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INTERNATIONAL STANDARD

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colour inside

Measuring relays and protection equipment –
Part 149: Functional requirements for thermal electrical relays

Relais de mesure et dispositifs de protection –
Partie 149: Exigences fonctionnelles pour relais électriques thermiques

IEC 60255-149:2013

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FOREWORD

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International Standard IEC 60255-149 has been prepared by IEC technical committee 95: Measuring relays and protection equipment.

This first edition cancels and replaces IEC 60255-8, published in 1990.

The text of this standard is based on the following documents:

FDIS	Report on voting
95/313/FDIS	95/317/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of IEC 60255 series, under the general title *Measuring relays and protection equipment,* can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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MEASURING RELAYS AND PROTECTION EQUIPMENT –

Part 149: Functional requirements for thermal electrical relays

1 Scope

This part of the IEC 60255 series specifies minimum requirements for thermal protection relays. This standard includes specification of the protection function, measurement characteristics and test methodologies.

The object of this standard is to establish a common and reproducible reference for evaluating dependent time relays which protect equipment from thermal damage by measuring a.c. current flowing through the equipment. Complementary input energizing quantities such as ambient, coolant, top oil and winding temperature may be applicable for the thermal protection specification set forth in this standard. This standard covers protection relays based on a thermal model with memory function.

The test methodologies for verifying performance characteristics of the thermal protection function and accuracy are also included in this Standard.

This standard does not intend to cover the thermal overload protection trip classes indicated in IEC 60947-4-1 and IEC 60947-4-2, related to electromechanical and electronic protection devices for low voltage motor-starters.

The thermal protection functions covered by this standard are as follows:

Protection function	**IEC 61850-7-4**	**IEEE C37.2**
Thermal overload protection	**PTTR**	49
Rotor thermal overload protection	**PROL**	49R
Stator thermal overload protection	**PSOL**	49S

General requirements for measuring relays and protection equipment are specified in IEC 60255-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at *http://www.electropedia.org*)

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60255-1, *Measuring relays and protection equipment – Part 1: Common requirements*

IEC 61850-7-4, *Communication networks and systems for power utility automation – Part 7-4: Basic communication structure – Compatible logical node classes and data classes*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in IEC 60050-447, as well as the following apply.

3.1
hot curve
for a thermal electrical relay with a total memory function, characteristic curve representing the relationship between specified operating time and current, taking into account thermal effect of a specified steady-state load current before the overload occurs

Note 1 to entry: Hot curve is a plot of a particular time-current solution for a first-order thermal system differential equation, assuming a specific constant overload current and a specific preload current.

3.2
cold curve
for a thermal electrical relay, characteristic curve representing the relationship between specified operating time and current, with the relay at reference and steady-state conditions with no-load current flowing before the overload occurs

Note 1 to entry: Cold curve is a plot of a particular time-current solution for a first-order thermal system differential equation, assuming a specific constant overload current when there is no preload.

3.3
basic current
I_B
specified limiting (nominal) value of the current for which the relay is required not to operate at steady-state conditions of the equipment to be thermally protected

Note 1 to entry: The basic current serves as a reference for the definition of the operational characteristics of thermal electrical relays. The basic settings of a thermal electrical protection function are made in terms of this basic current (I_B) and the thermal time constant (τ) of the protected equipment.

3.4
equivalent heating current
I_{eq}
current which takes into account the additional heating sources such as imbalance currents and/or harmonics

3.5
factor *k*
factor by which the basic current (I_B) is multiplied to obtain the maximum permissible continuous operating current value of the equipment to be thermally protected, which is used in the thermal characteristic function

Note 1 to entry: The factor k indicates the maximum permissible constant between phase current (full load) and the basic (nominal) current of the protected equipment.

3.6
previous load ratio
ratio of the load current preceding the overload to basic current under specified conditions

3.7
reference limiting error
limiting error determined under reference conditions

[SOURCE: IEC 60050:2010, 447-08-07]

3.8
temperature rise
difference between the temperature of the part under consideration and a reference temperature

Note 1 to entry: The reference temperature may be for example the ambient air temperature or the temperature of a cooling fluid.

