

Monitoring of Surge-Protective Devices in Low-Voltage Power Distribution Systems

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EATON Electrical Surges Happen!

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Significance

Part 7 – Mitigation techniques

A review paper on how the industry has developed monitoring method to indicate the “health” of permanently-connected surge-protective devices (SPDs) typically installed at industrial or commercial facilities. These SPDs can be located anywhere in the electrical distribution system. Because these devices are primarily connected in parallel (the so-called “one port” type), failure of the SPD does not necessarily cause any immediately noticeable symptoms for the user. Many of these devices are not inspected once they are installed and the user is not aware of their operating status. Therefore monitoring becomes essential in maintaining the surge protection within the facilities.

MONITORING OF SURGE-PROTECTIVE DEVICES IN LOW-VOLTAGE POWER DISTRIBUTION SYSTEMS

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1. Introduction

Surge-protective devices (SPDs) are installed at most industrial or commercial facilities to protect equipment against transient events. These SPDs can be located anywhere in the electrical distribution system. Because these devices are primarily connected in parallel (the so-called “one port” type), failure of the SPD does not necessarily cause any immediately noticeable symptoms for the user. Many of these devices are not inspected once they are installed and the user is not aware of their operating status. Therefore monitoring becomes essential in maintaining the surge protection within the facilities. There is a lack of thorough information on monitoring of SPDs, especially if looking beyond the visual indicators.

The monitor is a critical part of the SPD as it tells the world if the SPD is working. If the surge protection were removed from a location, there would be no immediate change to the electrical system that would affect the occupant. However, if a large surge event then occurred, there could be many damaged systems in the building. The monitor can show that the SPD is connected and that it is operating correctly. Nevertheless, the SPD still requires some type of maintenance system to systematically inspect each SPD unit and determine its operating status.

The monitor can be visual, for instance green and red Light Emitting Diodes (LEDs), audible, or electrically connected signals. Visual signals are the most common type encountered in the field. There can be just one light or a whole array of lights indicating the functionality of various parts of the product. Audible alarms are useful in a low-traffic area. Both of these types of annunciators are only useful within a small local area. Local or remote electrical monitoring has been done primarily by dry contacts that change state in the event the SPD fails. This signal can be routed to a building system or a remote location.

In this paper, we focus on the concerns of permanently-wired SPDs in industrial or commercial facilities rather than the application of plug-in consumer-type SPDs.

2. Types of Monitors

Manufacturers offer a wide choice of SPD monitoring approaches, raising questions of pros and cons depending on the application needs. The following paragraphs provide a brief description of some possible approaches, summarized in Table I.

A. *No Monitor*

Some SPDs, such as most surge arresters, do not have any type of explicit monitoring. Although some arresters have a thin white paper sheet that burns or is damaged during a fault (which is really

a form of visual indication), most models rely on the user to notice a ruptured case or tripped circuit breaker. The issue is that without a detailed visual inspection, the facility can be unprotected for a significant length of time before someone notices. This is also true for surge protection built into most power supplies used to protect the electronics they supply.

TABLE I
 SUMMARY OF LOCAL MONITORING FEATURES

Type of monitoring	Features	Advantages	Limitations
No Monitor	None	No electronics to fail	Cannot determine status of unit
Visual Indicator	LEDs / neon lamps	Immediately visible to anyone looking at the unit	Non-standard meaning of lights, on/off can be misinterpreted as no monitor
Audible Alarm	Buzzer / horn	Immediately noticeable to anyone near the unit	Can be annoying, might be silenced and then ignored
Electrical Indicator	Form C relay / optoisolators	Remote monitoring, integration into building automation systems	Limited information
Surge Counter	Surge counting	Actual count of surge events	No reference level to compare
Other Counters	Sag / swell / outage and others	Indication of system power quality	No reference level to compare
Protection Remaining	Internal component counting	Indication of life remaining on the unit	Many failures are due to exogenous events and not predicted by life remaining
Event Recording	Date/time stamps, event values	Correlation of monitoring and external events, level of event	Accuracy not as good as a power quality meter – but that is not the purpose of SPD monitoring

B. Visual Indicators

Other SPDs have included monitor lights that indicate their operational status. At the most basic level, these lights are used to tell the user if the SPD has power or not. There can be one light or one light per phase wire. The light used is usually either a light-emitting diode (LED) or a neon lamp although other types are possible.

