Burdens & Current Transformer Requirements of MiCOM Relays

Application Notes

B&CT/EN AP/B11

CONTENTS

1. ABBREVIATIONS & SYMBOLS

The following abbreviations and symbols are used in this document:

Symbol		Description	Units
ALF	=	Accuracy Limit Factor or K_{ssc}	
ANSI	=	American National Standards Institute	
C	=	IEEE standard C57.13 "C" classification	V
CT	=	Current Transformer	
DT	=	Definite Time	
E/F	=	Earth Fault	
f_{min}	=	Minimum required operating frequency	Hz
f_n	=	Nominal operating frequency	Hz
Idiff>	=	Current setting of P63x biased differential or high impedance REF element	Iref
IDMT	=	Inverse Definite Minimum Time	
IEC	=	International Electrotechnical Commission	
IEEE	=	Institute of Electrical and Electronics Engineers	
I>>	=	Current setting of short circuit element (P220)	I_n
I'_f	=	Maximum internal secondary fault current (may also be expressed as a multiple of I_n)	A
I_f	=	Maximum secondary through fault current	A
I_{fe}	=	Maximum secondary through fault earth current	A
$I_{f\ max}$	=	Maximum secondary fault current (same for all feeders)	A
$I_{f\ max\ int}$	=	Maximum secondary contribution from a feeder to an internal fault	A
$I_{f\ Z1}$	=	Maximum secondary phase fault current at Zone 1 reach point	A
$I_{fe\ Z1}$	=	Maximum secondary earth fault current at Zone 1 reach point	A
I_{fn}	=	Maximum prospective secondary earth fault current or 31 x *I>* setting (whichever is lowest)	A
I_{fp}	=	Maximum prospective secondary phase fault current or 31 x *I>* setting (whichever is lowest)	A
I_n	=	Current transformer nominal secondary current	A
I_{np}	=	Current transformer nominal primary current	A
I_o	=	Earth fault current setting	A
IR,m2	=	Second knee-point bias current threshold setting of P63x biased differential element	Iref
Iref	=	Reference current of P63x calculated from the reference power and nominal voltage	A
Is	=	Current setting of high impedance REF element	A
Is1	=	Differential current pick-up setting of biased differential element	A
Is2	=	Bias current threshold setting of biased differential element	A
I_{sn}	=	Stage 2 and 3 earth fault setting	A
I_{sp}	=	Stage 2 and 3 setting	A
I_{st}	=	Motor start up current referred to CT secondary side	A
K	=	Constant or dimensioning factor (may also be lower case)	
k1	=	Lower bias slope setting of biased differential element	%
k2	=	Higher bias slope setting of biased differential element	%
K_s	=	Dimensioning factor dependent upon through fault current (P521)	
K_{ssc}	=	Short circuit current coefficient or ALF (generally 20)	

Symbol		**Description**	**Units**
K_t	=	Dimensioning factor dependent upon operating time (P521)	
m1	=	Lower bias slope setting of P63x biased differential element	
m2	=	Higher bias slope setting of P63x biased differential element	
N	=	Maximum earth fault current/core balanced CT rated primary current or CT ratio	
n	=	Factor dependent upon location of CT secondary star point	
O/C	=	Overcurrent	
P_n	=	Rotating plant rated single phase power	W
R_b	=	Total external load resistance	Ω
R_{ct}	=	Resistance of current transformer secondary winding	Ω
REF	=	Restricted Earth Fault	
R_l	=	Resistance of single lead from relay to current transformer	Ω
rms	=	Root mean square	
R_r	=	Resistance of any other protective relays sharing the current transformer	Ω
R_{rn}	=	Impedance of relay neutral current input at $30I_n$	Ω
R_{rp}	=	Impedance of relay phase current input at $30I_n$	Ω
R_s	=	Value of stabilising resistor	Ω
SEF	=	Sensitive Earth Fault	
S_{VA}	=	Nominal output	VA
t'	=	Duration of first current flow during auto-reclose cycle	s
T_1	=	Primary system time constant	s
t_{fr}	=	Auto-reclose dead time	s
tIDiff	=	Current differential operating time (P521)	s
T_s	=	Secondary system time constant	s
VA	=	Current transformer rated burden (VA_{ct})	VA
V_c	=	"C" class standard voltage rating	V
V_f	=	Theoretical maximum voltage produced if CT saturation did not occur	V
V_{in}	=	Input voltage e.g. to an opto-input	V
V_k	=	Required CT knee-point voltage	V
V_p	=	Peak voltage developed by CT during internal fault conditions	V
V_s	=	Stability voltage	V
VT	=	Voltage Transformer	
X_t	=	Transformer reactance (per unit)	pu
X/R	=	Primary system reactance/resistance ratio	
X_e/R_e	=	Primary system reactance/resistance ratio for earth loop	
ω	=	system angular frequency	rad

Note: Specific relay settings used in this document are displayed in italics. Refer to the relevent relay Technical Guide for information on setting the relay.

2. INTRODUCTION TO CURRENT TRANSFORMERS

The importance of current transformers in the transmission and distribution of electrical energy cannot be over emphasised. The efficiency of current transformers, and associated voltage transformers, affect the accurate metering and effective protection of transmission and distribution circuits and connected plant.

Current and voltage transformers insulate the secondary (relay, instrument and meter) circuits from the primary (power) circuit and provide quantities in the secondary which are proportional to those in the primary. The role of a current or voltage transformer in protective relaying is not as readily defined as that for metering and instrumentation. Whereas the essential role of a measuring transformer is to deliver from its secondary winding a quantity accurately representative of that which is applied to the primary side, a protective current or voltage transformer varies in its role according to the type of protection it serves.

There is no significant difference between a protective voltage transformer and a measuring voltage transformer, the difference being only in the nature of the voltage transformed. Normally the same transformer can serve both purposes; for provided the protective voltage transformer transforms reasonably accurately, its duty will have been fulfilled. This cannot be said for current transformers as the requirements for protective current transformers are often radically different from those of metering. In some cases the same transformer may serve both purposes but, in modern practice, this is the exception rather than the rule. The primary difference is that the measuring current transformer is required to retain a specified accuracy over the normal range of load currents, whereas the protective current transformer must be capable of providing an adequate output over a wide range of fault conditions, from a fraction of full load to many times full load.

2.1 Current transformer magnetisation

The primary current contains two components. These are the secondary current which is transformed in the inverse ratio of the turns ratio and an exciting current, which supplies the eddy current and hysteresis losses and magnetises the core. This latter current flows in the primary winding only and therefore, is the cause of the transformer errors. The amount of exciting current drawn by a current transformer depends upon the core material and the amount of flux which must be developed in the core to satisfy the burden requirements of the current transformer.

It is, therefore, not sufficient to assume a value of secondary current and to work backwards to determine the value of primary current by invoking the constant ampere-turns rule, since this approach does not take into account the exciting current. In the case when the core saturates, a disproportionate amount of primary current is required to magnetise the core and, regardless of the value of primary current, a secondary current will not be produced.

2.2 Limiting secondary voltage (V_k)

The limiting secondary voltage of the excitation characteristic is defined by IEC as the point at which a 10% increase in secondary voltage produces a 50% increase in exciting current. It may, therefore, be regarded as a practical limit beyond which a specified current ratio may not be maintained as the current transformer enters saturation and is also commonly referred to as the knee-point voltage. In this region the major part of the primary current is utilised to maintain the core flux and since the shunt admittance is not linear, both the exciting and secondary currents depart from a sine wave. The ANSI/IEEE knee-point voltage definition is not identical, as will be discussed later.

2.3 Rated accuracy limit factor

A current transformer is designed to maintain its ratio within specified limits up to a certain value of primary current, expressed as a multiple of its rated primary current. This multiple is known as the current transformer's rated accuracy limit factor (ALF).

3. TYPES OF PROTECTION CURRENT TRANSFORMERS

Generally, there are three different types of CTs:

- High remanence type CT
- Low remanence type CT
- Non remanence type CT

The behaviour of CTs according to different standards but belonging to the same type is in principle the same.

3.1 High remanence CTs

The high remanence type has no given limit for the remanent flux. The CT has a magnetic core without any air gaps and the remanent flux might remain for almost infinite time. The remanent flux can be up to 70-80% of the saturation flux. Typical examples of high remanent type CTs are class P, PX, TPS, TPX according to IEC 60044 and non-gapped class C according to ANSI/IEEE.

3.2 Low remanence CTs

The low remanence type has a specified limit for the remanent flux. The magnetic core is provided with small air gaps to reduce the remanent flux to a level that does not exceed 10% of the saturation flux. Examples are class TPY according to IEC 60044-6 and class PR according to IEC 60044-1.

3.3 Non remanence CTs

The non remanence type CT has practically negligible level of remanent flux. The magnetic core has relatively large air gaps in order to reduce the secondary time constant of the CT (to lower the needed transient factor) which also reduces the remanent flux to practically zero level. An example is class TPZ according to IEC 60044-6.

4. CURRENT TRANSFORMER STANDARDS

The behaviour of inductive CTs in accordance with IEC 60044-1 and IEEE C57.13 is specified for steady state symmetrical AC currents. The more recent standard IEC 60044-6 is the only standard that specifies the performance of inductive CTs (classes TPX, TPY and TPZ) for currents containing exponentially decaying DC components of defined time constant. This section summarises the various classes of CTs.

4.1 IEC 60044-1

4.1.1 Class P

Class P current transformers are typically used for general applications, such as overcurrent protection, where a secondary accuracy limit greatly in excess of the value to cause relay operation serves no useful purpose. Therefore a rated accuracy limit of 5 will usually be adequate. When relays, such as instantaneous ‘high set’ overcurrent relays, are set to operate at high values of overcurrent, say 5 to 15 times the rated current of the transformer, the accuracy limit factor must be at least as high as the value of the setting current used in order to ensure fast relay operation.

