RMS Mors Smitt
A Wabtec company

2V73 Setting Guide

High Impedance Differential Relay

relay monitoring systems pty ltd

Advanced Protection Devices

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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_{tf}.

ii) System voltage, V_{sys}.

iii) Minimum fault current, I_{min}.

iv) Circuit breaker short circuit rating, I_{cb}.

v) Maximum through fault current, $I_{tf} = S_{tf} / (\sqrt{3} \times V_{sys})$.

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.

$2.5mm^2$ wire = 7.6Ω/km = 0.0076Ω/m
$4.0mm^2$ wire = 4.2Ω/km = 0.0042Ω/m
$6.0mm^2$ wire = 3.0Ω/km = 0.0030Ω/m

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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.

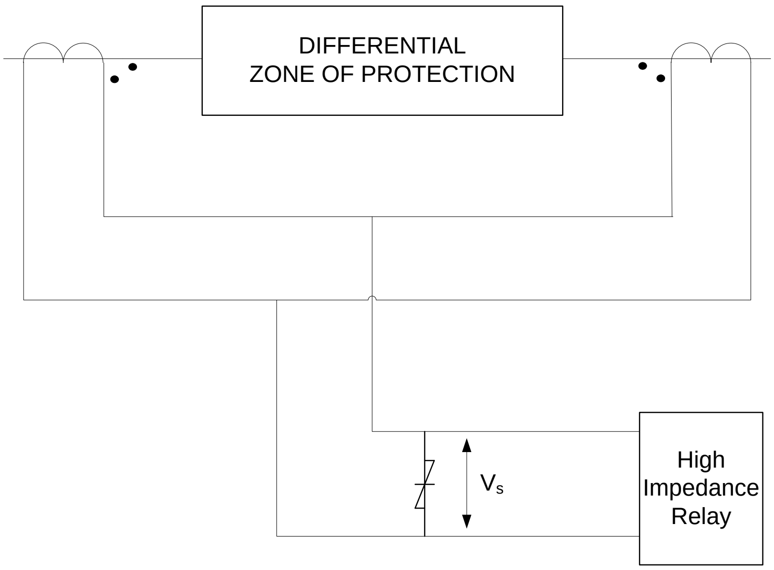
That is:

$$V_s > V_{stab} \quad ...(1)$$

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.

Under 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.

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

$$V_{stab} = I_{tf} \times T \times (R_{CT} + R_L) \quad ...(2)$$

where,

V_{stab} = stability voltage.

I_{tf} = 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 since 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:

$$V_s < V_K / 2 \quad ...(3)$$

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 Stabilising Resistor

In High Impedance schemes using current operated relays 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 'stabilising' resistor is provided in series with the relay to increase the relay circuit setting.

In the case of the 2V73, an external Stabilising resistor is not normally required as the relay is equipped with an internal chain of resistors for stabilisation purposes to achieve the required level of V_s.

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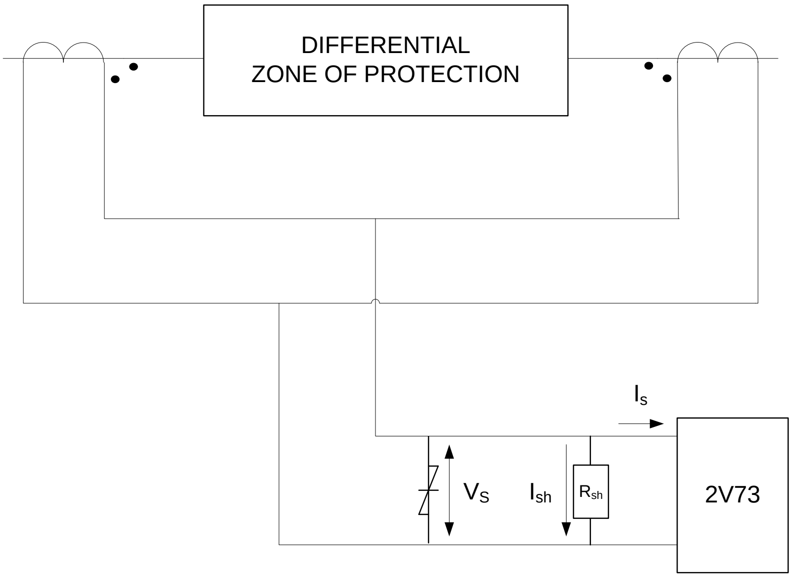
2.4 Shunt Resistor

Depending on the relay operate current the use of a Shunt resistor may be required to ensure the scheme does not operate due to CT current spill on through faults or minimum primary operating currents nominated in relevant standards, client specification or in the absence of these good engineering practice.



