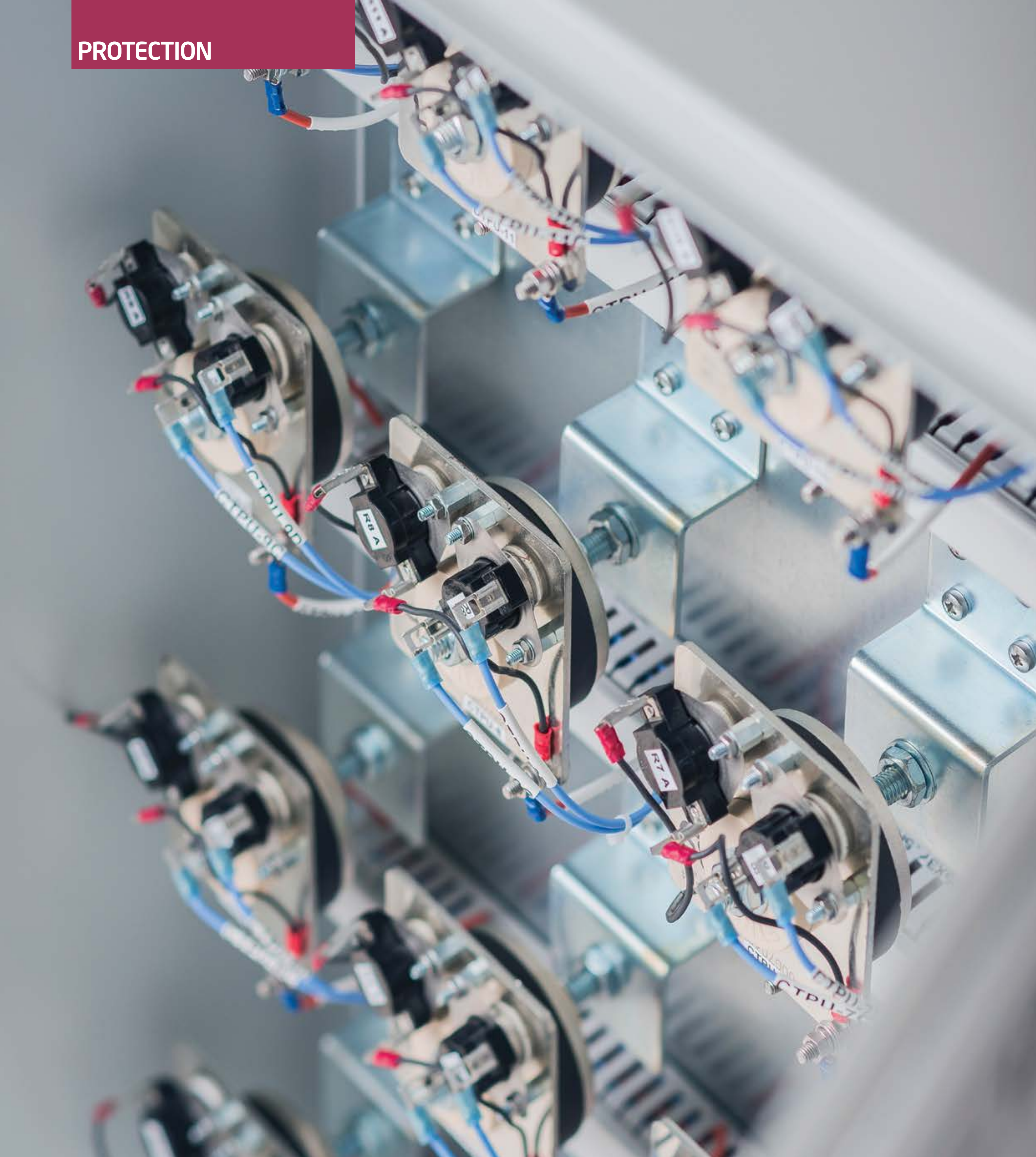

ABSTRACT

Current transformers are used to monitor large currents within power grids and power stations, producing a current in the device's secondary winding that is proportional to the current flowing in its primary winding. Varistors are used to protect current transformers by preventing an open circuit condition if the secondary is disconnected, which can cause high voltages and arcing. Silicon carbide varistors are a superior solution for protecting current transformers due to their ability to limit voltages even in sustained high ambient temperature conditions. IEEE-compliant silicone carbide varistors form the basis of robust and reliable current transformer protection units capable of operating for decades in situ.

