



Powerware

WHITE PAPER

**Proportioning Surge Protection and Fusing
- Fuse selection for surge applications**

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1 PURPOSE

This document provides information about the selection of protective devices for surge protection equipment. Issues covered include device type, current rating and connection methods.

2 INTRODUCTION

The fusing of surge protective devices (SPDs) is a contentious issue and in many cases has been handled badly by SPD specifiers and installers because they don't necessarily understand the special requirements of fusing SPDs. The fact that SPDs can and do fail is a 'given' and whilst we all agree that *some* form of protection is required, there is little agreement on the methods used. Usually, the manufacturer only makes a minimal recommendation - usually a current rating and/or standards reference. At best, the installer follows these instructions AND actually consults a standard. Unfortunately, for ad-hoc installations, little thought is usually given. This means that you end up either with no over-current protector, an appropriate one or an inappropriate one.

- With **no** over-current protector, substantial damage may occur to the installation under cases of overvoltage, extreme surge current or the SPD merely coming to the end of it's useful life. This will almost certainly result in localised loss of power to the installation. This also contravenes most, if not all electrical codes anyway, so it is unlikely in practice. There are many circumstances though, when a separate SPD protector is not required – read on.
- An **appropriate** over-current protector will withstand expected surge events whilst releasing under true fault conditions to limit damage to the SPD only.
- An **inappropriate** solution may protect the installation but cause a power outage. It may allow damage to occur by disconnecting the SPD under expected surge conditions. At worst, it will never be able to protect the SPD because the line's rating is so low that the main fuses will disconnect the supply first. In some circumstances (low-current, highly-exposed installations), this is unavoidable – read on.

What is also important is to understand is why SPDs fail in the first place. The truth is, most SPDs will last for many years. The things that cause sudden failure (in descending order of occurrence) are:

1. External supply faults such as overvoltage (faulty transformer, MV lines across LV lines etc)
2. Local supply faults (broken or ungrounded neutral).
3. Wrongly-selected SPD voltage.
4. A surge in excess of the SPD's rating.
5. A fault within the SPD itself (usually tested at factory).

The first 2 (and main) causes are unavoidable, and will most likely cause further damage to other parts of the installation. Number 3 can be avoided by selecting SPDs with adequate MCOV for the service. Number 4 is rare and generally only occurs when a direct strike occurs to the supply infrastructure. Again, as in 1 & 2, substantial damage may also occur to other parts of the installation. Number 5 is usually dealt with by factory testing and is unlikely to occur in the field. Exposure to heat and moisture can be a cause of early failure in SPDs that haven't been stored or installed correctly.

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Understanding these points, it can be seen that most faults that would damage an SPD would also cause other damage to an installation. For this reason, it is usually accepted that it would always be safer to disconnect the site from the source of the fault than to simply disconnect the SPD and leave the site powered. In some cases (see below), this is not acceptable, but for most it is. Just bear in mind that the client is expecting that their investment will be protected under the majority of reasonable events that may occur.

At the other end of the scale, it is pointless pretending that ANY solution is 100% capable of protecting a site against unforeseen events, regardless of cost. To this end, AS1768 and various EN standards recommend a risk-management principle to be applied, which is admirable IF the system designer knows ALL the numbers. The truth is, most systems are simply over-engineered because the designer simply doesn't have the required information, doesn't understand the problem, or fears the client's litigious nature!

3 THE NOT-SO-SIMPLE PROBLEM

Surely, an issue as simple as over-current protection requires little thought these days? When it comes to protecting SPDs, some different rules apply, compared to other applications.

For example, interrupt rating is very important when selecting any protective device but with SPD protection, the ability to withstand comparable currents (15-100kA) for short periods of time (< 1ms) WITHOUT releasing is more important.

In normal operation, SPDs draw very little power – few exceed 250mA, except devices that incorporate filter components. This means that the installation of an SPD generally does not add to maximum demand, allowing the fuses to be sized close to the supply rating.

A protective device for an SPD must:

- Have an interrupt rating suitable for the application. As SPDs are normally connected immediately after the main isolator, they may have to be able to interrupt 15-100kA under fault conditions.
- Not release under expected surge conditions. This will effectively disconnect the SPD from the system, removing protection from the site. Surge ratings range from 3kA for a sub-board to 100kA+ for a highly exposed or important site.
- When required to release, they must do so quickly. Time delay methods increase the likelihood of damage occurring and of the fault current mitigating to a higher level, such as a transformer fuse.

Then there is the inescapable fact that a system's ability to be protected without loss of supply is directly proportional to its supply rating. What this means is that the higher the service rating, the easier it is to protect. In sizing SPD systems, many designers forget this. It is not a simply a matter of site exposure either. For example, a highly exposed 400A service would be easier to protect than a medium exposure 40A service. It all comes down to how much protection the client requires – so much it hurts, or somewhat less?

