

2V73 Setting Guide

High Impedance Differential Relay

relay monitoring systems pty ltd

Advanced Protection Devices



1. INTRODUCTION

This document provides guidelines for the performance calculations required for high impedance circulating current protection.

2. PROCEDURE FOR PERFORMANCE CALCULATIONS

2.1 Data Required

2.1.1 System Information

- i) Maximum through fault level, S_{ff} .
- ii) System voltage, V_{sys} .
- iii) Minimum fault current, I_{min} .
- iv) Circuit breaker short circuit rating, I_{cb} .
- v) Maximum through fault current, $I_{ff} = S_{ff} / (\sqrt{3} \times V_{sys})$.

2.1.2 Current Transformer Information

The CTs used in this type of scheme should be of the high accuracy and low leakage reactance type.

1. All the current transformers should have identical turns ratio.
2. The knee point voltage of the current transformers should be at least twice the relay setting voltage. The knee point voltage is expressed as the voltage at fundamental frequency applied to the secondary circuit of the current transformer which when increased in magnitude by 10% causes the magnetizing current to increase by 50%.
3. The current transformers should be of the low leakage reactance type. Class 'PX' current transformers to IEC60044 meet the above requirements and this type are recommended.
 - i) CT turns ratio, T .
 - ii) CT secondary resistance, R_{CT} .
 - iii) CT knee-point voltage, V_K .
 - iv) CT magnetizing characteristic, VI curve.
 - v) CT lead loop resistance, R_L .

The CT lead resistances can be calculated from the layout drawings. In the worst case a maximum lead resistance can be estimated from the figures below.

2.5mm² wire = 7.6Ω/km = 0.0076Ω/m

4.0mm² wire = 4.2Ω/km = 0.0042Ω/m

2.1.3 Protection Relay Information

- i) Operating current or current setting range, I_s .
- ii) Operating voltage or relay burden expressed in voltage, V_r .

2.2 Relay Setting Voltage

The protection relay must remain stable under maximum through fault conditions, when a voltage is developed across the protection due to the fault current. The relay setting voltage must be made equal or greater than this maximum voltage for the protection to remain stable.

That is:

$$V_s > V_{stab} \dots(1)$$

where,

V_s = relay setting voltage.

V_{stab} = stability voltage.

The fault current may contain a transient d.c. component current which can cause saturation of the current transformer core and thus distortion of the secondary current. Therefore in order to calculate the required setting voltage, it is assumed that one of the protection CT's saturates. In these conditions the healthy CT's are driving current through the parallel impedance of the saturated CT with leads and the protection relay. The saturated CT impedance is represented by its secondary winding resistance, and the maximum lead loop resistance between the CT and the relay must also be considered.

For the simple case of two current transformers, the voltage developed across the relay is given by:

$$V_{stab} = I_{ff} \times T \times (R_{CT} + R_L) \dots(2)$$

where,

V_{stab} = stability voltage.

I_{ff} = maximum through fault current.

T = CT turns ratio.

R_{CT} = CT secondary winding resistance.

R_L = CT lead loop resistance.

In most practical systems where more than two current transformers exist, the same equation is used based on the fact that this represents the most onerous condition. R_L is chosen for the longest distance between any two CT's in parallel.

In addition, the relay setting voltage should be less than half of the knee point voltage of any CT in the protection scheme.

That is:

$$V_s < V_K / 2 \dots(3)$$

where,

V_s = relay setting voltage.

V_K = CT knee point voltage.

The criteria outlined above establishes maximum and minimum values for the relay setting voltage.

2.3 Stabilizing Resistor

The relay voltage setting range may not be sufficient to be set to the required level of V_s as calculated previously, due to the relay's low burden. In such cases a 'stabilizing' resistor is provided in series with the relay to increase the relay circuit setting.

However for a relay calibrated in voltage this is not normally required.

The resistor can be sized as follows:

$$V_s - V_r = I_s R_s \dots(4)$$

where,

R_s = stabilizing resistance required.

Using the maximum and minimum voltages calculated by (2) & (3), a resistance range can be obtained from which a suitable resistor can be chosen. After which the actual relay circuit setting voltage can be calculated.

