

## Function description for high impedance busbar protection

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## 1 Introduction

High impedance protection system is a simple technique which requires that all CTs used in the protection scheme have relatively high knee point voltage, similar magnetizing characteristic and the same ratio. These CTs shall be installed in all ends of the protected object. In order to make the scheme, all CTs belonging to one phase shall be connected in parallel.

Typical high impedance differential scheme is shown in Figure 1. Note that only one phase is shown in this figure. Due to the parallel CT connections the high impedance differential relay can only measure the operating quantity. That means that there is no any stabilizing quantity in such schemes. Therefore in order to guaranty the stability of the relay during external faults the operating quantity must not exceed the set pickup value.

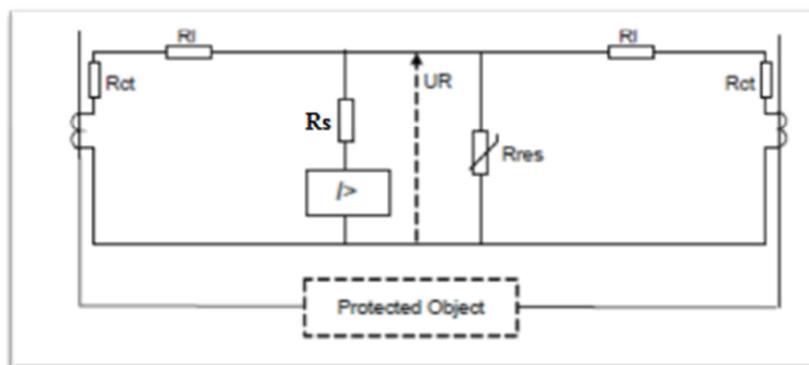


Fig.1 Typical high impedance differential scheme

For external faults, even with severe saturation of some of the current transformers, the voltage across the CT paralleling point shall not rise above the relay pickup value. To achieve that a suitable value for setting resistor  $R_s$  shall be selected in such a way that the saturated CT provides a much lower impedance path as compared with the measuring branch. Thus, in case of an external fault causing current transformer saturation, the non-saturated current transformers will drive most of the spill differential current through the secondary winding of the saturated current transformer and not through the measuring branch. The voltage drop across the saturated current transformer secondary winding will appear also across the measuring branch; however it will typically be relatively small. Therefore, the pick-up value of the relay has to be set above this false operating voltage.

In case of an internal fault, the fault current tries to flow through the measuring branch. Due to high ohmic value of setting resistor this will result in a steep voltage increase across the whole scheme and fast saturation of all current transformers. The differential relay is designed to operate under such conditions.

To ensure reliable operation with internal faults, the knee-point voltage of the current transformers used in the scheme must be about two times the set pickup voltage.

Often the non-linear resistors are required in order to limit the over voltages during internal fault to less than 2kV peak value, which is standard insulation level for used for secondary equipment and wiring. The differential protection sensitivity corresponds to the sum of magnetizing currents of all parallel connected current transformers, current drawn by non-linear resistor and the relay operating current for set pick-up voltage.

## 2 Description of high impedance functions in 670 and 650 Series

High impedance function as implemented in 670 and 650 Series is based on phase segregated protection function. Depending on the ordered type of the IED, up to nine single-phase high impedance function can be available.

For each of such single –phase function, the measuring principle is based on one single CT input into the IED with external stabilizing resistor and voltage dependent resistor (see Figure 1).

The tables 1, shows, examples of the operating currents for different sets of operating voltages and selected resistances for 1A CT input.

| Operating voltage | Stabilizing resistor R ohms | Operating current level 1 A | Stabilizing resistor R ohms | Operating current level 1 A | Stabilizing resistor R ohms | Operating current level 1 A |
|-------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 20 V              | 1000                        | 0.020 A                     | --                          | --                          | --                          | --                          |
| 40 V              | 2000                        | 0.020 A                     | 1000                        | 0.040 A                     | --                          | --                          |
| 60 V              | 3000                        | 0.020 A                     | 1500                        | 0.040 A                     | 600                         | 0.100 A                     |
| 80 V              | 4000                        | 0.020 A                     | 2000                        | 0.040 A                     | 800                         | 0.100 A                     |
| 100 V             | 5000                        | 0.020 A                     | 2500                        | 0.040 A                     | 1000                        | 0.100 A                     |
| 150 V             | 6000                        | 0.020 A                     | 3750                        | 0.040 A                     | 1500                        | 0.100 A                     |
| 200 V             | 6800                        | 0.029 A                     | 5000                        | 0.040 A                     | 2000                        | 0.100 A                     |

Table 1: Operating value for 1A CT input.