Rated output burdens higher than 15VA and rated accuracy limit factors higher than 10 are not recommended for general purposes. It is possible, however, to combine a higher rated accuracy limit factor with a lower rated output and vice versa. When the product of these two exceeds 150, the resulting current transformer may be uneconomical and/or of unduly large dimensions.

Class P current transformers are defined so that, at rated frequency and with rated burden connected, the current error, phase displacement and composite error shall not exceed the values given in the table below.

Accuracy Class	Current Error at Rated Primary Current	Phase Displacement at Rated Primary Current		Composite Error at Rated Accuracy Limit Primary Current
		Minutes	Centiradians	
5P	±1%	±60	±1.8	5%
10P	±3%			10%

4.1.2 Class PR

A current transformer with less than 10% remanence factor due to small air gaps for which, in some cases, a value of the secondary loop time constant and/or a limiting value of the winding resistance may also be specified.

4.1.3 Class PX

A current transformer of low leakage reactance for which knowledge of the transformer secondary excitation characteristic, secondary winding resistance, secondary burden resistance and turns ratio is sufficient to assess its performance in relation to the protective relay system with which it is to be used.

Class PX is the definition in IEC 60044-1 for the quasi-transient current transformers formerly covered by class X of BS 3938, commonly used with unit protection schemes.

Class PX type CTs are used for high impedance circulating current protection and are also suitable for most other protection schemes.

4.2 IEC 60044-6

4.2.1 Class TPS

Protection current transformers specified in terms of complying with class TPS are generally applied to unit systems where balancing of outputs from each end of the protected plant is vital. This balance, or stability during through fault conditions, is essentially of a transient nature and thus the extent of the unsaturated (or linear) zones is of paramount importance. It is normal to derive, from heavy current test results, a formula stating the lowest permissible value of V_k if stable operation is to be guaranteed.

The performance of class TPS current transformers of the low (secondary) reactance type is defined by IEC 60044-6 for transient performance. In short, they shall be specified in terms of each of the following characteristics:

- Rated primary current
- Turns ratio (the error in turns ratio shall not exceed ±0.25%)
- Secondary limiting voltage
- Resistance of secondary winding

Class TPS CTs are typically applied for high impedance circulating current protection.

4.2.2 Class TPX

The basic characteristics for class TPX current transformers are generally similar to those of class TPS current transformers except for the different error limits prescribed and possible influencing effects which may necessitate a physically larger construction. Class TPX CTs have no air gaps in the core and therefore a high remanence factor (70-80% remanent flux). The accuracy limit is defined by the peak instantaneous error during the specified transient duty cycle.

Class TPX CTs are typically used for line protection.

4.2.3 Class TPY

Class TPY CTs have a specified limit for the remanent flux. The magnetic core is provided with small air gaps to reduce the remanent flux to a level that does not exceed 10% of the saturation flux. They have a higher error in current measurement than TPX during unsaturated operation and the accuracy limit is defined by peak instantaneous error during the specified transient duty cycle.

Class TPY CTs are typically used for line protection with auto-reclose.

4.2.4 Class TPZ

For class TPZ CTs the remanent flux is practically negligible due to large air gaps in the core. These air gaps also minimise the influence of the DC component from the primary fault current, but reduce the measuring accuracy in the unsaturated (linear) region of operation. The accuracy limit is defined by peak instantaneous alternating current component error during single energization with maximum DC offset at specified secondary loop time constant.

Class TPZ CTs are typically used for special applications such as differential protection of large generators.

4.3 IEEE C57.13

4.3.1 Class C

The CT design is identical to IEC class 10P but the rating is specified differently. Refer to Appendix B for equivalent ratings and conversion formulae between IEC and IEEE classifications.

5. CHOICE OF CURRENT TRANSFORMER CURRENT RATING

5.1 Primary winding

The current transformer primary rating is usually chosen to be equal to or greater than the normal full load current of the protected circuit to avoid thermal overload and overheating of the CT. Standard primary ratings are given in IEC 60044-1. The maximum ratio of current transformers is typically limited to 3000/1 due to size limitation of the current transformer and, more importantly, the fact that the open circuit voltage would be dangerously high for large current transformer primary ratings, such as those encountered on large turbo alternators (e.g. 5000A). It is standard practice in such applications to use a cascade arrangement, 5000/20A together with 20/1A interposing auxiliary current transformer.

5.2 Secondary winding

The total secondary burden of a current transformer includes not only the internal impedance of the secondary winding, the impedance of the instruments and relays which are connected to it, but also that of the secondary leads. A typical value of rated secondary current is 5A provided that the length of the leads between the current transformers and the connected apparatus does not exceed about 25 metres. Up to this length the additional burden due to the resistance of the pilots is reasonably small in relation to the total output of the transformer. In installations with longer lead lengths, the use of 1A secondaries is sufficient to keep the lead losses within reasonable limits. Losses vary as the square of the current and so are reduced to 1/25th of those for 5A secondaries.

6. BURDENS AND CURRENT TRANSFORMER REQUIREMENTS

6.1 Overcurrent and feeder management protection relays

6.1.1 P111

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.2VA at I_n
	5A	
Earth	1A	< 0.2VA at I_n
	5A	

Auxiliary supply

Case Size	Relay	Nominal Burden*
35mm DIN rail or flush mount	P111	4.5VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	48V	0.5VA
	230V	0.6VA

CURRENT TRANSFORMER REQUIREMENTS

The relay may be installed to directly measure the primary current, where the nominal system voltage is less than 1kV, by passing the primary conductor through the guiding channels in the relay housing.

Where external CTs are used, IEC class P is recommended with an ALF equal to or greater than 10. e.g. 5VA 5P10 or 30VA 10P10.

If a range greater than $10I_n$ is used, then a CT of rated power greater than that calculated should be specified, in order for the ALF at real load to be sufficient (i.e. greater than maximum setting).

For low voltage applications, recommended LV CTs may be ordered with the relay from the manufacturer.

6.1.2 P120 - P123, P125 - P127

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.025VA at I_n
	5A	< 0.3VA at I_n
Earth	1A	< 0.008VA at $0.1I_n$
	5A	< 0.01VA at $0.1I_n$

Voltage circuit

VT Input	V_n	VT Burden
All (P125 - P127)	57 - 130V	0.074W at 57V
		0.38W at 130V
		1.54W at 260V
	220 - 480V	0.1102W at 220V
		0.525W at 480V
		2.1W at 960V

Auxiliary supply

Case Size	Relay	Nominal Burden*	Maximum Burden
Size 4/20TE	P120 - P123, P125	< 3W or 8VA	< 6W or 14VA
Size 6/30TE	P126, P127	< 3W or 8VA	< 6W or 14VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Relay Auxiliary Voltage	Burden
Per energised opto-input	-	10mA
Per energised output contact	-	0.25W or 0.4VA

CURRENT TRANSFORMER REQUIREMENTS

The current transformer requirements are based on a maximum prospective fault current of $50I_n$ and the relay having an instantaneous setting of $25I_n$. These CT requirements are designed to provide operation of all protection elements.

CT specification

Nominal Rating	Nominal Output	Accuracy Class	Accuracy Limit Factor (ALF)	Limiting Lead Resistance
1A	2.5VA	10P	20	1.30Ω
5A	7.5VA	10P	20	0.11Ω

Where the criteria for a specific application are in excess of those detailed above, or the actual lead resistance exceeds the limiting values, the CT requirements may need to be increased according to the formulae in the following sections. For specific applications such as SEF and REF protection, refer to the sections below for CT accuracy class and knee-point voltage requirements as appropriate.

Minimum knee-point voltage

Non-directional/directional DT/IDMT overcurrent and earth fault protection

Time-delayed phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Time-delayed earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq I_{sp} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - residual CT connection

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - core-balance CT connection

Core-balance current transformers of metering class accuracy are required and should have a limiting secondary voltage satisfying the formulae given below:

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Note: It should be ensured that the phase error of the applied core balance current transformer is less than 90 minutes at 10% of rated current and less than 150 minutes at 1% of rated current.

High impedance REF protection

The high impedance REF element shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor.

$$V_k \geq 4 \times Is \times R_s$$

$$R_s = \frac{I_f}{Is} \times (R_{ct} + 2R_l)$$

Note: Class 5P or PX CTs should be used for high impedance REF applications.

High impedance differential protection

The relay can be applied as a high impedance differential protection to 3 phase applications such as busbars, generators, motors etc. The high impedance differential protection shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor.

$$V_k \geq 4 \times Is \times R_s$$

$$R_s = 1.4 \times \frac{I_f}{Is} \times (R_{ct} + 2R_l)$$

Where $X/R \leq 40$ and through fault stability with a transient dc offset in the fault current must be considered, the following equation can be used to determine the required stability voltage.

$$V_s = \left[\left(0.007 \times X/R\right) + 1.05\right] \times I_f \times (R_{ct} + 2R_l)$$

If the calculated stability voltage is less than ($Is \times R_s$) calculated above then it may be used instead.

Note: Class 5P or PX CTs should be used for high impedance differential applications.

6.1.3 P124

This model is available as either:

- Self-powered (P124S) - powered by > $0.2I_n$ secondary current, or;
- Dual-powered (P124D) - powered by either > $0.2I_n$ secondary current or an auxiliary supply.