KEYWORDS:

Varistor, silicon carbide varistor, current transformer, current transformer protection unit

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Varistors play a critical role in ensuring the safe and reliable operation of electrical circuits by acting as control or compensation elements to ensure optimal operating conditions or to prevent excessive voltages from being reached

Silicon carbide varistors: the failsafe choice for current transformer protection

1. Introduction

1.1 Varistors and how they work

A varistor (varying resistor) is a semiconducting device with a voltage-dependent resistance. Sometimes known as a voltage dependant resistor (VDR) or a metal oxide varistor (MOV, which refers to a specific type of varistor), varistors play a critical role in ensuring the safe and reliable operation of electrical circuits by acting as control or compensation elements to ensure optimal operating conditions or to prevent excessive voltages from being reached.

1.2 Current transformers

Current transformers are installed worldwide in high voltage power grids and in power generation plants. A current transformer produces a stepped down alternating current in its secondary winding, proportional to the current in its primary winding. To do this, the current transformer has a large number of turns in its secondary winding, typically 400 to 800 turns but often greater for high current systems, and usually just one turn in its primary. This allows for safe monitoring and measurement of the primary current.

2. Protecting current transformers using varistors

Varistors respond to the increasing voltages that occur during open-circuit conditions in a current transformer, preventing

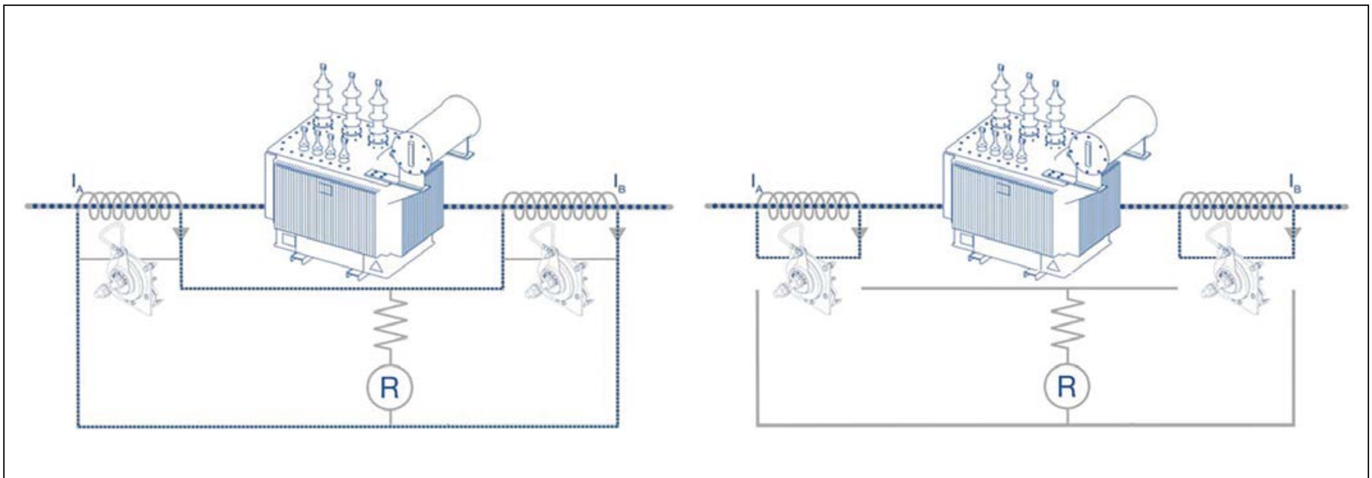


Figure 1. Normal operation with current transformer protection (left), open circuit condition with current transformer protection (right)

