THERMAL OVERLOAD CALCULATION

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THERMAL OVERLOAD PROTECTION (49)

Thermal overload protection is a safety feature that prevents electrical equipment from overheating and getting damaged. It works by monitoring the current flowing through the equipment and cutting off the power if it gets too high. This can happen for a number of reasons, such as:

- The equipment is being overloaded, for example, if a motor is trying to drive too much machinery.
- The equipment is malfunctioning, for example, if there is a short circuit.
- The ambient temperature is too high, for example, if the equipment is installed in a hot attic.

There are two main types of thermal overload protection:

- **Thermal fuses**: These are simple devices that contain a heat-sensitive material that melts when the temperature gets too high. Once the fuse melts, it breaks the circuit and cuts off the power.
- **Thermal relays**: These are more complex devices that use a bimetallic strip to sense the temperature. The bimetallic strip is made of two metals with different rates of expansion. When the temperature rises, the two metals expand at different rates, causing the strip to bend. This bending can then be used to trip a switch and cut off the power.

Thermal relay

Thermal overload protection is important for safety because electrical equipment can get very hot and can potentially start fires if they are not properly protected. It is also important for the lifespan of the equipment, as overheating can shorten its life.

Thermal overload protection is used in a wide variety of electrical equipment, including motors, transformers, and power supplies. It is an essential safety feature that helps to keep electrical equipment safe and reliable.

SIEMENS RELAY THERMAL OVERLOAD CALCULATION

THERMAL OVERLOAD [SIEMENS]

The thermal overload protection is designed to prevent thermal overloads from damaging the protected equipment. The protection function represents a thermal replica of the equipment to be protected (overload protection with memory capability). Both the previous history of an overload and the heat loss to the environment are taken into account.

Applications

- In particular, the thermal overload protection allows the thermal status of motors, generators and transformers to be monitored.
- If an additional thermal input is available, the thermal replica may take the actual ambient or coolant temperature into account.

RELAY SETTING [SIEMENS]

Setting factor (k)	:	1.05
Time constant (Tau.th)	:	17.5

Setting Factor / K-Factor (k): The thermally permissible continuous current for the equipment being protected.

Set Value K-FACTOR $$k = \frac{I_{max\ prim}}{I_{Nom\ Obj.}} \cdot \frac{I_{Nom\ Obj.}}{I_{Nom\ CT\ prim}}$$

Imax prim = Permissible thermal primary current of the motor

INom Obj. = Nominal current of the protected object

INom CT prim = Nominal primary CT current

Time constant (Tau.th): The overload protection tracks overtemperature progression, employing a thermal differential equation whose steady state solution is an exponential function.

The Time constant (Tau.th) is used in the calculation to determine the threshold of overtemperature and thus, the tripping temperature.

$$\text{Set Value } \tau_{th} \text{ (min)} = \frac{1}{60} \cdot \left(\frac{I_{1sec}}{I_{max\ prim}}\right)^2$$

Nominal current (Inorm): Nominal current of protected object

Initial state of mach. (A): Initial state of machine in percentage of thermal state

$$A = \left(\frac{Ipre}{k\,.\,Inorm}\right)^2$$

THERMAL OVERLOAD CALCULATION [SIEMENS]

Formula for primary values:	
Trip Characteristic curve for $I / (k \cdot I_{Nom}) \leq 8$	
$t = \tau_{th} \cdot \ln \dfrac{\left(\dfrac{I}{k \cdot I_{Nom}}\right)^2 - \left(\dfrac{I_{pre}}{k \cdot I_{Nom}}\right)^2}{\left(\dfrac{I}{k \cdot I_{Nom}}\right)^2 - 1}$	
with	
t	Trip time in minutes
τ_{th}	Heating-up time constant
In	Actual load current
I_{pre}	Preload current
k	Setting factor per IEC 60255-8
I_{Nom}	Nominal current for the protected object

The above is the formula for thermal overload.

