***overvoltages*** exclusively inside end-user facilities, in a noble attempt to characterize the environment so that appropriate surge-protective devices could then be prescribed for specific locations. What this measurement yields, however, is no longer the surge characteristic of the monitored ***system***, but the ***residual voltage*** of whatever SPDs are installed nearby.

Thus, the results of any measurement campaign conducted in the future and limited to voltage transients will be totally irrelevant, worse yet, misleading. Such measurements will provide a false sense of security based on the uncontrolled presence of undefined surge-protective devices. The results might lead to the erroneous conclusion that the surge environment being monitored is benign (Aspnes et al., 1985)[13]. But this might not be the case; for instance if a user were to install an SPD with clamping voltage and current-handling capability lower than those of SPDs already in place, the newly installed SPD would then "attract" incoming surges. These surges, in turn, might have a current-delivery capability beyond the limited capacity of the new SPD. Although such a situation might be rare, it would be an unpleasant surprise to the unwary end-user. To draw a parallel, the practice of deriving surge-current protection schemes from the measurement of surge voltages in the presence of unknown SPDs is akin to deriving power-frequency fault-current protection from voltage measurements made during a fault, rather than applying the well-developed overcurrent coordination practice used by power system engineers.

A recent draft document proposed for monitoring Power Quality mistakenly included the characterization of "the energy in the surges" by making measurements only of voltage as a function of time, integrating the square of the voltage, and dividing the result by an arbitrary resistance, such as the characteristic impedance of the wiring. The basis for this approach may have been rooted in the fact that in the past (mid-eighties), disturbance monitors did print out results labeled as "joules." However, regardless of the source, practices based on this misconception have now been recognized as erroneous and have been discontinued. Recognition should be given to Goedbloed's work, previously cited, in which he created the term "energy measure" to assess a parameter involving the integral of the voltage square as a useful way of obtaining some information on the strength of a surge event, but he avoided the pitfall of presenting the concept in terms of joules.

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* An often-cited document, ANSI/IEEE C62.41, *Recommended Practices on Surge Voltages in AC Power Circuits*, provides in graphical form a description of the frequency of occurrences vs. peak values of the surges at ***unprotected locations***. This specification of unprotected locations still reflects the only available data base and the mind-set of users concerned with the need for adding surge protection in an installation where none is provided -- which is no longer the present situation.

A NEW APPROACH FOR MEASUREMENT OR INDIRECT ASSESSMENT OF SURGE CURRENTS

In contrast to the traditional and potentially misleading recording of surge voltages, a change to measuring or at least indirectly assessing the surge current (both magnitude and waveform or duration) would provide more meaningful information on today's surge environment. Two ideas for obtaining that type of information are described in this paper. The first idea is based on installing a varistor with very low clamping voltage and recording the current drawn by that varistor. This approach would yield new and detailed information based on actual surge-current measurements. A second approach would use field-failure data from appliances such as packaged SPDs or light bulbs combined with a laboratory replication of their failure modes. This replication would allow credible conjectures on the field conditions that led to the failure of the appliances. The outcome of this second approach would yield a statistical upper bound on the magnitude and frequency occurrence of surges with high energy-delivery capability.

First approach: Direct measurement of available surge currents

In this first approach, an SPD with the minimum tolerable voltage rating across the power line would be connected at various points of an installation, one location at a time, to serve as a "magnet" attracting the impinging surges. This SPD would be specially sized and well-characterized to ensure the "magnet" function of drawing most of the available surge current.

Two limitations have to be recognized in this approach. The first is the requirement that the SPD operates on the brink of drawing excessive standby current with the line voltage at its upper practical range. The second is the potential impact of other SPDs located upstream of the "magnet." These other SPDs would compete in attracting the available surge current, because of their connection in the so-called "cascade" arrangement (Martzloff and Lai, 1992)[14]. A "calibrated" SPD could be designed by NIST in cooperation with varistor manufacturers to provide the necessary characteristics of low clamping voltage, on the secure side of the brink. The surge current attracted by the varistor could then be recorded to find the true character of surge events at that location, despite the presence in the local system of any unknown and uncontrolled SPDs.

