Multifunction Protection and Switchgear Control Unit

REF542*plus*

Manual Motor Protection with ATEX – Certification

CE Conformity Declaration

The product „ Multifunctional Protection and Bay Control Unit REF542*plus*“ is designed and manufactured complying to the corresponding international standards of the series EN 50081, EN 50082 for EMC-Guidelines and EN 60255-6 for Low Voltage Directive of the European Parliament and Council

Table of Contents

1 Introduction

This part of the manual for the multifunctional protection and switchbay control unit REF542*plus* primarily focuses on the integrated motor protection functions. section and its subsections contain information on:

- The basic principle of functioning
- Setting of the parameters
- Representation of the tripping characteristic

2 Abbreviations and Definitions

In the following the abbreviations and definitions used in thid manual are listed.

2.1 Abbreviations

AIS	**A**ir **I**solated **S**witchgear
AR	**A**uto **R**eclosure
CT	**C**urrent **T**ransformer
DFT	**D**iscrete **F**ourier **T**ransformation
EMC	**E**lectro **M**agnetic **C**ompatibility
FUPLA	**FU**nktionblock **P**rogramming **LA**nguage
GIS	**G**as **I**solated **S**witchgear
HMI	**H**uman **M**achine **I**nterface
LCD	**L**iquid **C**rystal **D**isplay
LED	**L**ight **E**mitting **D**iode
LAG	**L**on **A**pplication **G**uide
LV	**L**ow **V**oltage
MC	**M**icro **C**ontroller
PC	**P**ersonal **C**omputer
RHMI	**R**emote **H**uman **M**achine **I**nterface, the same meaning as HMI
VDEW	Association of German Electrical Utilities

2.2 Definitions

There are notes and warnings on hazards at the beginning of every section and also in the text. They are in a different font to distinguish them from normal text.

The safety warnings must be observed in all circumstances. If they are not observed, no guarantee claims will be accepted.

Note

A note indicates items that are significant in the specific context. A note may contain information on the interplay of various software components and appears as shown below.

Example:

Note

Please read this section completely for information on the various formats for safety notes.

Hazard information level 1

Level 1 hazard information indicates hazards affecting substations and devices. It should always be observed, because otherwise function interruptions or malfunctions may occur. An example is shown below:

Caution

Do not make any changes to the FUPLA unless you are familiar with the REF542*plus* and the configuration software

Hazard information level 2

Level 2 hazard information indicates hazards affecting life and limb. It must be observed to avoid injury to the operator or other personnel.

Example:

Warning!

Never attempt to remove the protection covers on the bus bars by force.

3 References:

[DIN1] DIN EN 60255 -8 / VDE0435 Part 3011: Electrical Relay, Thermal Electrical Relay (IEC60255-8:1990, modified), June 1998, VDE-Publisher GmbH, Berlin

[DIN2] DIN EN 50014/ VDE 0170/171 Part 1: Electrical apparatus for potentially explosive atmospheres – General requirements, February 2000, VDE-Publisher GmbH, Berlin

[DIN3] DIN EN 50019 / VDE 0170/0171 Part 6: Electrical apparatus for potentially explosive atmospheres – Increased safety „e“ 2000, June 2001, VDE-Publisher, Berlin

[OM1] Opeartor’s Manual, 1VTA100172-Rev.02, en

[CM1] Configuration Tool Manual, 1VTA100003-Rev.03, en

[PM1] Protection Functions, 1VTA100002, Rev.03, en

[MA3] Manual Part 3, Installation and Commission, 1 VTA100004

[MA4] Manual Part 4, Communication, 1VTA100005

[DO1] **REF542*plus*:** Risikoanalyse und sicherheitsgerichtetes Verhalten, 1VTA300137

4 Motor protection functions

Overloading conditions cause impermissible temperature rises in motors and may result in premature fatigue and aging. If this type of condition persists, thermal destruction of the components cannot be excluded.

With regard to the protection functions, a distinction has to be made between overloads caused by starting processes and overloads occurring during operation. During starting, both in the winding of the rotor and in the winding of the stator, currents may be present that are well above regular on-load currents. A fast tripping must be generated in case a disturbance does occur during startup, for instance, in the event of a rotor block or motor start under heavy load condition. In order to prevent overloading conditions, also the number of starts needs to be limited.

While the motor is running, overloads may occur as a result of the working loads. For monitoring such operating conditions, the temperature is calculated on the basis of a thermal model.

For motor protection purposes, the REF542*plus* field control and protection device therefore includes the following functions:

During the starting process

- Blocking rotor protection
- Motor start protection
- Number of starts protection

During operation

- Thermal overload protection
- Unbalanced load protection or optionally a simple positive sequence monitoring

In all cases, the momentary motor temperature is crucial for the motor protection functions. The REF542*plus* therefore uses a common thermal replica of the first order for determining the motor temperature. Consequently, decisions can be taken by all applied protection functions, depending on the momentary value of the calculated motor temperature.

The thermal replica referred to above is started immediately, as soon as the current flows through the motor windings. Thus, the motor protection in the REF542*plus* is designed as an thermal overload protection with a total memory function in accordance with standard IEC 60255 – 8 [DIN1], since a previous loading condition is always taken into consideration and is being tracked by the thermal replica.

Unbalanced load protection is provided as a phase failure protection caused by an open-circuit condition (broken phase connection). This type of protection enables monitoring of the negative-sequence component which causes a temperature rise in the laminated core of the rotor. Optionally, in case of small motors a simple positive sequence monitoring function can be applied instead.

4.1 Supervision of a blocking rotor

When the rotor is blocked, the current in the motor increases and is determined by the starting current which magnitude is a multiple of the rated motor current. In order to prevent a thermal overload, a fast tripping must be generated. The blocking rotor is supervised by a special, overcurrent definite time protection function which generates a tripping signal with settable delay as soon as an adjustable current threshold is exceeded.

4.1.1 Setting parameters

For operation, the parameters need to be set as shown below:

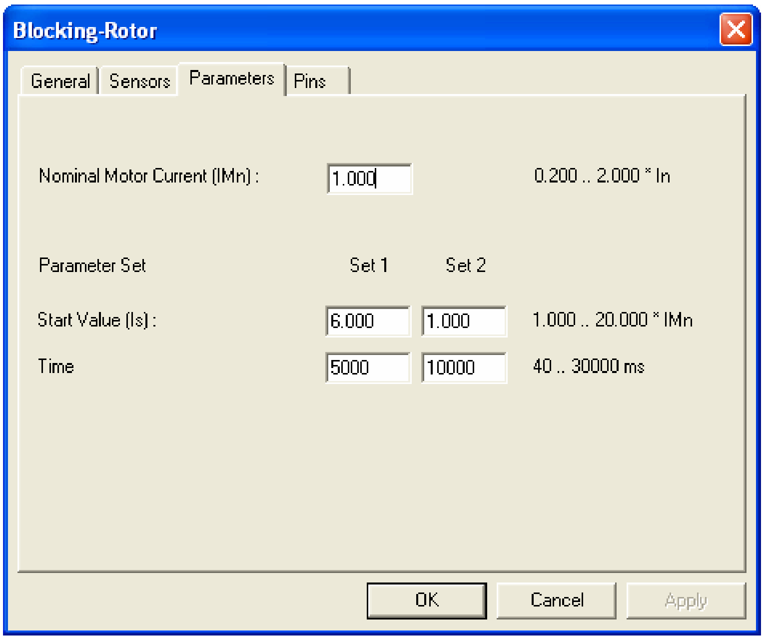


Figure 1: Parameter settings for monitoring the rotor blocking

Where:

IMn	Nominal motor current, related to the nominal current In of the current transformer or current sensor
Start value	Threshold value, related to the nominal motor current IMn
Time	Tripping time in ms.

As soon as the start value for the current during the starting process is exceeded, the time for generating the trip is started. The start value is specified in the manufacturer's data sheet for the current in case of blocked rotor. The time for the tripping can be set to approximately to the permissible blocking time. If a sensor for detecting the rotor movement is available, the signal can be used for blocking this protection function.

4.1.2 Functional check

For checking the blocking rotor monitoring functions, it is recommended to use single- or three-phase testing equipment. By varying the test current it is possible to observe the generation of the start signal and, after the preset time has expired, the tripping signal.

4.2 Motor start protection

Overloading of the motor may occurred if the duration of the starting process is extended due to heavy load condition. The startup behavior is impacted by the connected load. Such overloads are normally more critical for the rotor (rotor-critical motors) than for the stator. Manufacturers of the motor usually specify a permissible current / time starting integral $I^2 T$ for their motors. Alternatively, a special note may indicate the magnitude of the maximum permissible starting current and the maximum permissible starting time.

The current/time starting integral is proportional to the thermal short-time loading of the motor. It is derived by integrating the current curve i(t) into the time interval from 0 to $T_{starting}$:

$$I^2 \cdot T = \int_0^{T_{Starting}} i(t)^2 dt \qquad (1.)$$

Where:

I:	Admissible starting current
T:	Admissible duration of the motor start
i(t):	Current as a function of time t

In order to simplify the calculation process, it is assumed that the starting current during heavy startup until the generation of the fast tripping is constant. Under this condition, the above equation can be approximated by the equation below:

$$I^2 \cdot T = I_{Starting}^2 \; T_{Starting} \qquad (2.)$$

where:

$I_{starting}$	Motor startup current
$T_{starting}$	Motor startup time

The motor start protection function in the REF542*plus* can therefore supervised the motor startup behavior for temperature overload conditions using the calculation method based on equation (2). The current/time starting integral is calculated as soon as the preset response value of the starting current is exceeded within the first 100 ms during the motor starting process. The tripping signal is generated if the current/time starting integral exceeds the specified value of I^2 T.

A startup is registered if the motor current changes from values below 0.10 of the rated motor current up to values above the preset threshold value of the starting current within 100 ms.. The starting signal is reset again as soon as the motor current falls below the preset threshold value of the starting current. If the motor current drops below 0.10 of the rated motor current, the motor is assumed to be at standstill. This definition is necessary for determining the thermal model later.

4.2.1 Setting parameters

For operation, the parameters need to be set as shown below the following illustration:

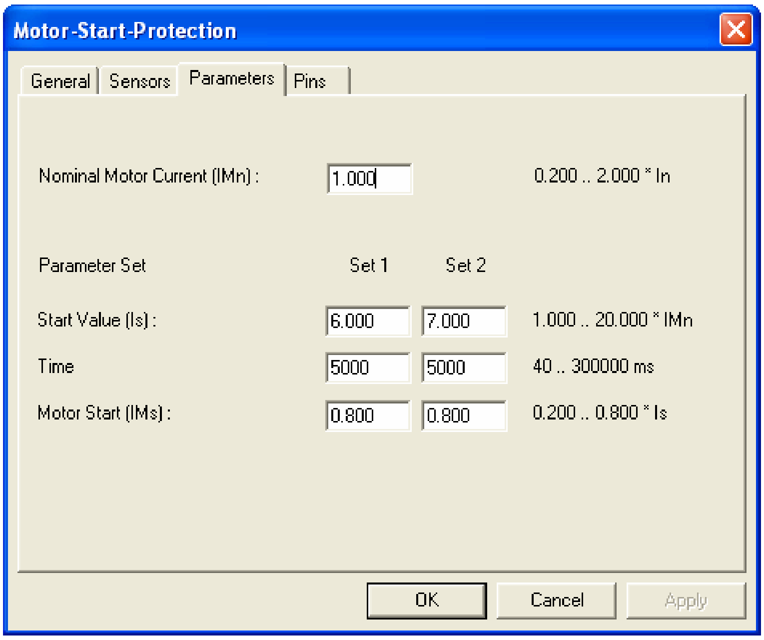


Figure 2: Setting parameters for motor start protection

Where:

IMn	nominal motor current
Start value Is	start current value, related to the nominal motor current, as a measure for the permissible temperature rise
Time	permissible time for determination of the current/time starting integral
Motor start (IMs)	the setting for detecting a starting process, related to the start value Is

In the following example, it is assumed that the blocking current of the motor corresponds to a 6-fold nominal motor current and that the permissible blocking time is 5 sec. Generally, the blocking current can be assumed to be identical with the starting current under heavy load condition. In this case, the starting value is set to 6 IMn (nominal motor current) and the time is set to 5000 ms. The startup is supervised based on the setting for motor startup, e.g. 0.8 as shown in figure 2. As soon as a starting current is detected, the protection function for motor startup monitoring is started and the current/time starting integral is calculated. The tripping time depends on the magnitude of the actual starting current.

If, in the example above, a starting current of a 0.8 starting value Is is assumed, the starting current will be 0.8 x 6 = 4,8 of the rated motor current IMn. A tripping signal is generated after a time of

$$t = \frac{6^2\ 5}{4.8^2}\ \mathrm{s} = 7.81\,\mathrm{s}$$

4.2.2 Tripping characteristic

The tripping characteristic for the motor start protection function can be approximated in a simplified approach through equation (3). The current of blocked motor can be assumed as the same for the starting current. The permissible startup time can be calculated accordingly from the blocking time. The following curve shows the tripping of the motor startup monitoring at t6IB equal to 5sec, as a function of I/I_B where I_B represents the basic current or the rated motor current respectively. The tripping characteristic is mostly defined by the expression of t6IB. This way, it is possible to calculate the tripping time as follows:

$$\left(\frac{I}{IB}\right)^2 t = 6^2\;5\,\mathrm{s} \text{ respectively } t = \frac{36\;5}{\left(\frac{I}{IB}\right)^2}\,\mathrm{s} = \frac{180}{\left(\frac{I}{IB}\right)^2}\,\mathrm{s}$$

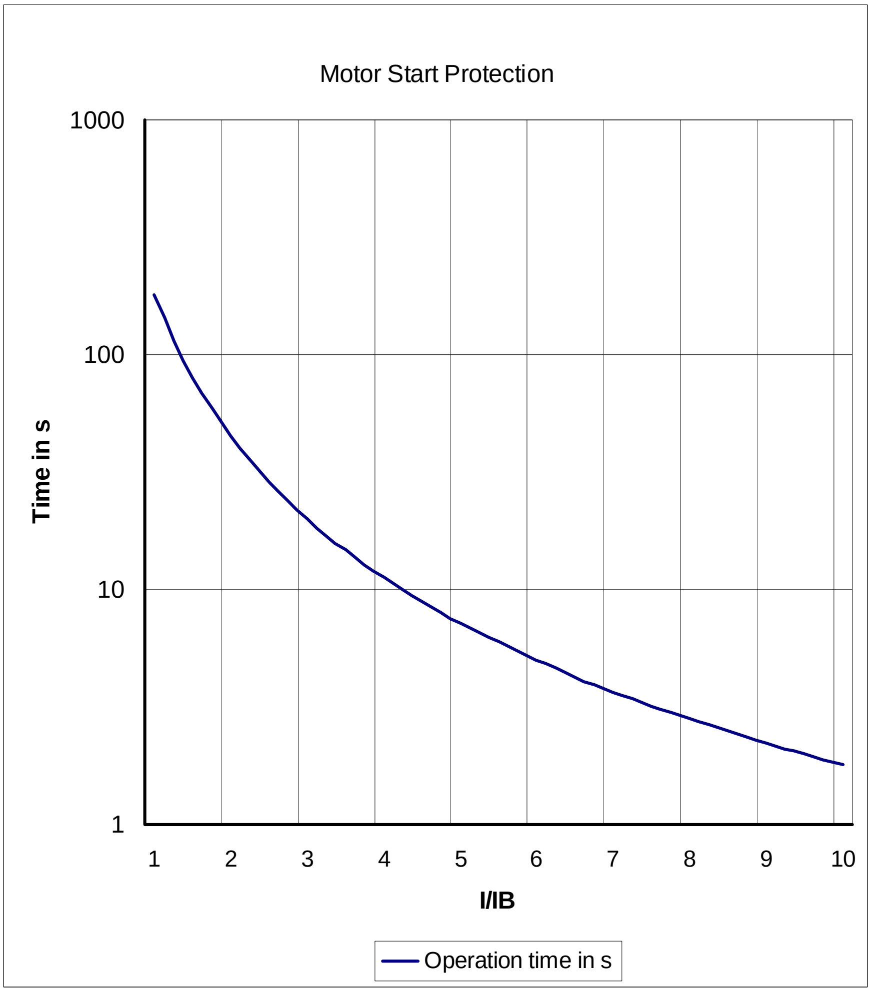


Figure 3: Tripping characteristic for motor startup monitoring for t6IB = 5sec

The table below gives an overview of the times relevant to the tripping characteristics of the motor startup monitoring.

Table 1: Tripping time of the motor startup monitoring for t6IB=5s.

I/I_B	Tripping time in s
1,00	180,00
1,50	80,00
2,00	45,00
2,50	28,80
3,00	20,00
4,00	11,25
5,00	7,20
6,00	5,00
7,00	3,67
8,00	2,81
9,00	2,22
10,00	1,80

4.2.3 Functional check

For checking the motor startup monitoring function, it is recommended to use single- or three-phase testing equipment. By varying the test current it is possible to detect the generation of the triggering signal and, after expiration of the time defined by the tripping characteristic, the tripping as well. The tripping time is independent upon single-phase or three-phase current injection.