2.4 Thermal Rating of Resistors

The resistors incorporated in the scheme must be capable of withstanding the associated thermal conditions.

2.4.1 Continuous Power Rating

The continuous power rating of a resistor is defined as:

$$P_{con} = (I_{con})^2 R \dots(5)$$

where,

P_{con} = resistor continuous power rating.

I_{con} = continuous resistor current i.e. the operating current of the relay.

R = resistance.

2.4.2 Half-second Power Rating

The rms voltage developed across a resistor for maximum internal fault conditions is defined as:

$$V_f = (V_k^3 \times R \times I_{fs})^{1/4} \times 1.3 \dots(6)$$

where,

V_f = rms voltage across resistor.

V_k = CT knee point voltage.

R = resistance.

I_{fs} = maximum secondary fault current which can be calculated from the circuit breaker rating, I_{cb} , if the maximum internal fault current is not given. The maximum internal fault current is usually the same as the maximum through fault current.

Thus the half-second power rating is given by:

$$P_{half} = V_f^2 / R \dots(7)$$

where,

P_{half} = half-second power rating.

V_f = rms voltage across resistor.

R = resistance.

2.5 Voltage Limiting Resistor

The previous calculations produced a voltage setting for through fault stability, now the case for an internal fault needs to be considered. The maximum primary fault current will cause high voltage spikes across the relay at instants of zero flux since a practical CT core enters saturation on each half-cycle for voltages of this magnitude. If this voltage exceeds 3kV peak then it is necessary to suppress the voltage with a non linear resistor (Metrosil) in a shunt connection which will pass the excess current as the voltage rises.

The formula to calculate this voltage is:

$$V_{pk} = 2 \times (2V_k [V_{fs} - V_k])^{1/2} \dots(8)$$

where,

V_{pk} = peak value of the voltage waveform.

V_k = CT knee point voltage.

V_{fs} = value of voltage that would appear if CT did not saturate.

= $I_{fs} \times (R_{CT} + R_L + R_s + R_r)$, where R_r is relay resistance

The Metrosil must be chosen to match the relay circuit setting voltage (i.e. its characteristic must not change significantly until beyond the relay setting V_s) and it must be capable of passing the maximum prospective fault current that can be transformed by the CT.

The type of Metrosil required is chosen by its thermal(energy) rating as defined by the formula:

$$P = 4 / \pi \times I_{fs} \times V_k \dots(9)$$

where,

P = thermal metrosil rating, Joules

π = pi = 3.14159265.

I_{fs} = maximum secondary fault current which can be calculated from the circuit breaker rating, I_{cb} , if the maximum internal fault current is not given. The maximum internal fault current is usually the same as the maximum through fault current.

V_k = CT knee point voltage.

There are two types of Metrosil available the 3 inch type with a maximum rating of 8kJ/s and the 6 inch type with a maximum rating of 33kJ/s.

A 6" Metrosil is recommended as standard with 2V73.

2.6 Primary Fault Setting

The primary operating current or fault setting may be calculated from:

$$I_p = (nI_e + I_s + I_{nir}) / T \dots(10)$$

where,

- I_p = primary fault setting.
- n = number of CTs in parallel.
- I_e = exciting current of each CT at the relay circuit setting voltage (assuming all CTs are identical).
- I_s = operating current of relay at the relay circuit setting voltage.
- I_{nir} = current in metrosil at the relay circuit setting voltage.
- T = CT turns ratio.

I_p should fall within the recommended fault setting given by the relevant standard, the clients specification or in the absence of these good engineering practice, and be greater than a specified minimum, I_m (where I_m is a percentage of the minimum primary fault current, I_{min}).

If the calculated primary fault setting I_p is lower than a specified minimum (i.e. it is too sensitive) small increases can be achieved by increasing the relay setting voltage V_s and hence increasing the CT exciting current I_e . Alternatively, when the required increase in fault setting is large, the correct setting can be obtained by connecting a shunt setting resistor.

The current required through the shunt resistor is given by:

$$I_{sh} = I_m T - nI_e - I_s - I_{nir} \dots(11)$$

where,

- I_{sh} = current through shunt resistor.
- I_m = percentage of the minimum primary fault current I_{min} .
- T = CT turns ratio.
- n = number of CTs in parallel.
- I_e = exciting current of each CT at the relay circuit setting voltage (assuming all CTs are identical).
- I_s = operating current of relay at the relay circuit setting voltage.
- I_{nir} = current in non linear resistor at the relay circuit setting voltage.

