# Surge protection guidelines for VacClad-W metal-clad switchgear


## Abstract

Eaton's VacClad-W metal-clad switchgear is applied over a broad range of circuits, and is one of the many types of equipment in the total system. The distribution system can be subject to voltage transients caused by lighting or switching surges.


## Introduction

Recognizing that distribution system can be subject to voltage transients caused by lighting or switching, the industry has developed standards to provide guidelines for surge protection of electrical equipment. Those guidelines should be used in design and protection of electrical distribution systems independent of the circuit breaker interrupting medium. The industry standards are:

ANSI C62
*Guides and Standards for Surge Protection*

IEEE 242—Buff Book
*IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*

IEEE 141—Red Book
*Recommended Practice for Electric Power Distribution for Industrial Plants*

IEEE C37.20.2
*Standards for Metal-Clad Switchgear*

IEEE C57.142
*Guide to Describe the Occurrence and Mitigation of Switching Transients Induced by Transformers, Switching Device, and System Interaction*

Eaton's medium-voltage metal-clad and metal-enclosed switchgear that uses vacuum circuit breakers is applied over a broad range of circuits. It is one of the many types of equipment in the total distribution system.

Whenever a switching device is opened or closed, certain interactions of the power system elements with the switching device can cause high frequency voltage transients in the system. Due to the wide range of applications and variety of ratings used for different elements in the power systems, a given circuit may or may not require surge protection.

Therefore, Eaton does not include surge protection as standard with its metal-clad or metal-enclosed medium-voltage switchgear. The user exercises the options as to the type and extent of the surge protection necessary depending on the individual circuit characteristics and cost considerations.

## Surge protection

The following are Eaton's recommendations for surge protection of medium-voltage equipment. **Please note these recommendations are valid when using Eaton's vacuum breakers only. In all cases described below, Eaton highly recommends performing a switching transient study to determine the transient response, and properly select and rate the transient mitigation equipment.**

### Surge protection recommendations

**Note:** The complete surge protection for power system equipment consists of a surge arrester in parallel with an RC snubber. Eaton can custom design and supply an RC snubber to the specific characteristics of the system of interest, and highly recommends this approach. The abbreviation RC snubber used in the text below refers to Eaton's custom device. Alternatively, standard, one-size-fits-all devices are available from other manufacturers. The abbreviation Protec Z used in the text below refers to Surge Protection Device manufactured by NTSA. An equivalent device offered by other manufacturers, such as Type EHZ by ABB, can also be used.

1. For circuits exposed to lightning, surge arresters should be applied in line with Industry standard practices.
2. Transformers
    a. Close-coupled to medium-voltage primary breaker: Provide transients surge protection, such as surge arrester in parallel with RC snubber, or Protec Z. The surge protection device selected should be located and connected at the transformer primary terminals or it can be located inside the switchgear and connected on the transformer side of the primary breaker.

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b. Cable-connected to medium-voltage primary breaker: Provide transient surge protection, such as surge arrester in parallel with RC snubber, or Protec Z for transformers connected by cables with lengths up to 200 feet, depending on the size of cable and number of conductors per phase. The surge protection device should be located and connected at the transformer terminals. In general, no surge protection is needed for transformers with basic impulse level (BIL) withstand ratings equal to that of the switchgear and connected to the switchgear by cables at least 200 feet or longer. For transformers with lower BIL than the switchgear, provide surge arrester in parallel with RC snubber or Protec Z.

RC snubber and/or Protec Z damp internal transformer resonance:

The natural frequency of transformer windings can under some circumstances be excited to resonate by the switching frequency. Transformer windings in resonance can produce elevated internal voltages that produce insulation damage or failure. An RC snubber or a Protec Z applied at the transformer terminals as indicated above can damp internal winding resonance and prevent the production of damaging elevated internal voltages. This is typically required where rectifiers, UPS or similar electronic equipment is on the transformer secondary.