4.3 Number of starts protection

As a part of the motor protection function, the number of starts protection shall monitor the startups. In this context, a distinction is made between cold starts and warm starts. To detect the number of start, the start signal of above mentioned function blocks “Block Rotor” and “Motor Start” can be combined together in logical OR function and connected to the input SI. If the signal on this input changes from 0→ 1, the counter will be incremented. The status of the counter will be taken over to the number of warm start, if the temperature of the motor according to the thermal overload protection is exceeded. The permissible numbers of which are normally specified by the motor manufacturer. If this is not the case, it is normally to be assumed for 2 cold starts and 1 warm start.

Whether the start is a cold start or a warm start depends on the result calculated for the thermal replica. The temperature from which on the starts are interpreted as warm restarts can be parameterized. If the calculated temperature is below this value, a cold start is assumed.

Moreover, a reset time is parameterized in order to obtain the following results:

- If the startup has been successful only a number of permissible attempts, the number of starts counted is set back by one (minus one) after the reset time (cooling-off time) has expired.
- When the number of preset starts has been reached, the protection function enters the so called start status (START output). This signal can be used to block a restart of the motor. After the reset time is expired, the number of start counter will be decremented and enable the motor start again.
- If there is another startup, the protection function will generate a trip signal immediately. The trip signal (TRIP output) will be pending until the reset time has expired.

4.3.1 Setting parameters

For operation purposes, the parameters need to be set as shown below:

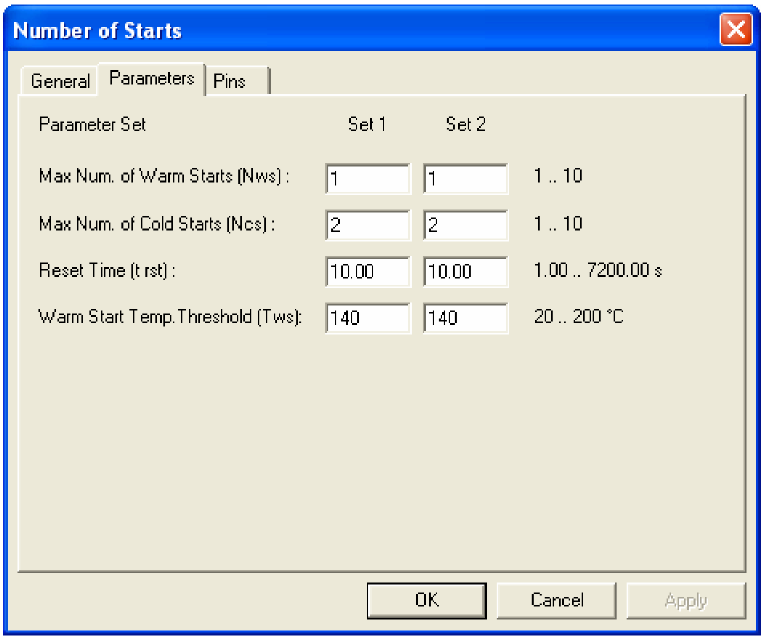


Figure 4: Setting parameters for thermal protection

Where:

Nws	Permissible number of starts in warm condition
Ncs	Permissible number of starts in cold condition
Reset time (trst)	Time to decrement the counter
Tws	Warm start temperature threshold

The settings should be, in accordance to today standard, provided for 1 warm start and 2 cold starts. The temperatures for warm motor condition can be specified at 90% of the thermal capacity contents of the motor. The thermal capacity content of the motor, in turn, depends on the setting of the thermal overload protection.

The thermal capacity content is determined by the setting in the thermal overload protection function. For instance, if the settings of this protection function are such that the environment temperature is selected to be 40°C and the rated motor temperature is set to 130°C, the entire thermal memory contents is determined by the difference between these two temperatures. Thus, 90°C corresponds to thermal memory contents of 100%. If the warm condition has been defined to be 90% of the thermal memory contents, the temperature for the warm start of the motor needs to be set to

(0.9 x 90°C) + 40°C = 121 °C

If according to the “old” Standard the number of start should be set to be 3 cold-start and 2 warm-start, so the temperature limit for the warm condition should be set accordingly. In general the temperature limit can be calculated for 50 to 60% of the thermal memory. After the first start, the motor temperature should then reach the warm condition of the motor.

4.3.2 Functional check

For checking the function of this monitoring the number of starts, it is recommended to use single- or three-phase testing equipment for load simulation in the thermal protection function. Dependent on the temperature calculated by the thermal protection, the number of starts in cold condition or in warm condition can be tested. The functional check of the thermal protection is described in the following paragraph.

4.4 Thermal overload protection

For motor protection, the thermal overload protection based on the thermal replica is one of the major functions for supervising the motor for temperature violations on account of overloads during operation. In the REF542*plus*, a thermal replica with a total memory function has been implemented in accordance with the applicable standard [DIN1]. In the following, the thermal replica and the setting options are dealt with.

For simulating the temperature rise in the motor, a thermal homogenous-body model with losses is assumed. The figure 5 below illustrates the principle of the model.

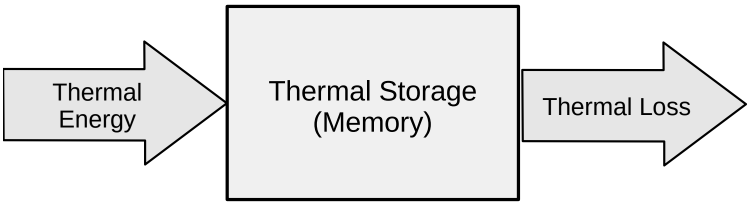


Figure 5: Thermal homogenous-body model with losses

On account of the loads present during the operation conditions, the load current in the motor can be taken as a measure for the quantity of energy, which feed the temperature rise in the motor. The size of the thermal energy is proportional to the square value of the load current. Due to the existing motor cooling a portion of the thermal energy will be discharged in the form of energy loss. The rest of the thermal energy is stored in the motor. The size of the stored energy is proportional to the motor temperature.

For calculating the motor temperature, the above-mentioned thermal model can be simulated by a simple electrical circuit. The next figure shows the circuit diagram.

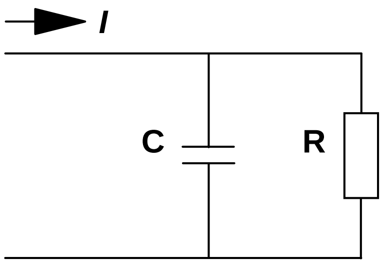


Figure 6: Circuit diagram for determining the motor temperature

From the circuit diagram, the following analogy is obtained:

- The energy flow is proportional to charging current for the capacitor
- The thermal capacity is simulated by capacitor C

- The heat losses is represented by resistor R

During charging, a voltage is present at the capacitor. The capacitor voltage is again proportional to the motor temperature. The voltage characteristic can be determined based on the equation below:

$$u(t) = i(t)\,R\,(1 - e^{-t/\tau}) + i_p\,R\,e^{-t/\tau} \qquad (4.)$$

Where:

u(t) Voltage characteristic as a function of time,

t Time

i(t) Charging current characteristic as a function of time

R Resistor

τ Time constant resulting from the product of R and C

i_p Biasing current before the charging process

The time constant for the time-related voltage variation is determined by the capacitor and the resistor. In accordance with the analogy mentioned above, it is possible to equate the voltage characteristic with the temperature, the charging current with the amount of thermal energy supplied, and the biasing current with the heat condition before the temperature rise. This leads to the equation below for determining the temperature characteristic:

$$\Delta\vartheta(t) = \Delta\vartheta(E)\,(1 - e^{-t/\tau}) + \Delta\vartheta_p\,e^{-t/\tau} \qquad (5.)$$

Where:

$\Delta\vartheta$(E) Time-related characteristic of the temperature change during temperature rise

t Time

E Heat energy supplied

$\Delta\vartheta_p$ State of the temperature before temperature rise as a result of preloading

After a transformation, the time required until a certain temperature $\Delta\vartheta$ (*t*) is reached can be determined as follows:

$$t = \tau \ln \frac{\Delta\vartheta(E) - \Delta\vartheta_p}{\Delta\vartheta(E) - \Delta\vartheta(t)} \qquad (6.)$$

Since the temperature resulting from the temperature rise depends on the amount of thermal energy supplied - which, in turn, is square-proportional to the current in the motor - the above equation can be rewritten for the rated motor current like this:

$$t = \tau \ln \frac{\left(\frac{I}{I_{Mn}}\right)^2 - \frac{\vartheta_p - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}}{\left(\frac{I}{I_{Mn}}\right)^2 - \frac{\vartheta_t - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}} \qquad (7.)$$

Where:

I Actual loading current in the motor

I_{Mn} Nominal motor current as a reference variable

ϑ_p Initial temperature due to preloading

ϑ_u Ambient temperature as a reference variable

ϑ_{Mn} Rated motor temperature when loaded with rated current

ϑ_t Motor temperature reached after a certain time span

In the applicable standard [DIN1], the characteristic is specified by the equation below:

$$t = \tau \ln \frac{I^2 - I_p^2}{I^2 - (k\, I_B)^2} \qquad (8.)$$

where

I Loading current in the motor

I_p Preloading current in the motor

I_B Basic current or rated current of the motor

k Overload constant within a range of 1 to 1.2

Equation (7) can be transformed and related to the basic or nominal current of the motor:

$$t = \tau \ln \frac{\left(\frac{I}{I_B}\right)^2 - \left(\frac{I_p}{I_B}\right)^2}{\left(\frac{I}{I_B}\right)^2 - k^2} \qquad (9.)$$

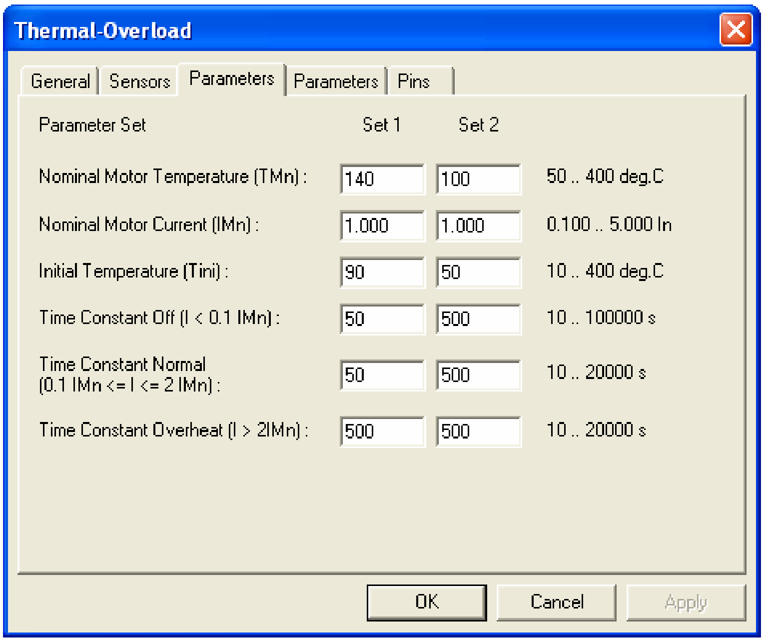
As a result, equation (6) and (8) indicate that the setting for constant

$$k = \sqrt{\frac{\vartheta_t - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}} \qquad (10.)$$

can be derived from the setting for the temperatures. The temperature setting is a measure for the thermal capacity. The denominator in the root equation above is equal to the nominal capacity contents under nominal operation condition of the motor. The numerator is identical to the extended thermal capacity of the motor for tripping and only allowed for a very short time duration..

4.4.1 Setting parameters

For operation purposes, the parameters need to be set as shown below:



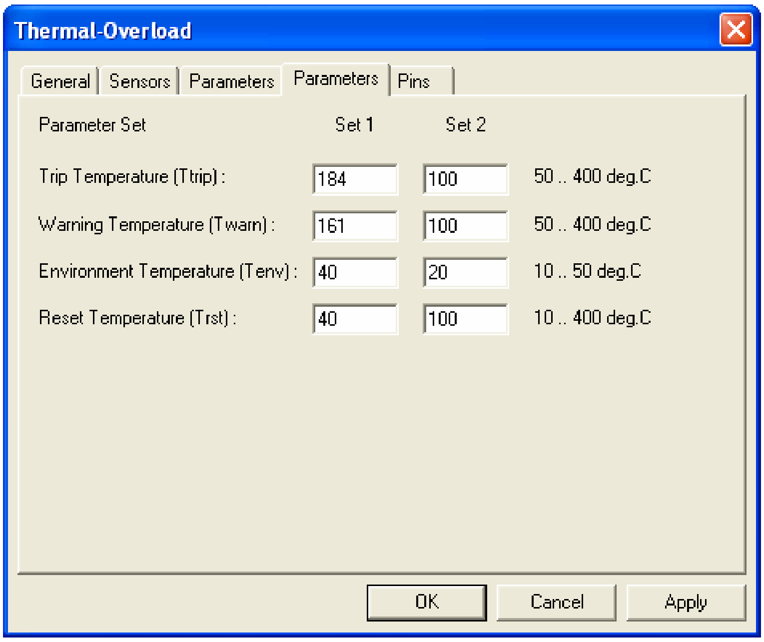


Figure 7: Setting parameters for thermal protection

Where:

TMn	Nominal motor temperature (permissible operating temperature)
IMn	Nominal motor current referred to the nominal current of the current transformer
Tini	Initial temperature of the thermal memory after switching on the auxiliary voltage .
TCOff	Cooling-off time constant at I < 0.1 IMn (motor at standstill)
TCNormal	Time constant at 0.1 IMn < I < 2 IMn (motor in normal operation)
TCOverheat	Time constant at I > 2 IMn (motor during startup/accelerating)
Ttrip	Temperature for tripping
Twarn	Temperature for warning
Tenv	Environment temperature
Trst	Temperature after resetting the function

4.4.1.1 Setting the time constant:

For setting the time constant, it is assumed that the motor is rotor-critical. Furthermore, it is assumed that the preset thermal capacity has been reached if, after expiration of the blocking time, the cold motor still remains rotor-locked. Therefore, equation (9) delivers the following relationship:

$$\tau = \frac{t_e(\text{cold})}{\ln \frac{(I_A/I_{Mn})^2}{(I_A/I_{Mn})^2 - k^2}} \qquad (11.1)$$

where:

τ	Heating time constant to be calculated for rotor-critical motors and which can be equated to the setting for "TCOverheat“
te (cold)	Permissible maximum blocking time for cold motor condition
IA	Blocking current or maximum starting current
IMn	Nominal motor current
k	Overload constant which

If according to the latest standard the blocking time of the motor in warm condition is given, then the calculation can be done according to the following equation:

$$\tau = \frac{t_e(\text{warm})}{\ln \frac{(I_A/I_{Mn})^2 - 1}{(I_A/I_{Mn})^2 - k^2}} \qquad (11.2.)$$

According to the standard the warm condition is defined, if the motor reach the steady state condition during the operation with the nominal motor current. That is why the preload condition is equal to 1.

Thus, the value for TCOverheat (the time constant for motor operation at overload above 2 times the rated motor current) can be calculated on the basis of equation (11.1). The temperature rise time constant TCNormal for non-rotor-critical motors could, in principle, be chosen larger than the above temperature rise time constant. If this parameter is unknown, however, the same value can be set, as it is safe to expect a timely tripping in this case. As experience has shown, the cooling-off time constant while the motor is at zero rotation TCOff should be set within 3 times to 5 times the value of TCNormal.

4.4.1.2 Setting the temperature

After the time constants have been determined, the thermal capacity needs to be defined. For this purpose, it is necessary to define the maximum overtemperature for the thermal memory respectively thermal capacity. According to [DIN1, DIN2] the condition for the environment temperature for operation is 40°C. The maximum overtemperature K for normal operation or the temperature of operation under nominal condition respectively, is given by the corresponding thermal class and the temperature class according to the following table 2.

Table 2: Maximum overtemperature in K during normal operation at 40°C ambient temperature

Thermal Class	Temperature Class					
	T1	T2	T3	T4	T5	T6
A	50	50	50	50	50	40
E	65	65	65	65	65	40
B	70	70	70	70	70	40
F	90	90	90	90	55	40
H	115	115	115	90	55	40

If, for example, a motor with a thermal class F and a temperature class T3 is certified, so the allowable maximum overtemperature is according to the table above 90°K. As a consequence, the environment temperature ϑ_U respectively Tenv of the thermal protection function must be set to 40°C and the nominal or rated temperature TMn ϑ_{Mn} to 130°C. The difference of above temperature respectively the maximum overtemperature of 90°K or 90°C is equal to 100% thermal capacity. In general the tripping of the thermal protection may be set at thermal capacity greater then 100%. According to [DIN1] the constant k may be selected up to 1.2. Consequently the thermal capacity of 144% may be 144% before the tripping of the thermal protection is generated.

Table 3: Maximum overtemperature in K during short time overload operation at 40°C ambient temperature

Thermal Class	Temperature Class					
	T1	T2	T3	T4	T5	T6
A	120	120	120	90	55	40
E	135	135	135	90	55	40
B	145	145	145	90	55	40
F	170	170	155	90	55	40
H	195	195	155	90	55	40

With help of tables 2 and 3, the value for setting constant (k) or the root of the extended memory contents can be calculated on the basis of equation (10) if the motor is to be run up to limit temperature.

In the following example, it is assumed that the motor winding is of thermal class F and of temperature class T1. The environment temperature is according to [DIN3] to be set to 40°C. In accordance with table 2, the rated motor temperature is 130°C and, in accordance with table 3, the limit temperature for the generation of the tripping signal is 210°C. Therefore the setting constant is

$$k = \sqrt{\frac{\vartheta_t - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}} = \sqrt{\frac{210 - 40}{130 - 40}} = 1{,}27 \qquad (12.)$$

According to the standard the k-value shall be in the range of 1.0 to 1.2. This means, that the thermal memory content should be set in the range of 100 to 144%.