WITH OUT PRE-LOAD [COLD CONDITION]

As per the setting, k-factor = 1.05, Tau.th = 17.5min,

Consider, [Nominal current of protected object] Inorm = 1A

For cold condition, the initial thermal state of the machine, A = 0

By applying the values in the formula and we get, The trip time @ cold condition,

$$t = \mathrm{Tau.th} * \ln\left(\frac{\left(\frac{\mathrm{Iactual}}{\mathrm{k\,.\,Inorm}}\right)^2 - \left(\frac{\mathrm{Ipre}}{\mathrm{k\,.\,Inorm}}\right)^2}{\left(\frac{\mathrm{Iactual}}{\mathrm{k\,.\,Inorm}}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 17.5 * \ln\left(\frac{\left(\frac{2.0}{1.05 * 1}\right)^2 - \left(\frac{\mathrm{Ipre}}{\mathrm{k\,.\,Inorm}}\right)^2}{\left(\frac{2.0}{1.05 * 1}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 17.5 * \ln\left(\frac{(1.905)^2 - (0)}{(1.905)^2 - 1}\right) \textit{ in minutes}$$

$$t = 17.5 * \ln\left(\frac{3.628117914}{3.629117914 - 1}\right) \textit{ in minutes}$$

$$t = 17.5 * \ln(1.380500431) \textit{ in minutes}$$

$$\mathbf{t =} 17.5 * 0.3224460648 = \mathbf{5.642806134} \quad \textit{\textbf{in minutes}}$$

$$\mathbf{t =} 5.642806134 * 60 = \mathbf{338.5683681} \quad \textit{\textbf{in seconds}}$$

WITH PRE-LOAD [HOT CONDITION]

As per the setting, k-factor = 1.05, Tau.th = 17.5min, Inorm = 1A

For hot condition, **consider** the initial thermal state of the machine, A = 90% = 0.9

By applying the values in the formula and we get,

The trip time @ hot condition,

$$t = \mathrm{Tau.th} * \ln\left(\frac{\left(\frac{\mathrm{Iactual}}{\mathrm{k\,.\,Inorm}}\right)^2 - \left(\frac{\mathrm{Ipre}}{\mathrm{k\,.\,Inorm}}\right)^2}{\left(\frac{\mathrm{Iactual}}{\mathrm{k\,.\,Inorm}}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 17.5 * \ln\left(\frac{\left(\frac{2.0}{1.05 * 1}\right)^2 - (0.9)^2}{\left(\frac{2.0}{1.05 * 1}\right)^2 - 1}\right) \; \textit{in minutes}$$

$$t = 17.5 * \ln\left(\frac{(1.905)^2 - (0.9)^2}{(1.905)^2 - 1}\right) \; \textit{in minutes}$$

$$t = 17.5 * \ln\left(\frac{3.628117914 - 0.81}{3.629117914 - 1}\right) \; \textit{in minutes}$$

$$t = 17.5 * \ln(1.071887228) \; \textit{in minutes}$$

$$\mathbf{t} = 17.5 * 0.06942085974 = \mathbf{1.214865045} \quad \boldsymbol{in\ minutes}$$

$$\mathbf{t} = 1.214865045 * 60 = \mathbf{72.89190272} \quad \boldsymbol{in\ seconds}$$

MICOM RELAY THERMAL OVERLOAD CALCULATION

THERMAL OVERLOAD [MICOM]

The thermal overload protection is designed to prevent thermal overloads from damaging the protected equipment.

In order for the Thermal overload protection function to operate correctly, it is essential that the circuit breaker to be closed and its associated closing signal, 52a, to be recognized by the relay.

RELAY SETTING [MICOM]

Ith = Therm. O/L current setting (A)	:	0.48	
T1 = Overload time constant (mins)	:	20	
T2 = Start-up time constant (mins)	:	25	
Tr = Cooling time constant (mins)	:	350	
K = Neg. sequence current heating	:	3	Constant proportional to the thermal capacity of the motor ('K Coefficient' default setting = 3)

THERMAL OVERLOAD CALCULATION [MICOM]

Thermal replica

Both the positive or RMS and negative sequence currents are analysed, to monitor the thermal state accounting for any phase unbalance present. This thermal model takes into account the overheating, which will be generated by the negative phase sequence current in the rotor.