2.4.1 Criteria 1 - Turns Ratio Error CT spill

Class PX CTs are permitted to have a turns ratio error not exceeding ±0.25%. The relay must not operate for a CT spill condition due to turns ratio error on through faults.

I_s > I_{spill}

I_{spill} = [(2 x % turns ratio error) / 100] x I_{tf} x T …(4)

If the spill current is greater than the relay operate current a shunt resistor is added to the relay circuit to increase the effective operate current.

The current required through the shunt resistor is given by :

I_{sh} = I_{spill} - I_s …(5)

2.4.2 Criteria 2 - Primary Fault Setting

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

$I_p = (nI_e + I_s + I_{nlr}) / T$ ...(6)

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_{nlr} = current in metrosil at the relay circuit setting voltage.

T = CT turns ratio.

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I_p should fall within the recommended fault setting given by the relevant standard, the clients specification or in the absence of these then 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:

$$I_{sh} = I_m T - nI_e - I_s - I_{nlr} \quad ...(7)$$

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_{nlr} = current in non-linear resistor at the relay circuit setting voltage.

2.4.3 Required Shunt Resistance

The required shunt resistance is derived from :

$$R_{sh} = V_s / I_{sh} \quad ...(8)$$

where,

R_{sh} = shunt resistance.

V_s = relay circuit setting voltage.

I_{sh} = current through shunt resistor.

From Criteria 1 and Criteria 2 choose the lowest calculated resistance value.

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2.5 Thermal Rating of Resistors

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

2.5.1 Continuous Power Rating

The continuous power rating of a resistor is defined as:

$$P_{con} = (V_{con})^2 / R \quad ...(9)$$

where,

P_{con} = resistor continuous power rating.

V_{con} = continuous resistor voltage i.e. the operating Voltage of the relay.

R = resistance.

2.5.2 Half-second Power Rating

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

$$V_f = (V_k^3 \times R_{sh}/R_R \times I_{fs})^{1/4} \times 1.3 \quad ...(10)$$

where,

V_f = rms voltage across resistor.

V_K = CT knee point voltage.

R_{sh} = shunt resistance.

R_R = relay 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:

$$P_{half} = V_f^2 / R_{sh} \quad ...(11)$$

where,

P_{half} = half-second power rating.

V_f = rms voltage across resistor.

R_{sh} = shunt resistance.

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2.6 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:

$$V_{pk} = 2 \times (2V_k [V_{fs} - V_k])^{1/2} \quad ...(12)$$

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.

$$V_{fs} = (I_{tf} / N) \times (R_{sh} // R_r) \quad ...(13)$$

R_r = is relay resistance

R_{sh} = is shunt resistance

For $R_r >> R_{sh}$, eqn (13) becomes

$$V_{fs} = (I_{tf} / N) \times (R_{sh}) \quad ...(14a)$$

If no shunt resistor is utilised (i.e. $R_{sh} = \infty$) then, eqn (13) becomes

$$V_{fs} = (I_{tf} / N) \times (R_r) \quad ...(14b)$$

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 also chosen by its Rated Energy Absorption.

The energy absorption requirement is determined by the total fault energy.

The fault power is defined by the formula:

$$P = (4 / \pi) \times I_{fs} \times V_k \quad ...(15)$$

where,

P = thermal metrosil rating, Joules/s

π = pi = 3.14159265.

I_{fssec} = 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.

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The fault energy is determined by the relationship:

E = P x Tf ...(16)

where,

E = Fault power (watts or Joules/s)

Tf = Fault duration (seconds, this is typically taken to be 1 sec as a worst case)

The rated energy absorption of a 6" Spec 887 Metrosil is 33 kJ.