In this example, the tripping is not supposed to occur at a limit temperature of 210 °C. So a smaller setting constant k has to be chosen. For this example, the setting constant k shall be set to 1.1. This will limit the increase of the memory contents to 121%. Based on equation (10), the tripping temperature can be calculated: (1.21x90) °C + 40°C = 149°C. It is now possible to calculate the tripping time with the equation below:

$$t = \tau \ln \frac{\left(\frac{I}{I_{Mn}}\right)^2 - \frac{\vartheta_p - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}}{\left(\frac{I}{I_{Mn}}\right)^2 - \frac{\vartheta_{TRIP} - \vartheta_u}{\vartheta_{Mn} - \vartheta_u}} \qquad (13.)$$

In this case, I is the instantaneous on-load current, IMn is the nominal motor current, ϑ_p the temperature due to an assumed specific preloading, ϑ_{env} is the environment temperature, ϑ_{Mn} is the nominal motor temperature, and ϑ_{TRIP} is the temperature causing tripping.

When the auxiliary voltage is switched on for the first time, the thermal replica will begin to operate with a specified memory content which is determined by the setting for T ini. This memory contents defined the preloading at this switching on momentary. It is to be recommended to choose the setting for the warm condition of the motor within a range of 80 ... 100% of the memory contents. For instance, with a setting of 90% memory contents it is necessary firstly to determine the entire memory contents on the basis of temperature settings TMn and Tenv.

Based on the above example, the thermal capacity is proportional to the temperature difference of

$$130°C - 40°C = 90°C$$

In accordance with the above example, a thermal capacity preloading has to be set to 0.9 or 90%. As a result, the setting has to be

$$T\text{ini} = 40°C + 0{,}9(90°C) = 121°C$$

If the auxiliary voltage is shut down, the instantaneous motor temperature is provided, in that particular moment, with the absolute time of the built-in real-time clock and saved in a non-volatile memory. Provided that the motor remains off during the failure of the auxiliary voltage, a cooling-off of the motor is assumed with a time constant TCOff. When the auxiliary voltage is recovered again, the entire outage time of the auxiliary voltage will be determined based on the stored time data. It may be assumed that the real-time clock in the REF542*plus* will continue to run for a period of at least 2 hours at the required accuracy.

The initial temperature for continuing the thermal monitoring of the motor is calculated with the equation below:

$$Tini = (Toff - Tenv)\, e^{-\frac{td}{TC\,off}} + Tenv \qquad (14.)$$

Where:

Tini	Initial temperature for continuing the calculation
Toff	Temperature in the moment of the failure of the DC supply
Tenv	Setting for the ambient temperature
td	Duration of the power down of the auxiliary voltage
TCOff	Setting for the cooling-off time constant after switching off the motor

4.4.1.3 Setting the temperature after reset

For functional testing purposes, another temperature setting "T rst“ is provided. If a reset signal is present at the input of the function block, the motor temperature is reset to the preset reset temperature.

For instance, if a tripping characteristic without preloading is to be checked, temperature setting T rst has to be equated to the setting of the environment temperature T env. For checking a characteristic with 100% preloading (hot curves), temperature setting T rst has to be set equal to the setting of the rated motor temperature T nom.

4.4.2 Tripping characteristic

The following paragraph deals with a tripping characteristic where the tripping time is specified as 6 times the basic current I_B which is to be equated to the rated motor current. In this context, it is assumed that the setting constant k is 1.1. This means that with the above setting the setting constant for the memory contents is expanded to 121%.

In accordance with [DIN3], blocking time t_E should not be below 5sec. Based on equation 11.1, the setting of the time constant for the REF542*plus* is:

$$\tau = \frac{5\,s}{\ln\left(\frac{36}{36 - 1{,}21}\right)} = 146\,s \qquad (15.)$$

Tripping characteristics with a time constant τ = 146sec corresponding to a setting of t_{6IB} equal to 5sec - without (cold curves) and with 100% preloading (hot curves) - are illustrated below in graphic form. 100% preloading means that the motor operates under nominal condition at rated current. If there is an overload, the motor can be switched off quickly due to the fact that the thermal capacity contents or the rate of the preloading is being taken into consideration.

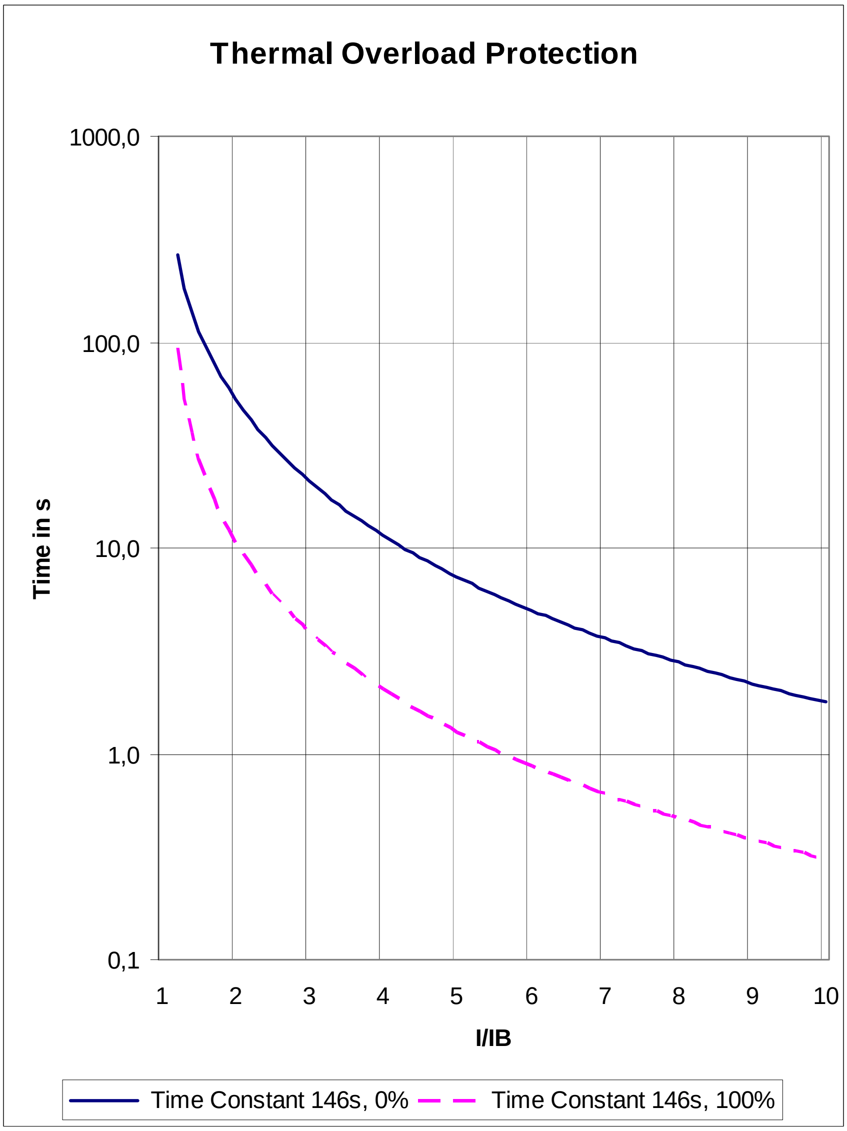


Figure 8: Tripping characteristic for thermal protection at τ = 146sec or t_{6IB} = 5sec

If in contrary the blocking time in warm condition is stated, so the equation 11.2 should be applied:

$$\tau = \frac{5\,\mathrm{s}}{\ln\left(\frac{36-1}{36-1{,}21}\right)} = 830\,\mathrm{s} \qquad (16.)$$

The time constant can be, due to the applied thermal replica, very strong divergent from the first one. In this case after 5s only 21% of the thermal capacity is filled. So the time constant is around 6 times higher than the first one.

The table below summarizes the times resulting for the tripping characteristic with and without 100% preloading.

Table 4: Tripping time for thermal protection at t_{6IB} = 5sec or τ = 146sec

I/I_B	0% preloading	100% preloading
1,15	359,79	153,76
1,20	267,81	94,71
1,40	140,25	36,04
1,60	93,43	21,11
1,80	68,26	14,37
2,00	52,60	10,59
2,20	42,00	8,21
2,40	34,43	6,58
2,60	28,79	5,42
2,80	24,47	4,55
3,00	21,08	3,88
4,00	11,48	2,06
5,00	7,24	1,28
6,00	4,99	0,87
7,00	3,65	0,64
8,00	2,79	0,49
9,00	2,20	0,38
10,00	1,78	0,31

4.4.3 Functional check

For functional testing, we recommend to use three-phase testing equipment. If a functional test is to be carried out with single-phase testing equipment, attention is to be paid to the fact that the current has to be raised in order to achieve the same r.m.s. value as with a three-phase system. For calculating the memory contents, the REF542*plus* assumes that the root-mean-square value of the current in the individual phases is present.

$$I_{Mittel}(3\text{pol}) = \sqrt{\frac{I_{L1}^2 + I_{L2}^2 + I_{L3}^2}{3}} \qquad (17.)$$

Where:

$I_{mittel\ (3\text{-pole})}$	Root-mean-square value of the current causing the temperature rise in a three-pole functional test
I_{L1}	Current in conductor L1
I_{L2}	Current in conductor L2
I_{L3}	Current in conductor L3

Therefore, in a single-phase test equipment, a temperature rise at a current of is assumed.

$$I_{Average}(1\text{pol}) = \sqrt{\frac{I_{L1}^2}{3}} \qquad (18.)$$

Where:

$I_{\text{average (1-pole)}}$	Root-mean-square value of the current causing the temperature rise in a single-pole functional test
I_{L1}	Current in conductor L1,

Therefore in a single-phase test, the current

$$I(1\text{pol}) = I(3\text{pol})\sqrt{3} \qquad (19.)$$

shall be increased by factor √3 in order to obtain a temperature rise that is comparable to the one in a three-pole functional test.

4.5 Unbalanced load protection

The unbalanced load protection is intended to provide protection and monitoring of electrical equipment against/for asymmetrical loading. Unbalance load protection is mostly applied for protecting motors or generators.

The unbalanced load is calculated from the negative-phase-sequence component of the three-phase conductor currents and has to be generated — in accordance with the definitions given in the applicable regulations — on the basis of the relationship between the current of the negative-phase-sequence component and the rated current of the equipment that is to be protected. Since an unbalanced load leads to impermissible temperature rises in the laminated core of the rotor, it is necessary to generate a tripping signal which is square-dependent on the unbalanced load in case the permissible values are being exceeded. By means of the square-dependency, it is possible to replica a temperature rise without losses (adiabatic curves). The tripping time can be derived as follows:

$$t = \frac{K}{I_2^{\,2} - I_s^{\,2}} \qquad (20.)$$

Where:

t	Tripping time derived from the above temperature rise constant
K	Temperature rise constant depending on the type of equipment
I_2	Unbalanced load related to the rated current
I_s	Response value for monitoring impermissible temperature rises

When a tripping took place, it is usually advisable not to restart the motor immediately after the trip. The unbalanced load protection in the REF542*plus* has therefore been provided with the option to block motor reconnection by means of an output signal. Within the blocking time, the memory contents is subjected to linear clearing for the tripping time. If the component to be protected is reconnected without waiting for a complete cool-off, it is possible that another trip will take place - if the unbalanced load limit is exceeded again - much faster than would be expected theoretically. In addition, it is possible to reduce the duration of the blocking time, if necessary, in percentages.

4.5.1 Setting parameters

For operation purposes, the parameters need to be set as shown below:

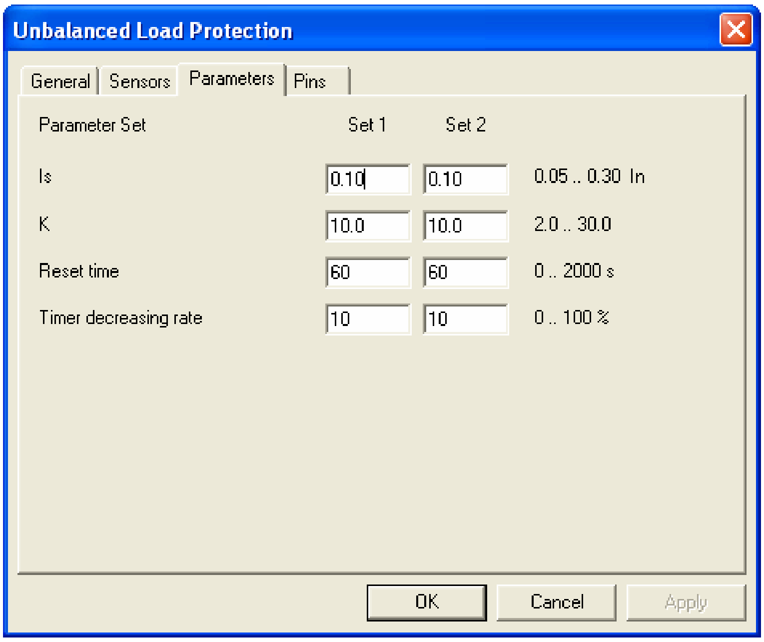


Figure 9: Tripping characteristic for thermal protection at τ = 146sec or t_{6IB} = 5sec

Where:

Is	Current starting value, related to the rated current of the current transformer or current sensor
K	Temperature rise constant for the item of equipment to be protected
Reset time	Time up until complete clearing of the thermal memory contents
Discharge rate	Reduction of the reset time in percentages

4.5.1.1 Setting the current starting value

The unbalanced load protection is activated only after the unbalanced load current has exceeded the preset current starting value Is. Normally, the motor or generator manufacturer can provide information on this setting. During operation, an unbalanced load of 10% of the rated current does not cause an impermissible temperature rise in the motor or generator. So, it is possible to set the current starting value to 0.1 of the rated current of the motor or the generator. The unbalanced load protection is activated and started if the unbalanced load is larger than the starting value.

4.5.1.2 Setting the tripping time

For the unbalanced load protection function, the tripping time is not set directly. The size of the temperature rise constant K and the size of the unbalanced load finally determines the tripping time in accordance with the equation given above. The temperature rise constant K should be provided by the manufacturer of the motor or the generator.

The following example demonstrates how to calculate the tripping time constant. In this context, the following data are assumed:

K = 10

IMn = 80A (rated current of the motor)

In = 100A (rated current of the current transformer)

If an open-circuit condition is present, the currents in the other two conductors are of equal size and have a phase displacement of 180°. Furthermore, it is assumed that both of the currents are identical with the rated current. Under this condition, the unbalanced load current I2 is:

I2 = 0.577 In

If this value is inserted into the equation above, the tripping time is 30.9s.

As the rated current of the current transformer is not identical to the rated motor current — in this example the rated current of the current transformer is 100A and the one of the motor is 80A — the setting of the temperature rise constant has to be corrected based on the relationship between the rated motor current and the transformer rated current, as shown in the equation below:

$$K = t_{AUS}\left[\left(\frac{I_{Mn}}{In}\frac{I2}{In}\right)^2 - \left(\frac{I_{Mn}}{In}\frac{Is}{In}\right)^2\right] \quad (21.)$$

The constant which is to be set at the REF542*plus* field control and protection device for the above example is:

$$K = 30{,}9\left[\left(\frac{80}{100}\,0{,}577\right)^2 - \left(\frac{80}{100}0{,}1\right)^2\right] = 6{,}38 \quad (22.)$$

4.5.2 Tripping characteristic

The following paragraphs deal with the tripping characteristic at an assumed temperature rise constant K of 5. At the same time, it is assumed that the response threshold or the current starting value is 0.1 or 10%. The tripping time can then be derived by applying equation (13).

$$t = \frac{5}{I_2^{\,2} - 0{,}1^2} \quad (23.)$$

The following figure shows the tripping characteristic, where the unbalanced load current I2 is referred to the nominal current of the motor Imn.

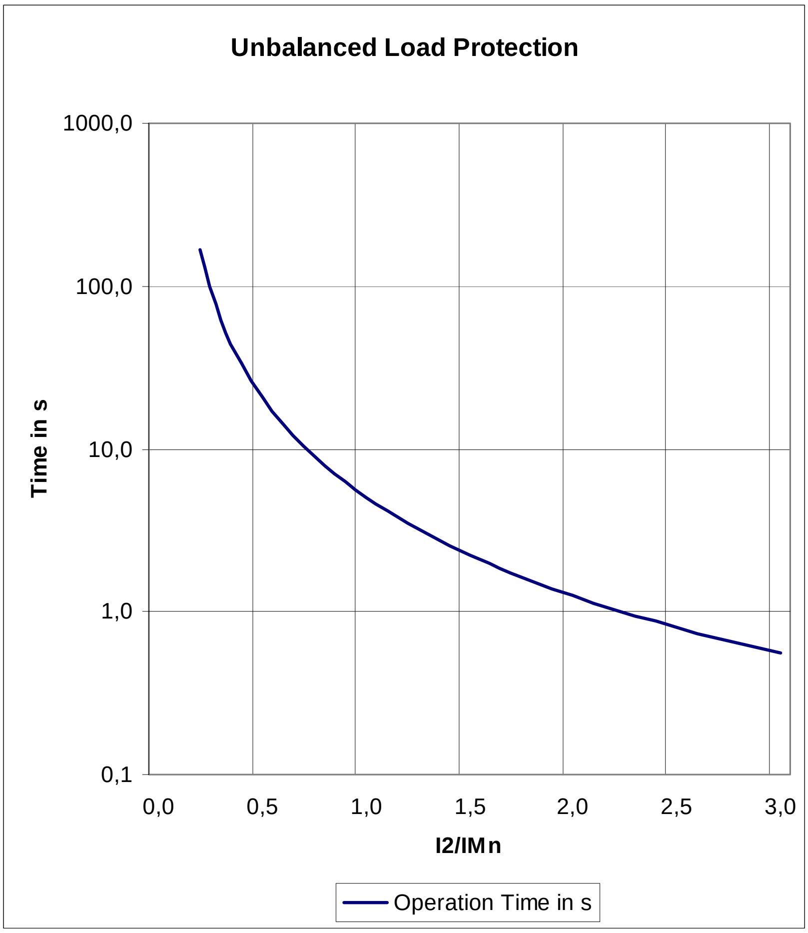


Figure 10: Tripping characteristic for thermal protection at τ = 146sec or t_{6IB} = 5sec

The table below gives an overview of the times resulting for the tripping characteristic.