The equivalent motor heating current is calculated by:

$$I_{eq} = \sqrt{(I_1 2 + K I_2^2)}$$

Note: This equation is used in software version A4.x(09) and before

or

$$I_{eq} = \sqrt{(I_{rms}^2 + K I_2^2)}$$

Note: This equation is used in software version B1.0(20) or later

Where :

I_1 = Positive sequence current

I_{rms} : root mean square current

I_2 : negative sequence current

K is a constant proportional to the thermal capacity of the motor

The equivalent motor heating current is calculated every 20 ms. The maximum value recorded will then be utilized by the thermal algorithm.

Thermal trip

A multiple time constant thermal replica is used, in order to take into account different operating conditions of the motor : overload, starting or cooling conditions.

The equation used to calculate the trip time at 100% of thermal state is :

$$t = \tau \ln((k^2 - A^2)/(k^2-1))$$

Where the value of τ (thermal time constant) depends on the current value absorbed by the motor :

Over load time constant $\tau = T_1$ if $I_{th} < I_{eq} <= 2I_{th}$

Start-up time constant $\tau = T_2$ if $I_{eq} > 2I_{th}$

Cooling time constant $\tau = T_r$ if interrupting device opened

Measured thermal load (or thermal capacity) $k = I_{eq} / I_{th}$

Ith is thermal setting

A is initial state of the machine in percentage of the thermal state

The initial state of the machine is included in the time to trip calculation algorithm so that the operating time for a thermal trip will be decreased in case of a hot motor start.

The above is the formula for thermal overload.

[COLD CONDITION]

As per the setting,

Therm. O/L current setting, Ith = 0.48 A

Overload time constant, T1 = 20 min

Start-up time constant, T2 = 25 min

Cooling time constant, Tr = 350 min

Negative sequence current heating factor, K = 3

Since it is cold condition, Initial Thermal state of machine, A = 0

By applying the values in the formula and we get,

The trip time @ cold condition,

$$t = \mathrm{Tau} * \ln\left(\frac{\left(\frac{\mathrm{Ieq}}{\mathrm{Ith}}\right)^2 - (\mathrm{A})^2}{\left(\frac{\mathrm{Ieq}}{\mathrm{Ith}}\right)^2 - 1}\right) \; in\ minutes$$

CASE 1: CB Close & Ith < Ieq< = 2Ith

Injected current is,

Ir = 1.45 <0°

Iy = 1.45 <-120°

Ib = 1.45 <120°

$$\mathrm{Ieq} = \sqrt{(\mathrm{I1}^2 - \mathrm{K.I2}^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$\mathrm{I1} = \frac{\mathrm{Ir} + \mathrm{aIy} + \mathrm{a}^2\mathrm{Ib}}{3} \quad , \quad \mathrm{a} = 1 < 120°$$

$$I1 = \frac{1.45 < 0° + 1 < 120° * \ 1.45 < -120° + (1 < 120°)^2 * \ 1.45 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 1.45; θr = 0°;

Iy = 1.45; θy = -120°;

Ib = 1.45; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 1.45 * cos(0) + 1.45 *i* * sin(0)

Ir = 1.45 * 1 + 0

Ir = 1.45

Iy = 1.45 * cos(-120) + 1.45 *i* * sin(-120)

Iy = 1.45 * -0.5 + 1.45 *i* * -0.866

Iy = -0.725 – 1.2557 *i*

Ib = 1.45 * cos(120) + 1.45 *i* * sin(120)