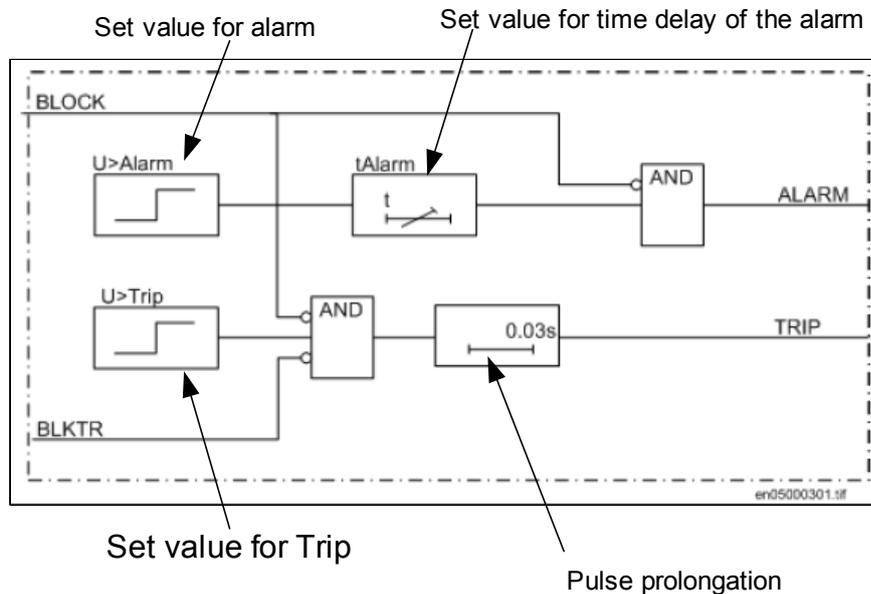


Figure 2: Simplified logic diagram for measured analogue quantities within one phase.

## 2.1 CT secondary circuit supervision

Any interruption of a CT secondary circuit up to the paralleling interconnections will cause an unbalance current in the protection function equivalent to the load being carried by the relevant primary circuit. Even though this degree of spurious output is below the effective setting the condition cannot be ignored, since it is likely to lead to differential protection unwanted operation under any through fault condition.

In the conventional schemes, the supervision was carried out to detect such conditions by connecting a separate sensitive alarm relay across the bus wires of each zone. Since a relay of this order of sensitivity is likely to operate during through faults, a time delay, of few seconds, is applied to avoid unnecessary alarm Signals.

## 2.2 Set values for CT supervision and bus wire shortening scheme

In the present design of high impedance function as available in 670 and 650 Series, the supervision of CT bus wires is integrated within the main protection function (setting  $U > Alarm$ ). Each single phase high impedance function has separate operating alarm level with settable time delay which is used to give alarm for problems with associated CT secondary circuit. The output of the alarm stage shall be used to activate an external shorting of the differential circuit CT bus wires and hence avoiding continuous high voltage in the CT circuit and the possible unwanted operation of the differential protection function.

| Group / Parameter Name                        | IED Value | PC Value | Unit | Min   | Max    |
|---|-----------|----------|------|-------|--------|
| ✓ HZPDIF: 1                                   |           |          |      |       |        |
| ✓ Setting Group1                              |           |          |      |       |        |
| ✓ Operation                                   |           | On       |      |       |        |
| ✓ SeriesResistor                              |           | 500      | ohm  | 10    | 20000  |
| Set value for alarm level → U>Alarm           |           | 10       | V    | 2     | 500    |
| Set value for alarm level time delay → tAlarm |           | 5,000    | s    | 0,000 | 60,000 |
| Set value for Trip level → U>Trip             |           | 50       | V    | 5     | 900    |

Figure 3: Setting parameter for high impedance protection function.

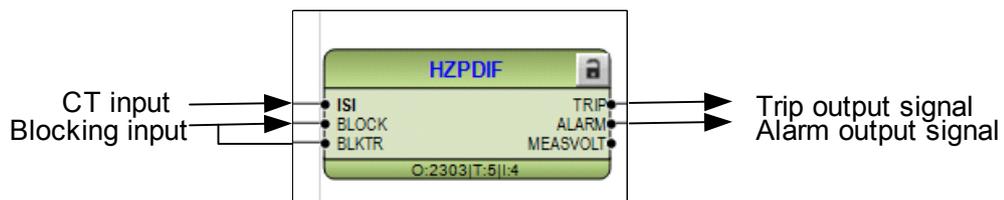


Figure 4: Input /Output configuration for high impedance function.