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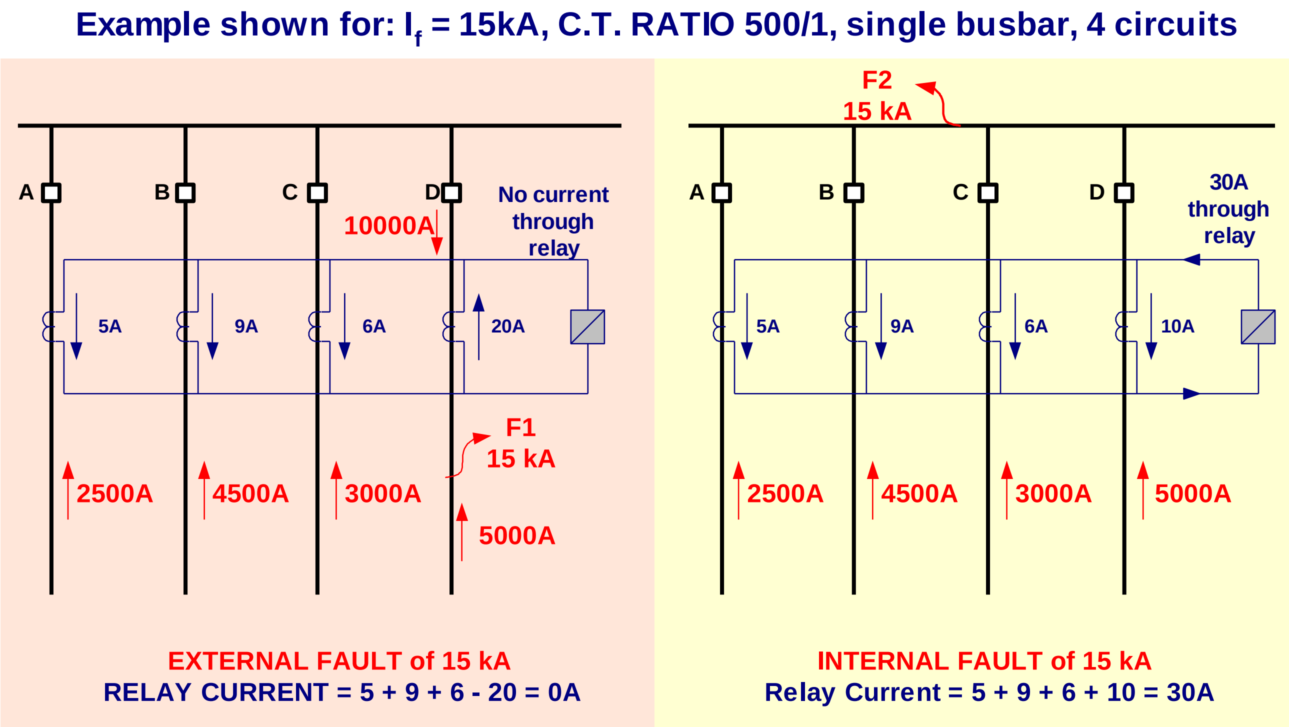
3. WORKED EXAMPLE

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

Figure 1 - Simplified circulating current scheme



3.1 Data

3.1.1 System Information

i) Maximum through fault level, S_{tf} = 570MVA

ii) System voltage, V_{sys} = 22kV

iii) Minimum fault current, I_{min} = 2kA

iv) Circuit breaker short circuit rating, I_{cb} = 25kA

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

i) CT turns ratio, T = 1/500

ii) CT secondary resistance, R_{CT} = 1.0Ω

iii) CT knee-point voltage, V_K = 200V

iv) CT lead loop resistance, R_L = 1.0Ω (assume figure for worst case)

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3.1.3 Protection Relay Information (2V73)

i) The 2V73 has a fixed operating current of 14 to 29mA depending on voltage setting.

ii) 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_{tf} $= S_{tf} / (\sqrt{3} \times V_{sys})$
I_{tf} $= 570 \times 10^3 kVA / (\sqrt{3} \times 22\ kV)$
$= 15{,}000A$

From eqn (2)

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

V_{stab} $> (15000A / 500) \times (1 + 1)$
$> 60V$

From eqn (3)
V_s $< V_K / 2$ ...(3)
V_s $< 200V / 2$
$< 100V$

Thus, to maintain stability for maximum through fault current and ensure reliable operation for an in zone fault :

$60V < V_s < 100V$.

Choose nearest setting to say 80V.

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 25-115V in 15V steps.

3.3 Stabilising Resistor

The 2V73 is a relay calibrated in voltage and a series stabilising resistor is not required.