Table 5: Tripping time for the unbalanced load protection

I2/IMn	Tripping Time
0,20	166,67
0,30	62,5
0,40	33,33
0,50	20,83
0,60	14,23
0,70	10,42
0,80	7,94
0,90	6,25
1,00	4,95
1,20	3,5
1,30	2,98
1,40	2,56
1,50	2,23
2,00	1,25
2,50	0,8
3,00	0,56

4.5.3 Functional check

For a functional check of the unbalanced load protection, we recommend to use three-phase testing equipment. By switching the phase sequence (e.g. L1, L3, L2) at the connections, a unbalanced load current can be simulated. The amplitude of the symmetrical conventional tripping current, related to the rated current, is identical to the size of the unbalanced load current to be checked.

If only single-phase testing equipment is available, the conventional tripping current can be connected either via two conductors, e.g. L2 and L3, or only to one conductor, e.g. L1. If the tripping current is connected to two conductors, the conventional tripping current has to be increased in accordance with the following equation

$$I2(\mathrm{L2-L3}) = \sqrt{3}\, I(\mathrm{3pol}) \qquad (24.)$$

so that the behavior can be checked properly. In the case of a conventional tripping current injection in one of the conductors, the conventional tripping current has to be increased by factor 3 in accordance with the equation below

$$I2(\mathrm{L1}) = 3\, I(\mathrm{3pol}) \qquad (25.)$$

5 Setting example

The following paragraph presents an example for setting the motor protection functions which are used for thermal supervision. Special consideration is given to the setting of the following functions:

- Rotor block protection
- Motor start protection
- Thermal overload protection
- Number of starts protection

The setting of the unbalanced load protection function, which is needed for the supervision of the asymmetrical operating conditions, has been described in the previous paragraph.

In the following figure an example of the FUPLA – configuration of the function blocks for motor protection - Block Rotor, Motor Start, Number of Start Supervision and Thermal overload - are shown.

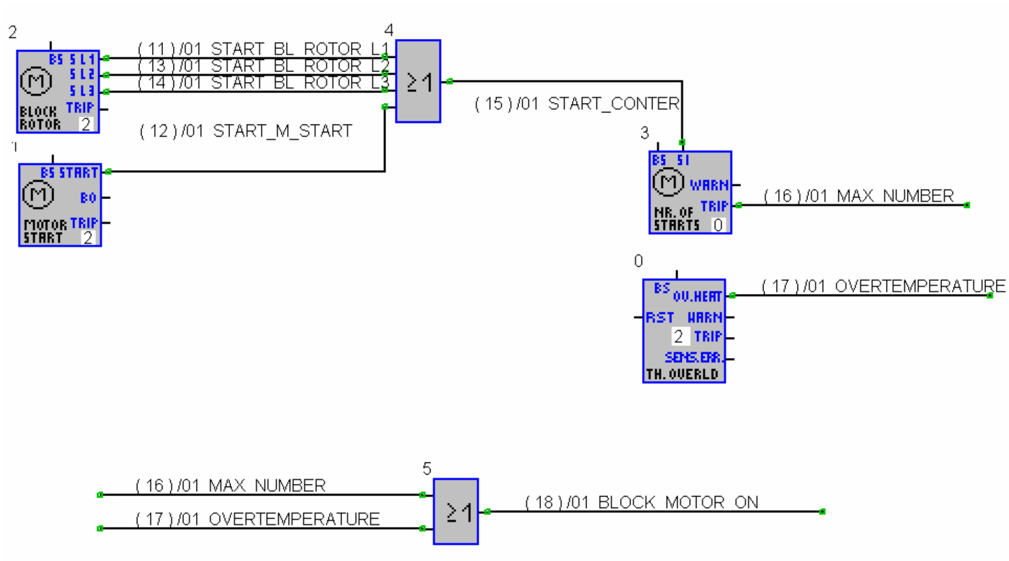


Figure 11: Example of a FUPLA – configuration for the motor protection

For the setting example, a medium voltage motor is assumed to have the following relevant data:

Rated motor current I_{Mn}	91A
Wärmeklasse	B
Temperaturklasse	T3
Blocking current I_E	7.9
Blocking time t_E (warm)	8sec
Current transformer rated current	100A/1A

5.1 Rotor block protection

The rated motor current is known. Since the primary current transformer rated current is 100A, the rated motor current or the motor current Ie at the REF542*plus* has to be set to

$$IMn = \frac{91A}{100A} In = 0{,}91\ In$$

For detecting a rotor blocking, only the overcurrent criterion is to be used. In this case, a rotor blocking is assumed to be present if the motor current is at 90% of the blocking current. Thus, the starting value is

$$Start = 0.9 \times 7.9\ Ie = 7.11\ IMn$$

The time setting is selected as the following:

$$Time = 8.0\ s = 8000\ ms$$

5.2 Motor start protection

For the motor startup monitoring function, the setting for the rated motor current or motor current IMn is done in the same way as for the rotor blocking monitoring described earlier. After that, the starting value and the time can be defined in accordance with the motor data:

$$Start = 7{,}9\ IMn$$

and

$$Time = 8\ s\ \text{respectively}\ 8000\ ms$$

The motor startup is set to the following setting:

$$Motorstart = 0.7\ Is$$

Thereby Is means the setting for the starting value.

5.3 Thermal overload protection

For this function, the rated motor current can be entered.

$$IMn = 91\ A$$

The motor winding is specified at thermal class B. In this context, it is assumed that the ambient temperature is

$$Tenv = 40\ °C$$

As a result of the thermal class and the temperature class indicated above, according to table 2 and 3 the rated temperature for the REF542*plus* will be

$$Tnom = (40 + 70)°C = 110\ °C$$

and the maximum temperature for tripping:

$$Tmax = 145\ °C$$

Setting constant k can be calculated by applying equation (10).

$$k = \sqrt{\frac{145°C - 40°C}{110°C - 40°C}} = 1{,}22$$

In accordance with standard [DIN1], however, the constant value should be within a range of 1.0 to 1.2. If the highest possible setting of the setting constant

$$k = 1{,}2$$

is chosen, it is possible to calculate the temperature setting in reverse order.

$$\vartheta_t = (1{,}2)^2\,(110°C - 40°C) + 40°C = 141°C$$

As a result, it is possible to define the temperature for tripping on the REF542*plus*

$$T\max = 141°C$$

With this setting the thermal memory contents can be expanded to 144%. A warning signal has to be generated, for instance, if the thermal memory contents of 120% is reached. This way, it is possible to determine the temperature setting for the warning signal.

$$Twarn = \left(\frac{120}{100}\,(110°C - 40°C)\right) + 40°C = 124\ °C$$

For the commissioning or after an auxiliary power fail with a long time duration it is necessary to set the initial temperature Tini. In this case, we recommend for selecting a temperature for the warm operating condition of the motor, for instance, a temperature at a thermal memory contents of 100%. Accordingly, an initial temperature of

$$Tini = (110°C - 40°C) + 40°C = 110°C$$

will be assumed.

Since the motor has to be assumed as being rotor-critical without forced cooling, both of the time constants as well as for the temperature rise in operating condition as also for the overload or fault condition should be identical. The time constant can be calculated by applying equation (11.2).

$$\tau = \frac{8{,}0\ s}{\ln \dfrac{7{,}9^2 - 1}{7{,}9^2 - 1{,}2^2}} = 1112\ s$$

As a result, the two time constants should be set as follows:

$$TC\ Normal = TC\ Overheat = 1112\ s$$

If the motor is no longer running and is not rotating, cooling-off will take place slowly as there is no more rotation. Generally, the cooling-off process can be assumed with time constant that is three times the value for normal operation. Therefore the time constant for cooling-off at standstill is set as follows:

$$TCoff = 3\ \ 1112\ s = \ 3336\ s$$

5.4 Number of starts protection

In accordance with the recommendations given in the relevant operation guidelines, the setting of the number of starts from cold condition is

$$Number\ of\ Coldstart = 2$$

and the setting of the number of starts from warm condition is

$$\text{Number of Warmstart} = 1$$

According to the selected setting, after each start the thermal memory will be filled up by 45%. After 2 start the thermal memory will reach 90% of the nominal value. So the temperature for the warm start is reached if the thermal memory content is 100%. This way, it is possible to define the temperature for the warm start.

$$\text{Tini} = \left(\frac{100}{100}\ (141°C - 40°C)\right) + 40°C = 141°C$$

The time for motor cool-off can be assumed to be 0.6 of the setting of the time constant TCOff. After expiration of this time the thermal memory is reduced by approximately 45%. A warm start can at least be performed.

$$\text{Time} = 0.6\ 3336 = 2001\,\text{s}$$

5.5 Tripping characteristic

The figure below shows the tripping characteristic of the motor in cold condition.

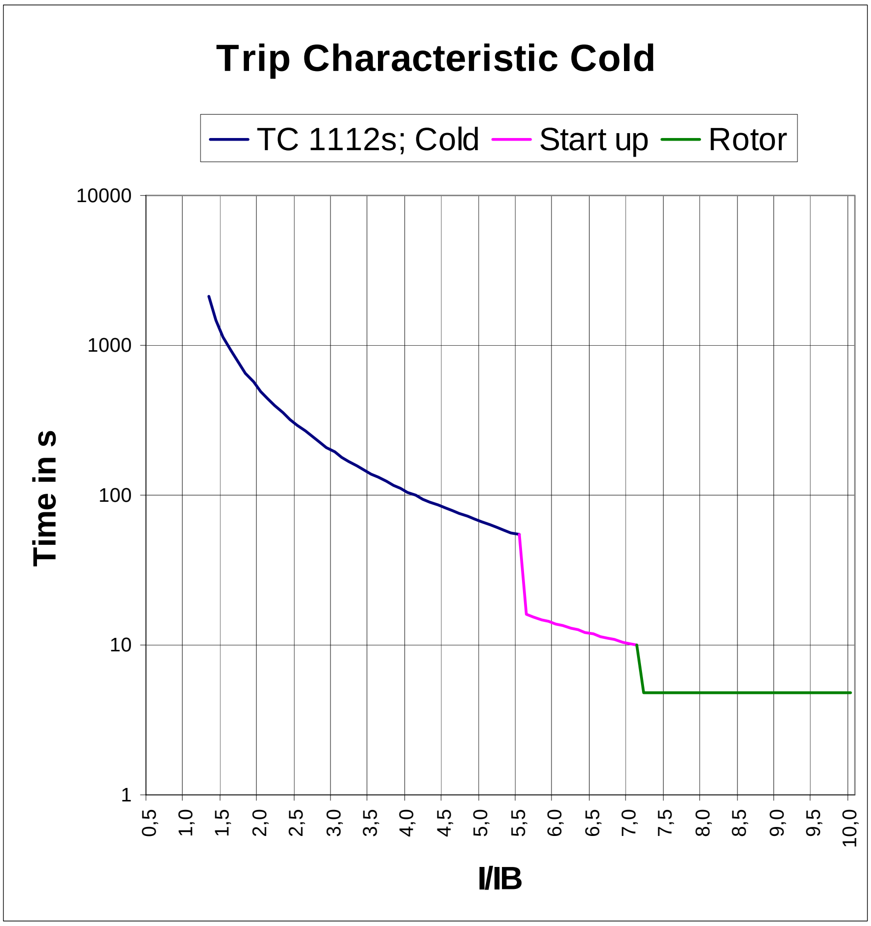


Figure 12: Tripping characteristic from a combination of the protection functions

The tripping characteristic is formed from a combination of the motor protection functions. Within a 1.2 to 4.7 basic current or rated motor current IB, a tripping is effected by the thermal protection function; within a range of 4.7 ... 6.3 basic current or rated motor current IB, a tripping is effected by the motor startup monitoring function. In the range above 6.3 IB, a tripping is effected by the rotor monitoring function. The higher the temperature rise or the thermal memory contents, the shorter the tripping time of the thermal protection function. The illustration below shows how the tripping time changes in comparison with the one applicable to the cold condition.

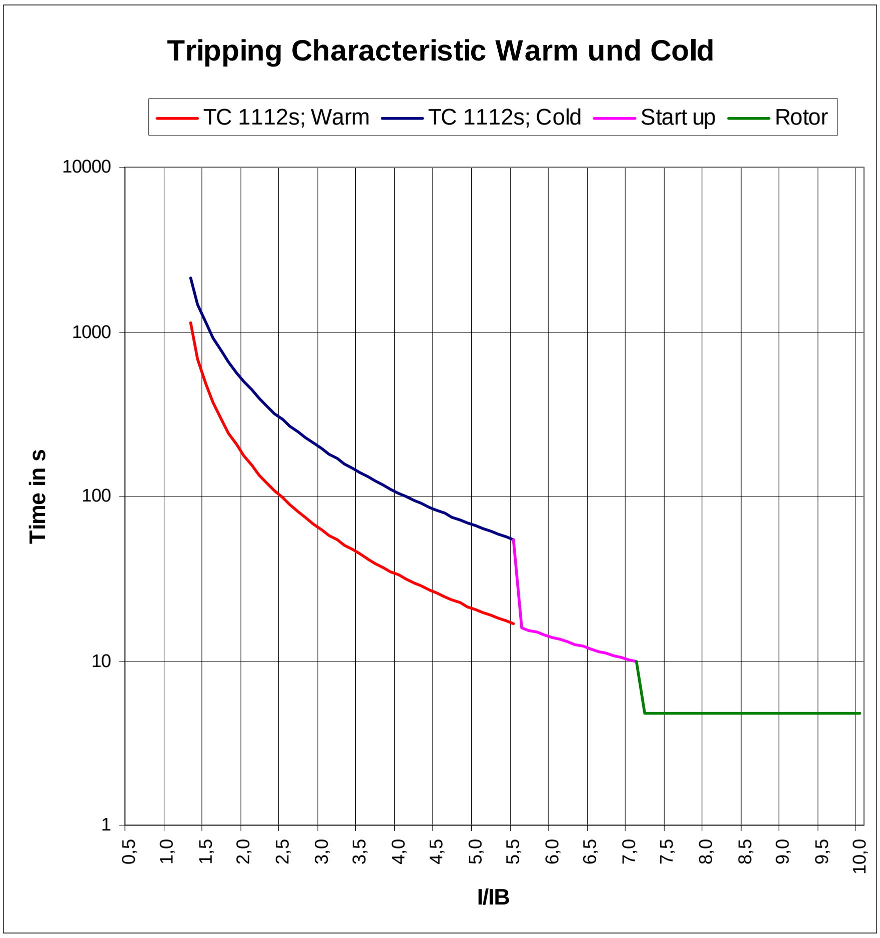


Figure 13: Reducing the tripping time at a 100% preloading

5.6 Behavior after recovering of the auxiliary voltage

When the auxiliary voltage of the REF542plus fails, the motor to be protected must also be switched off. The duration of the failure of the auxiliary voltage can be supervised by the internal real time clock. The clock is able to operate in the next 2 hours with the required accuracy. As soon as the auxiliary voltage recovers again, the cooled down motor temperature is calculated according to equation 14. The result of the calculated temperature is now used as initial temperature to continue the thermal overload protection of the motor.

In this example the following are assumed:

td = 10 Min = 600 s

Tfail = 141°C

Tenviro = 40°C

Zk off = 1026 s

After recovering of the auxiliary voltage the following temperature will be used for continuing the operation of the motor protection:

$$Tini = \left((141 - 40)\ e^{-\frac{600s}{1026s}} + 40 \right) °C = 96°C$$

where:

td	Duration of the failure of the auxiliary voltage
Tfail	Temperature at the moment failure occurrence
Tenviro	Setting of the environmental temperature
TimeConst I < 0.1 Ie	Setting of the time constant for cooling down the motor at standstill
Tini	Initialtemperature for the continuation of the protection task

6 Operation of the REF542*plus*

In this chapter you will find the following information:

Operator’s responsibilities

Guarantee provisions

General safety notes

Special safety warnings that must always be observed when working with the REF542*plus*.

6.1 Operator's responsibilities

Please observe the following information for the operator:

The operating personnel for the REF542*plus* must have the appropriate qualifications for work on the unit.