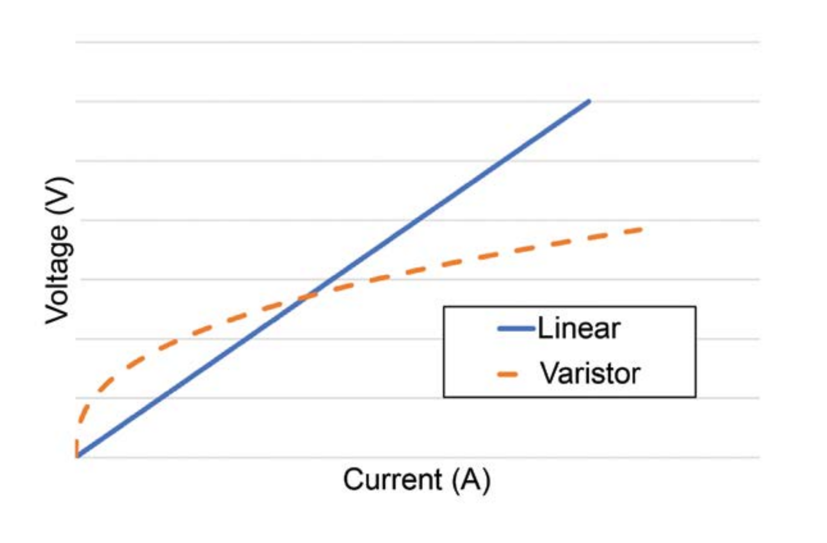


Figure 2. Comparison of a varistor and a linear resistor VI response

Silicon carbide is an advanced material with intrinsic semiconducting properties, capable of operating at high voltages and energies

potentially dangerous overvoltage events, should the secondary be disconnected from the burden while the primary is still energised. A typical configuration for a High Impedance Differential Relay scheme is shown in Fig. 1.

A current transformer's secondary winding current is determined by its ratio. The secondary windings are designed to be permanently connected into a very low impedance, known as a 'burden', typically ranging from 0.1–4 Ω, for CTs rated at 1.5–60 VA. Should the secondary winding become disconnected, for example, if there is damage to the wiring while the primary winding is energised, the current transformer becomes a step-up voltage transformer.

Due to the large ratio, high voltages start to be produced immediately, which can exceed the current transformer's rated voltage insulation. This can short out the windings, which has the potential to damage the current transformer, pose a shock hazard to maintenance engineers and even lead to a fire within installations, which could be especially destructive in systems where the current transformer is connected to a large transformer filled with mineral oil.

2.1 Operational hazards

- High voltages are produced by unburdened CTs with energised primaries, which can damage the current transformer's winding insulation, potentially rendering it inoperable.
- High voltage discharges can also cause fires in the insulation, leading to extensive damage, especially in the case of oil-filled transformers.
- Unexpected high voltages also pose a safety hazard and electrocution risk for personnel.

3. Silicone carbide varistors

Silicon carbide (SiC) is a semiconductor that finds use in power electronics and can operate at high voltages and energies. These devices are comprised of a silicon carbide-composite electroceramic material, and function like a network of back-to-back diodes. Their voltage-current relationship is shown in Fig. 2, compared with a typical resistor.

At low voltages, varistors have a high effective resistance, which drops as the voltage increases. At operational voltages, a varistor has a very low resistance which can limit the voltage and dissipate the energy by allowing high current flow.

4. Current transformer protection units

Current transformer protection is designed to be permanently connected across the terminals of the current transformer and operate without the need for user intervention.

Under normal conditions, the varistor remains a passive (non-conducting) load when it is connected directly across a current transformer's secondary windings, drawing a small leakage current, typically less than 1 mA for most schemes.

This leakage current must be considered to prevent inaccuracies in the measurement of the current transformer.