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	2.5VA
	5A	
Earth	1A	2.5VA
	5A	

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 6/30TE	P124D	3W or 6VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Relay Auxiliary Voltage	Burden
Per energised opto-input (for P124D)	24 to 60V dc	≤ 9mA
	48 to 150V dc	≤ 4.7mA
	130 to 250V dc/ 100 to 250V ac	≤ 2.68mA
Per energised output contact	-	0.25W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	< 10mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

Assuming that the CT does not supply any circuits other than the MiCOM P124, in practice, the following CT types are recommended:

- 5VA 5P10 or 5VA 10P10 (for 1A or 5A secondaries)

6.1.4 P130C, P132, P138, P139

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.1VA
	5A	
Earth	1A	
	5A	

Voltage circuit

VT Input	V_n	VT Burden
	50 - 130V	< 0.3VA rms at 130V

Auxiliary supply

Case Size	Relay	Nominal Burden*	Maximum Burden
Compact	P130C	8W	10W
40TE	P132, P139	12.6W	34.1W
	P138	13W	32W
	P132, P139	14.5W	42.3W
	P138	13W	32W

* Typical minimum burden at 220V dc with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	19 to 110V dc	0.5W ±30%
	> 110V dc	$V_{in} \times 5mA \pm 30\%$

CURRENT TRANSFORMER REQUIREMENTS

CT specification

Nominal Rating	Nominal Output	Accuracy Class	Accuracy Limit Factor (ALF)	Limiting Lead Resistance
1A	2.5VA	10P	20	1.30Ω
5A	7.5VA	10P	20	0.11Ω

Where the criteria for a specific application are in excess of those detailed above, or the actual lead resistance exceeds the limiting values, the CT requirements may need to be increased according to the formulae in the following sections.

Note: The P138 may be applied at low system frequencies of 16⅔Hz or 25Hz. Any VA or knee-point voltage quoted must apply at the chosen nominal frequency (f_n).

Minimum knee-point voltage

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

DT/IDMT overcurrent and earth fault protection

Time-delayed phase overcurrent	$V_k \geq k \times I_{fp} \times (R_{ct} + R_l + R_{rp})$
Time-delayed earth fault overcurrent	$V_k \geq k \times I_{fn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

If the P13x is to be used for definite-time overcurrent protection, then the dimensioning factor, k, that must be selected is a function of the ratio of the maximum short-circuit current to the pick-up value and also of the system time constant, T_1. The required value for k can be read from the empirically determined curves in Figure 1. When inverse-time overcurrent protection is used, k can be determined from Figure 2.

Theoretically, the CT could be dimensioned to avoid saturation by using the maximum value of k, calculated as follows:

$$k \approx 1 + \omega T_1$$
$$= 1 + X/R$$

However, this is not necessary. Instead, it is sufficient to select the dimensioning factor, k, such that the correct operation of the required protection is guaranteed under the given conditions.

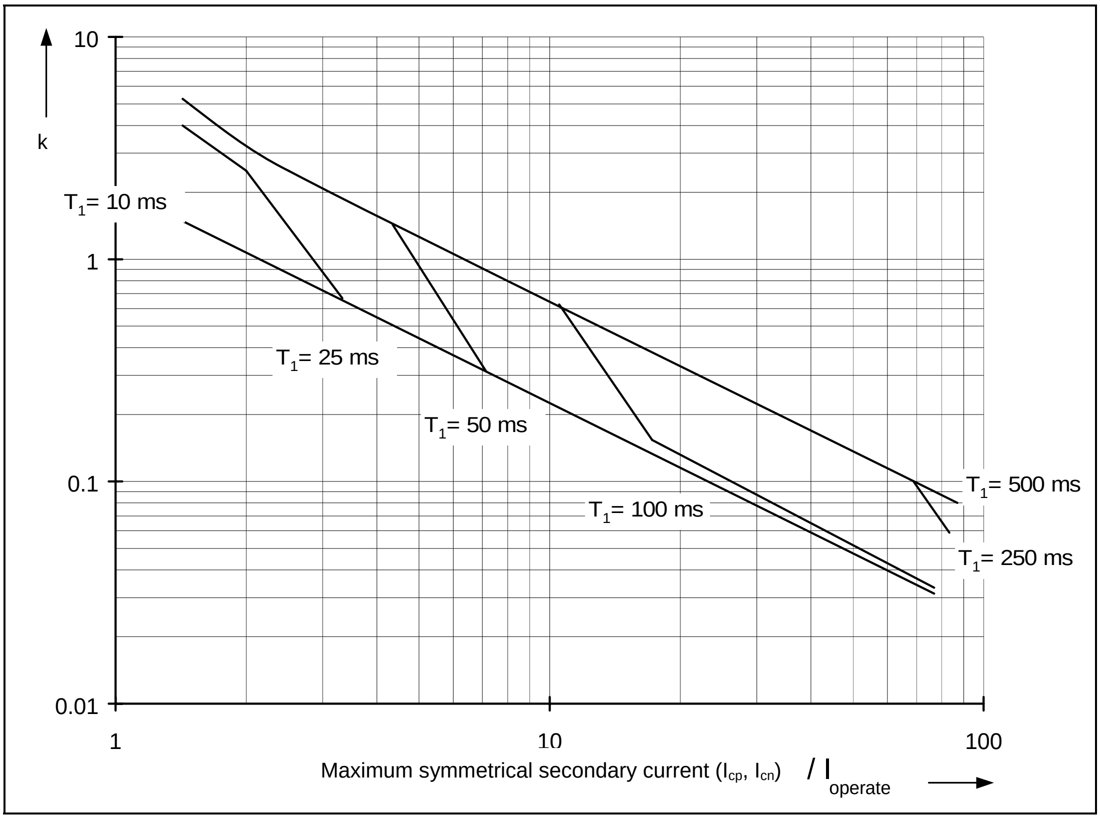


Figure 1: Dimensioning factor, k, for definite time overcurrent protection (f_n = 50Hz)

Note: $T_1 = \frac{X/R}{\omega} = \frac{X/R}{2\pi \times f_n}$ (in seconds)

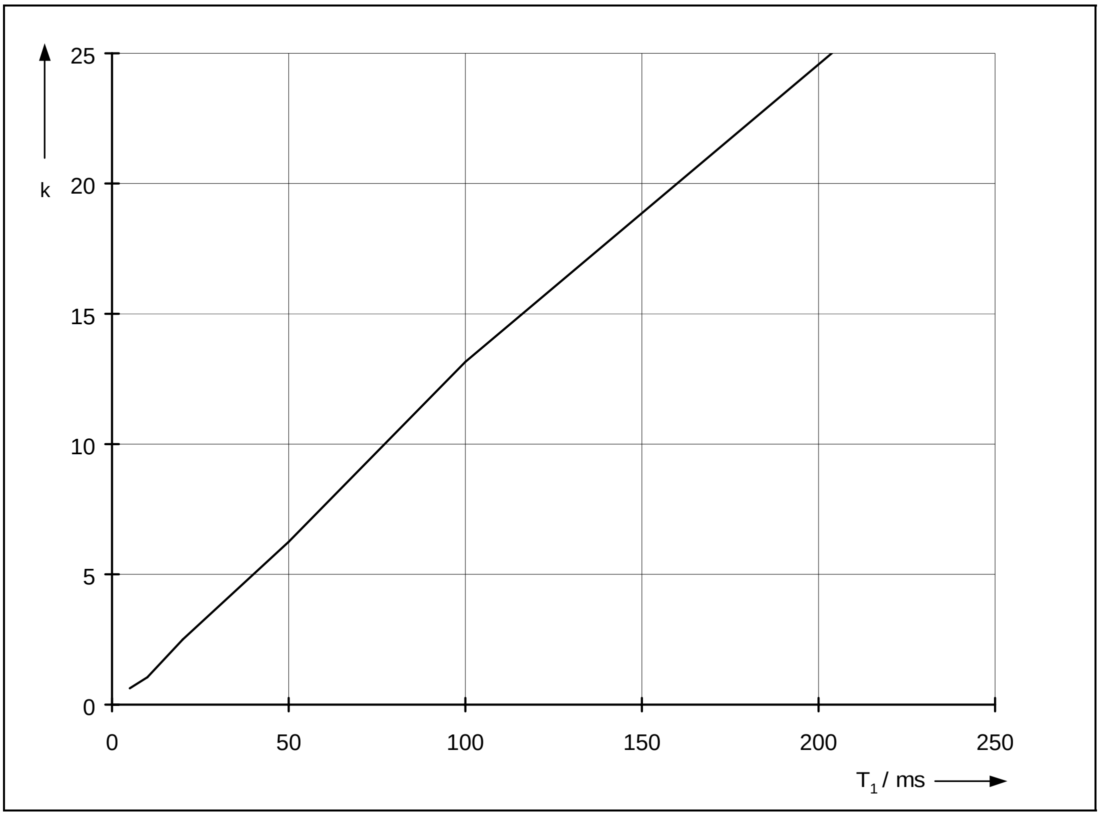


Figure 2: Dimensioning factor, k, for inverse time overcurrent protection (f_n = 50Hz)

6.1.5 P141 - P145

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
All	100 - 120V	< 0.02VA rms at 110V
	380 - 480V	< 0.02VA rms at 440V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P141, P142	11W or 24VA
Size 12/60TE	P143 - P145	11W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W
With optional 10Mbps Ethernet card	-	2.25W
With optional 100Mbps Ethernet card	-	3.75W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

The current transformer requirements are based on a maximum prospective fault current of $50I_n$ and the relay having an instantaneous setting of $25I_n$. These CT requirements are designed to provide operation of all protection elements.

CT specification

Nominal Rating	Nominal Output	Accuracy Class	Accuracy Limit Factor (ALF)	Limiting Lead Resistance
1A	2.5VA	10P	20	1.30Ω
5A	7.5VA	10P	20	0.11Ω

Where the criteria for a specific application are in excess of those detailed above, or the actual lead resistance exceeds the limiting values, the CT requirements may need to be increased according to the formulae in the following sections. For specific applications such as SEF and REF protection, refer to the sections below for CT accuracy class and knee-point voltage requirements as appropriate.