Ib = 1.45 * -0.5 + 1.45 *i* * 0.866

Ib = -0.725 + 1.2557 *i*

$$I1 = \frac{\{ 1.45 + (-0.5 \ + \ i\ 0.866) * (-0.725 \ - 1.2557\ i) \ + \ (-0.5 \ + \ i\ 0.866)^2 * (-0.725 + 1.2557\ i) \ \}}{3}$$

$$\mathbf{I1} = \frac{\{\,1.45 + 1.4499\ \ +\ 1.4499\,\}}{3} = \mathbf{1.4499 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2}\ \ ,\ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{1.4499^2 + 0^2} = \mathbf{1.4499}\ ,\ \ \boldsymbol{\theta}\mathbf{1} = \tan^{-1}\frac{0}{1.4499} = \mathbf{0}$$

$$\mathbf{I1 = 1.4499\ \ < 0°}$$

For calculating Negative sequence,

$$\mathrm{I2} = \frac{\mathrm{Ir} + \mathrm{a}^2\mathrm{Iy} + \mathrm{aIb}}{3}\ \ ,\ \ \mathrm{a} = 1 < 120°$$

$$\mathrm{I2} = \frac{1.45 < 0° + (1 < 120°)^2 *\ 1.45 < -120° + 1 < 120° *\ 1.45 < 120°}{3}$$

$$\mathrm{I2} = \frac{\{\,1.45 +\ (-0.5\ +\ i\,0.866)^2 * (-0.725\ - 1.2557\,i)\ + (-0.5\ +\ i\,0.866) * (-0.725 + 1.2557\,i)\,\}}{3}$$

$$\mathbf{I2} = \frac{\{\,1.45 - 0.72497 + 1.25565\,i - 0.72494 - 1.2557i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2}\ \ ,\ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0}\ ,\ \ \boldsymbol{\theta}\mathbf{2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0\ \ < 0°}$$

To find the equivalent motor heating current is calculated by:

$$\text{Ieq} = \sqrt{\text{I1}^2 + \text{K} * \text{I2}^2}$$

$$\mathbf{Ieq} = \sqrt{1.4499^2 + 3 * 0^2} = 1.4499 \approx \mathbf{1.45}$$

Our condition,

- ⇨ Ith < Ieq <= 2Ith
- ⇨ 1.05 < 1.45 <= 2.1

In this case, Tau = T1 = 20min

The formula can be given as,

$$\text{t} = \text{T1} * \ln\left(\frac{\left(\frac{\text{Ieq}}{\text{Ith}}\right)^2 - (\text{A})^2}{\left(\frac{\text{Ieq}}{\text{Ith}}\right)^2 - 1}\right) \textit{ in minutes}$$

$$\text{t} = 20 * \ln\left(\frac{\left(\frac{1.45}{1.05}\right)^2 - (0)^2}{\left(\frac{1.45}{1.05}\right)^2 - 1}\right) \textit{ in minutes}$$

$$\text{t} = 20 * \ln\left(\frac{1.9070295 - 0}{1.9070295 - 1}\right) \textit{ in minutes}$$

$$\text{t} = 20 * \ln(2.1025) \textit{ in minutes}$$

$$\mathbf{t} = 20 * 0.7431271004 = \mathbf{14.862542} \quad \boldsymbol{in\ minutes}$$

$$\mathbf{t} = 14.862542 * 60 = \mathbf{891.7525205} \quad \boldsymbol{in\ seconds}$$

CASE 2: CB Close & Ieq > 2Ith

Injected current is,

Ir = 2.5 <0°

Iy = 2.5 <-120°

Ib = 2.5 <120°

$$\text{Ieq} = \sqrt{(\text{I1}^2 - \text{K.I2}^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$\text{I1} = \frac{\text{Ir} + \text{aIy} + \text{a}^2\text{Ib}}{3} \quad , \quad \text{a} = 1 < 120°$$

$$\text{I1} = \frac{2.5 < 0° + 1 < 120° * \ 2.5 < -120° + (1 < 120°)^2 * \ 2.5 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 2.5; θr = 0°;

Iy = 2.5; θy = -120°;