During an open circuit condition, the varistor is exposed to the increasing voltage and intrinsically becomes an active load at the pre-determined clamping limit, limiting the voltage across the terminals and preventing damage. Fig. 3 shows the typical setup for current transformer protection, where:

I_{Pri} = Primary current
I_{Sec} = Secondary current
V_{Sec} = Voltage across the CT
N_{turns} = Number of turns of the CT windings (primary turns equal to 1 in this example)
Z = Impedance of the burden, or if disconnected, the voltage-dependent impedance of the CTPU

During an open circuit condition, the SiC varistor is exposed to an applied current and performs as an active load, limiting the voltage across the terminals and preventing damage

When an open circuit exceeds 3500 V peak, the secondary winding terminals should be provided with voltage limiting devices (varistors or spark gaps)

Fig. 4 shows a Metrosil Current Transformer Protection Unit (CTPU). The thermostatic switch manages the thermal cycling within the unit when the current transformer is in an open circuit condition. Thermal cycling prevents the device from overheating and allows for the time it may take to send an engineer to rectify the issue. A second thermostatic switch is also mounted on the heat sink plate for remote monitoring. This switch is in an open circuit until a fault occurs, and then will periodically close and open as the CTPU thermally cycles. This second switch can be connected to a substation's Supervisory Control and Data Acquisition (SCADA) system, and the periodic signal will alert engineers that the device is under load, and that there is an open circuit condition on that particular CT.

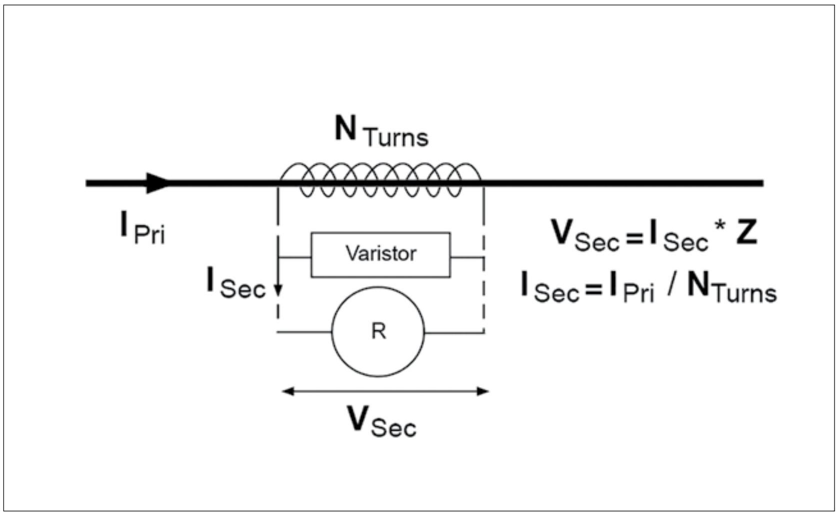


Figure 3. How current transformer protection is typically connected

5. Standards

Current transformer protection should adhere to IEEE C57.13 – 2008 (Section 6.7.1), which states:

"Current transformers should never be operated with the secondary circuit open because hazardous crest voltages may result… when the open circuit exceeds 3500 V peak, the secondary winding terminals should be provided with voltage limiting devices (varistors or spark gaps). The voltage limiting device should be able to withstand an open-circuit situation for a period of 1 min without damage to the secondary circuit. The voltage limiting device may need to be replaced after such an abnormal condition."