Therefore, the shunt setting resistance is:

$$R_{sh} = V_s / I_{sh} \dots(12)$$

where,

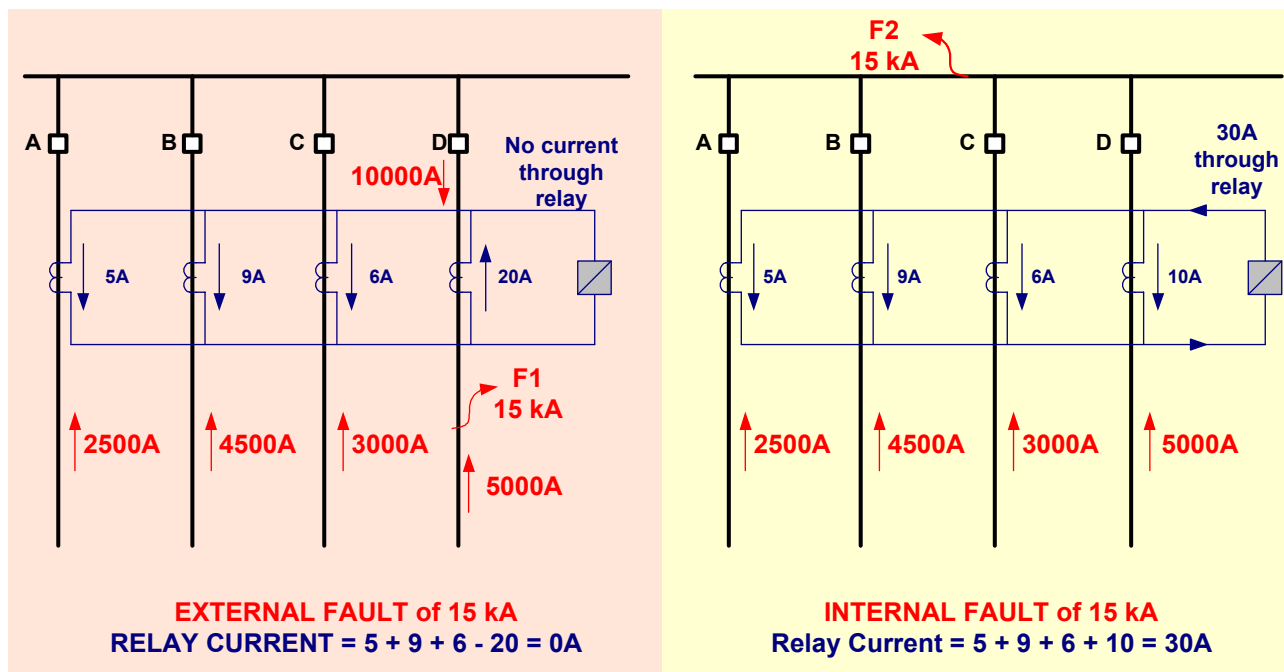
- R_{sh} = shunt resistance.
- V_s = relay circuit setting voltage.
- I_{sh} = current through shunt resistor.

3. WORKED EXAMPLE

The following worked example is based on the application shown in figure 1.

Figure 1 - Simplified circulating current scheme

Example shown for: $I_f = 15\text{kA}$, C.T. RATIO 500/1, single busbar, 4 circuits



3.1 Data

3.1.1 System Information

- Maximum through fault level, $I_{fr} = 15\text{kA}$
- System voltage, $V_{sys} = 22\text{kV}$
- Minimum fault current, $I_{min} = 2\text{kA}$
- Circuit breaker short circuit rating, $I_{cb} = 25\text{kA}$

3.1.2 Current Transformer Information

The CTs are low leakage reactance type having an accuracy class 'PX' in accordance with IEC 60044.