3. Arc-Furnace Transformers—Provide surge arrester in parallel with custom RC snubber at the transformer terminals. Switching of Arc-Furnace Transformers produce transients with significant magnitude and energy requiring RC snubbers with custom ratings.
4. Motors—Provide surge arrester in parallel with RC snubber, or Protec Z at the motor terminals. For those motors using VFDs, surge protection should be applied and precede the VFD devices as well. For high reliability motor applications, install station class surge arresters in parallel with RC snubbers.
5. Generators—Provide station class surge arrester in parallel with RC snubber, or Protec Z at the generator terminals.
6. Capacitor Switching—Provide surge arresters at the line-side of the capacitor bank. Make sure that the capacitor's BIL withstand rating is equal to that of the switchgear. In the case of harmonic filter banks, install additional surge arresters on the line reactors. Further, for multi-step capacitor banks or capacitor banks in close proximity,back-to-back switching transient effects can be minimized with the application of inrush limiting reactors.
7. Shunt Reactor Switching—
   a. Provide surge arrester in parallel with RC snubber, or Protec Z at the reactor terminals.
   b. Series Current Limiting Reactor Switching—Provide surge arrester in parallel with RC snubber, or Protec Z at both reactor terminals. Alternatively, the RC snubber can be installed in parallel with the series current limiting reactor.
8. Motor Starting Reactors or Reduced Voltage Auto-Transformers (RVAT)—Provide surge arrester in parallel with RC snubber, or Protec Z at the reactor tap in use and/or RVAT terminals and/or motor terminals.
9. Switching Underground Cables—Surge protection not needed.
10. Voltage Transformers (VTs) and Control Power Transformers (CPTs)—In certain power system configurations, VTs and CPTs installed inside the switchgear are susceptible to:
    a. Voltage transients induced by opening and closing of upstream switching device.
    b. Low frequency (less than power frequency of 50/60 Hz) ferro-resonance when de-energizing a long run of power cables connected to those transformers.
    c. Classical ferro-resonance due to single-phase switching or energization of certain VT configurations.
    d. Internal resonance where the natural frequency of the primary windings can under some circumstances be excited to resonate by the switching frequency. Eaton does not provide surge protection for VTs and CPTs as standard. Eaton recommends performing a power system switching transient study to determine need for surge protection (surge arrester, RC snubber, damping resistor, other solution) for given power system components.

### Switching transients study

Eaton's Power System Engineering group can perform the switching transient study using the Electromagnetic Transients Program (EMTP) to determine the transient response, and properly select and rate the transient mitigation equipment.

The switching transient study can simulate in EMTP the various transient concerns described above including primary switching of transformers, arc-furnace transformer switching, motor and generator switching, generator breaker transient recovery voltage (TRV) evaluation, capacitor isolated switching and back-to-back switching, switching of shunt reactors and series current limiting reactors as well as transients associated with RVAT contactor switching. VTs and CPTs require a special focus of transient studies involving EMTP simulation of switching, ferro-resonance and internal resonance.

Through the EMTP study, the surge capacitor and resistor components of the RC snubber are precisely selected for each application, to match the electrical system surge impedance and to provide superior transient suppression. The EMTP study also provides the recommendation for the best location of the snubber assembly to protect the transformer, generator or motor. When appropriate for all systems under study, but especially in the case of VTs and CPTs, the EMTP study will recommend additional forms of surge protection, mitigation techniques and/or alternative equipment ratings and configurations.

## Types of surge protection devices

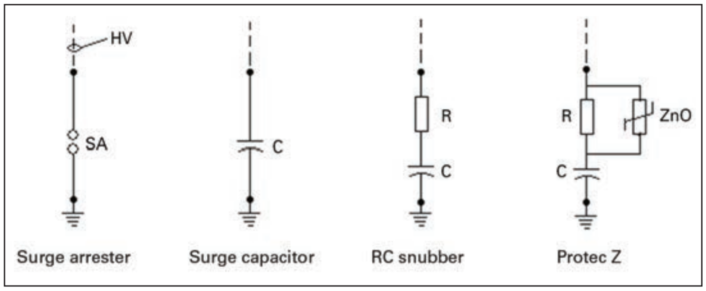


**Figure 1. Surge protection devices**

Generally surge protective devices should be located as closely as possible to the circuit component(s) that require protection from the transients, and connected directly to the terminals of the component with conductors that are as short and flat as possible to minimize the inductance. It is also important that surge protection devices should be properly grounded for effectively shunting high frequency transients to ground.

### Surge arresters

The modern metal-oxide surge arresters are recommended because this latest advance in arrester design ensures better performance and high reliability of surge protection schemes. Manufacturer's technical data must be consulted for correct application of a given type of surge arrester. Notice that published arrester MCOV (maximum continuous operating voltage) ratings are based on 40 °C or 45 °C ambient temperature. In general, the following guidelines are recommended for arrester selections, when installed inside Eaton's medium-voltage switchgear:

Solidly grounded systems—Arrester MCOV rating should be equal to 1.05 x $V_{LL}$/(1.732 x T), where $V_{LL}$ is nominal line-to-line service voltage, 1.05 factor allows for +5% voltage variation above the nominal voltage according to ANSI C84.1, and T is derating factor to allow for operation at 55 °C switchgear ambient, which should be obtained from the arrester manufacturer for the type of arrester under consideration. Typical values of T are: 0.946 to 1.0.