Many failures of SPDs, especially those not provided with an internal disconnect, result in a short circuit that trips the upstream circuit breaker, making it obvious that something is wrong, but resetting the breaker might not necessarily pinpoint the problem to the failed SPD: In the case of an SPD with internal disconnect, the coordination between the disconnect and the upstream breaker might be such that both will disconnect. Then, resetting the breaker will return the power system to “normal” and the user might think that all is well – but no surge protection is provided, hence the need for a clear indication.

Depending on the design of the specific SPD, the user might get an on/off indication. However, there is a problem in that the maintenance staff might not fully understand the differences in the meaning of these lights and thus not notice the failure of the unit (Martzloff, 1998 [1]). Further, neon lights can burn out after a year or two and transform the unit to a model with no monitor as describe above.

More advanced models include a two-state light, usually LEDs that have a longer life than a neon lamp. These models use a green/red indication. Normally the green LED will be illuminated telling the maintenance staff the unit is operating normally. If the unit faults, the unit will turn off the green LED and turn on the red LED. Some of the models can have more than two states. By adding a yellow LED, a three-state version can be created. The actual meaning of the yellow LED varies by manufacturer.

Like the on/off indicator above, this version can have a multiple state indicator per phase or just one for the complete unit. Because the meaning of these lights is not standardized, there is the possibility of misunderstanding their meaning unless clear explanations are conspicuously provided next to the light. More complex monitors would also require text within the instruction manual to fully describe the functioning of the monitor and the meaning of all possible combinations of lights beyond that indicated on the product itself.

C. Audible Alarms

The problem that can occur with any type of visual indicator is that people might not notice or pay attention to the signal. Audible alarms are much more difficult to ignore. However, a noisy environment can easily swamp the small buzzers that are common in SPD monitors. In most conditions, especially normal office environments, the sound can be heard through in the hallway next to the electrical room, even through a wall or closed door. Options included for the audible alarm can be important for some users, for instance:

- Can the buzzer be silenced after the unit has faulted? Imagine sitting next to a faulted SPD for several days until it can be replaced.
- If it can be turned off, is it obvious to nearby personnel whether the alarm is active or in silence mode?
- A power outage will result in the SPD losing power and then starting up again after the power returns. Does the SPD return to the previous condition, alarm silenced or not, or does the SPD start up in the same state every time?
- Assume that the unit has the alarm silenced as default, the maintenance personnel will need to reset the alarm silence function after every power outage.

D. Electrical Indicators

The most common type of electrical indicator is the Form C relay. This relay has one set of contacts that include a normally-open, normally-closed contact with a common terminal. There are various different actions for this type of monitoring.

The first question with a Form C relay is what is considered the normal position? Although the normal condition for an SPD is powered, relay markings are the opposite, 'normal' is unpowered condition. The person using the relay in a building automation system must connect the unit in such a way that it tells the system that it is not faulted when powered and operating normally.

The second question to ask is if power is lost, does that relay switch or not? It can be assumed that the relay will reverse conditions under a fault condition, that is, the normally open terminals will become closed while the normally closed terminals will become open. However, it is not clear what happens during a power failure. Is the power loss considered a fault where the relay changes state, or is the power loss normal, and the monitoring system therefore sees no change? Answers to these questions should provide the building maintenance group with enough information to understand the operation of the relay.

Although connecting to building automation system is one of the more common uses of the Form C relay, it is not the only use. With the help of an external power supply, a large red lamp can be connected through the normally open circuit. If the unit changes state, the relay will close and turn on the lamp that can then alert the maintenance staff of the problem. In some environments, a horn can be used to announce the fault audibly.

Besides the Form C relay, there are other ways to annunciate the status. An optoisolator with a transistor output is one example. This example requires an external circuit to interface with the transistor to couple to a building automation system or power an external lamp. Some units offer only a normally open or normally closed contact, while other manufacturers offer multiple contacts.

It is essential that the electrical ratings published by the manufacturer be observed. Relays have maximum voltage, current, power and VA ratings that should not be exceeded. For dry contact monitoring, this is not an issue due to the low power and voltage associated with dry contact monitoring, but when connecting external loads, the ratings can easily be exceeded and the load can damage the relay and render the SPD and its monitor inoperable. In the worst case, the relay can weld in one position and be unable to indicate the proper function.