Minimum knee-point voltage

Non-directional/directional DT/IDMT overcurrent and earth fault protection

Time-delayed phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Time-delayed earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq I_{sp} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - residual CT connection

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - core-balance CT connection

Core-balance current transformers of metering class accuracy are required and should have a limiting secondary voltage satisfying the formulae given below:

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Note: It should be ensured that the phase error of the applied core balance current transformer is less than 90 minutes at 10% of rated current and less than 150 minutes at 1% of rated current.

Low impedance REF protection

When $X/R \leq 40$ and $I_f \leq 15I_n$:

$$V_k \geq 24 \times I_n \times (R_{ct} + 2R_l)$$

When $X/R \leq 40$ and $15I_n < I_f \leq 40I_n$ or $40 < X/R \leq 120$ and $I_f \leq 15I_n$:

$$V_k \geq 48 \times I_n \times (R_{ct} + 2R_l)$$

Note: Class 5P or better CTs should be used for low impedance REF applications.

High impedance REF protection

The high impedance REF element shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor.

$$V_k \geq 4 \times Is \times R_s$$

$$R_s = \frac{I_f}{Is} \times (R_{ct} + 2R_l)$$

Note: Class 5P or PX CTs should be used for high impedance REF applications.

High impedance differential protection

The relay can be applied as a high impedance differential protection to 3 phase applications such as busbars, generators, motors etc. The high impedance differential protection shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor.

$$V_k \geq 4 \times Is \times R_s$$

$$R_s = 1.4 \times \frac{I_f}{Is} \times (R_{ct} + 2R_l)$$

Where $X/R \leq 40$ and through fault stability with a transient dc offset in the fault current must be considered, the following equation can be used to determine the required stability voltage.

$$V_s = \left[(0.007 \times X/R) + 1.05\right] \times I_f \times (R_{ct} + 2R_l)$$

If the calculated stability voltage is less than ($Is \times R_s$) calculated above then it may be used instead.

Note: Class 5P or PX CTs should be used for high impedance differential applications.

6.2 Motor protection relays

6.2.1 P210, P211

BURDENS

Auxiliary supply

Case Size	Relay	Nominal Burden*
35mm DIN rail mount	P210	≤ 3.5VA
35mm DIN rail or flush mount	P211	4.5VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	48V	0.5VA
	230V	0.6VA

CURRENT TRANSFORMER REQUIREMENTS

The relay may be installed to directly measure the primary current, where the nominal system voltage is less than 1kV, by passing the primary conductor through the guiding channels in the relay housing.

Where external CTs are used, IEC class P is recommended with an ALF equal to or greater than 10. e.g. 5VA 5P10 or 30VA 10P10.

If a range greater than $10I_n$ is used, then a CT of rated power greater than that calculated should be specified, in order for the ALF at real load to be sufficient (i.e. greater than maximum setting).

For low voltage applications, recommended LV CTs may be ordered with the relay from the manufacturer.

6.2.2 P220, P225

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.025VA at I_n
	5A	< 0.3VA at I_n
Earth	1A	< 0.004VA at $0.1I_n$
	5A	< 0.01VA at $0.1I_n$

Voltage circuit

VT Input	V_n	VT Burden
All	57 - 130V	< 0.1VA at V_n
	220 - 480V	

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 6/30TE	P220, P225	< 3W or 6VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Relay Auxiliary Voltage	Burden
Per energised opto-input	-	< 10mA
Per energised output contact	-	0.25W

CURRENT TRANSFORMER REQUIREMENTS

Zero sequence current, a characteristic of earth faults, can be detected by either a residual connection of the three phase CTs or by the use of a core-balance CT. If the neutral of the motor is earthed through an impedance or isolated from earth in the case of an insulated network, a core-balance CT is preferred as it avoids possible problems with false zero sequence current detection arising from asymmetrical saturation of phase CTs during motor start-up. Starting currents can reach values up to several times (typically 5 – 6 times) the motor rated current. This phenomenon can be aggravated by the magnetisation of CTs when opposing residual fluxes exist in the CTs.

These issues may be overcome by employing suitable earth fault settings and by careful selection of the CTs, but the use of a core-balance transformer is recommended.

Motor Earthing	Recommended	Alternative
Solidly earthed	3 ph CTs (and stabilising resistance*)	3 ph CTs and core-balance CT
Impedance earthed	3 ph CTs and core-balance CT	3 ph CTs (and stabilising resistance*) or 2 ph CTs and core-balance CT
Insulated	3 ph CTs and core-balance CT	2 ph CTs and core-balance CT

* Where a residual CT connection is used, the value of stabilising resistance can be calculated from:

$$R_s = \frac{I_{st}}{I_o} \times (R_{ct} + nR_l + R_{rn})$$

n = 1, for 4 wire CT connection (star point at CTs)
n = 2, for 6 wire CT connection (star point at relay)

The short-circuit current setting, *I*>>, should be set less than 90% of the CT accuracy limit factor. Under these conditions tripping is guaranteed for fault currents up to 50 times the value of saturation current for symmetrical CT current output.

Breaking Device	I_n	IEC 60044-1 Specifications		
		Rated Output Burden (VA)	Accuracy Class	Accuracy Limit Factor (ALF)
Fused contactor	1A	$\geq 0.025 + (2R_l + R_r) \times I_n^2$	5P	10
	5A	$\geq 0.3 + (2R_l + R_r) \times I_n^2$	5P	10
Circuit breaker	1A	$\geq 0.025 + (2R_l + R_r) \times I_n^2$	5P	$\geq \frac{I_{fp}}{50 \times I_n}$
	5A	$\geq 0.3 + (2R_l + R_r) \times I_n^2$	5P	$\geq \frac{I_{fp}}{50 \times I_n}$

Note: A CT with accuracy class 10P may be used instead of 5P, however the thresholds of thermal overload and unbalance protection functions will be less precise. This may be acceptable where the motor has been oversized in relation to its purpose or is not used for heavy duty services.

6.2.3 P241 - P243

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
All	100 - 120V	< 0.06VA rms at 110V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P241	11W or 24VA
Size 12/60TE	P242	11W or 24VA
Size 16/60TE	P243	11W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W
With optional 10Mbps Ethernet card	-	2.25W
With optional 100Mbps Ethernet card	-	3.75W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

The current transformer requirements are based on a maximum prospective fault current of $50I_n$ and the relay having an instantaneous setting of $25I_n$. These CT requirements are designed to provide operation of all protection elements.

CT specification

Nominal Rating	Nominal Output	Accuracy Class	Accuracy Limit Factor (ALF)	Limiting Lead Resistance
1A	2.5VA	10P	20	1.30Ω
5A	7.5VA	10P	20	0.11Ω

Motor differential protection

For IEC standard protection class CTs, it should be ensured that class 5P are used.

6.3 Interconnection and generator protection relays

6.3.1 P341 - P344

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
All	100 - 120V	< 0.06VA rms at 110V
	380 - 480V	< 0.06VA rms at 440V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P341, P342	11W or 24VA
Size 12/60TE	P342, P343	11W or 24VA
Size 16/80TE	P343, P344	11W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

P341 CT requirements

The current transformer requirements are based on a maximum prospective fault current of $50I_n$ and the relay having an instantaneous setting of $25I_n$. These CT requirements are designed to provide operation of all protection elements.

CT specification

Nominal Rating	Nominal Output	Accuracy Class	Accuracy Limit Factor (ALF)	Limiting Lead Resistance
1A	2.5VA	10P	20	1.30Ω
5A	7.5VA	10P	20	0.11Ω

Where the criteria for a specific application are in excess of those detailed above, or the actual lead resistance exceeds the limiting values, the CT requirements may need to be increased according to the formulae in the following sections. For specific applications such as SEF and REF protection, refer to the sections below for CT accuracy class and knee-point voltage requirements as appropriate.

Minimum knee-point voltage

Non-directional/directional DT/IDMT overcurrent and earth fault protection

Time-delayed phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Time-delayed earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq I_{sp} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous overcurrent and earth fault protection

Instantaneous phase overcurrent $V_k \geq \frac{I_{fp}}{2} \times (R_{ct} + R_l + R_{rp})$

Instantaneous earth fault overcurrent $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - residual CT connection

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Non-directional/directional DT/IDMT SEF protection - core-balance CT connection

Core-balance current transformers of metering class accuracy are required and should have a limiting secondary voltage satisfying the formulae given below:

Non-directional/directional time delayed SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Non-directional instantaneous SEF $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rn})$

Directional instantaneous SEF $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Note: It should be ensured that the phase error of the applied core balance current transformer is less than 90 minutes at 10% of rated current and less than 150 minutes at 1% of rated current.

High impedance REF protection

Refer to the high impedance REF protection CT requirements for the P342 – P344 generator protection relays in the following section.

Reverse and low forward power protection

Refer to the reverse and low forward power protection CT requirements for the P342 – P344 generator protection relays in the following section.

P342 - P344 CT requirements

The current transformer requirements for each current input will depend on the protection function with which they are related and whether the line current transformers are being shared with other current inputs. Where current transformers are being shared by multiple current inputs, the knee-point voltage requirements should be calculated for each input and the highest calculated value used.

The P34x is able to maintain all protection functions in service over a wide range of operating frequency due to its frequency tracking system (5–70Hz).

When the P34x protection functions are required to operate accurately at low frequency, it will be necessary to use CTs with larger cores. In effect, the CT requirements need to be multiplied by f_n/f_{min}.