Ib = 2.5; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 2.5 * cos(0) + 2.5 *i* * sin(0)

Ir = 2.5 * 1 + 0

Ir = 2.5

Iy = 2.5 * cos(-120) + 2.5 *i* * sin(-120)

Iy = 2.5 * -0.5 + 2.5 *i* * -0.866

Iy = -1.25 – 2.165 *i*

Ib = 2.5 * cos(120) + 2.5 *i* * sin(120)

Ib = 2.5 * -0.5 + 2.5 *i* * 0.866

Ib = -1.25 + 2.165 *i*

$$\mathrm{I1} = \frac{\{\, 2.5 + (-0.5 \;+\; i\, 0.866) * (-1.25 - \;2.165\;\; i) \;+\; (-0.5 \;+\; i\, 0.866)^2 * (-1.25 \;+\; 2.165\, i)\,\}}{3}$$

$$\mathbf{I1} = \frac{\{\, 2.5 + 2.49989 \;\;+\;\; 2.49989\,\}}{3} = \mathbf{2.499927 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2} \;\;,\;\; \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{2.499927^2 + 0^2} = \mathbf{2.499927} \;,\;\; \boldsymbol{\theta 1} = \tan^{-1}\frac{0}{2.499927} = \mathbf{0}$$

$$\mathbf{I1 = 2.499927 < 0°}$$

For calculating Negative sequence,

$$\mathrm{I2} = \frac{\mathrm{Ir} + \mathrm{a}^2\mathrm{Iy} + \mathrm{aIb}}{3} \;\;,\;\; \mathrm{a} = 1 < 120°$$

$$I2 = \frac{2.5 < 0° + (1 < 120°)^2 * \ 2.5 < -120° + 1 < 120° * \ 2.5 < 120°}{3}$$

$$I2 = \frac{\{ 2.5 + (-0.5 \ + \ i\, 0.866)^2 * (-1.25 - \ 2.165 \ i) \ + \ (-0.5 \ + \ i\, 0.866) * (-1.25 \ + \ 2.165\, i) \}}{3}$$

$$\mathbf{I2 =} \frac{\{ 2.5 - 1.249945 + 2.1649047\, i - 1.249945 - 2.1649047 i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$r = \sqrt{x^2 + y^2} \ \ , \ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0} \ , \ \ \boldsymbol{\theta 2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0 \ < 0°}$$

To find the equivalent motor heating current is calculated by:

$$Ieq = \sqrt{I1^2 + K * I2^2}$$

$$\mathbf{Ieq =} \ \sqrt{2.499927^2 + 3 * 0^2} = 2.499927 \ \approx \mathbf{2.5}$$

Our condition,

- ⇨ Ieq > 2Ith
- ⇨ 2.5 > 2.1

In this case, Tau = T2 = 25min

The formula can be given as,

$$t = T1 * \ln\left(\frac{\left(\frac{Ieq}{Ith}\right)^2 - (A)^2}{\left(\frac{Ieq}{Ith}\right)^2 - 1}\right) \, in\ minutes$$

$$t = 25 * \ln\left(\frac{\left(\frac{2.5}{1.05}\right)^2 - (0)^2}{\left(\frac{2.5}{1.05}\right)^2 - 1}\right) \, in\ minutes$$

$$t = 25 * \ln\left(\frac{5.66893424 - 0}{5.66893424 - 1}\right) \; in\ minutes$$

$$t = 25 * \ln(1.214181642) \; in\ minutes$$

$$\mathbf{t =} 25 * 0.1940703038 = \mathbf{4.851757596 \quad \textit{in minutes}}$$

$$\mathbf{t =} 4.851757596 * 60 = \mathbf{291.1054557 \quad \textit{in seconds}}$$