3. Other Monitor Features

A. Surge Counters

A surge counter is a very common feature that was added to high-end monitors over the last decade. Users have often questioned the need for providing an SPD in a power distribution system. A perfect SPD will have no effect on the distribution system except during a transient event. During the surge, the SPD should reduce the impact on the distribution system such that there is no noticeable change. So a perfect SPD would be unnoticed by an end user and therefore raise the question of its need. At the same time, a site with no surge protection and few transients will behave in the same manner.

The solution to this lack of proof was a surge counter that records the number of times a transient event occurs. This is an effective method of showing that the SPD has actually been doing something. However, as the need for surge protection became more widely recognized, providing the proof of their operation became less important.

A surge counter can measure a variety of different physical phenomena. The monitor can measure the voltage and record voltages over a preset level as a surge. It can also measure the current and again anything over a preset current level is considered a surge. Surges are a high-frequency event. A frequency-dependant device can also be used to record a surge. In general, surge counters use a combination of frequency and voltage or current. An event that is high in frequency and voltage or current is very likely to be a surge and will be counted. Other ways of detecting a surge can be used, such as Hall effect sensors recording the magnetic field.

There are different sensitivities (thresholds) of these surge counters and this makes it difficult to compare the actual number of counts to those recorded at other sites (Martzloff and Gruz, 1988 [2]). More important would be a change in the number of counts per period. For example, a site that has had 3 surges per month over the last year and then changes to 23 counts in the last month should be looked at to determine what has changed in the past month.

B. Other Counters

A more recent addition to SPD monitoring has been the inclusion of counters for other power quality events. The most common counters have been capable of detecting sags, swells and outages (IEC 61000-4-30, [3]). Over- and under-voltages and dropouts have also been included in some monitors. They differ from the first three by the duration of the event.

Similar to the simple surge counter, for a power quality monitor, the most important attribute is not the number of events, but a change in the number of events. Assuming that a facility is operating with few problems, a small number of events can be considered as the nominal background noise and changes to this level are significant. Some locations might be experiencing trouble before the installation of these SPDs. In this case, the highest counts recorded can be used to begin diagnosing a distribution system problem. For example, at a site with 5 sags, 3 outages and 117 swells, one should be looking at problems dealing with abnormal high voltage and using equipment that can measure swells more accurately. Perhaps the incoming transformer is tapped too high and as loads are shut off, frequent swells occur.

An SPD with counters capable of recording different types of events should not be mistaken for a power quality analyzer. It can help indicate a power quality problem but it will not solve the problem alone. It is better to view it as a power quality indicator. However, the monitor can show, for instance, that the majority of counts are sags. Further, if the equipment having a problem is susceptible to voltage sags, this can indicate that a sag-mitigating device will improve the situation. The particular benefit of an SPD with multiple counters is that the SPD is needed for surge protection anyway and that it is always connected to the distribution system, constantly recording events. If a problem occurs, it can be reviewed to look for trends in the power to help choose what equipment to use to better measure the system or rule out a possible cause. Its limitation is that the device must be monitored on a systematic basis to get the most use out of its features.

C. Protection or Life Remaining

Ideally, it would be desirable to have an SPD that never fails. Unfortunately this would result in a product that is too expensive and would be too high in voltage protection levels to adequately protect downstream equipment. Alternatively, it would be very desirable to predict exactly when a unit would fail or need replacing. Again, this is not possible.

For small SPDs, the indicator lights are a form of remaining life indication. If the light is green or on, the life is 100%. When the light changes to red or off, the life remaining is 0%. Larger units utilize multiple internal surge components. Each component can be fused or monitored by some method. Then an effective life remaining function can be implemented by counting the number of active internal components and dividing by the nominal number of internal components. This scheme can be used to provide information for a green/yellow/red monitor or to provide a percent-remaining feature.

Another way to implement this feature is to measure one aspect of the surge protection such as a voltage let-through, leakage current, or voltage at a fixed current. This is more difficult to implement in practice as the effects of the distribution system must be removed and this will require the disconnection of the SPD from the system in order to measure the value. The additional maintenance and time means that it will rarely be performed consistently and repeatedly.