Low resistant grounded systems (systems grounded through resistor rated for 10 seconds)—Arrester 10-second MCOV capability at 60 °C, which is obtained from manufacturer's data, should be equal to 1.05 x $V_{LL}$, where $V_{LL}$ is nominal line-to-line service voltage, and 1.05 factor allows for +5% voltage variation above the nominal voltage.

Ungrounded or systems grounded through impedance other than 10-second resistor—Arrester MCOV rating should be equal to 1.05 x $V_{LL}$/T, where $V_{LL}$ and T are as defined above.

Refer to **Table 1** for recommended ratings for metal-oxide surge arresters that are sized in accordance with the above guidelines, when located in Eaton's switchgear.

### Surge capacitors

Metal-oxide surge arresters limit the magnitude of prospective surge overvoltage, but are ineffective in controlling its rate of rise. Specially designed surge capacitors with low internal inductance are used to limit the rate of rise of this surge overvoltage to protect turn-to-turn insulation. Recommended values for surge capacitors are: 0.5 µf on 5 and 7.5 kV, 0.25 µf on 15 kV, and 0.13 µf on systems operating at 24 kV and higher.

### RC snubber

An RC snubber device consists of a non-inductive resistor R sized to match surge impedance of the load cables, typically 20 to 30 ohms, and connected in series with a surge capacitor C. The surge capacitor is typically sized to be 0.15 to 0.25 microfarad. Under normal operating conditions, impedance of the capacitor is very high, effectively "isolating" the resistor R from the system at normal power frequencies, and minimizing heat dissipation during normal operation. Under high frequency transient conditions, the capacitor offers very low impedance, thus effectively "inserting" the resistor R in the power system as cable terminating resistor, thus minimizing reflection of the steep wave-fronts of the voltage transients and prevents voltage doubling of the traveling wave. The RC snubber provides protection against high frequency transients by absorbing and damping and the transients. Please note RC snubber is most effective in mitigating fast-rising transient voltages, and in attenuating reflections and resonances before they have a chance to build up, but does not limit the peak magnitude of the transient. Therefore, the RC snubber alone may not provide adequate protection. To limit peak magnitude of the transient, application of surge arrester should also be considered.

### Protec Z

A Protec Z device consists of parallel combination of resistor (R) and zinc oxide voltage suppressor (ZnO), connected in series with a surge capacitor. The resistor R is sized to match surge impedance of the load cables, typically 20 to 30 ohms. The ZnO is a gapless metal-oxide non-linear arrester, set to trigger at 1 to 2 PU voltage, where 1 PU = 1.412*(VL-L/1.732). The surge capacitor is typically sized to be 0.15 to 0.25 microfarad. As with RC snubber, under normal operating conditions, impedance of the capacitor is very high, effectively "isolating" the resistor R and ZnO from the system at normal power frequencies, and minimizing heat dissipation during normal operation. Under high frequency transient conditions, the capacitor offers very low impedance, thus effectively "inserting" the resistor R and ZnO in the power system as cable terminating network, thus minimizing reflection of the steep wave-fronts of the voltage transients and prevents voltage doubling of the traveling wave. The ZnO element limits the peak voltage magnitudes. The combined effects of R, ZnO, and capacitor of the Protec Z device provides optimum protection against high frequency transients by absorbing, damping, and by limiting the peak amplitude of the voltage wave-fronts. Please note that the Protec Z is not a lightning protection device. If lightning can occur or be induced in the electrical system, a properly rated and applied surge arrester must precede the Protec Z.

## Surge protection summary

**Minimum protection**: Surge arrester for protection from high overvoltage peaks, or surge capacitor for protection from fast-rising transient. Please note that the surge arresters or surge capacitor alone may not provide adequate surge protection from escalating voltages caused by circuit resonance. Note that when applying surge capacitors on both sides of a circuit breaker, surge capacitor on one side of the breaker must be RC snubber or Protec Z, to mitigate possible virtual current chopping.

**Good protection**: Surge arrester in parallel with surge capacitor for protection from high overvoltage peaks and fast rising transient. This option may not provide adequate surge protection from escalating voltages caused by circuit resonance. When applying surge capacitors on both sides of a circuit breaker, surge capacitor on one side of the breaker must be RC snubber or Protec Z, to mitigate possible virtual current chopping.

**Better protection**: RC snubber or Protec Z in parallel with surge arrester for protection from high frequency transients and voltage peaks.

**Best protection**: For optimum or best protection, a switching transient analysis is recommended, and surge protection needs as determined based on such study should be implemented.