Your operating personnel must be authorized to work with or on REF542*plus*. (E.g. switching authorization in substations)

Changes to the application as delivered may be made only by ABB personnel

For guarantee reasons, changes to the application as delivered made by the customer must always be approved by the appropriate ABB sales department

We recommend that only ABB personnel make adjustments to the unit. Once the guarantee has expired, the unit is opened at your own risk and is permitted after consultation with the ABB office that sold the unit.

6.2 Guarantee Provisions

The data provided in this documentation is intended solely to describe the product and must not be considered as assured properties. In the interest of users, we are continually striving to bring our products up to the latest state of the art in technology. For this reason there may be differences between the product and the product description and the manual.

If the instructions and recommendations of our documentation are observed, then, according to our experience, the best possible operational reliability of our products is guaranteed.

It is virtually impossible for comprehensive documentation to cover every possible event that may possibly occur when using technical devices and apparatus. We therefore request that our representatives or we be consulted in the event of any unusual incidents and in cases for which this Manual do not provide comprehensive information.

We explicitly refuse to accept any responsibility for all direct damages that occur as a result of erroneous usage of our devices, even if no special instructions on this are included in the manual.

The documentation has been carefully checked. If the user should find any defects in spite of this, we request that you inform us as quickly as possible.

We provide a 1 year guarantee for the functioning of the REF542*plus*.

The guarantee provisions are a component of the related contract documents.

Special arrangements may be made in consultation with the operator and will be specified in the contract documentation.

In general, all agreements, assurances, legal relationships and all ABB obligations arise from the current valid contract documentation, including any reference to the warranty provisions, which are not influenced by the content of this documentation.

ABB assumes no responsibility for damages resulting from improper use of REF542*plus*.

In the event of a guarantee claim, please contact the ABB office that sold the unit.

6.3 Safety Regulations

The safety notes in the following chapters represent only a general selection of the points that must be observed. Additional safety notes applicable to the actual content of the chapter can be found in the other specific parts of the manual.

Safety notes are either at the beginning of the section or directly at the relevant position in the text.

6.3.1 General safety notes

Documentation

Note — The content of the documentation supplied with the device must be followed in all circumstances when the device is in operation.

Operating an electrical device

Warning! — **When any electrical device is being operated, specific parts of the device are subject to voltage. If safety warnings are not followed, hazards to personnel and property will result. Personal injury and damage to property may also occur.**

Safe Operation

Note — The device must be properly transported and stored to ensure fault-free and safe operation. In addition, commissioning, control, service and maintenance must be properly and thoroughly conducted.

6.3.2 Specific safety information

Five safety rules

Warning! — **The five safety rules according the so called "VBG4 Electrical Substations and Equipment“ must be observed in all circumstances for personal safety:**

1. **Isolate the system before beginning work.**
2. **Secure against reactivation.**
3. **Ensure that there is no voltage.**
4. **Ground and short circuit.**
5. **Cover or shut out neighboring parts under power.**

Additional safety standards

Warning! **The following safety standards must be observed in all circumstances:**

1. **IEC 60255 for protection relays in high-voltage substations**
2. **DIN 57627 plug connections**

Working on and operating the device

Note Only qualified personnel may work on and operate the device.

Qualified personnel are:

Entrusted with the setup, installation, commissioning and operation of the device and the system in which it is installed.

Qualified and authorized to conduct switching operations in accordance with the standards of safety engineering. This specifically includes switching on and off, isolating, grounding and signage.

Trained in safety engineering standards and are familiar with the maintenance and use of safety equipment.

Trained in first aid.

6.3.3 Risk analysis and safety measures

The risk analysis and the safety measures are mentioned in [DO1]. It can be concluded, that the motor protection function in the REF542*plus* can fulfil the requirement class 3 of DIN V 19250. By means of the watch-dog function all emergency situation can be detected in order to switch off the protected motor. Consequently disturbances with possibly environment pollution can be avoid, even if the process is unmanned.

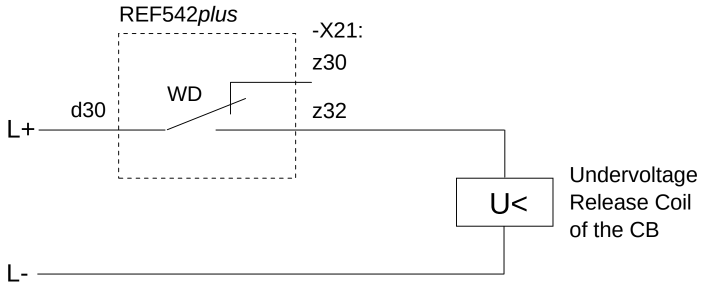


Figure 14: Tripping of the circuit breaker by undervoltage release coil

Above figure shows an example of a possible tripping of the circuit breaker in connection with the watch dog function in case of system failure. The watch dog function controls a relay with an normally open and normally close contact. In normal operation condition the normally open contact, which is always in closed position, is connected to a undervoltage release coil. The undervoltage release coil is supplied by a separate uninterruptible power supply. In case of an appearing system fault the circuit is opened by the watch dog contact and the circuit breaker will be trip mechanically.

Note Referring to DIN EN 954-1 of March 1997 the REF542*plus* fulfills the requirements according to category 2. In this case the failure will be detected by the implemented self supervision function, where the watch dog relay is directly wired to the release coil in order to trip the circuit breaker immediately.

7 Mounting and Installation

In this chapter you will find information:

on what to do first on delivery of the REF542*plus*

the requirements for the installation location and the environmental conditions,

how to set up the REF542*plus* and integrate it into the bay and

how to check the wiring to run the commissioning process.

7.1 Unpacking

The REF542 bay control and protection unit does not require special shipping protection. The packaging is adapted for the shipping type and destination. Please proceed as follows:

Visually inspect the unit and the packaging when unpacking it.
Any shipping damage found in the packaging or the unit should be reported immediately to the last shipper, who should be informed in writing of liability for the damage.

Check the delivery for completeness using the order documentation.
If there is anything missing or any discrepancies with the order documentation, contact the ABB sales office immediately.

Mount the unit as described in the following section. If the unit is not for immediate use, store it in a suitable place in its original packaging.

7.2 Mounting

The REF542 *plus* consists of two parts, a Central Unit and a separate Human Machine Interface (HMI) as the Control Unit. The Central Unit contains the power supply, processor and analog and binary Input and Output (I/O) modules, as well as optional modules for supplementary functions. The HMI Control Unit is a stand-alone unit with its own power supply. It can be installed on the Low Voltage (LV) compartment door or in a dedicated compartment close to the Central Unit. The HMI is normally used to set the protection parameters and to locally operate the switching devices in the switchbay. An isolated and shielded twisted pair according to the RS485 standard interface shall be used for the connection of the HMI as the Control unit to the Central Unit.

The figures below show the dimensions of the HMI Control Unit and Central Unit.

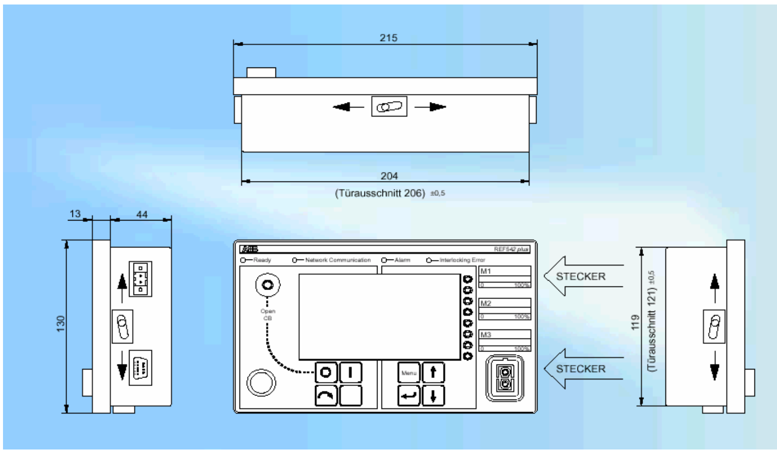


Figure 15: Dimension of the HMI Control Unit

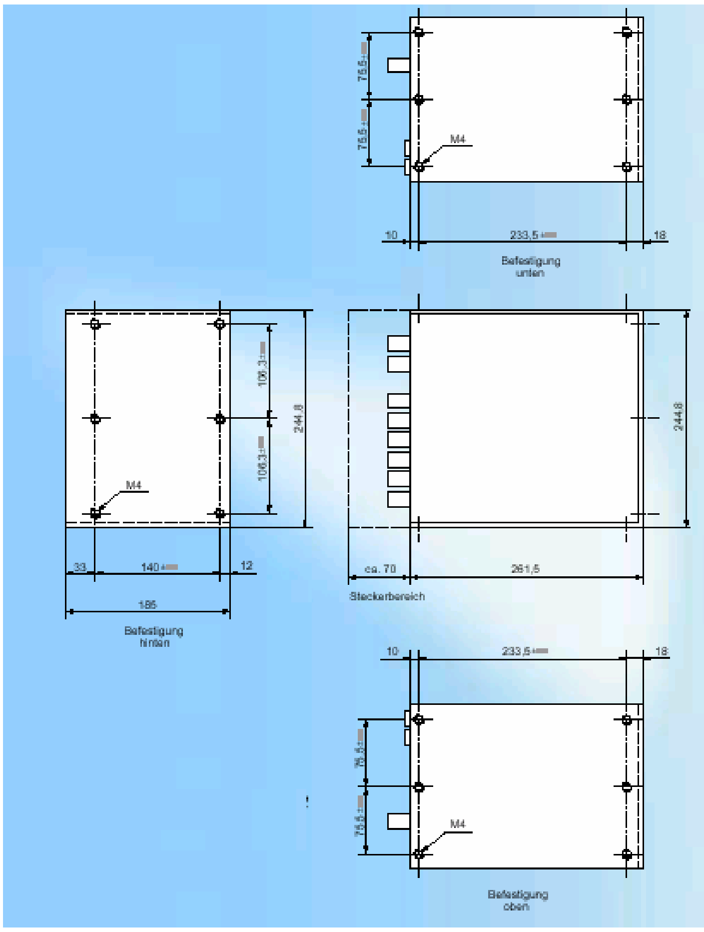


Figure 16: Dimension of the Central Unit case, standard version

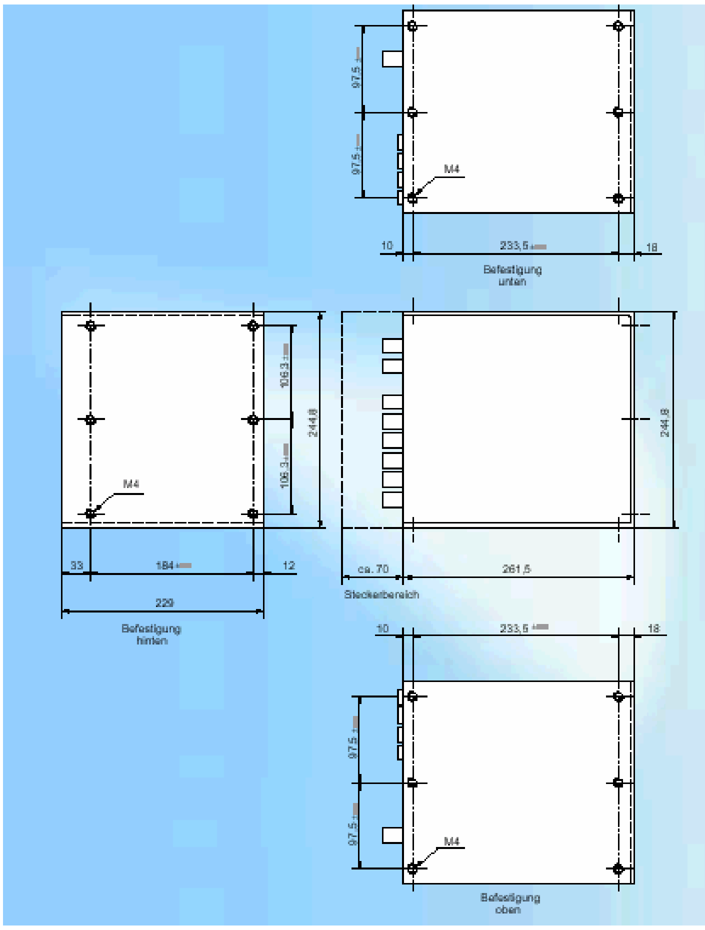


Figure 17: Dimension of the Central Unit case, wide version

7.2.1 Set-up Area and Required Environmental Conditions

Please note the following information regarding the set-up area:

Allow sufficient space for access to the. The connections must be easily accessible.

Access to the Central Unit in the LV compartment must be easy for the following reasons:

- to replace the unit,
- to expand the unit,
- to replace specific electronic equipment boards and
- to replace specific modules if necessary.

Because the unit is sensitive to non-permitted severe environmental conditions, please observe the following:

- The set-up area must be free of excessive air contamination (dust, aggressive substances).
- The natural air circulation around the unit must be free.
- The set-up area must maintain the specified environmental conditions

7.2.2 Installation in LV panels

Figure 18: REF542*plus* installed in gas-insulated switchgears (GIS)

Figure 19: REF542*plus* installed in air-insulated switchgears (AIS)

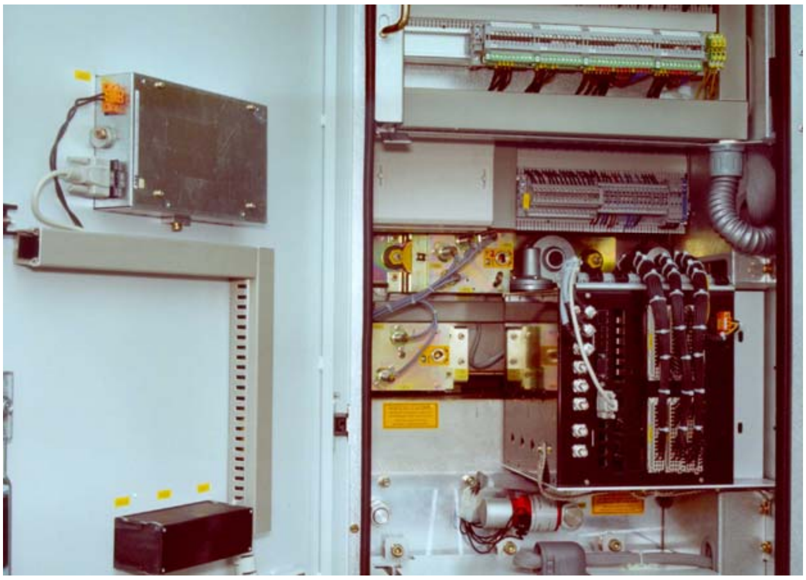


Figure 20: Example of mounting of the Central Unit in the LV compartment and the HMI on the door

7.2.3 Wiring the REF542*plus*

Follow the bay documentation supplied for the wiring.

In conclusion, the checks described in the following paragraphs can be done to ensure that the wiring is correctly installed.

7.2.3.1 Checking the current transformer circuits

To check that the current transformer and the current transformer circuits are wired correctly, run the following checks:

Polarity check
The polarity check (as close as possible to the REF542plus) is used to check the current circuit and also the installation position and the polarity of the transducer. The polarity of the transducers to one another can also be checked with load current.

Current feed with heavy current source (primary test instrument).
The current feed provides information on the transducer transformation and the correct wiring to the REF542plus. The power supply should be per conductor and run from conductor to conductor in each case. All line currents and the residual current should be checked here.
The transducer transformation can also be checked with load current.

Recording the magnetizing characteristic
Recording the magnetizing characteristic ensures that the REF542plus is connected to a protective core and not to a measuring core.

Checking the transducer circuit ground
Every independent current circuit may be grounded at only one point to prevent balancing currents resulting from potential differences.

Check the grounding of the cable current transformer (when used)
If the neutral current is measured by a cable current transformer, the cable shielding should first be returned through the cable current transformer before connecting it to the ground.

This enables weak ground faults currents that flow along the cable sheath to dissipate. In this way, they will not be incorrectly measured at their own relay feeder. The following shows another view of the cable current transformer grounding.

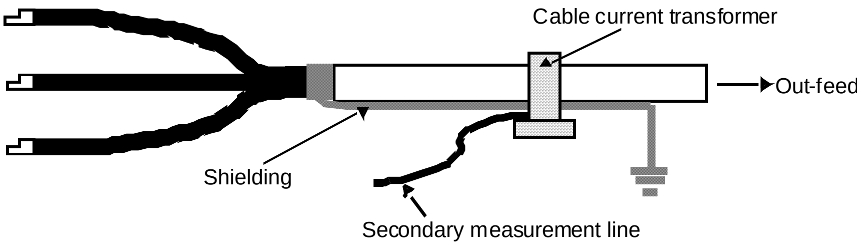


Figure 21: Grounding of a cable current transformer

7.2.3.2 Check the voltage transformer circuits

To check that the voltage transformer and the voltage transformer circuits are wired correctly, run the following checks:

Polarity check

Wiring check

Check the transformer circuit grounding

Check the voltage transformer for neutral point-ground voltage (when used).
To measure ground faults please proceed as follows: The voltage is referred to as neutral point-ground voltage of a ground fault measurement when it occurs with a metallic ground fault in the network between terminals "e“ and "n“ of the open delta winding.
In the event of a metallic ground fault in phase L1, the external phase-to-neutral voltages occur in phases L2 and L3 instead of the conductor-ground voltages. They are added geometrically and yield three times the amplitude between terminals "e“ and "n“.

