RMS Mors Smitt
A Wabtec company

# 2C73 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.

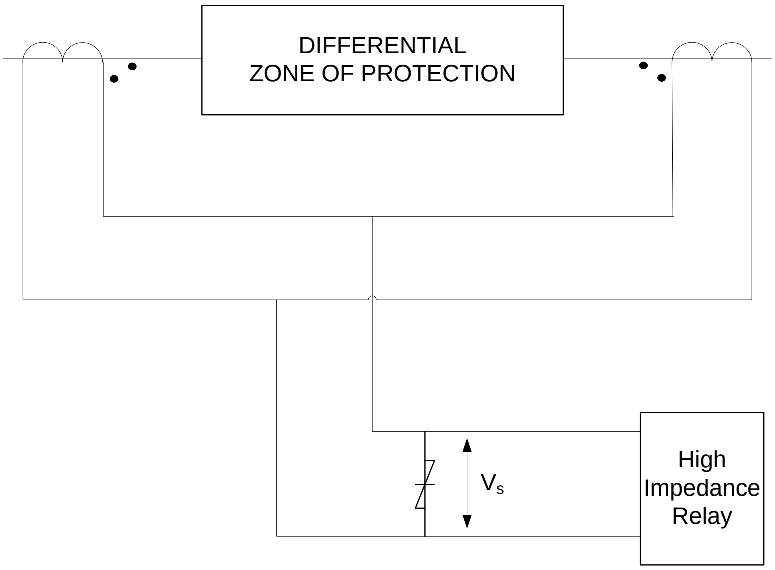
That is:

**$V_s > V_{stab}$ ...(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 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.

For reliable in zone operation 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 Primary Fault Setting

A suitable relay current setting now needs to be determined. The primary operating current or fault setting may be calculated from:

$$I_p = ( nI_e + I_s ) / T \quad ...(4)$$

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).

$I_s$ = relay current setting

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 $I_m$ may be a percentage of the minimum primary fault current, $I_{min}$).

This allows a relay operate current to be determined:

$$I_s = I_pT - nI_e \quad ...(5)$$



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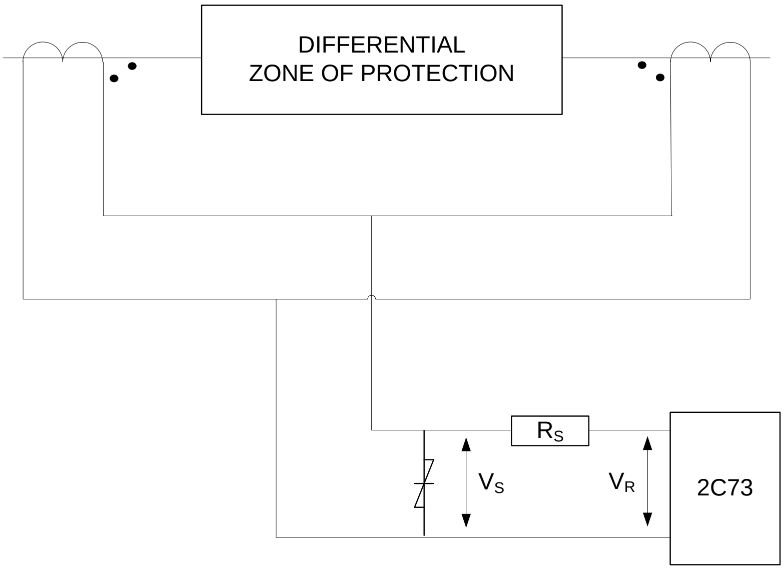
### 2.4 Stabilising Resistor

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.




The resistor is sized as follows:

$$R_s = V_s/I_s - (VA)/I_s^2 \quad ...(6)$$

where,

$R_s$ = stabilising resistance required.

$I_s$ = Relay current setting.

VA = Relay Burden

$V_s$ = Scheme setting voltage

Using the maximum and minimum voltages calculated by (2) & (3), a resistance range is obtained from which a suitable resistor can be chosen.

### 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 required continuous power rating of a resistor is defined as:

$$P_{con} = ( I_{con} )^2 R_s \quad ...(7)$$

where,

$P_{con}$ = resistor continuous power rating.