500/1A, 0.05PX200R1.0

- CT turns ratio, $T = 1/500$
- CT secondary resistance, $R_{CT} = 1.0\Omega$
- CT knee-point voltage, $V_K = 200\text{V}$
- CT lead loop resistance, $R_L = 1.0\Omega$ (assume figure for worst case)

3.1.3 Protection Relay Information (2V73)

- The 2V73 has a fixed operating current of 14 to 29mA based on voltage setting.
- The 2V73 is a voltage operated relay having seven equally spaced settings.
2V73 [A][A][A] = 25–325V in 50V steps.
2V73 [B][A][A] = 25–115V in 15V steps.

3.2 Relay Setting Voltage

Primary through-fault current:

$$I_{ff} = S_{ff} / (\sqrt{3} \times V_{sys})$$

$$I_{ff} = 15,000A$$

From eqn (2)

$$V_{stab} = I_{ff} \times T \times (R_{CT} + R_L) \dots(2)$$

$$V_{stab} = (15000A / 500) \times (1 + 1)$$

$$= 60V$$

From eqn (3)

$$V_s < V_K / 2 \dots(3)$$

$$V_s < 200V / 2$$

$$= 100V$$

Thus to maintain stability for maximum through fault current the relay needs to be set at a voltage in the range 60V to 100V.

The relay setting voltage is generally set to the nearest setting above V_{stab} .

$V_s = 75V$ on 2V73 [A][A][A] with setting range 25-325V in 50V steps.

$V_s = 70V$ on 2V73 [B][A][A] with setting range 15-115V in 15V steps.

3.3 Stabilizing Resistor

The 2V73 is a relay calibrated in voltage thus a series stabilizing resistor is not required.

3.5 Voltage Limiting Resistor

A 6" Metrosil is recommended as standard with 2V73.

3.6 Fault Setting

Table below shows nominal relay operate current at relay setting voltage.

Limits of relay operate current + metrosil current at relay setting voltage.

Where the relay setting voltage is low then the current in the metrosil is often ignored in calculations.

Range A (Volts)	25	75	125	175	225	275	325
Nominal (mA)	15	15	15	15	17	21	29
Limits (mA)	13	13	13	13	13	15	18
	to	to	to	to	to	to	to
	16	17	17	20	27	39	61

Range B (Volts)	25	40	55	70	85	100	115
Nominal (mA)	14	14	14	14	14	14	14
Limits (mA)	13	13	13	13	13	13	13
	to	to	to	to	to	to	to
	16	16	16	17	17	17	17

The primary operating current is:

$$\begin{aligned}
 I_p &= (nI_e + I_s + I_{nlr})/T \dots(10) \\
 I_p &= (4 \times 0.02 + 0.015) \times 500 \\
 &= 47.5A
 \end{aligned}$$

Application is a single busbar with 4 circuits, n= 4
 Assume CT magnetizing current at setting voltage $I_e = 20\text{mA}$ (refer to CT VI curve for actual figure).

The desired setting is 10% of the minimum primary fault current. i.e. $I_{\min} = 2\text{kA}$
 $10\% = 200A$

Therefore a shunt resistor is required to raise the primary operating current:

$$\begin{aligned}
 I_{sh} &= I_m T - nI_e - I_s - I_{nlr} \dots(11) \\
 I_{sh} &= 200A / 500 - (4 \times 0.02) - 0.015 \\
 &= 0.305A
 \end{aligned}$$

$$\begin{aligned}
 R_{sh} &= V_s / I_{sh} \dots(12) \\
 R_{sh} &= 75V / 0.305A \\
 &= 246\Omega \\
 R_{sh} &= 250\Omega
 \end{aligned}$$

$$\begin{aligned}
 I_p &= (nI_e + I_s + I_{nlr} + I_{sh})/T \dots(10) \\
 I_p &= (4 \times 0.02 + 0.015 + 0.3) \times 500 \\
 &= 197.5A
 \end{aligned}$$

The above ignores any current passed through the Metrosil at the setting voltage. With typical standard values for the Metrosil characteristic for B and C, the current at setting voltage would be very low, e.g. < 1mA.

3.4 Thermal Rating of Shunt Resistor

From eqn (5)

$$\begin{aligned}
 P_{con} &= (I_{con})^2 R \dots(5) \\
 P_{con} &= (0.3)^2 \times 250 \\
 &= 22.5W \text{ continuously}
 \end{aligned}$$

A 100W or 200W resistor is generally used as standard.

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