7.2.3.3 Checking the auxiliary voltage

The auxiliary voltage must be in the tolerance range of the power supply module and have the proper polarity under all operating conditions.

7.2.3.4 Check the tripping and signaling contacts

Conduct this check as shown in the bay documentation.

7.2.3.5 Check the binary inputs

Check the polarity and the voltage value of the binary inputs on the REF542 in accordance with the technical data of the binary inputs.

7.2.4 Grounding of the REF542*plus*

As can be seen in the following figure, the power supply board at connector X10 must be grounded to the housing. Therefore the middle pin must be connected to the grounding point in the LV compartment. Beside that, the shielding of the cable connection to the HMI control unit must also be connected to ground respectively to the housing.

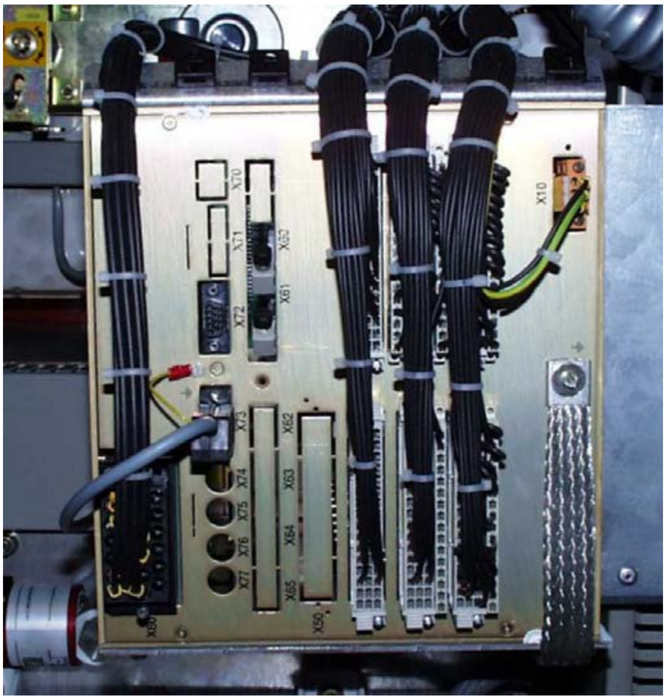


Figure 22: Grounding of the REF542*plus* Central Unit housing

To ensure the EMC (**E**lectro **M**agnetic **C**ompatibility) the housing must be grounded by a low impedance galvanic connection to the grounding system. As it is shown in the figure, an appropriate cable connection, which is fixed from a specific screw on the housing to the grounding system in the LV compartment, must be foreseen. That is why an interweaving cable is used for the grounding connection. If, due to the installation construction, the low impedance connection from the housing to the grounding system is already given, the additional grounding connection by the interweaving cable can be abstained from.

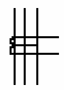
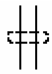
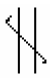
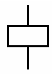
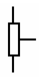
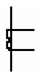
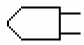
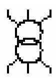
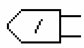
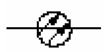
The housing of the HMI Local Control Unit must also be grounded too. As can be seen in the next figure, a specific grounding cable is to be connected from the housing of the HMI Local Control Unit to the grounding system in the LV compartment.

Figure 23: Grounding of the REF542*plus* HMI Local Control Unit

7.2.5 Typical examples of analog and binary connections

The following pages show examples for wiring analog inputs (measuring inputs) on the REF542*plus* with sensors or transducers, binary I/Os and analog output boards. Typical examples of usage in practice will be shown here. The following symbols are used in the circuit diagrams:

Table 6: Graphical symbols for electric diagram (IEC 60617)

Symbol	Legend	Symbol	Legend
	Energy flow from the bus bar		Ring core current transformer
	Energy flow towards the bus bar		Make contact
	Mechanical, pneumatic or hydraulic connection (link)		Break contact
	Earth, ground		Change-over break before make contact
	Conductors in a screened cable		Position switch, break contact
	Twisted conductors		Circuit breaker
	Connection of conductors		Disconnector
	Plug and socket male and female)		Operating device
	Resistor with one fixed tapping		Fuse
	Current transformer		Sensing element
	Three-phase transformer		Current sensing element
	Voltage transformer		Optical fibre cable

7.2.6 Connection Example of the REF542*plus* Analog Inputs

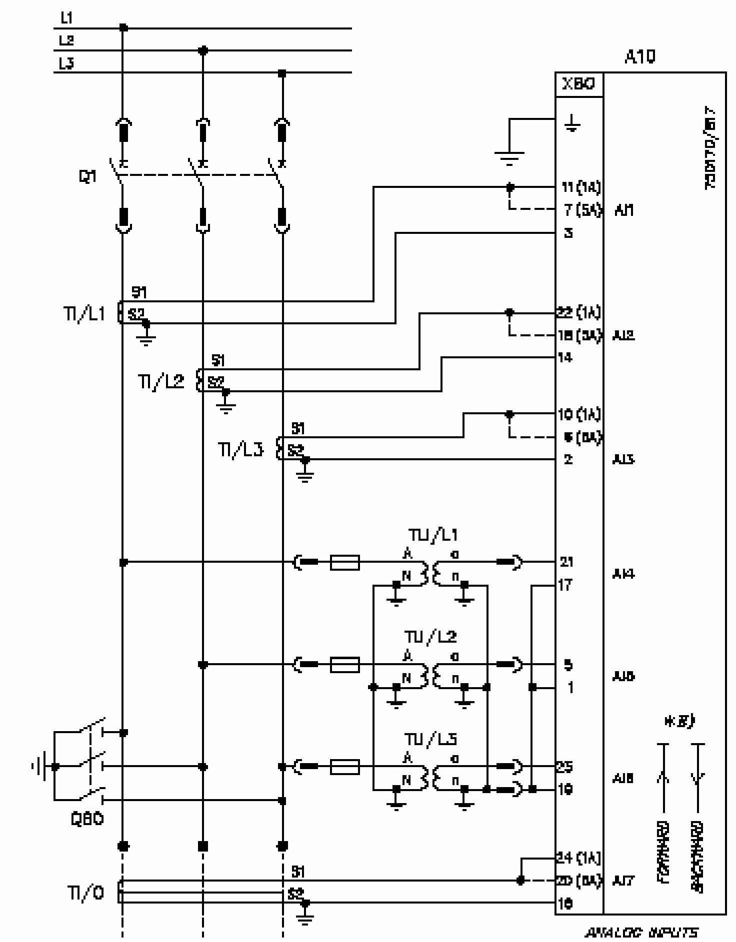


Figure 24: Example of connection diagram for incoming or outgoing bays with transformers

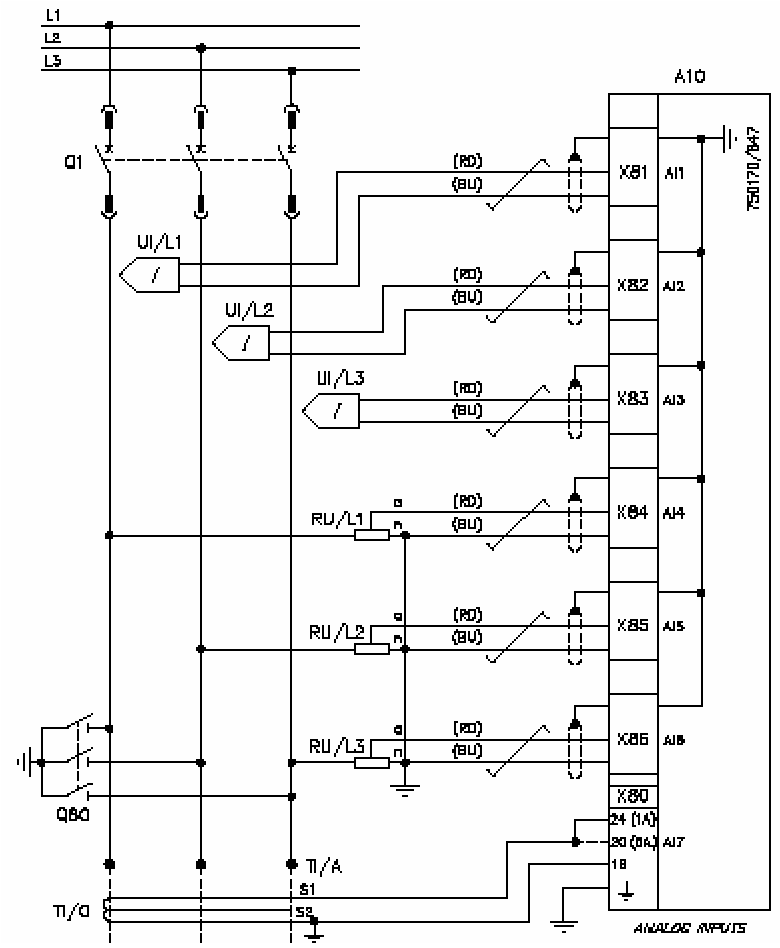


Figure 25: Example of connection diagram for incoming or outgoing bays with sensors

Caution **Due to accuracy requirements the length of the cable connection to the sensors in other bay respectively panels should be less than 7 m**

8 Commissioning

The following sections with their subsections contain information on:

- The devices and facilities required for the commissioning inspection.
- The required procedure for the commissioning inspection; For example, depending on the components to be tested: Protection, interlock conditions, communications, measured value recording and determining the direction.

8.1 Safety Information

The devices, adapters and procedures described are only examples. Experience and safety in handling the various devices is a requirement.

8.2 Switching on the feeder

Caution **Before switching on the feeder check that the REF542*plus* is fully functional in the corresponding bay. Pay particular attention to the protective functions and the interlocking!**

8.3 Test Equipment

The most important device for the commissioning of the REF542*plus* is an appropriate relay test equipment. The test equipment should have a three phase current and voltage system. Also the simulation of current and voltage sensors by the test equipment shall also be possible. For example a test equipment manufactured by KOCOS in Korbach/Germany can be used.

8.4 Testing the interlock conditions,

This test is intended to check the interlocking of the switchgear that the user wants and is required. The two types of interlocking must be taken into account here:

Bay-level interlocking of specific switchgear and

Station-level interlocking of the bay versus other bays.

The interlock conditions for the bay under test can be found in the order documentation. The interlock conditions specified by the user can be found there.

All possible circumstances must be checked.

8.5 Determining the transformer direction

The connection of the measuring inputs and the correct polarity of the current and voltage transformers or sensors is very important for distance, comparison and directional functions.

In addition to testing the polarity, the transformation ratio and the magnetizing characteristic, the wiring of the transformers/sensors must also be checked during these test.

8.5.1 Current transformer

The transformers must have a positive winding.

This can be easily checked with a 9 V battery and an analog DC voltmeter. If the primary coil of the current transformer is connected to the battery, the analog voltmeter connected on the secondary side must show positive. When the battery is disconnected, the voltmeter must measure a negative impulse.

The positive terminal of the battery must be connected to P1 of the primary coil and the positive input of the voltmeter to s1 for this test. The same applies for the negative terminal at P2 of the primary coil and the voltmeter negative input at s2 of the secondary coil.

The test setup for checking the direction of a core is shown in the following figure.

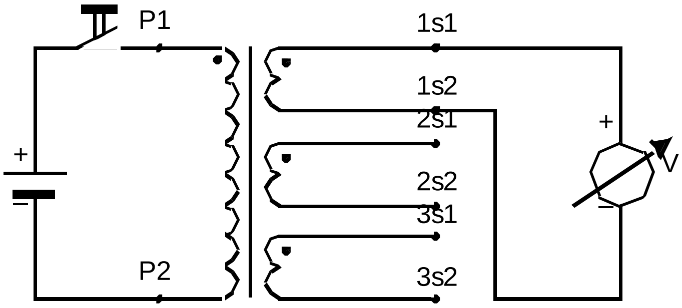


Figure 26: Setup for the polarity test of current transformers

This polarity check, also referred to as patch test, must be run for every core. To guarantee correct operation even with a multi core current transformer with different cores such as protection and measuring cores, it is recommended that the magnetizing characteristic (hysteresis) be recorded. A Variac with appropriately high voltage is connected to the secondary terminals. The flowing current is measured while the output voltage is rising. The characteristic of the measured values, voltage over current, yields the magnetizing characteristic of the core, which can then be compared with the manufacturer's data.

The transformation ratio of the current transformer cores is checked with a special primary current feed device. The feed device is primarily connected to the current transformer and the secondary value is measured at the secondary terminals of the transformer or at the protective cabinet with an ampere meter.

8.5.2 Voltage transformer

The same polarity test or patch test is run with voltage transformers. The difference is that the battery is connected to the secondary side and the analog DC test instrument to the primary coil of the voltage transformer.

The test setup for checking a core is shown in the following figure.

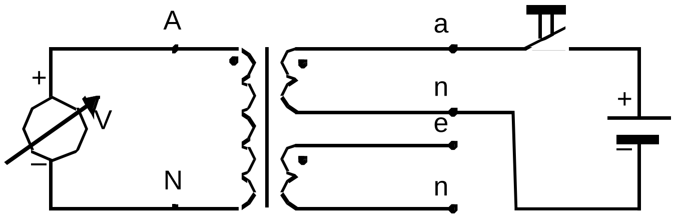


Figure 27: Polarity test of voltage transformers

Every core must be tested here.

If the Variac described in the current transformer section for recording the magnetizing characteristic has a sufficiently high output voltage (e.g. 500 V), it can also be used to run a qualitative test of the voltage transformer transformation ratio. The Variac voltage is applied to the primary side of the voltage transformer and a voltmeter is used to measure the secondary voltage at the corresponding transformer or protective cabinet terminals.

8.5.3 Current sensor

Because the current sensor, the Rogowski coil, is an air-core coil, it must be subjected to the same polarity test as the current transformers.

The test design is shown in the following diagram. A higher voltage value may be required for the battery.

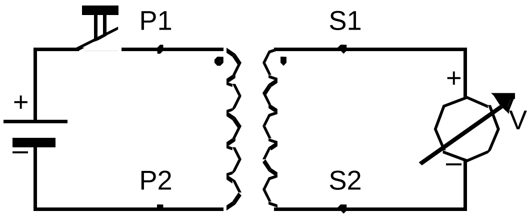


Figure 28: Polarity test of current sensors (Rogowski coil)

The transformation ratio is tested exactly as with a current transformer. The display in the REF542 protection and control unit can also be checked at the same time. It is not necessary to record a magnetizing characteristic with the Rogowski coil, because it is an air-core coil with no saturation characteristics.

8.5.4 Voltage sensor

The polarity of the voltage sensor, which is a resistive precision voltage divider, is checked as shown in the following diagram. The correct polarity of the voltage is measured by applying an appropriate DC voltage (e.g. 24V/DC) to the secondary terminals. The auxiliary voltage source can also be used if the transformation ratio is very high. The transformation ratio of the resistive divider is checked at the same time.

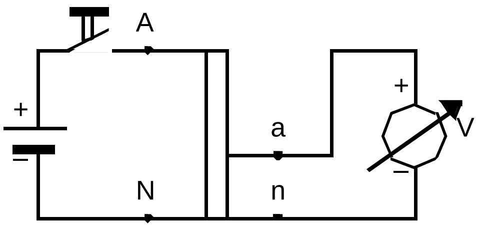


Figure 29: Polarity test of voltage sensors (resistive splitter)

8.6 Testing the measured value recording

Proper functioning of the transformers and sensors is important for proper functioning of the REF542*plus*. The measured-value processing of the unit and the set rated values must be tested for this reason.

The phase currents and phase voltages must be taken as measured input quantities. All other measured values are quantities derived from them.

Test as follows:

Check whether the set rated values match the rated values required by the user (in the order documentation).

If necessary, load the application into the PC from the REF542*plus*.

Select the menu item `Main Menu/Settings/Connections/Analog Inputs` in the configuration program. The rated values are shown in the dialog window that appears and, if necessary, changed.

Test the wiring of the transformers or sensors

Disconnect the transducers or sensors from the REF542*plus*.
The current transformers must be short-circuited, combination sensors disconnected.

Connect the test set to the REF542*plus*. The relevant current and voltage signals are applied to the analog inputs.
Set the required rated values on the test set

Table 7: Rated values of the current and voltage signals

Transducer/sensor	Rated value
Current transformer	1A or 5A
Voltage Transformer	100V
Rogowski coil	150 mV
Voltage sensor	2V

To test the phase sequence, set every phase separately to the rated value and then check the value on the LC display screen. At the end reset the phase to zero.

Generate one symmetrical system each for current and voltage with the rated values.

Check the calculated values. A three-phase current and voltage tester is recommended to test the power. By changing the phase angle between the current and the voltage system the calculation of reactive and effective values and of cos φ can be checked.

8.7 Testing the protective functions

To ensure that no damage has been caused by transport or setup and installation of the protection equipment and systems, secondary tests are run on the REF542*plus* protection and control unit with the configured protective functions.

Warning! **Always observe the applicable safety regulations when conducting the secondary test with an appropriate test set.**

Caution **When testing ensure that the limit values of the measuring inputs and the auxiliary voltage supply are not exceeded.**

9 Technical data

9.1 Analog input channels

Accuracy for measurement:	Class 1
Accuracy for protection applications:	Class 3
Accuracy of operation time: min ± 20 ms or	Class 3

9.1.1 Current and voltage transformer input values

Rated current In	1A or 5A
Rated voltage Un	100V (also suitable for 110V)
Rated frequency fn	50 Hz / 60 Hz

Thermal load capacity

Current path	250 I_n (peak value) dynamic, 100 I_n for 1s, 4 I_n continuous,
Voltage path	2 U_n /√3 continuous.