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

$R_s$ = resistance.



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### 2.5.2 Half-second Power Rating

The resistor must be capable of withstanding the associated power dissipation due to a fault condition.

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

$$V_f = ( V_k^3 \times R_S \times I_{fs} )^{1/4} \times 1.3 \quad ...(8)$$

where,

$V_f$ = rms voltage across resistor.

$V_K$ = CT knee point voltage.

$R_S$ = 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.

The half-second power rating is given by:

$$P_{half} = V_f^2 / R_S \quad ...(9)$$

where,

$P_{half}$ = half-second power rating.

$V_f$ = rms voltage across resistor.

$R_S$ = resistance.

### 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:

$$V_{pk} = 2 \times ( 2V_k [V_{fs} - V_k] )^{1/2} \quad ...(10)$$

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.

$$V_{fs} = ( I_{tf} / N ) \times ( R_S + R_r ) \quad ...(11)$$

$R_S$ = is the stabilising resistance

$R_r$ = is relay resistance



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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:

**$P = (4 / \pi) \times I_{fs} \times V_k$ ...(12)**

where,

P = Fault power (Watts or Joules/s)

$\pi$ = 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.

The fault energy is determined by the relationship:

**$E = P \times Tf$ ...(13)**

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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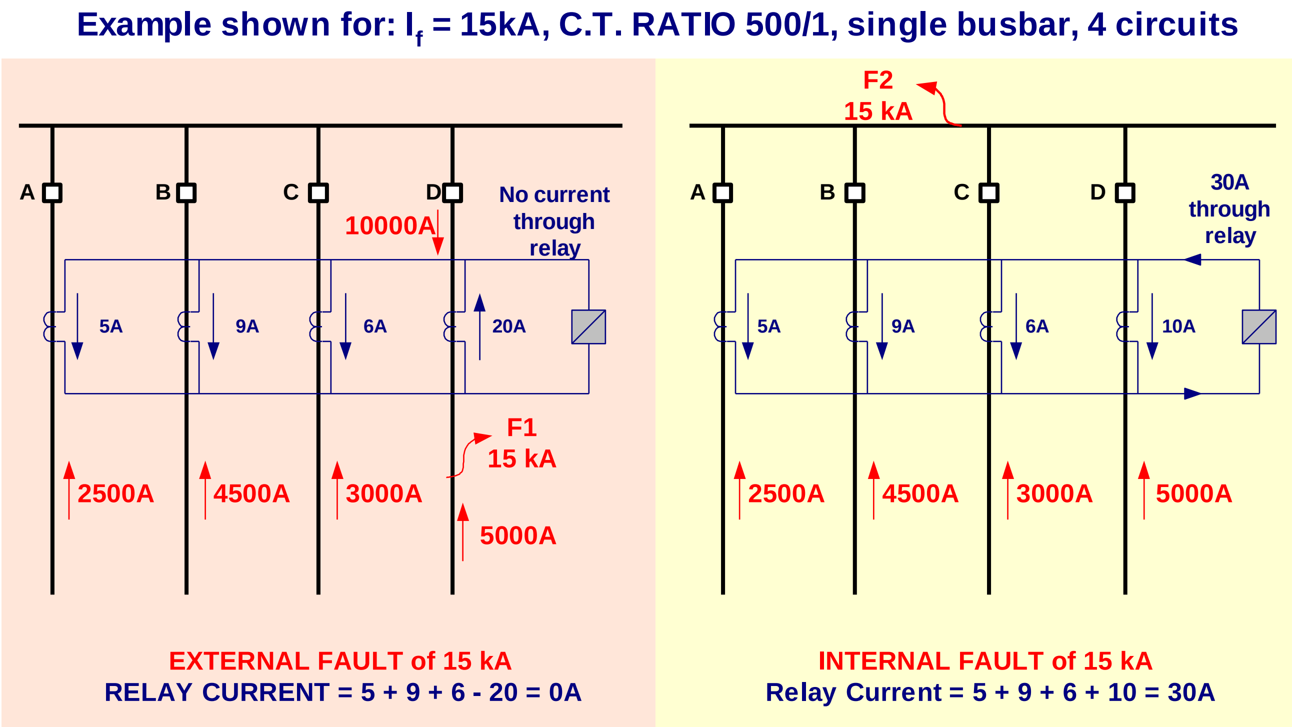
## 3. WORKED EXAMPLE

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 Current Setting (2C73)

Criteria 1

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

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

$I_s$ > $I_{spill}$
> 150mA

Criteria 2

The secondary operating current of the relay circuit is :

**$I_s = I_pT - nI_e$ ...(5)**

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.