There is also a problem with the failure boundaries. Due to the non-linearity of the components in SPDs, there can be little change in these attributes until the event that causes them to fail. This is also

a problem with the component counting method as well as the aspect measuring method. Events that cause a failure can damage a brand new product as easily as a product installed for years. The SPD will show 100%, right up to the event that destroys the unit.

D. Event Recording

An improvement to the counter on some models is the recording the magnitude of an event and time/date stamping of the event. This produces two clear and immediate benefits. First is the ability to go back in time and look at exactly when each event occurred. With a simple counter, the user would be required to record the amount of sags that occurred in each time period other-wise there is no way to tell if an event occurred last week or last year. If a machine was shutdown yesterday, with an event recording, the user can review the log to see what events had occurred just prior to the shutdown. Finding that a swell occurred within one second of the shutdown is much more useful than noting that one swell had occurred sometime in the last month.

The second benefit is the recording of magnitude. An 80 Vac sag on a 120 Vac system would be much more significant than a 108 Vac sag. Recording the event that shutdown a machine would be extremely helpful in fixing the problem. Event recording is much more useful than event counting, but it is still not a substitute for knowledgeable staff that can work to track down power quality issues.

4. Remote Monitoring

SPDs can be installed in electrical rooms and distant locations where there is not necessarily maintenance staff. This creates a need for monitoring from a remote location. There are several methods in use for observing an SPD at a distance. Manufacturers offer a choice of remote monitoring approaches, raising the questions of pros and cons depending on the application needs. The following paragraphs provide a brief description of possible approaches, summarized in Table II.

TABLE II
 SUMMARY OF REMOTE MONITORING FEATURES

Monitoring type	Features	Advantages	Limitations
Direct Connection	RS232, RS485	Full information from the unit	Limited distance, custom software,
Addressable Relay	Form C relay to addressable relay	Connections to building automation software, no distance limitation	Limited information from unit
Network Connectivity	LAN, WAN or control network connection	Full information over any distance and flexible network connection	Requires computer access – increasingly a standard feature in new facilities

A. Direct Connection

By far the most common type of connection, this is usually achieved by connection to the Form C relay. The amount of information is limited and is often only the status of the unit, operating or not. Some models have been able to transmit the information on each phase and send three separate signals to a remote station in the same building. The manufacturer that supplied the SPD can also supply this circuit. Then the optoisolator connection discussed above can be utilized by connecting to a dedicated product intended to supply remote information. However, the amount of information that can be sent is limited and the distance is generally limited to the same building as the SPD.

B. Addressable Relay

A sophisticated building automation system might not be able to directly connect to a Form C relay. To connect to building automation system, an addressable relay can be used. This is a device that can be addressed on a network and can read the status of a Form C relay. This allows the Form C relay on the SPD to be seen anywhere on the network. With the presence of wide area networks, this allows the status of the SPD to be determined anywhere in the world. However, the amount of information transmitted is very limited in this application.

C. Network Connectivity

For the most complete monitoring of the information that the SPD can provide, a network connection is required. Such connections generally fall into three categories: local connections such as RS232/RS485, industrial control systems such as Modbus, and local area networks such as Ethernet. For the most part, the differences in these networks are not important. The differences are in the implementations of the connected hardware and software. The presence of a network connection allows information to be transmitted anywhere it is needed. Modbus would likely be preferred in industrial settings while Ethernet connections would be more common elsewhere.

RS232 and RS485 will require a product-specific computer program to properly transfer the information in the SPD to the computer system that is eventually involved. Modbus and similar protocols require a driver specific to the SPD and the protocol. Finally, an Ethernet enabled SPD can be designed to use TCP/IP and connect directly to a computer by using a Web browser such as Netscape Navigator or Internet Explorer. The information is written into the SPD as a Web page that can be downloaded as needed without need for additional software on the host computer.

The above approaches provide a method of getting the information the SPD has collected into the user's 'hands'. However, only the last approach, using an imbedded Web page, allows for seamless computer upgrades and software upgrades. Since the viewing software is now effectively part of the operating system, the new computer will always have the required software without the need to separately install the SPD software. Computers are changed every two to three years in a business environment and often upgraded even more frequently. This situation creates a problem, as the SPD software might not work on the new computer or with the upgraded software. The other benefit of the Ethernet connected version is the ability to update the firmware by downloading a new image into the SPD if there are ever any issues that need to be resolved in the future.