Consumption

Current path	≤ 0.1 VA with I_n
Voltage path	≤ 0.25 VA with U_n

9.1.2 Current and voltage sensor input values

Voltage at rated current In	150 mV (rms)
Voltage at rated voltage Un	2V (rms)
Rated frequency fn	50 Hz / 60 Hz

9.2 Binary inputs and outputs

Each Binary I/O module has the following number of inputs and outputs:

9.2.1 BIO module with mechanical output relays (version 3)

14 input channels	Possible auxiliary voltage ranges: • 20 to 90 V DC (threshold 14 V DC) • 80 to 250 V DC (threshold 50 V DC) Each input has a fixed filter time of 1 ms. Additional filter time can be configured by software.	
6 power outputs (channels BO 1 to 6).	Maximum operating voltage Make current Load current Breaking capacity: 1 Contact 2 Contacts Operating time	250V AC/DC 8 A 6 A 75 Watt 300 W at L/R <15 ms 8 ms
2 signal outputs (BO7 and 8) and 1 Watchdog output (WD)	Maximum operating voltage Load current Operating time	250 V AC/DC 2 A 8 ms
Optional: 1 Static signal output on BO7	Maximum operating voltage Make current Load current R_{Ein} R_{Aus} Operating time	250 VDC 1.5 A (100ms) 0.7 A continuous 1,06 Ω 40 MΩ 1 ms
Coil supervision circuit	1 for channel BO2, to be supervised impedance ≤ 10 kΩ	

9.2.2 BIO module with static outputs

14 inputs (BI 1-14)	Auxiliary voltage range • 48 to 265 VDC (Threshold 35 VDC) Each input has a minimum fixed filter time of 5 ms. Additional filter time can be configured by software.	
3 power outputs (BO1,2 and 7)	Operating voltage Make current Load current Operating time	48 to 250 VDC 64 A 16 A 1 ms
4 power outputs (BO3 to 6)	Operating voltage Make current Load current Operating time	48 to 250 VDC 120 A 31 A 1 ms
2 Signal outputs (BO8,9) and 1 Watchdog output (WD)	Operating voltage Make current Load current R_{Ein} R_{Aus} Operating time	400 VDC 1.5 A (100ms) 0.7 A 1,06 Ω 40 MΩ 1 ms
Coil supervision circuits	2 for channel BO1 and BO2, to be supervised impedance ≤ 10 kΩ	

9.3 Interfaces

9.3.1 HMI Control Unit:

- Optical/electrical standard interface RS 232 to the Notebook PC (at the front)
- Electrical isolated standard interface RS 485 to the Base Unit (at the rear)

9.3.2 Base Unit:

- Electrical isolated standard interface RS 485 to the HMI
- Electrical standard interface RS 232 for service purposes

9.4 Analog output board (optional)

Four channel 0 to 20 mA or 4 to 20 mA

9.5 Analog input board (optional)

Six channel 4 to 20 mA

9.6 Communication (optional)

- SPABUS, optical interface, optional with SMA or ST connector, for plastic or glass fiber (multi mode)
- LON (according to ABB LAG1.4), optical interface with ST connector for glass fiber (multi mode)

- IEC 60870-5-103 with extension according to VDEW guidelines for controlling, optical interface with ST connector for glass fiber (multi mode)
- MODBUS RTU, electrical interface with two RS485 ports (twisted pair) or optical interface with two standard ST connector for glass fiber (multi mode)

9.7 Power supply

9.7.1 Base Unit

Rated voltage	110 VDC (-30%, +10%), 220 VDC (-30%, +10%) or 48 to 220 VDC (-15%, +10%)
Power consumption	≤ 20 W typical
Inrush current	Module 750168: 10A, 1ms; 35A, 100µs Module 750126: 8,3A, 1ms; 21A, 100µs
Harmonics	≤ 10%

9.7.2 HMI Control Unit

Rated voltage:	For auxiliary voltage in the range of: • 48 to 10 VDC (-15%, +10%) • 110 to 220 VDC (-15%, +10%)
Power consumption Harmonics	≤ 10 W or ≤ 6 W for backlight on or off ≤ 10%

9.8 Environmental conditions

Ambient operation temperature	-5 to + 55°C
Ambient transport and storage temperature	-20.to +70°C
Ambient humidity	Up to 95% without condensation

9.9 Degree of protection by enclosure

9.9.1 Central Unit

Housing	IP20

9.9.2 RHMI Control Unit

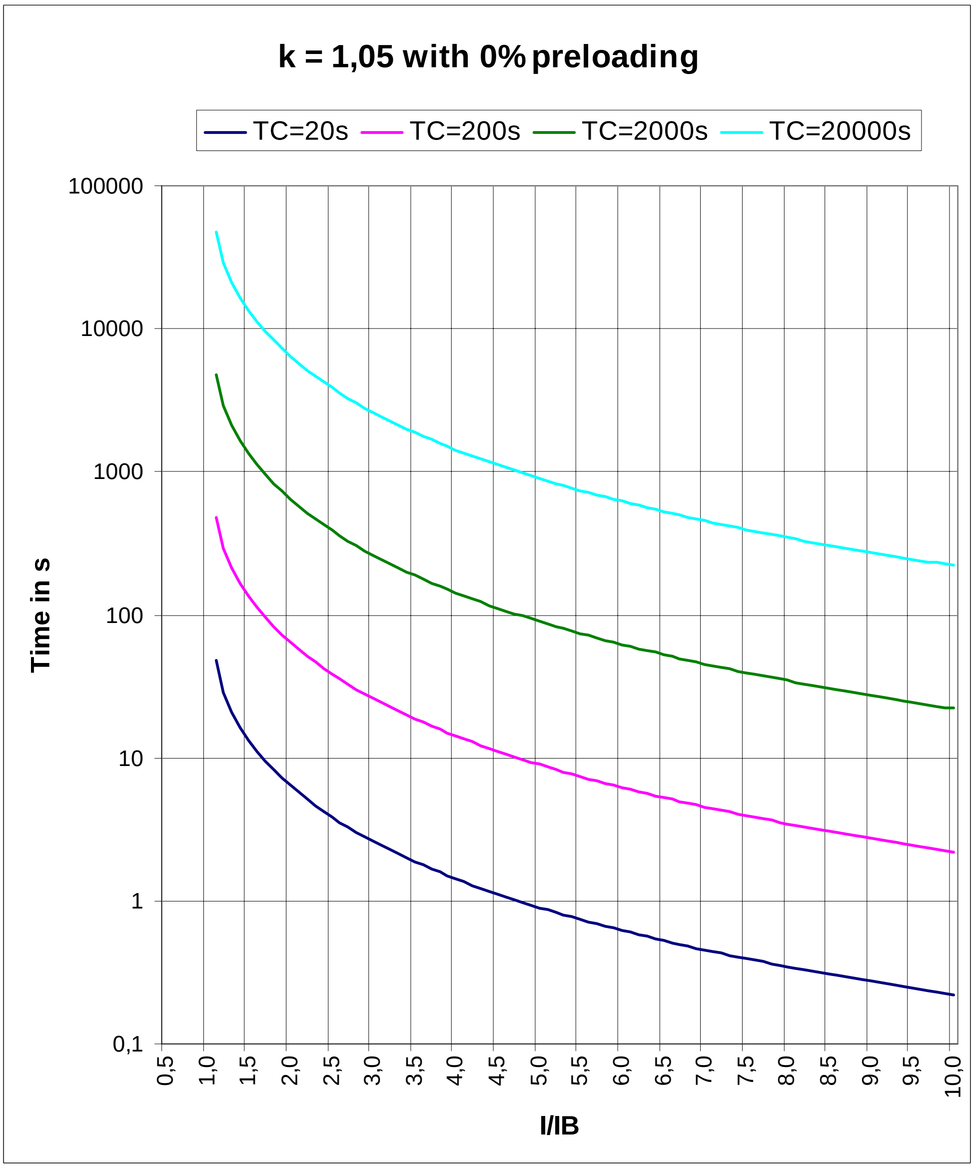
Front	IP 54
Rear	IP 22

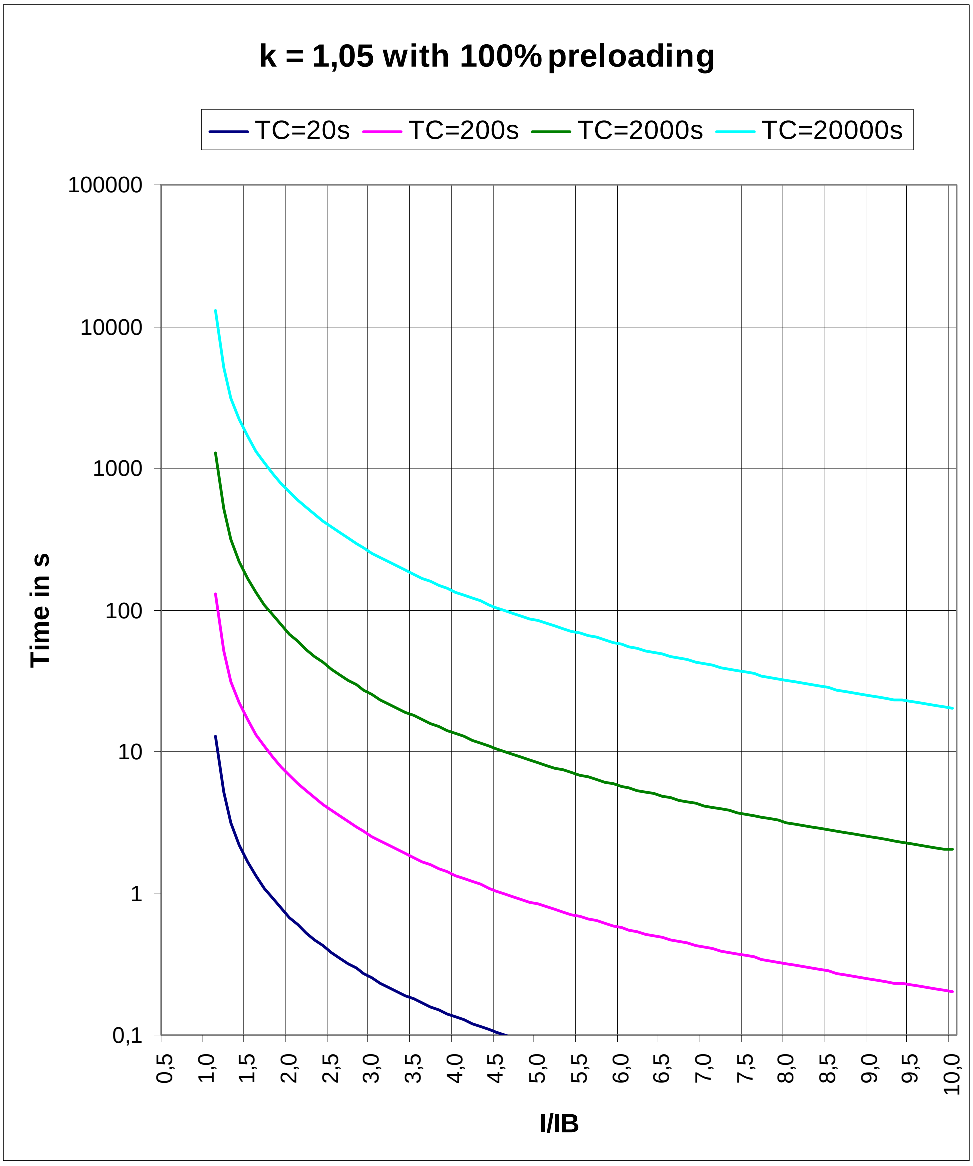
10 Appendix:

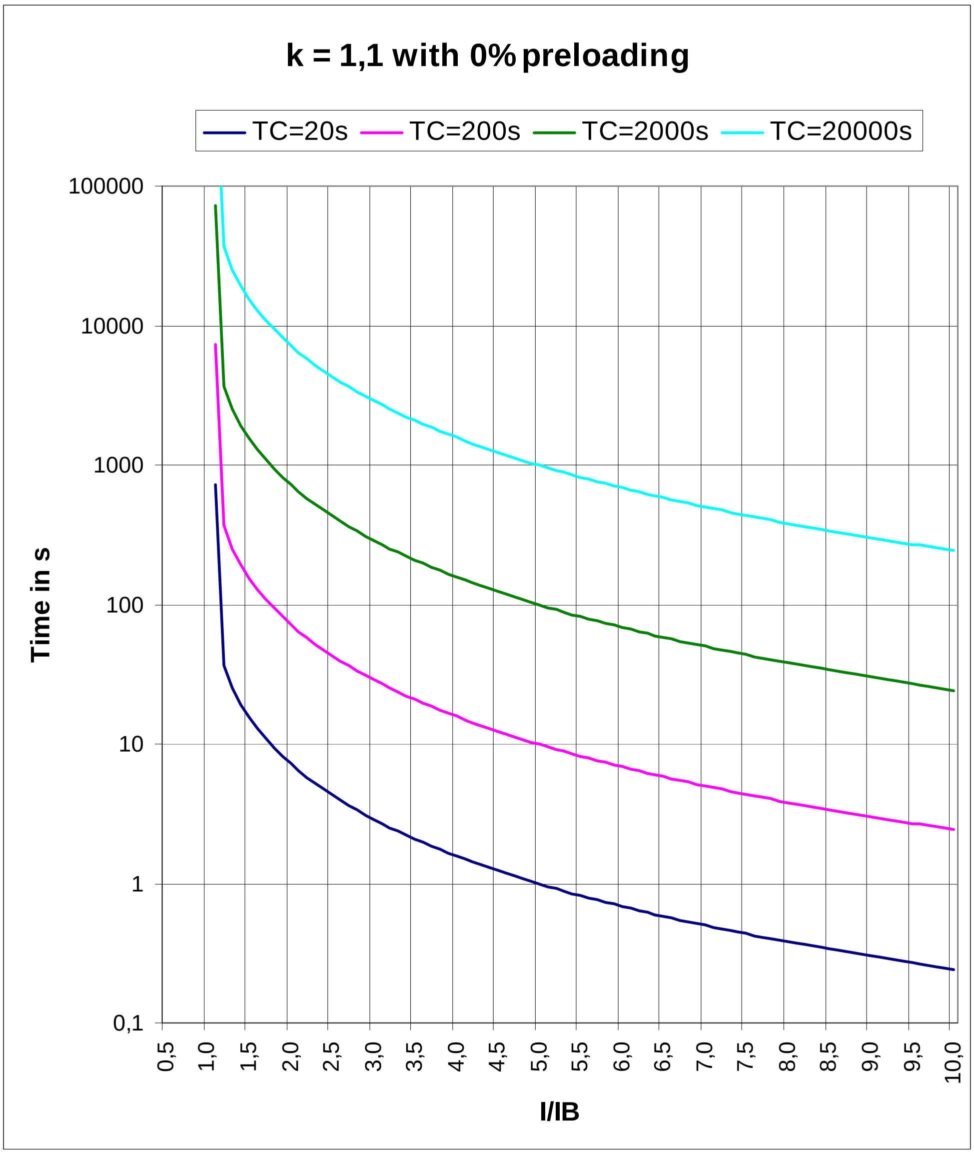
The tripping characteristics for the thermal overload protection depending on the setting of the time constant with constant k and the preloading as parameter are summarized. According to [DIN1] the preloading is assumed to be 0% (cold start), 90% and 100% (nominal condition) each time. In the figure the parameter for the time constant is named as Zkf instead of TC.