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

From eqn (5)

$I_s$ > ( $I_p$ x T ) - n$I_e$
> ( 200A x 1 / 500 ) - 4 x 0.02
> 320mA

To satisfy Criteria 1 and 2 choose $I_s$ = 400mA

i) The 2C73[B][A][*] has a 1A CT input with a current setting range of 200 to 800mA with 7 x 10% plug setting steps.
Select Is = 400mA

ii) The a.c burden < 1.2VA at pickup
Relay voltage is given by $V_r = VA_{RELAY}/I_s$ = 1.2/0.4 = 3 V also $R_r = VA_{RELAY}/( I_s )^2$ = 7.5 Ω

### 3.2 Relay Setting Voltage

Primary through-fault current:

**$I_{tf}$ = $S_{tf}$ / (√3 x $V_{sys}$)**
Itf = 570 x $10^3$kVA / (√3 x 22kV)
$I_{tf}$ = 15,000A



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To ensure stability for through faults apply 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 :

$60V < V_s < 100V$.

### 3.3 Stabilising Resistor

The calculated relay voltage of 3V developed by the 2C73 is insufficient to achieve the derived value of relay setting voltage Vs, thus a series stabilising resistor is required.

Using eqn (6) a resistance range may be derived

**$R_s = V_s/I_s - (VA)/I_s^2$ ...(6)**

For $V_s > 60V$ => $R_s > V_s/I_s - (VA)/I_s^2$
$R_s > (60/0.4A) - (1.2/0.4V) = 147\ \Omega$

For $V_s < 100V$ => $R_s < V_s/I_s - (VA)/I_s^2$
$R_s < (100/0.4A) - (1.2/0.4V) = 247\ \Omega$

Choose $R_s = 200\ \Omega$

Using eqn (6) the relay circuit setting voltage is

$V_s = I_sR_s + VA/I_s$
$= 0.4A \times 200\ \Omega + 1.2VA/0.4A$
$= 83V$

### 3.4 Thermal Rating of Stabilising Resistor

#### 3.4.1 Continuous Power Rating

From eqn (7)
**$P_{con}$ $= (I_{con})^2 R_s$ ...(7)**
$P_{con}$ $= (0.4)^2 \times 200\ \Omega$
$= 32W$ continuously

#### 3.4.2 Half-second Power Rating

From eqn (8)

**$V_f$ $= (V_k^3 \times R_s \times I_{fs})^{1/4} \times 1.3$ ...(8)**

$V_f$ $= (200V^3 \times 200\ \Omega \times 15{,}000A / 500)^{1/4} \times 1.3$
$= 608$ V


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From eqn (9)

**$P_{half}$ = $V_f^2 / R_s$ ...(9)**

$P_{half}$ = 608 V ² / 200 Ω
= 1848W for half a second

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

### 3.5 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.

From eqn (11)

**$V_{fs}$ = $( I_{tf}\ T ) \times ( R_s + R_r )$…(11)**
= ( 15,000 A / 500 ) x ( 200 Ω + 7.5 Ω )
= 6,225 V

From eqn (10)

**$V_{pk}$ = $2 \times (2V_k [V_{fs} - V_k])^{½}$ ...(10)**

= $2 \times (2 \times 200V \times [\ 6{,}225V - 200V\ ])^{½}$
= 3,105 V

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

The fault power is calculated from eqn (12).

**P = $(4 / \pi) \times I_{fs} \times V_k$ ...(12)**

= (4 / π) x (15,000A / 500) x 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 (13).

**E = P x Tf ...(13)**
= 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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