It therefore matters a great deal, whether or not the client can accept a power outage in preference to surge protection. If not, one must be careful not to make inappropriate decisions regarding fusing.

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3.1 Fuses vs. Circuit Breakers

One recommendation made by many surge practitioners is to avoid circuit breakers (CBs) altogether. This makes sense for a number of reasons. The main one being that there is no standard for CB performance under surge conditions, except for transmission line equipment. This means that certain 'features' in particular brands may make the device either more or less suitable for surge applications. Other reasons include:

- If the trip coil has appropriate characteristics, it will operate under surge conditions, releasing the CB. This will leave the site unprotected or, if a supply CB, unpowered. It also possesses a finite inductance, adding to the let-through voltage rating of the SPD.
- Most CBs include a 'tortuous path' to prevent damage under high-current release conditions by reducing the chance of destructive flashover inside the device. Unfortunately, to a surge, the tortuous path represents a very short, high impedance part of the surge path. In certain cases, the surge energy simply jumps *across* the path. This may not always damage the CB immediately but will definitely shorten its life and most likely cause it to release after the surge event.
- If a CB has tripped, it is all too easy just to reset it. The result can be disastrous if the fault hasn't been cleared beforehand. If the CB has tripped due to SPD malfunction, the SPD may ignite or the fault may mitigate to the primary disconnect, removing power from the site. In extreme cases, the operator may be injured if the CB is adjacent to the SPD. As fuses require replacement, there is more chance that the fault will be investigated (because you just can't reset it again afterwards, like a CB) or a service call to the SPD supplier will be made, avoiding the consequences of a 'quick fix'.
- Cost-wise, CBs have a limited interrupt capacity. Since primary surge protection must be fitted at the point-of-entry, an interrupt rating of 50kA may be required which is a rather expensive CB, compared to HRC fuses.

For these reasons, it is assumed that SPD system designers and specifiers will use HRC fuses for SPD protection. As Eaton is a manufacturer and supplier of both CBs and fuses, we *could* make more money selling CBs, but they are not the appropriate choice. In ALL cases, gG/gL fuses are specified. Do not use delay or semiconductor types.

3.2 FUSE SURGE RATINGS

Many engineers assume that fuses are not greatly affected by 8/20 μ s surges. As long as the interrupt rating is adequate, they don't think too much about the fuse current rating and simply apportion the fuse rating to be somewhat less than the supply fuses. In many cases, this works well, but in others, it is courting disaster. The reason is that the service fuse rating determines the maximum surge current that may be conducted through the system.

We have tested many different values and styles of HRC fuses, and although different styles of HRC fuse have slightly different characteristics, most seem to follow a similar trend, at least for fuses rated up to 690V. This means that for a given AC current rating, regardless of the actual brand or style of HRC fuse used, there is a maximum surge current that may be carried by the fuse without rupture. See Figure 1 and Table 1 following.

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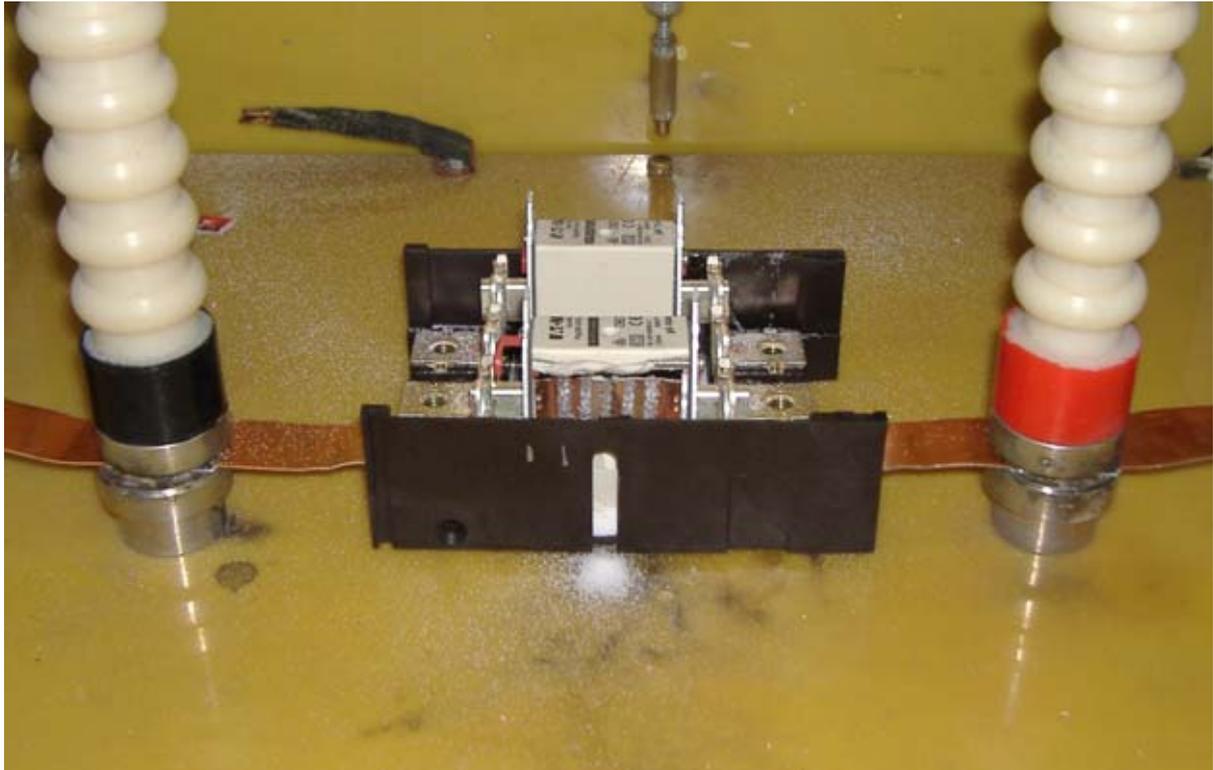