Generator differential protection - biased differential protection

The knee-point voltage requirements for the current transformers used for the current inputs of the generator differential function, with settings of *Is1* =0.05I_n, *k1* =0%, *Is2* =1.2I_n, *k2* =150%, and with a boundary condition of through fault current ≤ 10I_n, is:

$V_K \geq 50I_n (R_{ct} + 2R_L + R_r)$ with a minimum of $\frac{60}{In}$ for X/R <120 If <10In

$V_K \geq 30I_n (R_{ct} + 2R_L + R_r)$ with a minimum of $\frac{60}{In}$ for X/R < 40 If <10In

Where the generator is impedance earthed and the maximum secondary earth fault current is less than I_n then the CT knee point voltage requirements are:

$V_K \geq 25I_n (R_{ct} + R_L + R_r)$ with a minimum of $\frac{60}{In}$ for X/R <60 If <10In

$V_k \geq 30I_n (R_{ct} + R_L + R_r)$ with a minimum of $\frac{60}{In}$ for X/R <100 If <10In, X/R <120 If <5In

$V_k \geq 40I_n (R_{ct} + R_L + R_r)$ with a minimum of $\frac{60}{In}$ for X/R <120 If <10In

For Class-X current transformers, the excitation current at the calculated knee-point voltage requirement should be less than $2.5I_n$ (5% of the maximum prospective fault current, $50I_n$, on which these CT requirements are based). For IEC standard protection class CTs, it should be ensured that class 5P are used.

Generator differential protection - high impedance differential protection

If the generator differential protection function is used to implement high impedance differential protection, then the CT knee-point voltage requirement and value of associated stabilising resistor is:

$$V_k \geq 2 \times Is1 \times R_s$$

$$R_s = 1.5 \times \frac{I_f}{Is1} \times (R_{ct} + 2R_l)$$

Voltage dependent overcurrent, field failure and negative phase sequence protection

When determining the CT requirements for an input that supplies several protection functions, it must be ensured that the most onerous condition is met. This has been taken into account in the formula given below. The formula is equally applicable for CTs mounted at either the neutral-tail end or terminal end of the generator.

$$V_k \geq 20 \times I_n \times (R_{ct} + 2R_l + R_r)$$

For class PX CTs, the excitation current at the calculated knee-point voltage requirement should be less than $1.0I_n$. For IEC standard protection class CTs, it should be ensured that class 5P are used.

Directional sensitive earth fault protection

Residual CT connection

It has been assumed that the directional SEF protection function will only be applied when the stator earth fault current is limited to the stator winding rated current or less. Also assumed is that the maximum X/R ratio for the impedance to a bus earth fault will be no greater than 10. The required minimum knee-point voltage will therefore be:

$$V_k \geq 6 \times I_n \times (R_{ct} + 2R_l + R_r)$$

For class PX CTs, the excitation current at the calculated knee-point voltage requirement should be less than $0.3I_n$ (i.e. less than 5% of the maximum prospective fault current, $20I_n$, on which these CT requirements are based). For IEC standard protection class CTs, it should be ensured that class 5P are used.

Core-balance CT connection

Unlike a line CT, the rated primary current for a core-balance CT may not be equal to the stator winding rated current. This has been taken into account in the formula:

$$V_k > 6 \times N \times I_n \times (R_{ct} + 2R_l + R_r)$$

Note: The maximum earth fault current should not be greater than $2I_n$. i.e. $N \leq 2$. The core-balance CT must be selected accordingly.

Stator earth fault protection

The earth fault current input is used by the stator earth fault protection function.

Non-directional DT/IDMT earth fault protection

Time-delayed earth fault overcurrent elements $V_k \geq \frac{I_{fn}}{2} \times (R_{ct} + 2R_l + R_{rn})$

Non-directional instantaneous earth fault protection

Instantaneous earth fault overcurrent elements $V_k \geq I_{sn} \times (R_{ct} + 2R_l + R_{rn})$

Low impedance REF protection

When $X/R \leq 40$ and $I_f \leq 15I_n$:

$$V_k \geq 24 \times I_n \times (R_{ct} + 2R_l)$$

When $X/R \leq 40$ and $15I_n < I_f \leq 40I_n$ or $40 < X/R \leq 120$ and $I_f \leq 15I_n$:

$$V_k \geq 48 \times I_n \times (R_{ct} + 2R_l)$$

Note: Class PX or 5P CTs should be used for low impedance REF applications.

High impedance REF protection

The high impedance REF element shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor.

$$V_k \geq 4 \times Is \times R_s$$

$$R_s = \frac{I_f}{Is} \times (R_{ct} + 2R_l)$$

Reverse and low forward power protection

For both reverse and low forward power protection function settings greater than 3% P_n, the phase angle errors of suitable protection class current transformers will not result in any risk of maloperation or failure to operate. However, for the sensitive power protection if settings less than 3% are used, it is recommended that the current input is driven by a correctly loaded metering class current transformer.

Protection class current transformers

For less sensitive power function settings (>3% P_n), the phase current input of the P34x should be driven by a correctly loaded class 5P protection current transformer.

To correctly load the current transformer, its VA rating should match the VA burden (at rated current) of the external secondary circuit through which it is required to drive current.

Metering class current transformers

For low power settings (<3% P_n), the I_n sensitive current input of the P34x should be driven by a correctly loaded metering class current transformer. The current transformer accuracy class will be dependent on the reverse power and low forward power sensitivity required. The table below indicates the metering class current transformer required for various power settings below 3% P_n.

To correctly load the current transformer, its VA rating should match the VA burden (at rated current) of the external secondary circuit through which it is required to drive current. Use of the P34x sensitive power phase shift compensation feature will help in this situation.

Reverse and Low Forward PowerSettings %Pn	Measuring CT Class
0.5	0.1
0.6	
0.8	0.2
1.0	
1.2	
1.4	
1.6	0.5
1.8	
2.0	
2.2	
2.4	
2.6	
2.8	
3.0	1.0.

6.4 Distance protection relays

6.4.1 P430C, P432, P433, P435, P436, P437, P438, P439

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.1VA
	5A	
Earth	1A	
	5A	

Voltage circuit

VT Input	V_n	VT Burden
	50 - 130V	< 0.3VA rms at 130V

Auxiliary supply

Case Size	Relay	Nominal Burden*	Maximum Burden
Compact	P430C	4W	8W
40TE	P433, P435, P439	13W	29W
	P436	13W	37W
84TE	P433, P435, P437, P438, P439	13W	37W
	P432	13W	40W

* Typical minimum burden at 220V dc with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	19 to 110V dc	0.5W ±30%
	> 110V dc	$V_{in} \times$ 5mA ±30%

CURRENT TRANSFORMER REQUIREMENTS

CT specification

The current transformers should comply with the IEC 60044-1 class 5P fault limit values. If auto-reclosing is used, it is advantageous to use class TPY current transformers conforming to IEC 60044-6 Part 6 (current transformers having anti-remanence cores).

Note: The P436 and P438 may be applied at low system frequencies of 16⅔Hz or 25Hz. Any VA or knee-point voltage quoted must apply at the chosen nominal frequency (f_n).

Minimum knee-point voltage

Distance protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

Phase fault distance protection $V_k \geq k \times I_{fp} \times (R_{ct} + R_l + R_{rp})$

Earth fault distance protection $V_k \geq k \times I_{fn} \times (R_{ct} + 2R_l + R_{rp} + R_{rn})$

Theoretically, the CT could be dimensioned to avoid saturation by using the maximum value of k, calculated as follows:

$$k \approx 1 + \omega T_1$$
$$= 1 + X/R$$

However, this is not necessary. Instead, it is sufficient to select the dimensioning factor, k, such that the correct operation of the required protection is guaranteed under the given conditions.

The required dimensioning factor, k, for distance protection if auto-reclosing is not used can be obtained from Figure 3. The dotted line represents the theoretical characteristic maximum k = 1+ X/R.

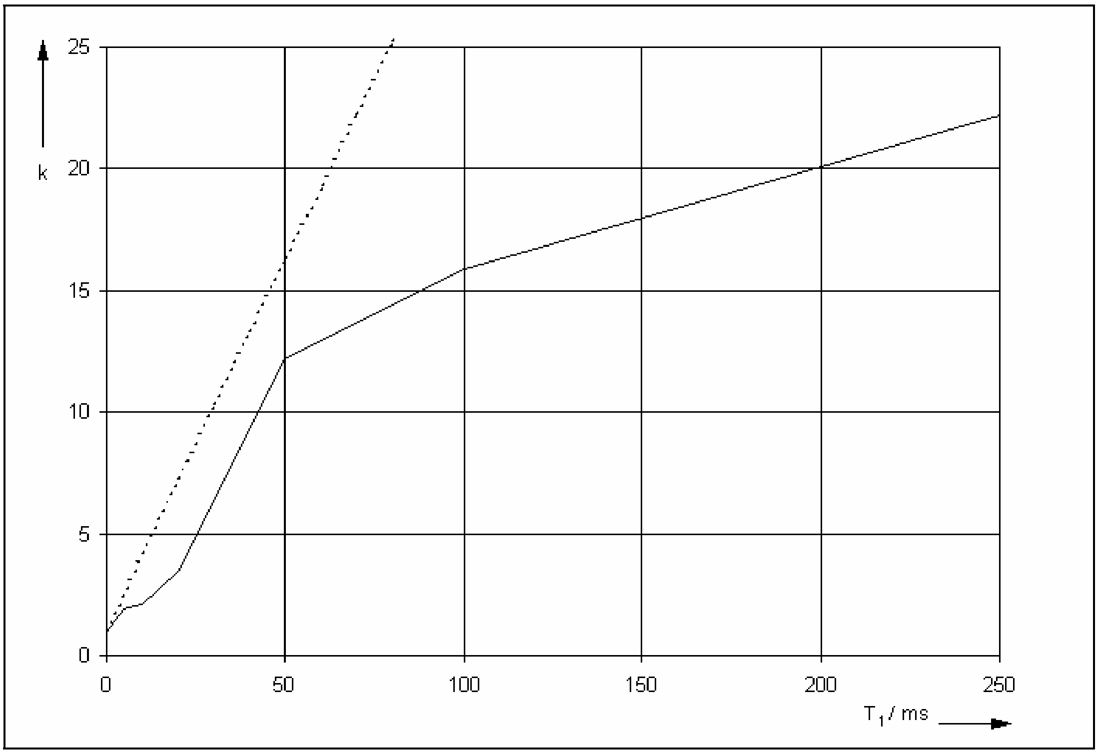


Figure 3: Dimensioning factor, k, for distance protection (f_n = 50Hz)

Note: $T_1 = \frac{X/R}{\omega} = \frac{X/R}{2\pi \times f_n}$ (in seconds)

This CT requirement ensures tripping of the distance element within 120ms at 95% of the set zone reach.