5. Disconnectors and Monitoring

The importance of providing monitoring that satisfies the mission of the SPD is influenced by the decision of the power system designer (specifier) in view of the present ambiguity of the requirement for internal vs. external disconnector function.

For instance, the IEC definition of SPD disconnector (IEC 61643-12:2002 [4]) mentions a "visible indication of SPD failure" but a note (not mandatory) states, in part, "Each disconnector may be integrated into the SPD or external to it." (Note the use of "may" as meaning permission according to IEC style.). Further on in the referenced IEC standard, the following sentence appears: "... It is also necessary to be sure that the adequate disconnector or back-up protection as suggested by the manufacturer is present and working..." Accordingly, the choice of internal vs. external is left to the discretion of the specifier.

Unlike the consumer-type SPDs market of two-port SPDs where one can find either a parallel-disconnector that merely disconnects failed SPD elements but leaves the load powered and unprotected or a series-disconnector that maintains protection by disconnecting the load (Martzloff, 1998 [1]), most hard-wired SPDs in power distribution systems are one-port (parallel, shunt) devices so that an internal disconnector will indeed remove a failed SPD from the power distribution system, leaving the loads powered but unprotected.

There are some SPD designs intended for surge and temporary overvoltage protection of unattended critical assets that intentionally do not contain a disconnector but instead positively make the failed SPD a very low impedance to cause tripping of the upstream breaker and thus activate an on-site standby emergency generator, avoiding the risk of leaving critical loads exposed to incoming surges with a disconnected one-port SPD. Remote monitoring the SPD status can alert system operators before the fuel storage of the emergency generator is exhausted.

6. Failure of Monitors

Monitoring of some sort is required in most applications to determine the status of the unit and to keep a facility fully protected. Yet it comes with a price to pay, both literally and figuratively. A tradeoff must be made between the needs of the location and the cost of the additional features. Further, adding complexity in the form of a monitor will reduce the reliability of the SPD as a whole. Given most applications, this is an acceptable or even required compromise. A good warrantee becomes more important with more complex monitors as the reliability, based purely on parts count, can decrease with higher-end monitoring. This is also true of products of all types and not just limited to SPD monitoring.

This brings up the topic of how does a monitor react to monitor failures. Some products will default to show a 'normal' signal while others will indicate a fault. The logic within the monitor can be done either by normal indication that is pulled to show a fault or a fault indication that is pushed to show a normal condition. In the first case, a fault in the circuit that is responsible for pulling the signal to show a fault will result in a normal signal even though the monitor has failed. In the second case, the same fault will result in a fault signal, as this is the default condition for the monitor. The difference between these two is only apparent when the monitor itself has failed. The pulled signal will show that everything is normal while the pushed signal will show a fault on the monitor. This function is very difficult to assess in field or to demand in a specification. Complete discussions of this aspect of monitoring are well beyond the scope of this paper, other than to point out this potential issue. This issue will not affect most users, but it can become important in operation-critical applications where a false positive signal could leave a sensitive location unprotected against surges for extended periods of time.

7. Monitor or SPD

The monitor is the SPD itself for most end users. Purchasing of SPDs is often based solely on the monitor rather than on the surge suppression function. Many specifications deal primarily with the monitor and only casually mention the presence of surge suppression. The appearance and features of the SPD monitor can overshadow the primary purpose of the SPD, which is to protect equipment against damage and operational errors caused by surge events. The SPD should be chosen first for its ability to protect the equipment and only then for its monitoring capability and features. SPD monitoring options should be chosen based on the needs of the facility, the needs of the users, and the ability to use the data. Future needs should also be reviewed as adding features later can be difficult or impossible without replacing the complete unit.

8. Examples of monitors

As mentioned above, there is a wide range of monitor functions and hardware offered by manufacturers. Figure 1 is an example of a local visual display with functions limited to a “keep it simple” philosophy. Figure 2 shows for a remote Form C set of contacts, and Figure 3 shows the complexity of hardware (and implied firmware and software) associated with a remote-reading function.