CASE 3: CB Open

Injected current is,

Ir = 1.45 <0°

Iy = 1.45 <-120°

Ib = 1.45 <120°

$$Ieq = \sqrt{(I1^2 - K.I2^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$I1 = \frac{Ir + aIy + a^2Ib}{3} \quad , \quad a = 1 < 120°$$

$$I1 = \frac{1.45 < 0° + 1 < 120° * \; 1.45 < -120° + (1 < 120°)^2 * \; 1.45 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 1.45; θr = 0°;

Iy = 1.45; θy = -120°;

Ib = 1.45; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 1.45 * cos(0) + 1.45 *i* * sin(0)

Ir = 1.45 * 1 + 0

Ir = 1.45

Iy = 1.45 * cos(-120) + 1.45 *i* * sin(-120)

Iy = 1.45 * -0.5 + 1.45 *i* * -0.866

Iy = -0.725 – 1.2557 *i*

Ib = 1.45 * cos(120) + 1.45 *i* * sin(120)

Ib = 1.45 * -0.5 + 1.45 *i* * 0.866

Ib = -0.725 + 1.2557 *i*

$$\mathrm{I1} = \frac{\{\,1.45 + (-0.5\ +\ i\ 0.866) * (-0.725\ - 1.2557\ i)\ +\ (-0.5\ +\ i\ 0.866)^2 * (-0.725 + 1.2557\ i)\,\}}{3}$$

$$\mathbf{I1} = \frac{\{\,1.45 + 1.4499\ \ +\ 1.4499\,\}}{3} = \mathbf{1.4499 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2}\ \ ,\ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{1.4499^2 + 0^2} = \mathbf{1.4499} \ , \quad \boldsymbol{\theta 1} = \tan^{-1}\frac{0}{1.4499} = \mathbf{0}$$

$$\mathbf{I1 = 1.4499 \ < 0°}$$

For calculating Negative sequence,

$$\text{I2} = \frac{\text{Ir} + \text{a}^2\text{Iy} + \text{aIb}}{3} \quad , \quad \text{a} = 1 < 120°$$

$$\text{I2} = \frac{1.45 < 0° + (1 < 120°)^2 * \ 1.45 < -120° + 1 < 120° * \ 1.45 < 120°}{3}$$

$$\text{I2} = \frac{\{\ 1.45 + \ (-0.5 \ + \ i\ 0.866)^2 * (-0.725 \ - 1.2557\ i) \ + (-0.5 \ + \ i\ 0.866) * (-0.725 + 1.2557\ i)\ \}}{3}$$

$$\mathbf{I2} = \frac{\{\ 1.45 - 0.72497 + 1.25565\ i - 0.72494 - 1.2557 i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$\text{r} = \sqrt{x^2 + y^2} \ , \quad \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0} \ , \quad \boldsymbol{\theta 2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0 \ < 0°}$$

To find the equivalent motor heating current is calculated by:

$$\text{Ieq} = \sqrt{\text{I1}^2 + \text{K} * \text{I2}^2}$$

$$\mathbf{Ieq} = \sqrt{1.4499^2 + 3 * 0^2} = 1.4499 \ \approx \mathbf{1.45}$$

Our condition,

In this case, Tau = Tr = 350min

The formula can be given as,

$$t = T1 * \ln\left(\frac{\left(\frac{Ieq}{Ith}\right)^2 - (A)^2}{\left(\frac{Ieq}{Ith}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln\left(\frac{\left(\frac{1.45}{1.05}\right)^2 - (0)^2}{\left(\frac{1.45}{1.05}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln\left(\frac{1.9070295 - 0}{1.9070295 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln(2.1025) \textit{ in minutes}$$

$$\mathbf{t} = 350 * 0.7431271004 = \mathbf{260.09448514} \quad \textbf{\textit{in minutes}}$$

$$\mathbf{t} = 260.09448514 * 60 = \mathbf{15,605.6691084} \quad \textbf{\textit{in seconds}}$$

[HOT CONDITION]