In a first implementation of this idea, the surge current would be recorded by using the current probe that is a common accessory of the various types of commercial power quality monitors owned or operated by hundreds of organizations and researchers. However, the frequency response of these current probes might not be appropriate for recording surge currents. A modified approach is now being investigated, using a current transformer with a higher frequency response. The output of the transformer, with an appropriate burden, is then fed to the voltage channel of the monitor, which has a better frequency response than the current-probe channel. The combination of the calibrated varistor, current transformer, and burden serves as a transducer converting the surge current into a voltage signal readily acceptable to existing power quality monitors.

In its elementary concept, this current-measurement approach will readily produce a spectrum of current surges describing the environment at the point of connection of the varistor. However, turning this local spectrum into a broad data base will require some information processing to take into consideration local conditions. These conditions might include the structure and ratings of the power supply system from the distribution transformer and downstream, the presence of a surge arrester on the primary of the transformer, local ground resistivity, etc. The results of the "Upside-Down House" modeling (Martzloff et al., 1995)[15] could be applied to determine how far downstream the low-voltage SPD can remain an effective and calibrated "magnet" of the available surge when other SPDs are present in the system. In this manner, one could characterize the strength of the surge event, shaped by the local power system, to deliver a surge current. In turn, this knowledge would allow prediction of the amount of energy that would be deposited in any candidate SPD, a factor which is presently unknown. By using two separate channels (high-frequency and 60-Hz responses, with appropriate sensitivity level) of the commercial monitor while recording the current drawn by the varistor, it will be possible to characterize swells as well as surges, increasing the information yield of the project.

Selecting the specially sized SPD at the brink, as discussed above, entails a definite probability that its rating will be exceeded under some circumstances, so that the varistor must be considered as expendable. A suitable overcurrent protection must then be provided in series with the varistor to clear the resulting short-circuit. To provide continued monitoring, several varistors could be connected in parallel, each with a fuse, in a "staircase" of incremental voltages to allow several stages of recording before all devices are consumed. This idea is now being explored, but first indications are that varistors will have to be very closely characterized to ensure this staircase of clamping voltages. For instance, characterizing the varistors by their nominal voltage (voltage at 1 mA DC) to select different voltages for the staircase does not necessarily ensure that the same difference will be maintained at higher levels of surge currents.

The ability to replace the expendable varistors would be essential if the staircase approach turns out to be impractical. A completely expendable transducer box -- including calibrated varistor(s), fuse(s), current transformer, and burden -- might not be practical in view of the investment necessary for the current transformer contained in the box. The SPDs could be enclosed in a safety-approved enclosure, with provision for replacing a failed SPD and its fuse, allowing the operator to resume monitoring. However, the need to open the box and replace components might be a deterrent to widespread acceptance. Success of the project would depend on recruiting researchers committed to obtaining this new type of data. An unresolved question at this stage is whether or not an approval by Underwriters Laboratories or some other agency would be necessary to make the transducer box acceptable for widespread connection to end-user facilities. Assuming that this suggestion receives encouragement from the engineering community, resolving these specific questions will be the next phase of the project.

Second approach: Replicating field failures

In this approach, failed appliances created in the laboratory would be compared to the appearance of failed appliances returned by end-users. A reasonable leap of faith is implied in this process that indeed the two failures resulted from similar surge (or swell) events. The conclusion would then be an experience-based assessment of the occurrence of such events at the failure level observed in the laboratory for the same appliance.

Some may point out all the factors that could make this leap of faith unreliable, confusing, misleading, etc. In fact, it is the very purpose of this paper to expose the idea so that the potential difficulties can be identified and hopefully dealt with by careful analysis of the data. This paper is presented as an invitation to colleagues and commercial organizations interested in a cooperative effort of sharing field failure data.