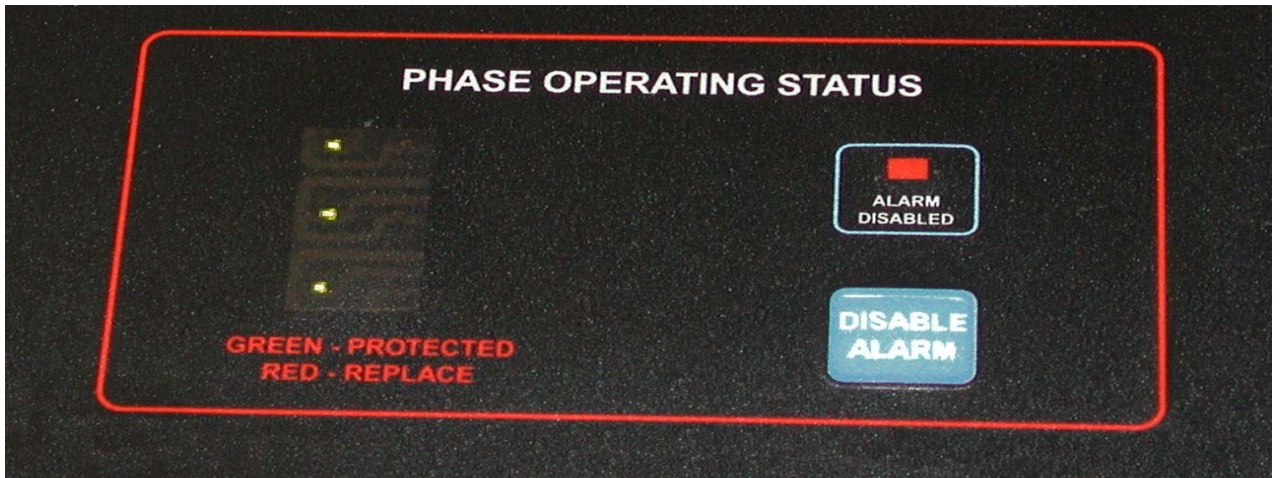


Figure 1 – Typical two color LED display (all green here) and audible alarm disable with visual indication of audible alarm being disabled