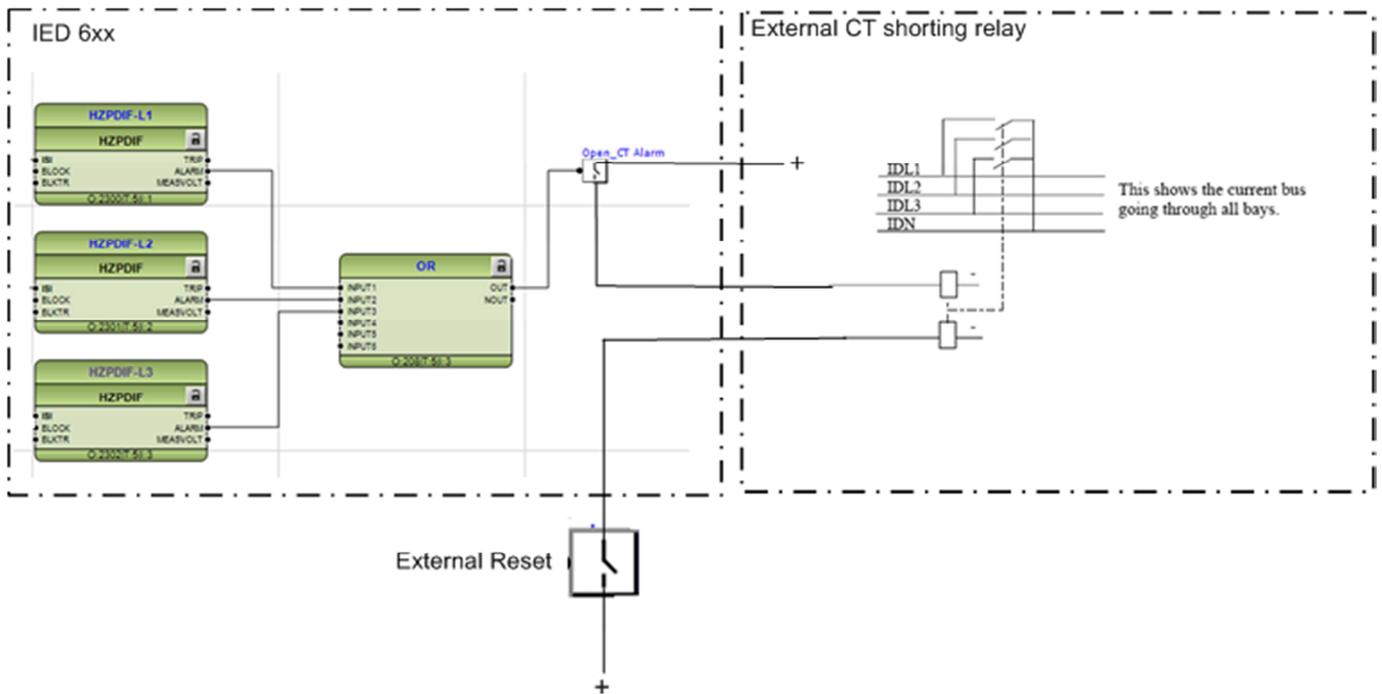


Figure 5: Principle diagram for external CT shorting relay.

CT circuit shorting is performed by an external auxiliary, heavy-duty throw over relay (e.g. ABB COMBIFLEX type **RXMVB 2**) activated from the alarm output from the respective zone. The same solution is used for main zones and check zone. CT alarm reset shall be initiated manually by the operator, after the CT circuit problem has been corrected.

### 3 CT requirements and performance

Current transformer requirements specified for high impedance protection application are based on the following conditions:

- During external faults, the scheme must remain stable.
- For internal faults, the current transformer must be able to drive sufficient current through the high impedance circuit to secure the tripping.

For external faults, the requirements are based on the assumption that the CT on the faulted circuit is completely saturated (worst condition). The voltage impressed upon the high-impedance differential relay connected across the CT summation point can be calculated as:

$$U_{R1} = \frac{I_{Max}}{CT\_ratio} * (R_{CT} + R_L)$$

$U_{R1}$  = Voltage developed across the relay for through fault conditions associated with fully saturated CT (V).