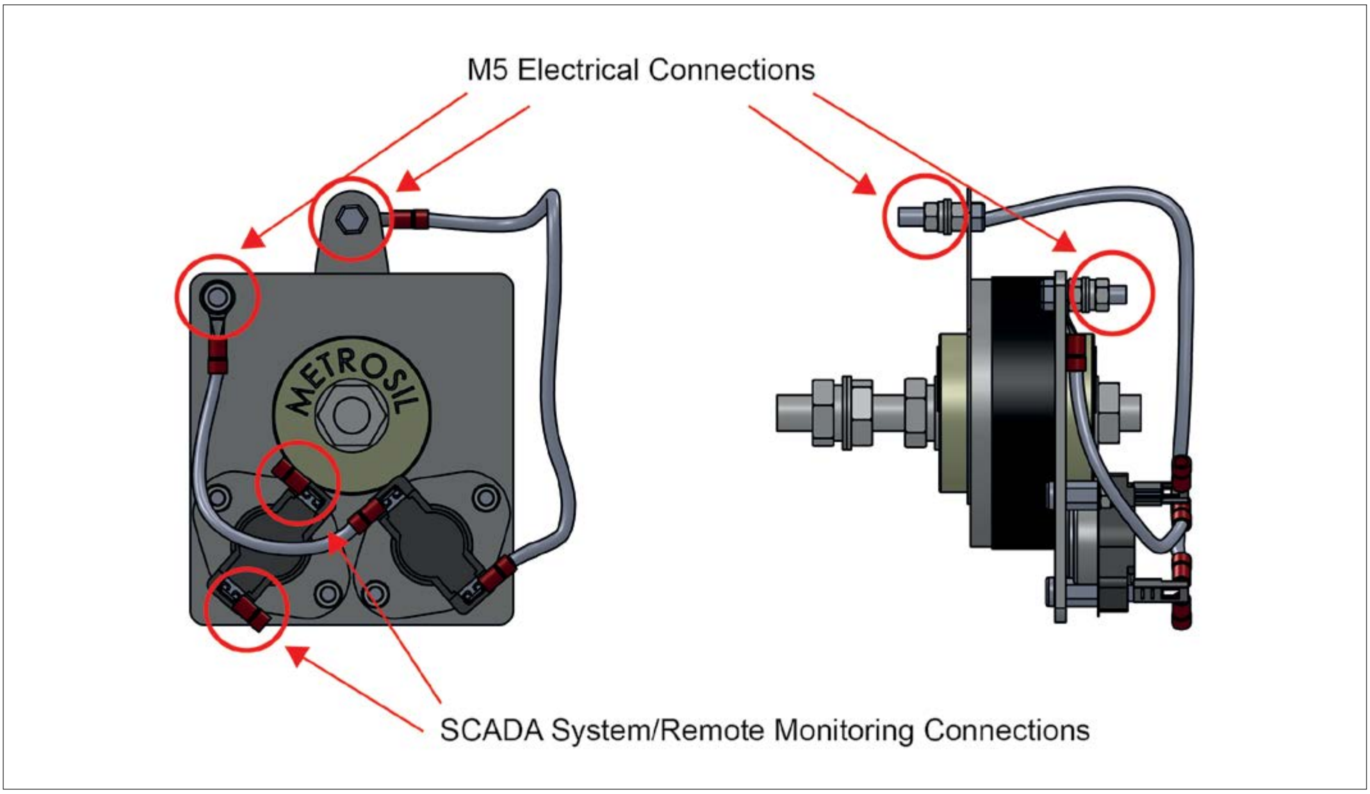
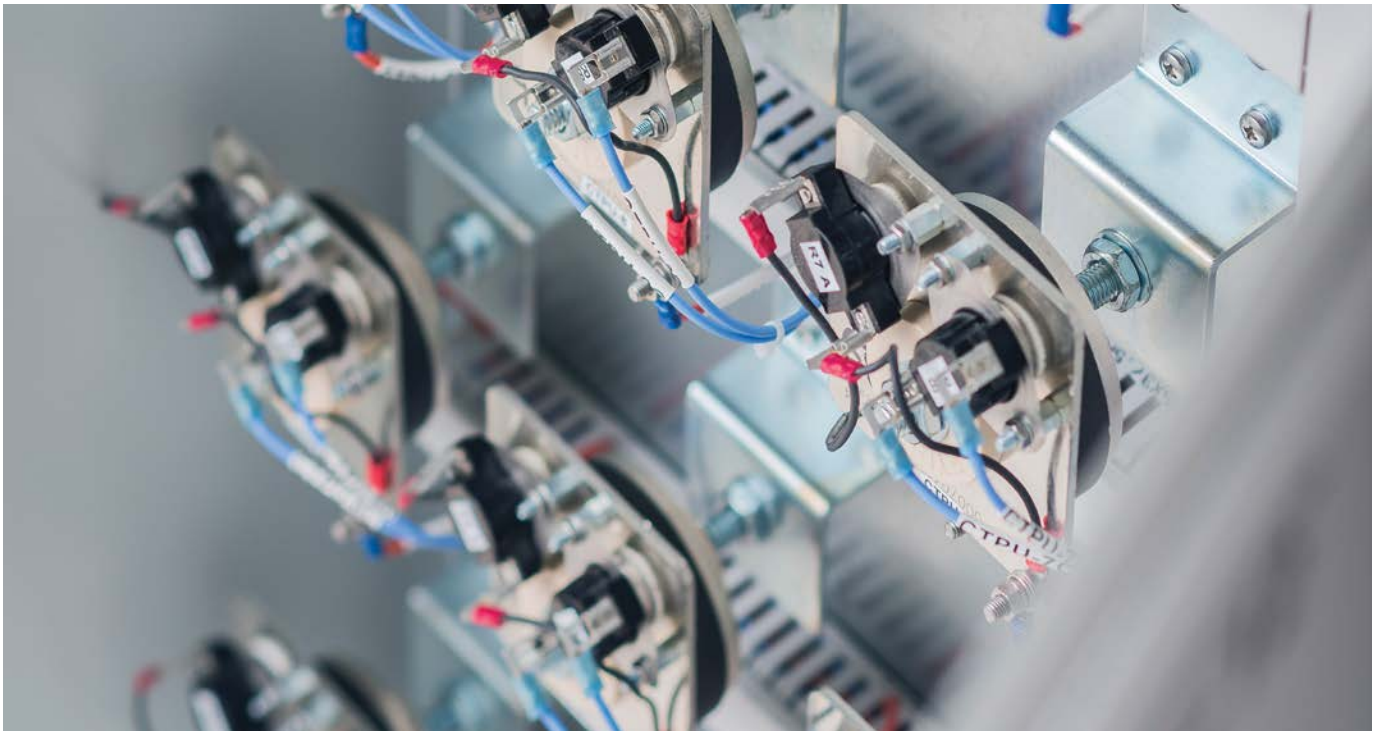