SPD field failure data

Manufacturers of packaged SPDs who accept or invite the return of SPDs that failed in the field might already have enough statistics on the rate of failures and have enough devices with a recognizable pattern of failure modes to implement this study. Assuming that they would be willing to share the information or at least input it into a neutral data collection point, laboratory experiments could then be conducted with deliberate overstresses aimed at reproducing the pattern of failure modes. From similar appearances, inferences might then be drawn on the type of overstress that occurred in the field. While recognizing the limitation of such inferences, compared to the ideal of actually recording the occurrence of a surge current, this approach would have the advantage of representing a summary from the millions of SPDs in permanent service, rather than a few observation points by power quality monitors that are limited in number and period of monitoring. Each SPD would act as a surge detector, akin to the clock motors that failed and provided surge statistics in the early sixties (a 100-to-1 reduction of failures when the withstand capability was raised from 2 kV to 6 kV), serving as one of the inputs to the data base for the IEEE 587 Guide -- now ANSI/IEEE C62.41 -- (Martzloff and Hahn, 1970)[3].

The cooperation of all organizations and individuals would be coordinated in cooperation with the IEEE and other standards-developing bodies. At this point, the thought of collecting failure information that some parties might wish to keep proprietary may appear to be wishful thinking. However, it is proposed for consideration and discussion, with the hope that the advantages of pooling data would help overcome concerns about any inadvertent disclosure of sensitive information.

Other field failure data

In addition to the clock motor story cited above, other common appliances can be viewed as unwittingly serving as surge or swell recorders. A very humble appliance, the incandescent light bulb, is a good example of how at least a "reality check" can be applied in assessing the surge environment. Anecdotal information collected by the author in the seventies, and now in the process of being updated at the Power Electronics Applications Center, shows that most light bulbs fail when subjected to surges in the range of 1000 to 1500 V. The failure mechanism of a light bulb under surge conditions involves an internal flashover bypassing the hot filament, triggered by the surge and followed by a power-frequency arc that burns out the filament at its point of attachment to the stems. The internal fuse in the bulb base then clears this power arc. From the fact that billions of light bulbs are connected to the 120 V systems in the United States, and only sporadic occurrences are reported of failures in excess of that implied by the published life of the bulb, it seems that occurrence of surges above 1500 V is not very frequent.

There are some limitations to the conclusions that can be drawn from such experience, such as the competing mechanism of excessive rms line voltage, unknown variation among bulb designs, etc. Nevertheless, the large number of data points resulting from the widespread use of light bulbs makes the data a reliable source of information if it is not misconstrued as pinpointing a narrow band of failure levels. Other appliances might also be used as unwitting surge recorders if their manufacturers and users would consider sharing field-failure information.

CONCLUSIONS - AN OPEN INVITATION

The two approaches presented in this paper are rooted in the expectation that enough interested parties would be motivated to participate in a pooling of information. Thus, the conclusions of this paper take the form of an open invitation to individuals and organizations for serious consideration (including peer-review criticism of the ideas) and, hopefully, participation in the data collection.

The first approach will require the development of a transducer box containing one or several varistors and an appropriate (moderate accuracy for low cost) current transformer. If such a transducer box can be developed and accepted for across-the-line connection, the next step would be to recruit enough participants willing to acquire the box and use their existing commercial monitor(s) to record the occurrences of such currents.

The second approach will require a policy decision by manufacturers that the perceived disadvantages of disclosing failure rates to a third party -- even with assurance of good faith custody of the information -- would be more than compensated by the benefit of a better characterization of the environment in which their products must operate.

Individual researchers and organizations are explicitly invited to contact the author with comments, suggestions of alternate approaches, and ideas for implementing this change in characterizing the surge environment.

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Alex McEachern and Don Worden contributed comments on the ideas presented here, at an early stage when the idea was presented in a two-page flyer distributed among IEEE colleagues, resulting in some evolution of the concept. The still anecdotal data on varistor characteristics and light bulb failure levels have been collected at the Power Electronics Applications Center in Knoxville, Tennessee. It is expected that more comprehensive tests will be pursued, leading to a formal publication of the results. Kermit Phipps contributed the information on the characterization of varistors for an eventual staircase configuration, and Doni Nastasi contributed the information on the failure levels of light bulbs under surge conditions. Thomas Key and JoAnne Surette reviewed the draft of this paper and made thoughtful suggestions. All are gratefully acknowledged.

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