As per the setting,

Therm. O/L current setting, Ith = 0.48 A

Overload time constant, T1 = 20 min

Start-up time constant, T2 = 25 min

Cooling time constant, Tr = 350 min

Negative sequence current heating factor, K = 3

Consider it is in hot condition and Initial Thermal state of machine, A = 90%

By applying the values in the formula and we get,

The trip time @ cold condition,

$$t = \text{Tau} * \ln\left(\frac{\left(\frac{Ieq}{Ith}\right)^2 - (A)^2}{\left(\frac{Ieq}{Ith}\right)^2 - 1}\right) \textit{ in minutes}$$

CASE 1: CB Close & Ith < Ieq< = 2Ith

Injected current is,

Ir = 1.45 <0°

Iy = 1.45 <-120°

Ib = 1.45 <120°

$$Ieq = \sqrt{(I1^2 - K.I2^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$I1 = \frac{Ir + aIy + a^2Ib}{3} \quad , \quad a = 1 < 120°$$

$$I1 = \frac{1.45 < 0° + 1 < 120° * \ 1.45 < -120° + (1 < 120°)^2 * \ 1.45 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 1.45; θr = 0°;

Iy = 1.45; θy = -120°;

Ib = 1.45; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 1.45 * cos(0) + 1.45 *i* * sin(0)

Ir = 1.45 * 1 + 0

Ir = 1.45

Iy = 1.45 * cos(-120) + 1.45 *i* * sin(-120)

Iy = 1.45 * -0.5 + 1.45 *i* * -0.866

Iy = -0.725 – 1.2557 *i*

Ib = 1.45 * cos(120) + 1.45 *i* * sin(120)

Ib = 1.45 * -0.5 + 1.45 *i* * 0.866

Ib = -0.725 + 1.2557 *i*

$$I1 = \frac{\{ 1.45 + (-0.5 \ + \ i\ 0.866) * (-0.725 \ - 1.2557\ i) \ + \ (-0.5 \ + \ i\ 0.866)^2 * (-0.725 + 1.2557\ i) \}}{3}$$

$$\mathbf{I1} = \frac{\{1.45 + 1.4499 \; + \; 1.4499\}}{3} = \mathbf{1.4499 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2} \;\; , \;\; \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{1.4499^2 + 0^2} = \mathbf{1.4499} \; , \;\; \boldsymbol{\theta 1} = \tan^{-1}\frac{0}{1.4499} = \mathbf{0}$$

$$\mathbf{I1 = 1.4499 \;\; < 0°}$$

For calculating Negative sequence,

$$\mathrm{I2} = \frac{\mathrm{Ir} + \mathrm{a}^2\mathrm{Iy} + \mathrm{aIb}}{3} \;\; , \;\; \mathrm{a} = 1 < 120°$$

$$\mathrm{I2} = \frac{1.45 < 0° + (1 < 120°)^2 * \; 1.45 < -120° + 1 < 120° * \; 1.45 < 120°}{3}$$

$$\mathrm{I2} = \frac{\{1.45 + \; (-0.5 \; + \; i\,0.866)^2 * (-0.725 \; - 1.2557\,i) \; + (-0.5 \; + \; i\,0.866) * (-0.725 + 1.2557\,i)\}}{3}$$

$$\mathbf{I2} = \frac{\{1.45 - 0.72497 + 1.25565\,i - 0.72494 - 1.2557i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2} \;\; , \;\; \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0} \; , \;\; \boldsymbol{\theta 2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0 \;\; < 0°}$$

To find the equivalent motor heating current is calculated by:

$$\mathrm{Ieq} = \sqrt{\mathrm{I1}^2 + \mathrm{K} * \mathrm{I2}^2}$$

$$\mathbf{Ieq =} \sqrt{1.4499^2 + 3 * 0^2} = 1.4499 \approx \mathbf{1.45}$$

Our condition,

- ⇨ Ith < Ieq <= 2Ith
- ⇨ 1.05 < 1.45 <= 2.1

In this case, Tau = T1 = 20min

The formula can be given as,

$$\mathrm{t} = \mathrm{T1} * \ln\left(\frac{\left(\frac{\mathrm{Ieq}}{\mathrm{Ith}}\right)^2 - (\mathrm{A})^2}{\left(\frac{\mathrm{Ieq}}{\mathrm{Ith}}\right)^2 - 1}\right) \textit{ in minutes}$$