[SOURCE: IEC 60050:2001, 151-16-26]

3.9
thermal equilibrium
thermal state reached when the temperature rise of the several parts of the machine do not vary by more than a gradient of 2 K per hour

[SOURCE: IEC 60050:1996, 411-51-08]

3.10
thermal time constant
T_{th}
time required for the temperature rise of the protected equipment relative to its initial temperature, to reach 63,2 % of its final, asymptotic value following a step increase in current

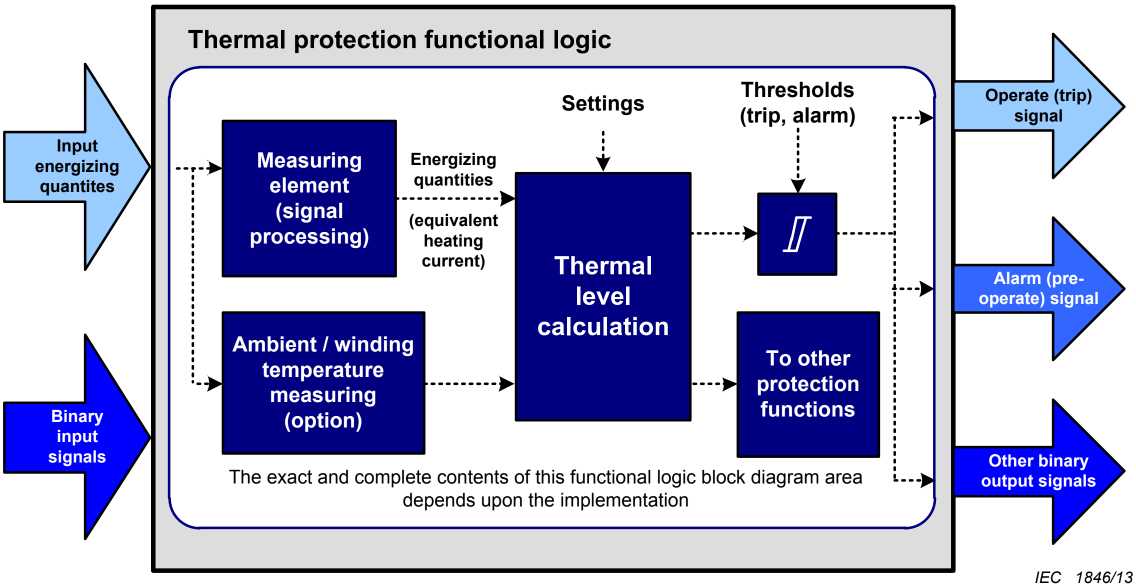
Note 1 to entry: The initial temperature for example can be ambient temperature.

3.11
thermal level
H
ratio expressed in percentage between the estimated actual temperature of the equipment and the temperature of the equipment when the equipment is operating at its maximum current ($k \times I_B$) for a long period, enough to allow equipment to reach its thermal equilibrium

4 Specification of the function

4.1 General

An example of a thermal protection function with its input energizing quantities, binary input signals, operate (trip), alarm and other binary outputs, and functional logic which includes measuring element, thermal level calculation, settings, and thresholds are shown in Figure 1. The manufacturer shall provide the functional block diagram of the specific thermal protection implementation.



IEC 1846/13

Figure 1 – Simplified thermal protection function block diagram

4.2 Input energizing quantities/energizing quantities

The input energizing quantities are the measuring signals, such as phase (or line) currents, and ambient/environmental or winding temperatures (if required or applicable). Their ratings and relevant requirements are specified in IEC 60255-1.

Input energizing quantities can be presented to the thermal protection functional logic either hardwired from current transformers and any additional input quantities such as ambient or winding temperature, or as a data packet over a communication ports using an appropriate data communication protocol, such as IEC 61850-9-2.

The input energizing quantities used by the thermal protection function need not be the current directly taken from the secondary side of the current transformers. Therefore the protection relay documentation shall state the type of energizing quantities used by the thermal protection function.

Examples of input energizing quantities are:

– single-phase current measurement;
– three-phase current measurement;
– positive and negative sequence current measurement;
– winding or ambient temperature sensor.

NOTE The ambient temperature, coolant temperature, top oil temperature or winding temperature of the equipment to be thermally protected can be measured by temperature sensors, such as resistance temperature detector (RTD), the values of which can be used for biasing the calculation of the thermal level replica specified in this standard. Output signals or values of these temperature sensors can be taken into account for the first-order thermal model algorithm, which can influence and compensate the calculated thermal level (based on the equivalent heating current and heating thermal time constant values).

4.3 Binary input signals

If any binary input signals (externally or internally driven) are used, their influence on the thermal protection function shall be clearly described on the functional logic diagram or in the protective device manufacturer documentation. Additional textual description may also be provided if this can further clarify the functionality of the input signals and their intended application or implementation.

Binary input signals to this function may emanate from a number of different sources. Examples include:

- traditionally wired to physical inputs;
- via a communications port from external devices;
- via internal logical connections from other functional elements within the relay.

The method of receiving the signal is largely irrelevant except to conform to operational requirements.

Definitions, ratings and standards for physical binary input signals are specified in IEC 60255-1.

The following are examples of binary input signal application in thermal protection.