**Table 1. Surge arrester selections—recommended ratings**

| Service voltage line-to-line kV | Distribution class arresters—kV ratings | | | | | | Station class arresters—kV ratings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Solidly grounded system | | Low resistance grounded system | | High resistance or ungrounded system | | Solidly grounded system | | Low resistance grounded system | | High resistance or ungrounded system | |
| | Nominal | MCOV | Nominal | MCOV | Nominal | MCOV | Nominal | MCOV | Nominal | MCOV | Nominal | MCOV |
| 2.30 | 3 | 2.55 | 3 | 2.55 | 3 | 2.55 | 3 | 2.55 | 3 | 2.55 | 3 | 2.55 |
| 2.40 | 3 | 2.55 | 3 | 2.55 | 6 | 5.10 | 3 | 2.55 | 3 | 2.55 | 6 | 5.10 |
| 3.30 | 3 | 2.55 | 3 | 2.55 | 6 | 5.10 | 3 | 2.55 | 3 | 2.55 | 6 | 5.10 |
| 4.00 | 3 | 2.55 | 6 | 5.10 | 6 | 5.10 | 3 | 2.55 | 6 | 5.10 | 6 | 5.10 |
| 4.16 | 6 | 5.10 | 6 | 5.10 | 6 | 5.10 | 6 | 5.10 | 6 | 5.10 | 6 | 5.10 |
| 4.76 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 |
| 4.80 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 |
| 6.60 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 |
| 6.90 | 6 | 5.10 | 6 | 5.10 | 9 | 7.65 | 6 | 5.10 | 9 | 7.65 | 9 | 7.65 |
| 7.20 | 6 | 5.10 | 6 | 5.10 | 10 | 8.40 | 6 | 5.10 | 9 | 7.65 | 10 | 8.40 |
| 8.32 | 9 | 7.65 | 9 | 7.65 | 12 | 10.20 | 9 | 7.65 | 9 | 7.65 | 12 | 10.20 |
| 8.40 | 9 | 7.65 | 9 | 7.65 | 12 | 10.20 | 9 | 7.65 | 9 | 7.65 | 12 | 10.20 |
| 11.00 | 9 | 7.65 | 9 | 7.65 | 15 | 12.70 | 9 | 7.65 | 10 | 8.40 | 15 | 12.70 |
| 11.50 | 9 | 7.65 | 10 | 8.40 | 18 | 15.30 | 9 | 7.65 | 12 | 10.20 | 18 | 15.30 |
| 12.00 | 10 | 8.40 | 10 | 8.40 | 18 | 15.30 | 10 | 8.40 | 12 | 10.20 | 18 | 15.30 |
| 12.47 | 10 | 8.40 | 12 | 10.20 | 18 | 15.30 | 10 | 8.40 | 12 | 10.20 | 18 | 15.30 |
| 13.20 | 12 | 10.20 | 12 | 10.20 | 18 | 15.30 | 12 | 10.20 | 12 | 10.20 | 18 | 15.30 |
| 13.80 | 12 | 10.20 | 12 | 10.20 | 18 | 15.30 | 12 | 10.20 | 15 | 12.70 | 18 | 15.30 |
| 14.40 | 12 | 10.20 | 12 | 10.20 | 21 | 17.00 | 12 | 10.20 | 15 | 12.70 | 21 | 17.00 |
| 18.00 | 15 | 12.70 | 15 | 12.70 | 27 | 22.00 | 15 | 12.70 | 18 | 15.30 | 27 | 22.00 |
| 20.78 | 18 | 15.30 | 18 | 15.30 | 30 | 24.40 | 18 | 15.30 | 21 | 17.00 | 30 | 24.40 |
| 22.00 | 18 | 15.30 | 18 | 15.30 | 30 | 24.40 | 18 | 15.30 | 21 | 17.00 | 30 | 24.40 |
| 22.86 | 18 | 15.30 | 21 | 17.00 | — | — | 18 | 15.30 | 24 | 19.50 | 36 | 29.00 |
| 23.00 | 18 | 15.30 | 21 | 17.00 | — | — | 18 | 15.30 | 24 | 19.50 | 36 | 29.00 |
| 24.94 | 21 | 17.00 | 24 | 19.50 | — | — | 21 | 17.00 | 24 | 19.50 | 36 | 29.00 |
| 25.80 | 21 | 17.00 | 24 | 19.50 | — | — | 21 | 17.00 | 24 | 19.50 | 36 | 29.00 |
| 26.40 | 21 | 17.00 | 24 | 19.50 | — | — | 21 | 17.00 | 27 | 22.00 | 39 | 31.50 |
| 33.00 | 27 | 22.00 | 30 | 24.40 | — | — | 27 | 22.00 | 36 | 29.00 | 45 | 36.50 |
| 34.50 | 30 | 24.40 | 30 | 24.40 | — | — | 30 | 24.40 | 36 | 29.00 | 48 | 39.00 |
| 38.00 | 30 | 24.40 | — | — | — | — | 30 | 24.40 | 36 | 29.00 | — | — |

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