$I_{Max}$  = Magnitude of the maximum primary through fault current.

CT\_ratio = Ratio of the used CTs in the scheme

$R_{CT}$  = CT secondary winding resistance ( $\Omega$ )

$R_L$  = The resistance of the secondary cable from the CT up to a common junction point ( $\Omega$ ). The loop resistance containing the phase and neutral wires must be used. Note that typically the CT circuits with longest cable run from the CT summation point shall be used for this calculation.

If voltage  $U_{R1}$  is smaller than the set voltage, then the relay will not operate for external fault and will remain stable. This condition defines the stability limit for the scheme and used also as base to set scheme pick up level for internal fault. Thus, the relay set value  $U_s$  shall be set higher than value calculated for external fault.

During internal fault, all CTs conducting the fault current will be feeding into high impedance relay, which will be actually connected in parallel with any idle CTs (passive load circuits). The voltage developed across the relay will approach the open circuit secondary voltage that the CTs can produce. Even for a moderate internal fault this voltage will be in excess of the value calculated for the maximum external fault as described above. Hence the current through the relay can reach value which is several times higher than the actual set value.

For an internal fault, the CTs attempt to force secondary current through the high-impedance differential relay and a relatively high voltage is developed to operate the measuring unit. However, for reliable performance and to obtain high speed operation for internal faults, rated equivalent secondary e.m.f.  $E_{al}$  of the used CTs must be higher than the set voltage,  $U_s$ . This is essential so that the operating current through the relay is a sufficient multiple of the applied current setting.

In accordance with the data stated in the application manual, for reliable and secure performance of the high impedance differential function in 670 and 650 Series, the rated equivalent secondary e.m.f.  $E_{al}$  (i.e. the knee point voltage) of the CTs must be larger than or equal to the required equivalent secondary e.m.f.  $E_{alreq}$  below:

The CTs connected to the IED must have a rated equivalent secondary e.m.f.  $E_{al}$  that is larger than or equal to the required equivalent secondary e.m.f.  $E_{alreq}$  below:

$$E_{al} \geq E_{alreq} = 2 \cdot U_s = 2 \cdot I_{kmax} \cdot \frac{I_{sn}}{I_{pn}} \cdot (R_{CT} + R_L)$$

where:

- $U_s$       Set operate value to the voltage relay (V)
- $I_{kmax}$     Maximum primary fundamental frequency fault current for through fault current for external faults (A)
- $I_{pn}$       The rated primary CT current (A)
- $I_{sn}$       The rated secondary CT current (A)
- $R_{CT}$      The secondary resistance of the CT ( $\Omega$ )
- $R_L$       The resistance of the secondary cable from the CT up to a common junction point ( $\Omega$ ). The loop resistance containing the phase and neutral wires, must be used for faults in solidly earthed systems and the resistance of a single-phase wire should be used for faults in high impedance earthed systems.

In simple words the knee point voltage of used CTs shall be at least twice the set voltage level!

Note that all used CTs within the high-impedance differential protection scheme should have identical turn ratios. Consequently auxiliary CTs cannot normally be used. Finally the used CT core shall be dedicated to this protection. Thus the other protection devices shall not be connected to this scheme.

#### 4 Time /current characteristics for high impedance protection function

For numerical based high impedance function relay currently available in 670 and 650 Series, the time versus measured current characteristics included in the Fig 7 below. To demonstrate function performance in comparison to same function used in electromechanical high impedance differential relay Figure 6 is provided as well. Finally the trip time for different fault current level is included in Table 2 as well.