1) When the thermal protection function is implemented with two operating modes of the protected equipment, such as power transformers with natural or forced ventilation, two-speed motors or a star/delta starting motor, a binary input can be implemented to discriminate the different operating modes and to select the required group of settings to be used for proper thermal protection application.
2) Another example of a binary input is to implement a reset function of the thermal memory during testing/commissioning procedures, using a binary input either directly hardwired or through data communications.

4.4 Functional logic

4.4.1 Equivalent heating current

The equivalent heating current I_{eq} takes into account the additional heating source such as imbalance currents and/or harmonics. The type of measurement of the equivalent heating current shall be stated in the protection relay documentation.

For the rms measurement, the manufacturer shall specify the bandwidth of the rms current measurement and define which harmonics are included in the equivalent heating current calculation.

Annex A gives an explanation of the definition of the equivalent heating current and different cases of implementation of thermal protection applications of electrical equipment.

4.4.2 Basic (setting) and operating current values for thermal protection

For the thermal electrical relay, the basic (setting) current value I_B is the specified limiting value of the current for which the relay is required not to operate. For motor or transformer applications, the basic current is usually set to the nominal current of the protected equipment.

To take into account the maximum continuous load current of the protected equipment, a factor k is applied to the basic (setting) current value, to determine the operating current for the thermal protection.

Therefore the value $k \times I_B$ defines the operating current of the thermal protection relays,

where

k may be a constant value or a user setting, as declared by the thermal relay manufacturer;

I_B is the basic (setting) current value expressed as the permissible current of the equipment to be thermally protected.

With the factor k, no operation of the thermal relay is guaranteed for phase currents equal to the setting value I_B. If the factor k is a user setting, it should include a range of at least 1,0 to 1,5. For motor or transformer applications, the factor k is usually set by the user, where $k \times I_B$ is equal to or less than maximum operating (full load) current of the equipment to be thermally protected. For relays which do not have a k factor setting (assumed to be fixed at 1,0) the setting for I_B should be adjusted to account for the k factor.

In some cases a fixed value of k may be defined by the manufacturer, equal to the accuracy of current measurement of the thermal electrical relay. This ensures that the thermal relay shall not operate for an operating current of I_B. In this case the ratio between the overload and the nominal current for the equipment being protected can be accommodated in the setting of the base current I_B.

4.4.3 Thermal level calculation

The thermal level calculation of the protected equipment is based on the equivalent heating phase current measurement and the recursive computation of a discrete-time equation of a differential first-order thermal model.

The thermal level $H(t)$ of the protected equipment is calculated by the following equation:

$$H(t) = \left(\frac{I_{eq}(t)}{k \cdot I_B}\right)^2 . \frac{\Delta t}{\tau + \Delta t} + \frac{\tau}{\tau + \Delta t} . H(t - \Delta t) \qquad (1)$$

where

$H(t)$ is the thermal level at time t;

$H(t-\Delta t)$ is the thermal level at time $t-\Delta t$;

Δt is the sample period which is the time interval between two consecutives samples of input currents;

$I_{eq}(t)$ is the equivalent heating phase current at time t (see 4.4.1 and Annex A);

$k \cdot I_B$ is the value of the maximum continuous current, including k factor;

τ is the heating/cooling thermal time constant of the equipment to be thermally protected, τ is assumed to be $\gg \Delta t$.

Derivation of differential and time-current equations and dynamics for a simple first-order thermal system are given in detail in Annex A.

For a particular steady-state case with a constant I_{eq}, the thermal level H can be calculated by the following particular and simplified equation:

$$H = \left(\frac{I_{eq}}{k \cdot I_B}\right)^2 \qquad (2)$$

The thermal electrical relay operates if the thermal level reaches 100 % of maximum thermal level threshold.

According to the mechanical design of the electrical equipment to be thermally protected, the heating thermal time constant and cooling thermal time constant can have different values. For example, for electric motor protection application, the heating thermal time constant is lower than the cooling thermal time constant due to the rotor rotation and self-ventilation operation when the motor is running. In these cases, the thermal level is calculated according to the phase current level, with two different thermal time constants, according to the following equations.

If $I_{eq}(t) \geq 0$ (or if $I_{eq}(t)$ is greater than a fixed input current threshold, stated by the thermal relay manufacturer), the thermal level can be computed by the following equation:

$$H(t)=\left(\frac{I_{eq}(t)}{k.I_B}\right)^2.\frac{\Delta t}{\tau_1+\Delta t}+\frac{\tau_1}{\tau_1+\Delta t}.H(t-\Delta t) \quad (3)$$

If $I_{eq}(t) \approx 0$ (or if $I_{eq}(t)$ is lower than a fixed input current threshold, stated by the thermal relay manufacturer), the thermal level can be computed by the following equation:

$$H(t)=\frac{\tau_2}{\tau_2+\Delta t}.H(t-\Delta t) \quad (4)$$

where

τ_1 is the heating thermal time constant of the equipment to be thermally protected;

τ_2 is the cooling thermal time constant of the equipment to be thermally protected.