Figure 4. Metrosil CTPU current transformer protection



In order to prevent damage to the relay, the parallel-connected Relay Protection Varistor safely clamps any overvoltage the protection relay may be subject to

5.1 Advantages

- Faster at discharging stored energy.
- Limit overvoltages as soon as they occur.
- Low leakage currents.
- No electromagnetic noise.
- Function as a passive load until an overvoltage occurs, which negates need for any additional detection.

7. Can CTPUs be used for relay system protection?

Differential relay systems are traditionally used to protect individual electrical plant assets by monitoring the ingoing and outgoing current from the plant equipment.

When a mismatch occurs, current flows through the relay, causing it to trip at a pre-determined level. This current can result in high voltages developing across the relay and its associated setting resistor.

A separate varistor device for relay protection is often used to protect the scheme from transient overvoltages during fault conditions. Current transformer protection varistors only protect the CTs from being open-circuited; they are unaffected by and work independently from the Relay Protection Device.

To prevent damage to the relay, the parallel-connected Relay Protection Device safely clamps any overvoltage the protection relay may be subject to.

To ensure protection and safe operation of current transformers and their associated high impedance relay systems, current transformer protection must be used in conjunction with a Relay Protection Device.

Bibliography

[1] IEEE C57.13 – 2008 (Section 6.7.1)

PEER REVIEWED

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Dr. Tom Galvin is the Lead Scientist at M&I Materials. He holds a PhD in Materials Science from the University of Sheffield, which was based on ternary carbide materials for Accident Tolerant Fuel cladding in the nuclear power industry. As well as working closely with the Metrosil team, he works on driving product innovation and development across M&I Materials.

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