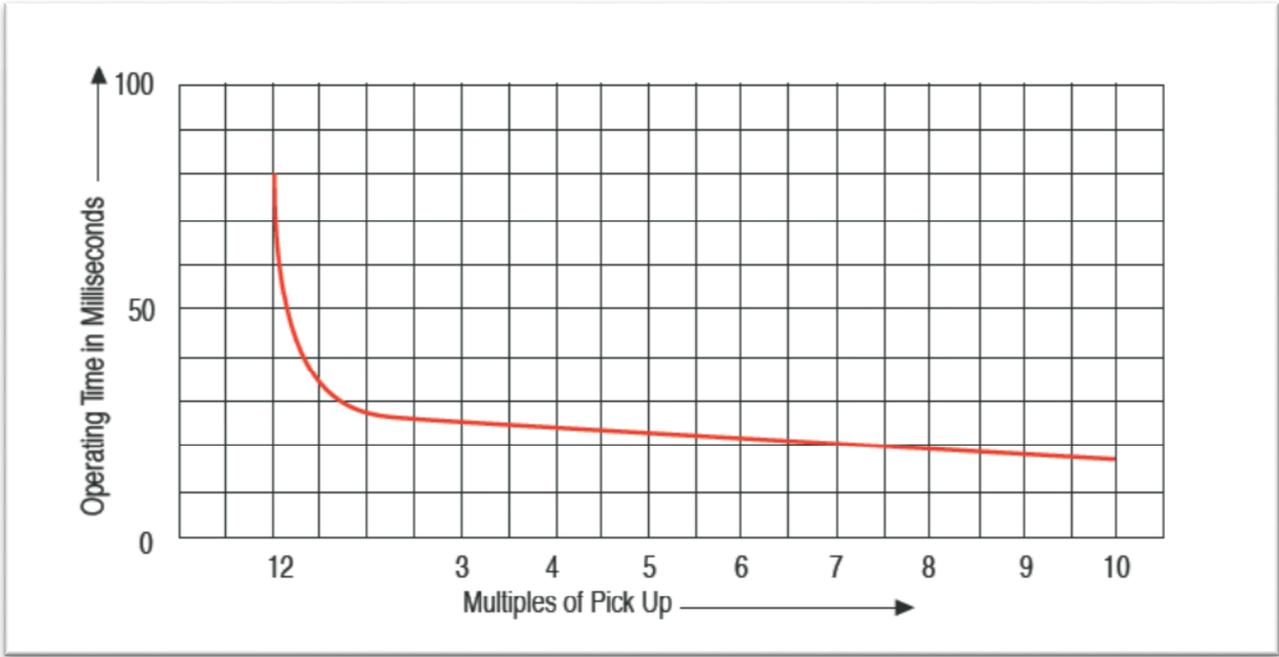


Fig.6: Time /current characteristics for electromechanical high impedance relay.