Figure 1.

An 80A NH-style fuse after exposure to a 50kA 8/20us pulse. As can be seen, the fuse literally exploded, covering the inside of the test chamber with filler material. The fuse at rear was not connected at the time. The rating eventually attributed to this fuse was 25kA.

Service fuse rating (A)	Service fuse surge rating (kA)	Maximum TVSS fuse (A) (Service-33%)	Corresponding max. TVSS fuse surge rating (kA)
32	7.5	20	<5
40	15	25	5
50	17.5	32	7.5
63	20	40	15
80	25	50	17.5
100	40	63	20
125	60	80	30
160	65	100	40
200	100	125	60
250	120	160	80
315	130	200	100
400	200	250	120
500	240	315	160
630	260	400	200

Table 1 – Fuse ratings vs. surge ratings

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From table 1 it can be plainly seen that it is not possible to conduct Category C surges through fuses rated below 40A. As Category C protection (15kA 8/20us) is generally considered the minimum for system protection, a 63A service is the lowest-rated service that could be rated as fit for exposure. In this case, one has to question the purpose of specifying highly rated SPDs on small or remote sites, beyond simply ensuring long life.

Note that the surge current is not presented as either I_n or I_{max} . The 15kA Category C level given is assumed to be I_n , requiring an SPD rated at 40kA I_{max} . If the designer wanted a 40kA I_n rating, the SPD fuse would be required to be rated at 100A. This implies a service rating of 150A or more. If the service was rated at only 63A, the supply fuses alone will only withstand 20kA! Even with the SPD protected by a 40A SPD fuse, it is likely that any surge great enough to rupture the 40A SPD fuse ($>15kA$) would also be likely to rupture the 63A supply fuse ($\sim 20kA$) as well.

The 'TVSS fuse rating' is simply the supply fuse less 33%, to allow some overhead. This level should only be used in systems with low average demand. For higher demand levels, a lower percentage of the supply rating should be apportioned to the SPD, although this becomes problematical for supplies below 200A.

TIP! From testing experience, the smaller the fuse package, the better its ability to withstand surges. BS88-style or cylindrical fuses are preferred over NH-style or 'block' fuses. If you have a choice, tag-style BS88 fuses are more reliable and offer a lower voltage drop under surge conditions. They are also less likely to explode or physically rupture, even under extreme surge conditions. The figures in table 1 are true for most types down to 63A. Below 63A, the data only applies to BS88-style fuses but should be representative of most types. For NH types, de-rate the surge rating by a further 25% below 63A.

3.3 What now?

It really comes down to how important it is for the site to remain active following a major surge event and the likelihood of that event occurring. In some cases, supply disconnection is not acceptable:

- The income generated by the system may far outweigh the equipment repair costs and running the system unprotected during peak times may be preferable to shutting it down for repair.
- Labour costs can be prohibitive. Sending a company technician to a remote site to replace small pieces of equipment in a timely manner is cheaper than having to send a team of qualified people to the same site in an emergency.
- The site may process materials for manufacture and the loss of power may cause expensive wastage.
- Public buildings, hospitals and hotels also require special treatment as laws generally require evacuation following loss of power.

Sites that will tolerate loss of power over protection are generally those that have large amounts of sensitive and expensive equipment and have been designed to withstand extended periods of power loss. Examples are sites with combined UPS and generator backup, such as call centres, hospital operating theatres, telephone exchanges and large network server systems.