If auto-reclosing is used, the dimensioning factor k for the CTs is increased as follows:

$$k + \left[1 + \omega \cdot T_1 \cdot \left(1 - e^{-\frac{t'}{T_1}}\right)\right] \cdot e^{-\frac{t_{fr}}{T_s}}$$

6.4.2 P441, P442, P444

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
	100 - 120V	< 0.03VA rms at 110V

Auxiliary supply

Case Size	Relay	Nominal Burden*	Maximum Burden
Size 8/40TE	P441	15W or 16VA	20W or 20VA
Size 12/60TE	P442	18W or 19VA	26W or 26VA
Size 16/80TE	P444	21W or 22VA	

* Typical burden with half of the opto-inputs and one output contact per board energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W
With optional 10Mbps Ethernet card	-	2.25W
With optional 100Mbps Ethernet card	-	3.75W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	$>$ 3.5mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

For accuracy, class PX or 5P CTs are recommended.

Minimum knee-point voltage

Distance protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

Phase fault distance protection

$$V_k \geq 0.6 \times I_{f\ Z1} \times (1 + X/R) \times (R_{ct} + R_l)$$

Earth fault distance protection

$$V_k \geq 0.6 \times I_{fe\ Z1} \times (1 + X_e/R_e) \times (R_{ct} + 2R_l)$$

The required knee-point voltage must be calculated for the three phase fault current at the Zone 1 reach and also for the earth fault current at the Zone 1 reach. The higher of the two calculated knee-point voltages is used.

6.4.3 P443, P445 (MiCO*Mho*)

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
Phase	100 - 120V	< 0.02VA rms at $\frac{110}{\sqrt{3}}$V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P445	12W or 24VA
Size 12/60TE		
Size 16/80TE	P443	12W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W
With optional InterMiCOM communications	-	1.25W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

For accuracy, class PX or 5P CTs are recommended.

Minimum knee-point voltage

Distance protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

Zone 1 reach point accuracy

$$V_k \geq 0.6 \times I_{f\ Z1} \times (1 + X/R) \times (R_{ct} + R_l)$$

Zone 1 close-up fault operation

$$V_k \geq 1.4 \times I_{f\ max} \times (R_{ct} + R_l)$$

The higher of the two calculated knee-point voltages is used. It is not necessary to repeat the calculation for earth faults, as the phase reach (3∅) calculation is the worst case for CT dimensioning.

6.5 Current differential protection relays

Selection of X/R ratio and fault level

The value of X/R ratio and fault level will vary from one system to another, but selecting the correct value for the CT requirements is critical. In the case of single end fed (radial) systems the through fault level and X/R ratio should be calculated assuming the fault occurs at the location of the remote CT. For systems where the current can feed through the protected feeder in both directions, such as parallel feeders and ring main circuits, further consideration is required. In this case the fault level and X/R ratio should be calculated at both the local and remote CTs. In doing so the X/R ratio and fault level will be evaluated for both fault directions. The CT requirements, however, should be based upon the fault direction that gives the highest knee-point voltage. Under no circumstances should the X/R ratio from one fault direction and the fault level from the other be used to calculate the knee-point. Doing so may result in exaggerated and unrealistic CT requirements.

6.5.1 P521

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.025VA at I_n
	5A	< 0.3VA at I_n
Earth	1A	< 0.008VA at $0.1I_n$
	5A	< 0.01VA at $0.1I_n$

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 6/30TE	P521	3W or 6VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	-	10mA
Per energised output contact	-	0.4W or 0.4VA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

For accuracy, class PX or 5P CTs are recommended.

Minimum knee-point voltage

Current differential protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

$$V_k \geq K_s \times K_t \times I_n \times (R_{ct} + 2R_l)$$

K_s is a constant depending on the maximum value of through fault current (as a multiple of I_n) and the primary system X/R ratio. K_s is determined as follows:

When $X/R < 40$:

$$K_s = \left[0.023 \times I_f \times (X/R + 55)\right] + \left[0.9 \times (X/R + 26)\right]$$

When $X/R \geq 40$:

$$K_s = \left[0.024 \times I_f \times (X/R + 44)\right] + \left[0.06 \times (X/R + 725)\right]$$

K_t is a constant depending on the current differential operating time (*tIDiff*) and the primary system X/R ratio.

For applications where the CT knee-point voltage is fixed (e.g. a retrofit application where the CTs are already installed), it may be possible to reduce the CT requirements by adding a small time delay to the relay. The *tIDiff* setting allows the user to increase the relay operating time thus making the relay more stable. For some applications a time setting of 50ms may reduce the required CT knee-point voltage by as much as 30%. Further reductions in CT knee-point are possible with longer time delays.

For applications where the relay is set for instantaneous operation, i.e. *tIDiff* =0s, K_t =1. When a time delay is applied, K_t is determined as follows:

When $X/R < 40$:

$$K_t = 1 - \left(6.2 \times tIDiff\right) \quad \text{for } tIDiff \leq 0.15\text{s}$$

$$K_t = 0.07 \quad \text{for } tIDiff > 0.15\text{s}$$

When $X/R \geq 40$:

$$K_t = 1 - \left(2.5 \times tIDiff\right) \quad \text{for } tIDiff \leq 0.25\text{s}$$

SEF protection

Core-balance CT connection

Core-balance CTs of metering class accuracy are required and should have a knee-point voltage satisfying the following formula:

$$V_k \geq I_{fn} \times (R_{ct} + 2R_l + R_{rn})$$

6.5.2 P541 - P546

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Voltage circuit

VT Input	V_n	VT Burden
All (P543 - P546)	100 - 120V	< 0.02VA rms at 110V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P541	11W or 24VA
Size 12/60TE	P542 - P544	11W or 24VA
Size 16/80TE	P545, P546	11W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W
With optional 10Mbps Ethernet card	-	2.25W
With optional 100Mbps Ethernet card	-	3.75W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

For accuracy, class PX or 5P CTs are recommended.

Minimum knee-point voltage

Current differential protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

$$V_k \geq K \times I_n \times (R_{ct} + 2R_l)$$

K is a constant depending on the maximum value of through fault current, I_f (as a multiple of I_n) and the primary system X/R ratio. K is determined as follows:

For relays set at *Is1* =0.2I_n, *k1* =30%, *Is2* =2I_n, *k2* =150% (*k2* typically set at 150% for two-ended current differential schemes):

When $(I_f \times X/R) \leq 1000 \times I_n$:

$$K \geq 40 + 0.07 \times (I_f \times X/R)$$
$$\& \quad K \geq 65$$

When $1000 \times I_n < (I_f \times X/R) \leq 1600 \times I_n$:

$$K = 107$$

For relays set at *Is1* =0.2I_n, *k1* =30%, *Is2* =2I_n, *k2* =100% (*k2* typically set at 100% for three-ended current differential schemes):

When $(I_f \times X/R) \leq 600 \times I_n$:

$$K \geq 40 + 0.35 \times (I_f \times X/R)$$
$$\& \quad K \geq 65$$

When $600 \times I_n < (I_f \times X/R) \leq 1600 \times I_n$:

$$K = 256$$

Earth fault protection

Core-balance CT connection

$$V_k \geq 6 \times N \times I_n \times (R_{ct} + 2R_l)$$

Note: Applicable when $X/R \leq 5$ and the maximum earth fault current is not greater than $2I_n$. i.e. $N \leq 2$. The core-balance CT must be selected accordingly.

6.5.3 P547

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P547	15W

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W
With optional 2nd rear communications	-	1.25W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

For accuracy, class PX or 5P CTs are recommended.

Minimum knee-point voltage

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

$$V_k \geq I_f \times \left[1 + \left(0.15 \times X/R\right)\right] \times \left(R_{ct} + 2R_l\right)$$

6.5.4 P591 - P595

Auxiliary supply

Case Size	Relay	Nominal Burden
Size 4/20TE	P591 - P594	4W
Compact	P595	7.8W at 220V dc

6.6 Transformer differential protection relays

6.6.1 P630C, P631 - P634, P638

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.1VA
	5A	
Earth	1A	
	5A	

Voltage circuit

VT Input	V_n	VT Burden
	50 - 130V	< 0.3VA rms at 130V

Auxiliary supply

Case Size	Relay	Nominal Burden*	Maximum Burden
Compact	P630C	8W	10W
40TE	P631 - P633	12.6W	34.1W
84TE	P632 - P634	14.5W	42.3W
	P638	13W	32W

* Typical minimum burden at 220V dc with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	19 to 110V dc	0.5W ±30%
	> 110V dc	V_{in} × 5mA ±30%

CURRENT TRANSFORMER REQUIREMENTS

CT specification

IEC 60044-1 accuracy class 5P or equivalent.

Note: The P638 may be applied at low system frequencies of 16⅔Hz or 25Hz. Any VA or knee-point voltage quoted must apply at the chosen nominal frequency (f_n).

Minimum knee-point voltage

Differential protection

The required knee-point voltage must be calculated for phase fault current and also for the earth fault current. The higher of the two calculated knee-point voltages is used.