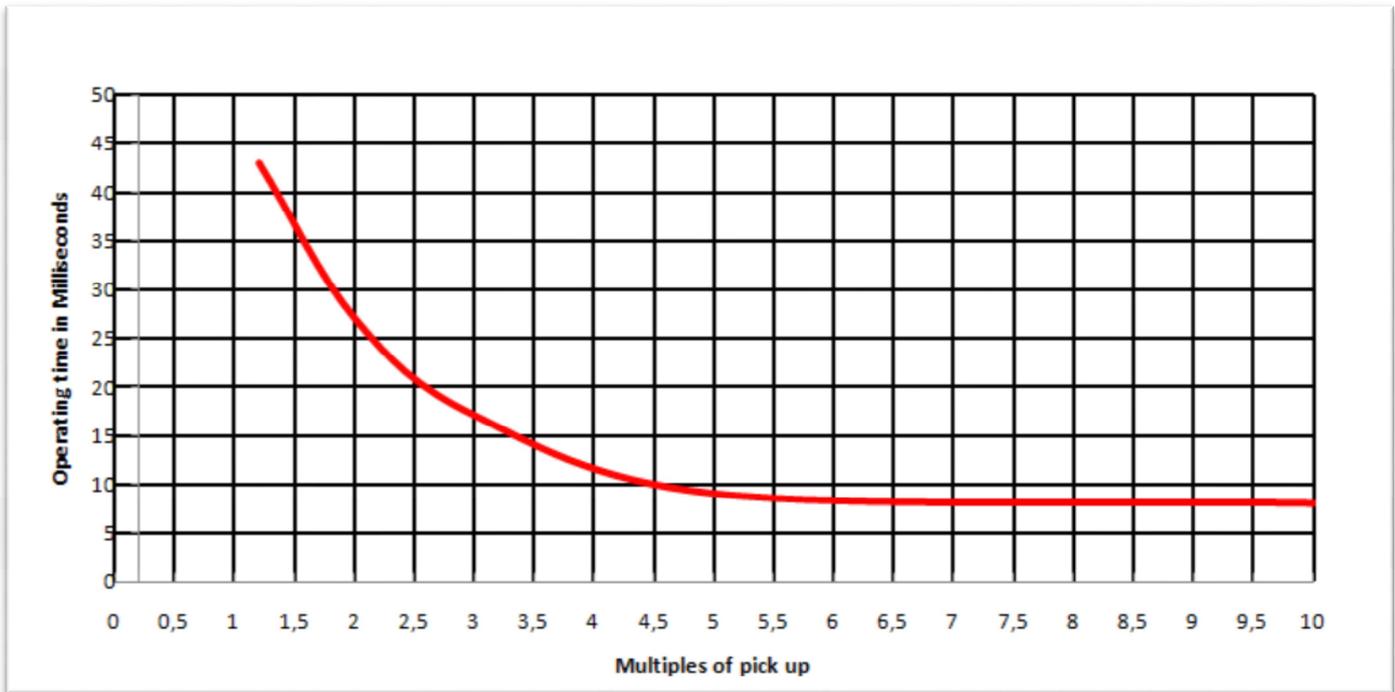


Fig 7. Time /Current characteristics for high impedance function in 670 and 650 Series.

| Multiples of pick up set value (V) | Measured trip time (msec.) | Multiples of pick up set value(A) |
|------------------------------------|----------------------------|-----------------------------------|
| 1.2                                | 43                         | 1.2                               |
| 2                                  | 27                         | 2                                 |
| 3                                  | 17                         | 3                                 |
| 5                                  | 9                          | 5                                 |
| 10                                 | 8                          | 10                                |

Table 2: Typical operate time for high impedance function in 670 and 650 Series

The minimum operate time of the protection function is 8msec at 10 times pick up set value. The operate time will remain at 8 msec for higher applied voltage.

## 5 Guidelines for the setting calculation for high impedance protection in 670 and 650 Series

### 5.1 Setting the pickup value

The stability of a high impedance differential scheme depends upon the fact that the relay set voltage is greater than the maximum false voltage which can appear across the relay circuit under a maximum through fault condition (i.e. external fault). This voltage can be determined by means of a simple calculation, which is already described in this document:

$$U_{R1} = \frac{I_{Max}}{CT\_ratio} * (R_{CT} + R_L)$$

For stability, the relay set voltage (setting  $U>Trip$ ) should be made higher than this calculated value  $U_{R1}$ . A safety factor of 1,1 can be used if it is necessary to accommodate future fault current variations.

Then check that the selected set voltage value does not exceed the 50% of the saturation voltage (i.e. knee point voltage or  $E_{al}$ ) of the used CTs.

### 5.2 Setting of the stabilizing resistor

Since the current measuring relay used in the scheme has a low burden, an external stabilizing resistor is required. The stabilizing resistor value  $R_S$  is then given by:

$$R_S = U>Trip / I_S$$

$U>Trip$  = relay set voltage (see Figure 3)

$I_S$  = Desired relay pick up current

Note that pickup current  $I_S$  shall not be less than 4% of the CT input rating (i.e. 40mA for 1A rated CT input). At the same time the relay pickup for the built-in Alarm Stage shall not correspond to current less than 2% of the CT input rating (i.e. 20mA for 1A rated CT input). This alarm pickup is calculated as follows:

$$I_A = U>Alarm / R_S$$

$U>Alarm$  = relay alarm voltage (see Figure 3)

$I_A$  = relay pick up current for the built-in alarm feature

Setting resistors which are offered together with 670 and 650 Series are adjustable. The selected  $R_S$  value shall be adjusted for every installation. For more details see ABB Document with ID: SA2007-000725.

The actually used  $R_S$  value shall be set in the IED under parameter *SeriesResistor* (see Figure 3).

### 5.3 Non-linear resistor (Metrosil)

During internal fault, the current will cause high voltage spikes across the relay. The peak voltage value  $V_{peak}$  produced under internal fault conditions can be estimated in accordance with the following formula:

$$V_{peak} = 2 * \sqrt{2 * E_{al} * \left( \frac{I_{Max}}{CT_{ratio}} * R_S - E_{al} \right)}$$

Note that all symbols used in this formula are previously defined in this document.

To protect the CT's, the secondary wiring, and the relay from damage due to excessively high voltages, a non-linear resistor is typically connected in parallel with the relay circuit (see Figure 1). These non-linear resistors (metrosils) are externally mounted together with the setting resistor. Refer to the IED Product Guide and the ABB Document with ID: SA2007-000725 for additional information.

#### 5.4 Relay primary sensitivity

The minimum primary operating current or the relay sensitivity can be calculated as follows:

$$I_{op} = CT_{ratio} * (n * I_e + I_S + I_M)$$

$I_{op}$  = primary current pickup

$n$  = number of CTs in parallel.

$I_e$  = excitation current of each CT at the set voltage

$I_M$  = current through the metrosil at the set voltage

$I_S$  = relay pick up current

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