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3.4 Shunt Resistor

Confirm requirement for a shunt resistor. The Tables below show nominal relay operate currents 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
Nominal Relay resistance (ohms)	1,670	5,000	8,330	11,670	13,240	13,100	11,210
Limits (mA)	13 to 16	13 to 17	13 to 17	13 to 20	13 to 27	15 to 39	18 to 61

Range B (Volts)	25	40	55	70	85	100	115
Nominal (mA)	14	14	14	14	14	14	14
Nominal Relay resistance (ohms)	1,790	2,860	3,930	5,000	6,070	7,140	8,210
Limits (mA)	13 to 16	13 to 16	13 to 16	13 to 17	13 to 17	13 to 17	13 to 17

For the purpose of this example we shall use data for Range B relay for setting of 70V

3.4.1 Criteria 1 - Turns Ratio Error CT spill

Class PX CTs are permitted to have a turns ratio error not exceeding ±0.25%. The relay must not operate for a CT spill condition due to turns ratio error on through faults.

For I_{tf} = 15,000A and from eqn (4)

I_{spill} = [(2 x turns ratio error) / 100] x I_{tf} x T
= [(2 x 0.25) / 100] x 15,000 x (1 / 500)
= 150mA

The spill current is greater than the relay operate current of 14mA therefore a shunt resistor needs to be added to the relay circuit to increase the effective operate current.

The current required through the shunt resistor is given by :

I_{sh} = I_{spill} - I_s …(5)
= 150mA - 14mA
= 136mA

3.4.2 Criteria 2 - Primary Fault Setting

The primary operating current may be calculated from:

I_p = $(nI_e + I_s + I_{nlr}) / T$ ...(6)

Application is a single busbar with 4 circuits, n= 4
Assume CT magnetizing current at setting voltage I_e = 20mA (refer to CT VI curve for actual figure).
The current passing through the Metrosil at the setting voltage is ignored. I_s=14mA for the chosen Range B setting of 70V.

From eqn (6)

I_p = $(nI_e + I_s + I_{nlr}) / T$
= (4 x 0.02A + 0.014A) x 500
= 47A

The relay circuit is not to operate at levels < 10% of the minimum primary fault current.
i.e. 10% of I_{min} = (10 / 100) x 2kA = 200A.

I_p < I_{min} therefore a shunt resistor is required.

The current required through the shunt resistor is given by:

I_{sh} = $I_mT - nI_e - I_s - I_{nlr}$ ...(7)
= (200A/500) - (4 x 0.02A) - 0.014A
= 306mA

3.4.3 Required Shunt Resistance

The required shunt resistance is derived from eqn (8).

Using the worst-case shunt current from Criteria 1 and Criteria 2.

In this case Criteria 2 I_{sh} is utilised.

R_{sh} = V_s / I_{sh} ...(8)
= 70V / 306mA
= 228 Ω

Choose R_{sh} = 200 Ω

3.5 Thermal Rating of Resistors

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

3.5.1 Continuous Power Rating

The continuous power rating of a resistor is defined as:

P_{con} = $(V_{con})^2 / R_{sh}$ ...(9)
= $(70V)^2$ / 200 Ω
= 24.5W

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3.5.2 Half-second Power Rating

From eqn (6)

V_f $= (V_k^3 \times R_R // R_{sh} \times I_{fs})^{1/4} \times 1.3$ ...(10)

V_f $= (200V^3 \times 200\ \Omega // 5{,}000\ \Omega \times 15{,}000A / 500)^{1/4} \times 1.3$
$= 602$ V

From eqn (7)
P_{half} $= V_f^2 / R$ ...(11)
P_{half} $= 602\ V^2 / 200\ \Omega$
= 1815W for half a second

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

3.6 Voltage Limiting Resistor

If the voltage developed across the relay circuit 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.

In our case $R_R >> R_{sh}$

From eqn (14a)
V_{fs} $= (I_{tf}\ T) \times (R_{sh})$…(14a)
$= (15{,}000\ A / 500) \times (200\ \Omega)$
$= 6{,}000$ V

From eqn (12)

V_{pk} $= 2 \times (2V_k [V_{fs} - V_k])^{1/2}$ ...(12)

$= 2 \times (2 \times 200V \times [6{,}000V - 200V])^{1/2}$
$= 3{,}046$ V

The peak value is > 3kV, therefore a non-linear resistor is required.

The fault power is calculated from eqn (15).

P $= (4 / \pi) \times I_{fs} \times V_k$ ...(15)

$= (4 / \pi) \times (15{,}000A / 500) \times 200V$
= 7.6 kW or kJ/s

For this fault power and assuming a fault duration of 1 sec the required energy absorption rating for the non-linear resistor is calculated from eqn (16).

E = P x Tf ...(16)
= 7.6 kJ/s x 1 sec
= 7.6 kJ

The rated energy absorption of a 6" Spec 887 Metrosil is 33 kJ.

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