The CT requirements are based on the default settings. For transformer differential protection; *Idiff>* = 0.2 Iref, *m1* = 0.3, *m2* = 0.7, *IR,m2* = 4 Iref, and for busbar differential protection; *Idiff>* = 1.2 Iref, *m1* = 0.2, *m2* = 0.8, *IR,m2* = 1.8 Iref.

Phase fault differential protection $V_k \geq K \times (R_{ct} + R_l)$

Earth fault differential protection $V_k \geq K_e \times (R_{ct} + 2R_l)$

K is a constant depending on the maximum value of through fault current (as a multiple of I_n) and the primary system X/R ratio. For phase faults, K is determined as follows:

When $(I_f \times X/R) \leq 500 \times I_n$:

$$K = 0.14 \times (I_f \times X/R)$$

When $500 \times I_n < (I_f \times X/R) < 1200 \times I_n$:

$$K = 70$$

For earth faults, K_e is determined as follows:

When $(I_{fe} \times X/R) \leq 500 \times I_n$:

$$K_e = 0.14 \times (I_{fe} \times X/R)$$

When $500 \times I_n < (I_{fe} \times X/R) < 1200 \times I_n$:

$$K_e = 70$$

Typical knee-point voltage requirement for transformer differential protection

The through fault stability required for most transformer applications is determined by the external through fault current and transformer X/R ratio. The through fault current in all but ring bus or mesh fed transformers is given by the inverse of the per unit reactance of the transformer. For most transformers, the reactance varies between 0.05 to 0.1pu, therefore typical through fault current is given by 10 to $20I_n$.

For conventional transformers (non-autotransformer), the X/R ratio is typically 7. This cancels out the 0.14 multiplier, leaving only the maximum secondary through fault current (I_f) to multiply with the loop resistance, giving:

$$V_k \geq I_f \times (R_{ct} + 2R_l)$$

Alternatively, as a conservative estimate:

$$V_k \geq \frac{(R_{ct} + 2R_l)}{X_t}$$

Low impedance REF protection

The CT requirements for low impedance REF protection are generally lower than those for differential protection. As the line CTs for low impedance REF protection are the same as those used for differential protection the differential CT requirements cover both differential and low impedance REF applications.

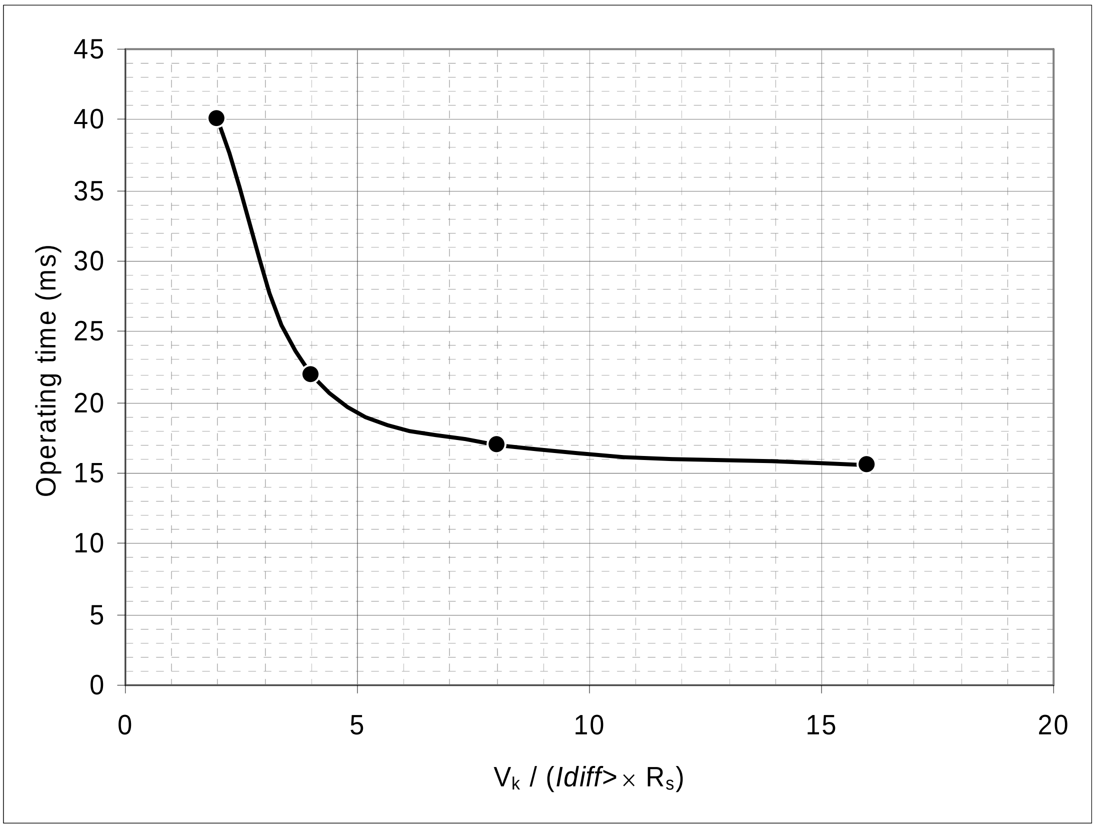
High impedance REF protection

The high impedance REF element shall maintain stability for through faults and operate in less than 40ms for internal faults provided the following conditions are met in determining the CT requirements and value of associated stabilising resistor:

$$V_k > 2 \times \mathit{Idiff>} \times R_s$$

$$R_s = 1.1 \times \frac{I_f}{\mathit{Idiff>}} \times (R_{ct} + 2R_l)$$

For faster operation of the REF element, a larger knee-point voltage will provide reduced operating times. Refer to the graph below showing the operating time of the REF element for differing ratios.



Note: The diagram is the result of investigations which were carried out for impedance ratios in the range of 5 to 120 and for fault currents in the range of 0.5 to 40 In.

6.7 Busbar protection relays

6.7.1 P741 - P743

BURDENS

Current circuit

	I_n	CT Burden
VA Burden	1A	<0.04VA at rated current
	5A	<0.01VA at rated current
Impedance	1A	<40mΩ over 0 - 30In
	5A	<8mΩ over 0 - 30In

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P742	16 - 23W
Size 12/60TE	P743	22 - 32W
Size 16/80TE	P741 (with all comms boards)	37 - 41W

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

The characteristics of the CTs are set in each peripheral unit (P742/P743), therefore allowing different classes of CTs to be used in the same scheme. The following CT specifications may be used:

IEC 60044-1 class 5P or PX (equivalent to BS 3938 class X)

IEC 60044-6 class TPX, TPY or TPZ

IEEE C57.13 class C.

Note: The following knee-point requirements can be converted to an equivalent C voltage classification as per Appendix B.

Minimum knee-point voltage

Differential protection

The knee-point voltage of the CTs should comply with the minimum requirements of the formulae shown below.

$$V_k \geq 0.5 \times I_{f\,max} \times (R_{ct} + 2R_l)$$

And for each CT:

$$V_k \geq I_{f\,max\,int} \times (R_{ct} + 2R_l)$$

The recommended specification makes it possible to guarantee a saturation time greater than 1.4ms with a remanent flux of 80% of maximum flux (class TPX). This provides a sufficient margin of security for CT saturation detection.

6.8 Circuit breaker fail protection relay

6.8.1 P821

BURDENS

Current circuit

CT Input	I_n	CT Burden
Phase	1A	< 0.025VA at I_n
	5A	< 0.3VA at I_n
Earth	1A	< 0.008VA at $0.1I_n$
	5A	< 0.01VA at $0.1I_n$

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 4/20TE	P821	2W or 5VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	-	< 10mA
Per energised output contact	-	0.25W or 0.4VA

CURRENT TRANSFORMER REQUIREMENTS

CT specification

Assuming that the CT does not supply any circuits other than the MiCOM P821, in practice, the following CT types are recommended:

- 5VA 5P10 (for 1A or 5A secondaries)

6.9 Voltage and frequency protection relays

6.9.1 P921 - P923

BURDENS

Voltage circuit

VT Input	V_n	VT Burden
All	57 - 130V	< 0.25VA
	220 - 480V	< 0.36VA

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 4/20TE	P921 - P923	3W

* Nominal is with 50% of the opto-inputs energised and one output contact per card energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Relay Auxiliary Voltage	Burden
Per energised opto-input	24 to 60V dc	10mA
	48 to 125V dc	5mA
	130 to 250V dc	2.5mA
Per energised output contact	-	0.25W or 0.4VA

6.9.2 P941 - P943

BURDENS

Voltage circuit

VT Input	V_n	VT Burden
All	100 - 120V	< 0.02VA rms at 110V
	380 - 480V	< 0.15VA rms at 440V

Auxiliary supply

Case Size	Relay	Nominal Burden*
Size 8/40TE	P941, P942	11W or 24VA
Size 12/60TE	P943	11W or 24VA

* Typical minimum burden with no opto-inputs or output contacts energised. See below for additional burdens.

Additional burdens on auxiliary supply

Additional Burden	Energising Voltage	Burden
Per energised opto-input	24 to 54V dc	0.09W
	110 to 125V dc	0.12W
	220 to 250V dc	0.19W
Per energised output contact	-	0.13W

Opto-inputs

Energising Voltage	Peak Current
0 to 300V dc	3.5mA

7. APPENDIX A

7.1 Converting an IEC 60044-1 protection classification to a limiting secondary voltage

The suitability of a standard protection current transformer can be checked against the limiting secondary voltage requirements, specified in this document.

An estimated limiting secondary voltage can be obtained as follows:

$$V_k \approx \frac{VA \times ALF}{I_n} + \left(ALF \times I_n \times R_{ct}\right)$$

If R_{ct} is not available, then the second term in the above equation can be ignored as it typically only adds a small amount to the estimated secondary limiting voltage.