NOTE 1 Generally τ_1 is used when the protected equipment is energized and τ_2 is used when the protected equipment is deenergized.

NOTE 2 The heating thermal time constant τ_1 is also used when the equipment is energized and the phase current is reduced to a lower level, which causes a lowering of the equipment thermal level, causing a decrease in the equipment temperature.

NOTE 3 Manufacturers can implement multiple heating and multiple cooling time constants to cover the variety of heating and cooling conditions. For example, during direct on-line motor starting the time constant used in the thermal model can be changed (decreased) to allow for reduced cooling capability of the rotor at standstill/low speed and then revert to a longer time constant when normal running speed is achieved.

For most thermal protection applications, such as self-ventilated motor and generator, two-speed motors, star/delta starting motor, the thermal time constants τ_1 and τ_2 are different. For some other applications, such as motors with separated, independent forced ventilation or cooling systems, power transformers with or without forced ventilation cooling systems, cables, and capacitors, the thermal time constants τ_1 and τ_2 may have the same value. Some specific applications, such as two-speed motors or where star/delta starting is used, additional heating time constants may be used.

4.4.4 Time-current limit characteristic equations and curves

4.4.4.1 General

The time-current characteristics shall be published by the relay manufacturer either in the form of equations or by graphical methods. The time-current equations for a simple thermal model are given here for cold state and hot state.

4.4.4.2 Cold curve

The cold curve for thermal protection relays is a particular solution of the first-order differential Equation (1) for the following conditions.

– Starting from a thermal level with no load current before the overload occurs. Therefore, the equipment temperature is considered as the ambient temperature and its thermal level is considered equal to zero.

– A constant phase current during the overload.

The cold time-current limit characteristic is given by the following time-current equation:

$$t(I_{eq}) = \tau \cdot \ln\left(\frac{I_{eq}^{2}}{I_{eq}^{2} - (k \cdot I_{B})^{2}}\right) \quad (5)$$

where

$t(I_{eq})$ is the theoretical operate time with a constant phase current I_{eq}, with no load current before (prior) the overload occurs;

I_{eq} is the equivalent heating current;

τ is the heating thermal time constant of the protected equipment;

k is a constant (fixed) value or a setting, declared by the thermal relay manufacturer;

I_B is the basic current value expressed as permissible current of the equipment to be thermally protected.

A typical example of time-current characteristic curve for cold state of a first-order thermal system with no previous load before overload occurs is shown in Figure 2.

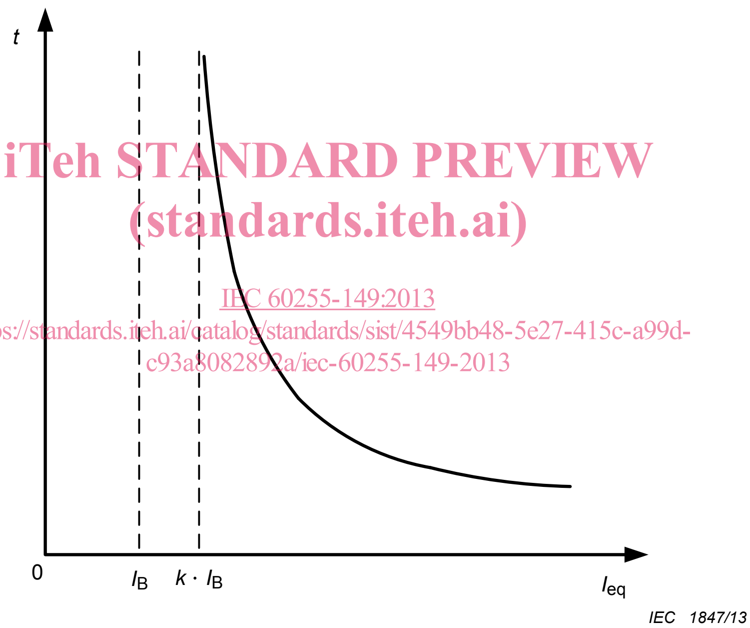


Figure 2 – Typical examples of characteristic curves for cold state of a first-order thermal system with no previous load before overload occurs

A detailed differential equation derivation, algorithm, dynamics, and cold time-current characteristic solution for the first-order thermal system are developed and given in Annex A.

4.4.4.3 Hot curve

The hot curve for thermal protection relays is a particular solution of the first-order differential Equation (1) and it is given by the following time-current equation:

$$t(I_{eq}) = \tau \cdot \ln\left(\frac{I_{eq}^{2} - I_{p}^{2}}{I_{eq}^{2} - (k \cdot I_{B})^{2}}\right) \quad (6)$$