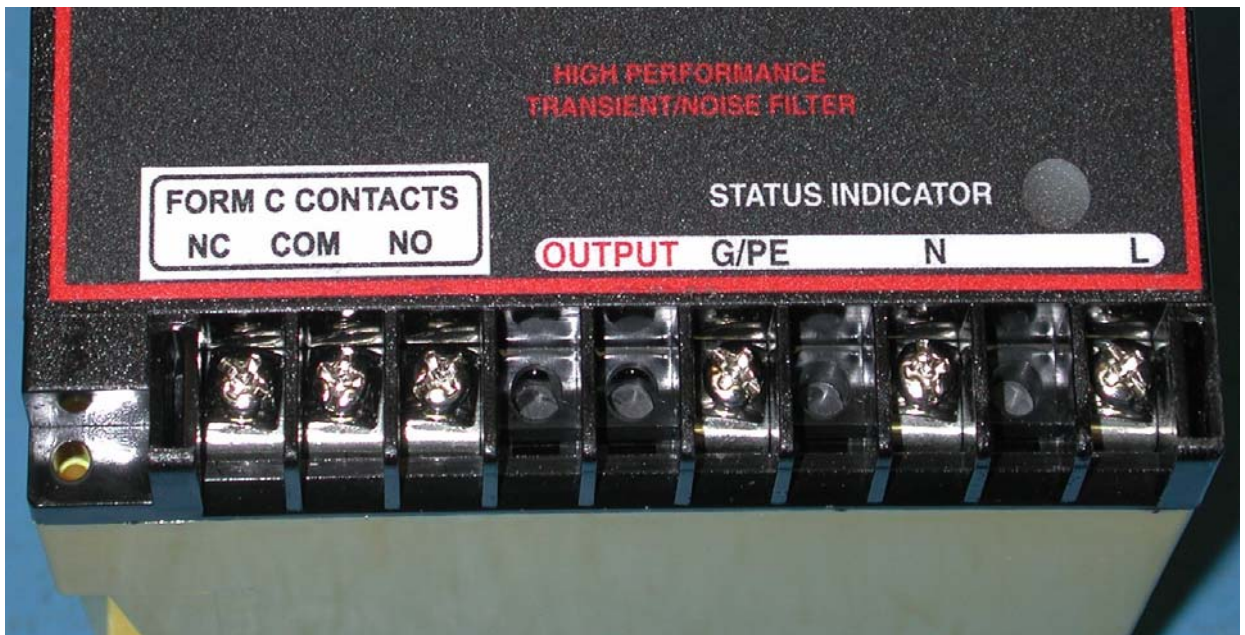


Figure 2 – SPD with Form C relay contacts terminals shown and output

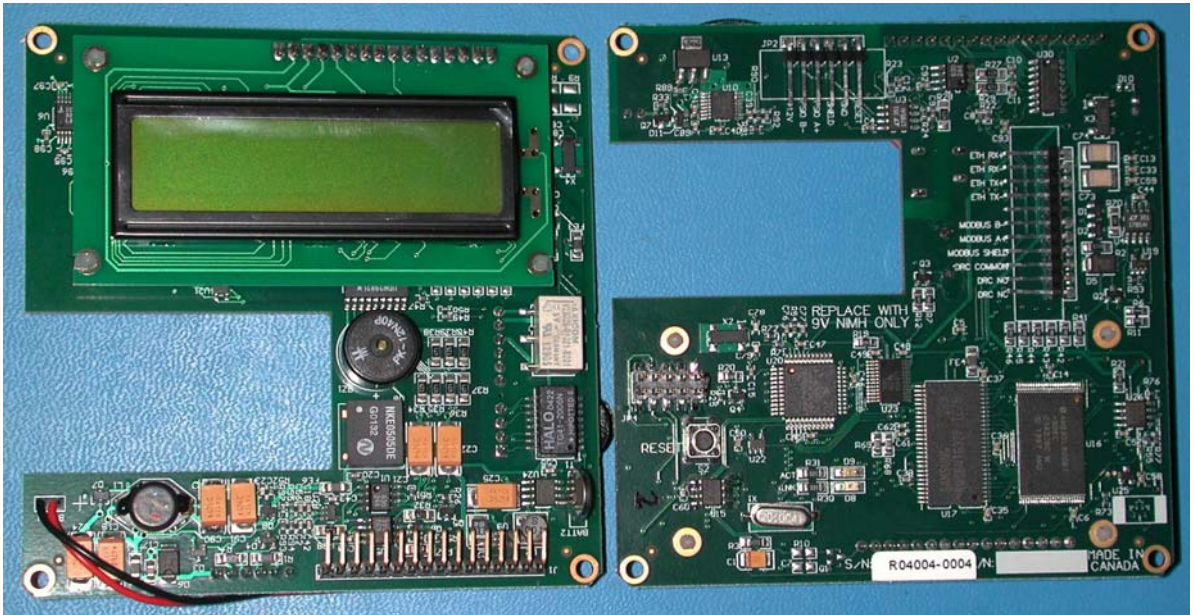


Figure 3 – Example of the complexity of a high end monitor with internal microprocessor, memory, battery backup, Ethernet, Modbus, LCD display, buzzer, Form C

9. Conclusions

Industry is offering a wide choice of monitoring methods and hardware implementations to provide the users and operators of distribution power systems with timely information on the status of installed surge-protective devices.

It is therefore important that at the design stage of a facility, or as later retrofit installation, the designers (specifiers) of the SPD package and monitoring hardware work in concert with the ultimate user of the facility to provide an approach that will satisfy the needs of the mission.

The authors hope that this paper and its summary tables will assist power distribution system designers in this important selection process.

10. References

- [1] Martzloff, F.D., “What Are the Lights on Your Surge Protector Telling You?” Power Quality Assurance, July/August 1998.
- [2] Martzloff, F.D. and Gruz, T.M., “Power Quality Site Surveys: Facts, Fiction, and Fallacies,” IEEE Transactions IAS-24, November/ December 1988.
- [3] IEC 61000-4-30 (2003-02): Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods.
- [4] IEC 61643-12 (2002) Surge protective devices connected to low-voltage power distribution systems – Selection and application principles.