To ensure that the current transformer has a high enough rating for the relay's burden it is necessary to work out the current transformer's continuous VA rating using the following formula:

$$VA_{ct} > I_n^2 \times (R_l + R_r)$$

Example 1:

An estimate of the secondary limiting voltage of a 400/5A current transformer of class 5P 10 with a rated output burden of 15VA and a secondary winding resistance of 0.2Ω will be:

$$V_k \approx \frac{15 \times 10}{5} + 10 \times 5 \times 0.2$$
$$= 40V$$

Example 2:

For a particular application of a 1A MiCOM overcurrent relay it is required to determine the most appropriate class P current transformer to be used. The secondary limiting voltage required has been calculated at 87.3V using a current transformer secondary winding resistance of 2Ω.

The current transformer rated output burden must be:

$$VA_{ct} \geq I_n^2 \times (R_l + R_r)$$
$$\geq 1^2 \times (1 + 0.025)$$
$$\geq 1.025VA$$

The nearest rating above this will be 2.5VA.

The accuracy limit factor required can be determined by:

$$V_k = \frac{VA \times ALF}{I_n} + ALF \times I_n \times R_{ct}$$
$$87.3 = \frac{2.5 \times ALF}{1} + ALF \times 1 \times 2$$
$$= 4.5 \times ALF$$
$$ALF = \frac{87.3}{4.5}$$
$$= 19.4$$

The nearest accuracy limit factor above 19.4 is 20.

Therefore the current transformer required to supply the MiCOM overcurrent relay will be a 2.5VA 10P 20. (i.e. 2.5VA is the rated burden, 10 (%) is the nominal accuracy class, 20 is the ALF).

8. APPENDIX B

8.1 Converting IEC 60044-1 standard protection classification to IEEE standard voltage rating

The MiCOM series protection relays are compatible with ANSI/IEEE CTs as specified in the IEEE C57.13 standard. The applicable class for protection is class "C", which specifies a non air-gapped core. The CT design is identical to IEC class P but the rating is specified differently.

The IEEE C class standard voltage rating required will be lower than an IEC knee-point voltage. This is because the IEEE voltage rating is defined in terms of useful output voltage at the terminals of the CT, whereas the IEC knee-point voltage includes the voltage drop across the internal resistance of the CT secondary winding added to the useful output. The IEC knee-point is also typically 5% higher than the IEEE knee-point.

Where IEEE standards are used to specify CTs, the C class voltage rating can be checked to determine the equivalent knee-point voltage (V_k) according to IEC. The equivalence formula is:

$$\begin{aligned} V_k &= (C \times 1.05) + (K_{ssc} \times I_n \times R_{ct}) \\ &= (C \times 1.05) + (100 \times R_{ct}) \end{aligned}$$

Note: IEEE CTs are always 5A secondary rated, i.e. I_n =5A, and are defined with an accuracy limit factor of 20, i.e. K_{ssc} =20.

The following table allows C57.13 ratings to be converted to a typical IEC knee-point voltage:

CT Ratio	R_{ct}*	IEEE C57.13 C Classification				
		C50	C100	C200	C400	C800
		V_k	V_k	V_k	V_k	V_k
100/5	0.04Ω	56.5V	109V	214V	424V	844V
200/5	0.08Ω	60.5V	113V	218V	428V	848V
400/5	0.16Ω	68.5V	121V	226V	436V	856V
800/5	0.32Ω	84.5V	137V	242V	452V	872V
1000/5	0.40Ω	92.5V	145V	250V	460V	880V
1500/5	0.60Ω	112.5V	165V	270V	480V	900V
2000/5	0.80Ω	132.5V	185V	290V	500V	920V
3000/5	1.20Ω	172.5V	225V	330V	540V	960V

* Assuming 0.002   /turn typical secondary winding resistance for 5A CTs.

9. APPENDIX C

9.1 Use of METROSIL non-linear resistors

“Metrosils” (non-linear resistors) are used to limit the peak voltage developed by the current transformers under internal fault conditions, to a value below the insulation level of the current transformers, relay and interconnecting leads, which are normally able to withstand 3000V peak.

The following formulae should be used to estimate the peak transient voltage (V_p) that could be produced for an internal fault. The peak voltage produced during an internal fault will be a function of the current transformer knee-point voltage and the prospective voltage (V_f) that would be produced for an internal fault if current transformer saturation did not occur.

$$V_p = 2\sqrt{2 \times V_k \times (V_f - V_k)}$$

$$V_f = I'_f \times (R_{ct} + 2R_l + R_s)$$

When the value given by the formulae is greater than 3000V peak, Metrosils should be applied. They are connected across the relay circuit and serve the purpose of shunting the secondary current output of the current transformer from the relay in order to prevent very high secondary voltages.

Metrosils are externally mounted and take the form of annular discs. Their operating characteristics follow the expression:

$$V = C \times I^{0.25}$$

where V = Instantaneous voltage applied to the Metrosil

C = Characteristic constant of the Metrosil

I = Instantaneous current through the Metrosil

With a sinusoidal voltage applied across the Metrosil, the RMS current would be approximately 0.52 times the peak current. This current value can be calculated as follows:

$$I_{(rms)} = 0.52 \times \left(\frac{\sqrt{2} \times V_{sin(rms)}}{C} \right)^4$$

where $V_{sin(rms)}$ = rms value of the sinusoidal voltage applied across the Metrosil.

This is due to the fact that the current waveform through the metrosil is not sinusoidal but appreciably distorted.

For satisfactory application of a Metrosil, it's characteristic should be such that it complies with the following requirements:

1. At the relay voltage setting, the Metrosil current should be as low as possible and no greater than ≈ 30mA rms for 1A CTs and ≈ 100mA rms for 5A CTs.

2. At the maximum secondary current, the Metrosil should limit the voltage to 1500V rms or 2120V peak for 0.25s. At higher relay voltage settings, it is not always possible to limit the fault voltage to 1500V rms, so higher fault voltages may have to be tolerated.

The following tables show the typical Metrosil types that will be required, depending on relay current rating, REF voltage setting etc.

Metrosil units for relays using 1A CTs

The Metrosil units for 1A CTs have been designed to comply with the following restrictions:

1. At the relay voltage setting, the Metrosil current should be less than 30mA rms.

2. At the maximum secondary internal fault current the Metrosil should limit the voltage to 1500V rms if possible.

The Metrosil units normally recommended for use with 1A CTs are as shown in the following table:

Relay Voltage Setting	Nominal Characteristic		Recommended Metrosil Type	
	C	β	Single Pole Relay	Triple Pole Relay
Up to 125V rms	450	0.25	600A/S1/S256	600A/S3/1/S802
125 - 300V rms	900	0.25	600A/S1/S1088	600A/S3/1/S1195

Note: Single pole Metrosil units are normally supplied without mounting brackets unless otherwise specified by the customer.

Metrosil units for relays using 5A CTs

These Metrosil units have been designed to comply with the following requirements:

1. At the relay voltage setting, the Metrosil current should be less than 100mA rms (the actual maximum currents passed by the units is shown below their type description).

2. At the maximum secondary internal fault current the Metrosil unit should limit the voltage to 1500V rms for 0.25s. At the higher relay settings, it is not possible to limit the fault voltage to 1500V rms hence higher fault voltages have to be tolerated (indicated by *, **, ***).

The Metrosil units normally recommended for use with 5A CTs and single pole relays are as shown in the following table:

Secondary Internal Fault Current	Recommended Metrosil Type			
	Relay Voltage Setting			
	Up to 200V rms	250V rms	275V rms	300V rms
50A rms	600A/S1/S1213 C = 540/640 35mA rms	600A/S1/S1214 C = 670/800 40mA rms	600A/S1/S1214 C = 670/800 50mA rms	600A/S1/S1223 C = 740/870* 50mA rms
100A rms	600A/S2/P/S1217 C = 470/540 70mA rms	600A/S2/P/S1215 C = 570/670 75mA rms	600A/S2/P/S1215 C = 570/670 100mA rms	600A/S2/P/S1196 C = 620/740* 100mA rms
150A rms	600A/S3/P/S1219 C = 430/500 100mA rms	600A/S3/P/S1220 C = 520/620 100mA rms	600A/S3/P/S1221 C = 570/670** 100mA rms	600A/S3/P/S1222 C = 620/740*** 100mA rms

* 2400V peak, ** 2200V peak, *** 2600V peak

In some situations single disc assemblies may be acceptable. Metrosil units for higher relay voltage settings and fault currents can also be supplied if required. Contact AREVA T&D for detailed applications.

Note: The Metrosil units recommended for use with 5A CTs can also be applied for use with triple pole relays and consist of three single pole units mounted on the same central stud but electrically insulated from each other. To order these units please specify "Triple pole Metrosil type", followed by the single pole type reference.

10. APPENDIX D

10.1 Fuse rating of auxiliary supply

Use of standard ratings between 6A and 16A is recommended. Low voltage fuse-links rated for 250V minimum and compliant with IEC60269-1 general application type gG with high rupturing capacity are acceptable. This gives equivalent characteristics to HRC "Red Spot" fuse types NIT/TIA often specified historically.

Where only one or two relays are wired as a fused spur, it is acceptable to use a 6A rating. Generally, five relays could be connected on a spur protected at 10A, and ten relays for a 15 or 16A fuse.

Note: This applies to MiCOM Px10, Px20, Px30 series devices. It also applies to Px40 series devices with hardware suffix C and later as these have inrush current limitation on switch-on to conserve the fuse-link.

The recommended external protective fuse for the auxiliary DC supply of the P59x series interface units is a 2A HRC (high rupture capacity) GE Red Spot type NIT or TIA, or if a UL recognised fuse is required, 2A time delay Gould type AJT2.

Alternatively, miniature circuit breakers (MCB's) may be used to protect the auxiliary supply circuits.

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