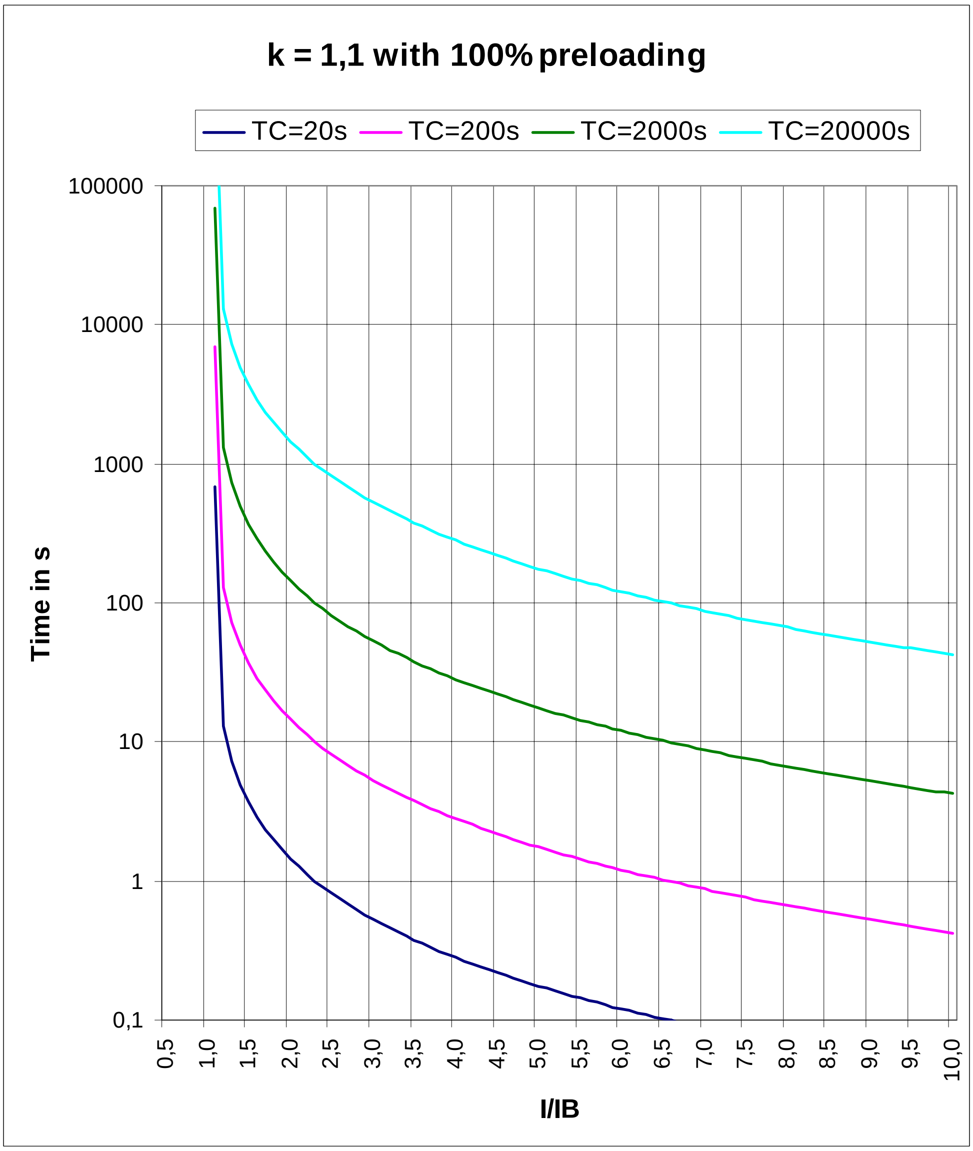
Note

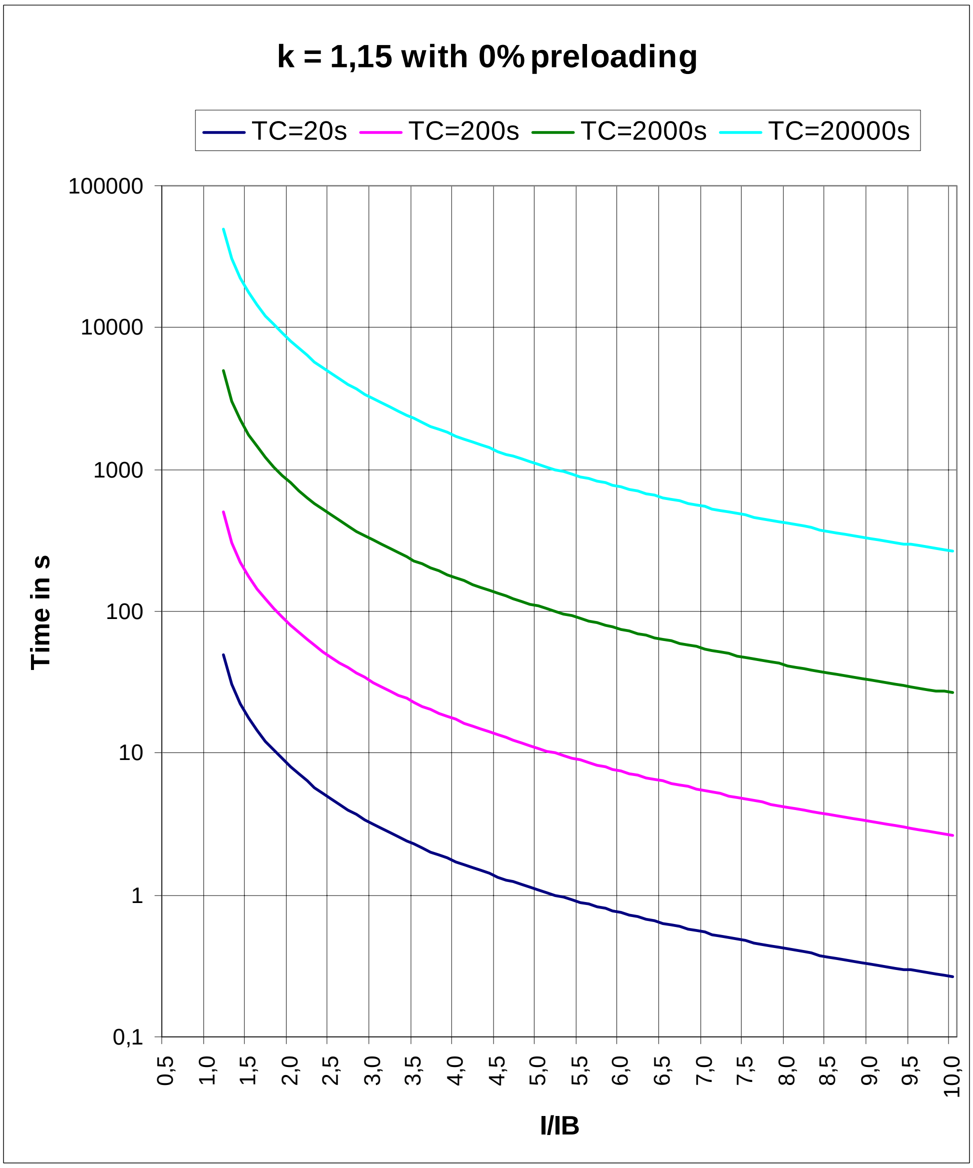
To show the flexibility of the thermal overload protection the tripping characteristics are represented according the whole range of setting parameter of the time constant Zkf or better TC. For practical application is in general a setting range between 200 and 2000s sufficient.

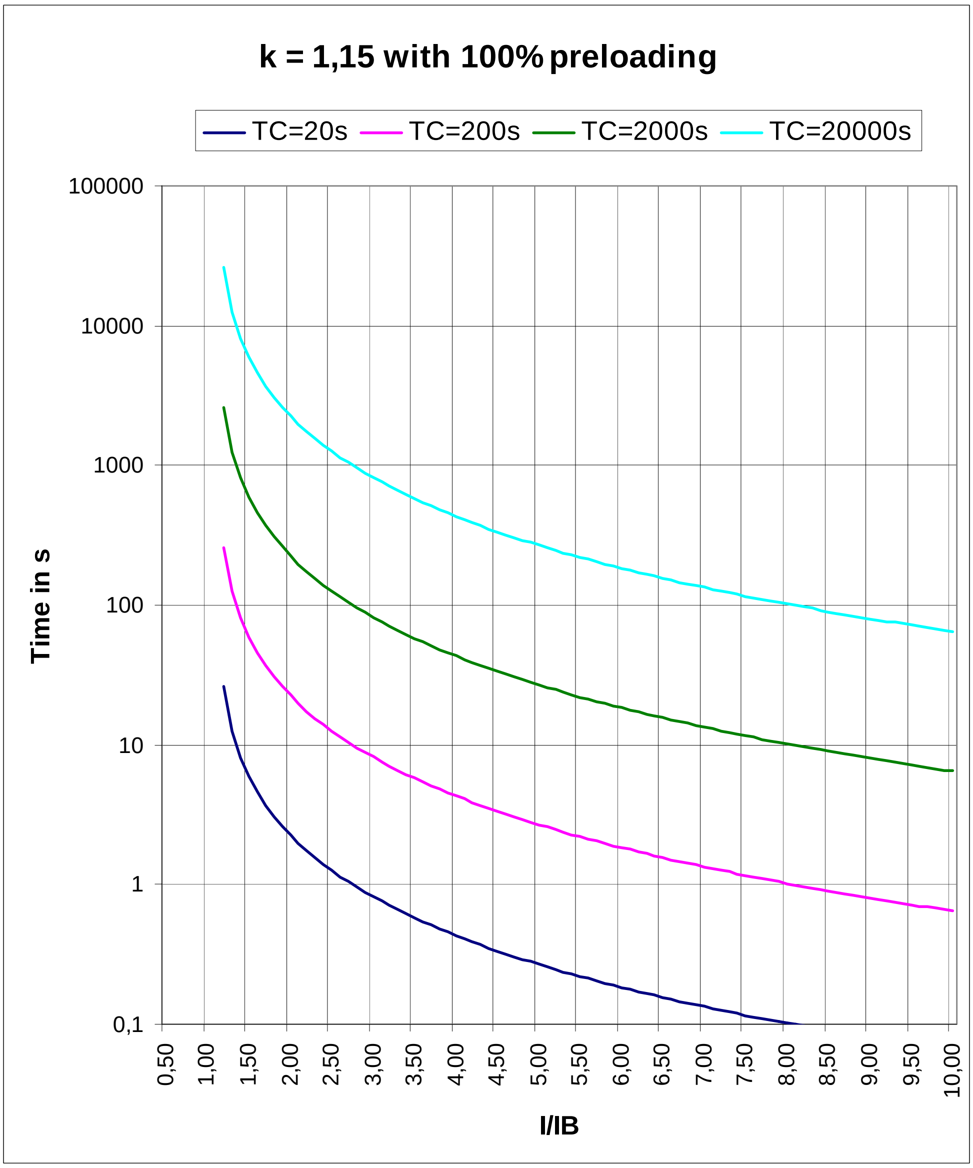


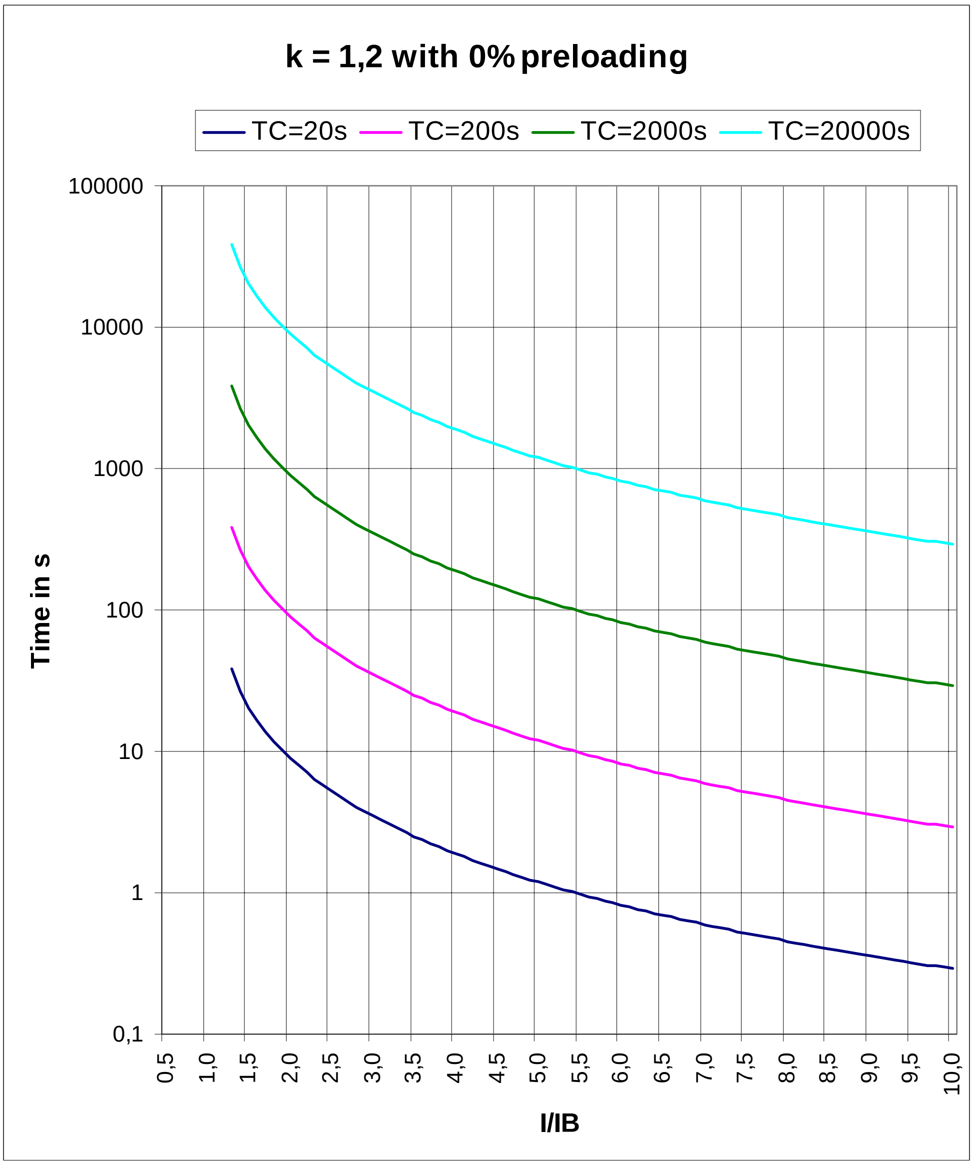

k = 1,05 with 100% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
Time in s
100000
10000
1000
100
10
1
0,1
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB

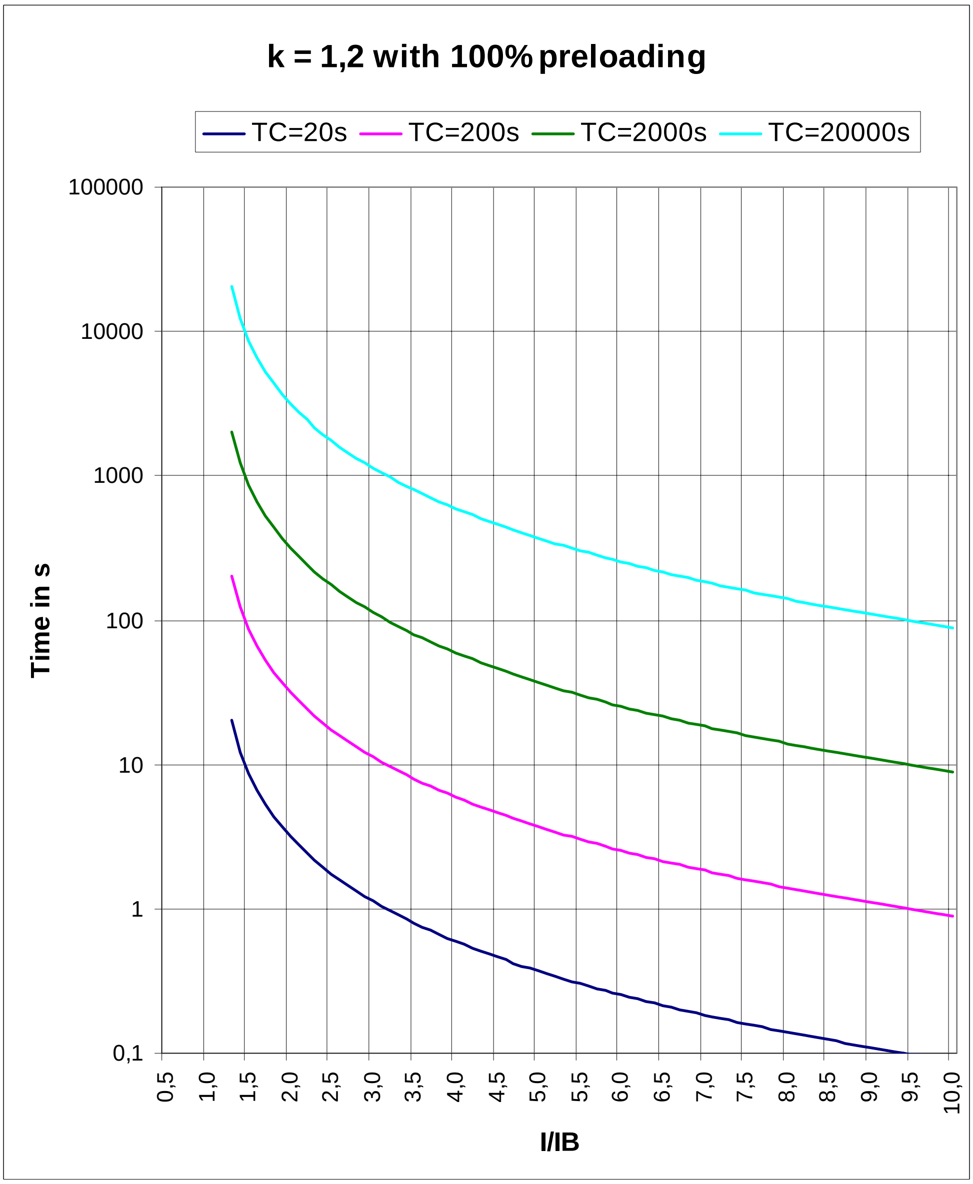

k = 1,1 with 0% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
Time in s
100000
10000
1000
100
10
1
0,1
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB


k = 1,1 with 100% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
100000
10000
1000
100
10
1
0,1
Time in s
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB


k = 1,15 with 0% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
Time in s
100000
10000
1000
100
10
1
0,1
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB


k = 1,15 with 100% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
100000
10000
1000
100
10
1
0,1
Time in s
0,50
1,00
1,50
2,00
2,50
3,00
3,50
4,00
4,50
5,00
5,50
6,00
6,50
7,00
7,50
8,00
8,50
9,00
9,50
10,00
I/IB


k = 1,2 with 0% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
Time in s
100000
10000
1000
100
10
1
0,1
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB


k = 1,2 with 100% preloading
TC=20s
TC=200s
TC=2000s
TC=20000s
100000
10000
1000
100
10
1
0,1
Time in s
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
9,5
10,0
I/IB