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Sites that are non-power loss tolerant must be rated in excess of 63A, just to meet a Cat C rating (80A for a small margin of safety). To meet a 15kA In level ($I_{max} = 40kA$), the site must be rated at 150A or more. The following table lists some points applicable to power loss tolerant and non-power loss tolerant sites:

Non-power loss tolerant	Power loss tolerant
No backup or backup time less than repair time.	Extended backup capability such as UPS with extended runtime or generator backup.
Raw materials subject to wastage	Processes not left running or allowed to stop.
Costly re-start procedure	Simple or automatic re-start procedure.
Power loss would involve evacuation of personnel.	Non-populated areas or technical operators trained in correct procedures.
Business income is directly related to provision of power (movie theatre etc)	Business income not directly related to provision of power (shop, outdoor etc)
Power loss may involve loss of property or life (multi-storey building, outdoor lighting system, parking station boom gates)	Site is environmentally benign and poses no threat under power loss conditions (domestic dwelling).
Medium to high power sites (>80A)	Low power sites (<80A)

A site doesn't have to possess all of these qualities – it may just be one, depending upon the client's needs. If the client is convinced that the site is non-power loss tolerant, remind them that power outages do occur and ensure that the rest of the site is power loss tolerant regardless of faults related to a faulty SPD. The last thing one needs is an irate client who blames his power outage on your recommended equipment!

4 SOLUTIONS

Once this decision is made, the rest of process is simple. The choice to the designer is whether to protect the SPD at or below the service rating.

4.1 Non-power loss tolerant sites

For non-power loss tolerant sites, assume that surge currents are below the level that will rupture the supply fuses (see Table 1). Then, determine the appropriately-rated SPD fuse and ensure that the SPD specified is rated for an In level at least equal to the expected surge current.:

- The maximum SPD fuse rating will always be at least 33% below the supply fuse rating and may be much lower in value for higher-powered installations.
- Low power sites and sites with high average load are harder to protect than those with intermittent loads. This is because the supply fuses have less 'headroom' under normal operation. In some cases, it may be necessary to connect the SPD fuses directly to the supply, instead of the secondary side of the supply fuses. This preserves the service fuses because fuses rated at 40 or 50A cannot conduct more than 10-15kA without rupture. By connecting the SPD fuses directly to the supply, the service and SPD fuses can be the same value. For example, a 100A service using series fusing could only support a surge rating of 20kA (63A SPD fuse) whereas connecting the SPD fuses directly to the supply gives a withstand rating of 40kA. This corresponds to a device rated at $I_n=40kA$, $I_{max}=100kA$, a relatively rugged SPD specification.
- The greater the difference between the supply fuse rating and the SPD fuse rating, the better coordination and the less chance that SPD failure will cause power loss. With higher-powered sites (surge rating of supply fuse is 2-3 times the intended SPD rating

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or more), little consideration is required as the SPD and supply fuses will coordinate correctly and SPD-induced power loss is unlikely. For example, a 1200A service, protected to a 100kA level (200A SPD fuse)

Referring to Table 1, select the SPD fuse appropriate to the service and no less than what will provide reliable operation at the desired surge current.

4.2 Power loss tolerant sites

For power loss tolerant sites, it is important to maximise surge current tolerance, to provide the maximum level of protection. Such sites usually have higher surge current withstand requirements and therefore, more performance is required from the fuse.

- In cases where the fuse required for SPD protection is higher in value than the supply fuses, the SPD fuses may be omitted altogether, utilizing the supply fuses for both service protection and SPD protection. ONLY DO THIS IF THE SUPPLY FUSES ARE gG/gL HRC TYPES.
- If the separate SPD fuse is omitted, the SPD may be wired in 'Kelvin' configuration, which prevents losses in cabling from increasing the let-through voltage under surge conditions. In 'Kelvin' mode, cables to the SPD may be relatively long without detriment to the protection level.
- With low power sites, it may be necessary to connect the SPD fuses directly to the supply, instead of the secondary side of the supply fuses. This preserves the service fuses because fuses rated at 32 or 40A cannot conduct more than 10-15kA without rupture. It also means that the line fuses have more chance of surviving a surge as they are not conducting surge currents. This means that the service and SPD fuses can be the same value, as the power consumption of an SPD in normal operation is negligible.

Referring to Table 1, select the fuse according to the supply current rating or, for medium powered systems, use Table 2 below:

SPD per-mode rating	Minimum SPD fuse size (A)
20kA	63
40kA	100
80kA	200
120kA	250
200kA	400

Table 2 – Fuse ratings vs. surge ratings

5 CONCLUSION

The information presented here should prove useful to engineering consultants, estimators and system designers. Whilst possibly appearing overly simplified, there is no point providing an intense level of descriptive detail when it is not required.

If installations are designed in accordance with the information presented here, a cost-effective, safe and reliable TVSS system should result.

Jon Point

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