



The simulation of the thermal condition of the motor is by means of a thermal register. The heating of the register is related to the square of the largest of the three line currents. The rate of cooling of the thermal register is directly related to the rate of heating. The value of the thermal register is called thermal capacity and it is used to simulate motor temperature.

100 percent thermal capacity means the motor temperature has reached the maximum allowed and is the level at which an overload trip will occur.

When the motor is stopped for a long period of time the thermal capacity used is zero, this is known as the 'cold condition', and the motor has the full 100 percent of its thermal capacity available for heating before a trip will occur.

When a motor starts and is running its temperature increases, after running at normal FLC for a period of time the motor will have reached a hot condition and a lower value of thermal capacity will be available.

The Hot/Cold Ratio setting determines the amount of available thermal capacity for a motor running at FLC i.e. hot condition, as given in the table below:

% Hot/Cold Ratio Setting	80	70	60	50	40	30	20
Steady State % Thermal capacity Running At 100% FLC	17	26	35	44	52	61	69
Available % Thermal Capacity For Overloads	83	74	65	56	48	39	31

For example if the Hot/Cold ratio setting is 60% and the motor has been running at normal FLC for some time the amount of thermal capacity available is 65% then the amount displayed by the relay is the amount used which is $100 - 65 = 35\%$.

Providing the motor running current does not exceed the fixed overload level (105% FLC) the thermal capacity used will never reach 100% and therefore will never trip on overload

When the running current exceeds the overload setting the thermal capacity will eventually reach 100% and trip the motor. The time taken depends on the present value of thermal capacity used and the t6x setting, which is set as the time to trip for a motor in a cold condition when the current is at 6 times the motor rated FLC. The heating constant is equal to t6x setting x 32 seconds.

The expected 'Time To Trip' is the time it will take to reach 100% thermal capacity at the present running current level is calculated and can be displayed by the relay.

If a motor speed switch is installed and connected to the relay it is then possible to decrease the thermal trip time to 50% of the set hot & cold curve operating times when the motor stops rotating, i.e. stalled.

The change in thermal capacity during a start is stored and a reset after a trip is only allowed if there is this much capacity available. For example if during a start the thermal capacity rises from 75% to 95% a required start capacity of 20% is stored. After an overload trip the relay will not reset until the thermal capacity has dropped to less than $(100\% - 20\%) = 80\%$. To allow faster restarts there is a maximum value for the stored change in thermal capacity. The last start data can be found in the Data Menu and this gives the start Thermal Capacity (i.e. the change), the peak current and start time.

The cooling time constant of a motor, i.e. the time taken for its temperature to drop is usually much longer than the heating constant. The Cooling Factor determines the rate of cooling.

The relay will inhibit and starting until there is sufficient thermal capacity to allow a start to take place.

For testing purposes the thermal capacity register can be reset to 0% in the unit settings of the relay. This can be prevented by enabling the password option, which controls access to any of the unit settings. Use of the "Authorise" digital input option, once energised, can override the password.

The settings for 't6x', 'Cooling Factor' and 'Hot/Cold Ratio' should be established from data obtained from the motor manufacturer. However, should it not be possible then the default settings for these are typical settings for normal



induction motors and may be used at the users own risk. The t6x setting can be set to 10% above the normal run up time, which can be established after the unit is installed by starting the motor and noting the 'Last Start Time' available in the relays start data page.

The present value of thermal capacity is stored in the EEPROM non-volatile memory during a failure or disconnection of the auxiliary supply. Upon restoration of the supply the former value will be maintained.

Referring to the Thermal Operating curves shown in the relay manual, the operating time at a certain multiple of motor FLC can be calculated for a particular motor by multiplying the corresponding time taken from the vertical scales by the setting of t6x.

As an example of applying the Thermal Overload protection to a motor let us establish the settings for a particular motor having the following characteristics:

Rating:	100Kw
System Volts	415 Volts
FLC:	180 Amps
CT ratio	200/5 Amps
Starting	DOL
Start Time	8 sec @ 6xFLC
Cold Withstand	22 Seconds
Hot Withstand	11 Seconds

The figures for Line Voltage, Motor FLC and CT Primary should be entered. For the Overload setting we will use the default pick-up setting of 105%.

The t6x setting must now be calculated. This is set as the time taken to trip at 6 x FLC for the Cold Starting condition and is set in conjunction with the Hot/Cold Ratio setting.

For the above typical motor the Hot Withstand time is 11 seconds, the Cold Withstand is 22 seconds, therefore the Hot/Cold ratio is calculated as $11/22 \times 100 = 50\%$.

As a general rule the relay should be set to trip at no closer than 80% of the Thermal withstand Time, which in this case is $80\% \times 22 \text{ sec} = 17.6 \text{ secs}$.

Therefore set t6x precisely at = 17.6 secs and set Hot/Cold Ratio = 50%
Else, we can round down and set t6X at 17.

From the standard Thermal Operating Curves the Cold curve trip times can be calculated by multiplying the setting t6x and the factor 't' for various multiples of FLC i.e.:

From the Thermal Fundamental Characteristic where t6x =1

The trip times would be:

Multiple of FLC	1.5	2.0	3.0	4.0	5.0	6.0
Trip time (secs)	21.55	10.31	4.18	2.28	1.44	1

For our example setting of 17.6 the trip times would be:

Multiple of FLC	1.5	2.0	3.0	4.0	5.0	6.0
Trip time (secs)	379	181.5	74	40	25	17.6

If t6x is rounded down to 17 the following trip times would apply:

Multiple of FLC	1.5	2.0	3.0	4.0	5.0	6.0
Trip time (secs)	366	175	71	39	24	17



From the Hot Curve for Hot/Cold Ratio =50% trip times can be calculated as follows:

Multiple of FLC	1.5	2.0	3.0	4.0	5.0	6.0
Trip Time (secs)	230	102	40	22	14	9.5

The curves shown on the right are the actual curves for the calculated figures and show that the setting has been chosen to provide close protection to take advantage of the motors capability and allow the possibility of an immediate restart from the Hot condition. However alternative settings can be made to provide faster tripping limited by the conditions of ensuring the motor can run up speed under healthy conditions without tripping.

If the Hot to Cold ratio is set to a figure other than the 3 standard curves drawn, then either the formula quoted below can be used or an approximation of the Hot curve can be drawn to calculate trip times.

(Starting/Cold Condition)

$$t_c = 32.a.log_e \frac{(p^2)}{p^2 - s^2}$$

where 'p' is multiple of motor FLC (per unit value)

's' is overload setting in per unit value e.g. 105%

'a' is setting of t6x in seconds

't_c' is the operating time in seconds

(Running/Pre-load Condition)

$$t_c = 32.a.log_e \frac{(p^2 - (1-H/C)(I_L)^2)}{p^2 - s^2}$$

Where 'I_L' is the steady state load prior to overload condition divided by motor FLC, e.g. if motor is running at FLC, I_L=1.

'H/C' is the hot/cold ratio in per unit value e.g. 40% hot to cold ratio = 0.40.

The Cool Time Factor is factory set at 200% unless specific information is available from the motor manufacturer to calculate the actual setting it is recommended that the default setting is used.

Further help on the application of thermal overload protection by contacting P&B Protection Relays.