$$\mathrm{t} = 20 * \ln\left(\frac{\left(\frac{1.45}{1.05}\right)^2 - (0.9)^2}{\left(\frac{1.45}{1.05}\right)^2 - 1}\right) \textit{ in minutes}$$

$$\mathrm{t} = 20 * \ln\left(\frac{1.9070295 - 0.81}{1.9070295 - 1}\right) \textit{ in minutes}$$

$$\mathrm{t} = 20 * \ln(1.209474995) \textit{ in minutes}$$

$$\mathbf{t =} 20 * 0.190186377 = \mathbf{3.803727541} \quad \textbf{\textit{in minutes}}$$

$$\mathbf{t =} 3.803727541 * 60 = \mathbf{228.2236525} \quad \textbf{\textit{in seconds}}$$

CASE 2: CB Close & Ieq > 2Ith

Injected current is,

Ir = 2.5 <0°

Iy = 2.5 <-120°

Ib = 2.5 <120°

$$Ieq = \sqrt{(I1^2 - K.I2^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$I1 = \frac{Ir + aIy + a^2Ib}{3} \quad , \quad a = 1 < 120°$$

$$I1 = \frac{2.5 < 0° + 1 < 120° * 2.5 < -120° + (1 < 120°)^2 * 2.5 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 2.5; θr = 0°;

Iy = 2.5; θy = -120°;

Ib = 2.5; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 2.5 * cos(0) + 2.5 *i* * sin(0)

Ir = 2.5 * 1 + 0

Ir = 2.5

Iy = 2.5 * cos(-120) + 2.5 *i* * sin(-120)

Iy = 2.5 * -0.5 + 2.5 *i* * -0.866

Iy = -1.25 – 2.165 *i*

Ib = 2.5 * cos(120) + 2.5 *i* * sin(120)

Ib = 2.5 * -0.5 + 2.5 *i* * 0.866

Ib = -1.25 + 2.165 *i*

$$\mathrm{I1} = \frac{\{\, 2.5 + (-0.5 \; + \; i\; 0.866) * (-1.25 - \; 2.165 \;\; i) \; + \; (-0.5 \; + \; i\; 0.866)^2 * (-1.25 \; + \; 2.165\; i) \,\}}{3}$$

$$\mathbf{I1} = \frac{\{\, 2.5 + 2.49989 \;\; + \; 2.49989 \,\}}{3} = \mathbf{2.499927 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2} \quad , \quad \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{2.499927^2 + 0^2} = \mathbf{2.499927} \;\; , \quad \boldsymbol{\theta 1} = \tan^{-1}\frac{0}{2.499927} = \mathbf{0}$$

$$\mathbf{I1 = 2.499927 < 0°}$$

For calculating Negative sequence,

$$\mathrm{I2} = \frac{\mathrm{Ir} + \mathrm{a}^2\mathrm{Iy} + \mathrm{aIb}}{3} \quad , \quad \mathrm{a} = 1 < 120°$$

$$I2 = \frac{2.5 < 0° + (1 < 120°)^2 * \ 2.5 < -120° + 1 < 120° * \ 2.5 < 120°}{3}$$

$$I2 = \frac{\{\,2.5 + (-0.5\ +\ i\,0.866)^2 * (-1.25 -\ 2.165\ \ i)\ +\ (-0.5\ +\ i\,0.866) * (-1.25\ +\ 2.165\,i)\,\}}{3}$$

$$\mathbf{I2} = \frac{\{\,2.5 - 1.249945 + 2.1649047\,i - 1.249945 - 2.1649047i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$r = \sqrt{x^2 + y^2}\ \ ,\ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0}\ ,\ \ \boldsymbol{\theta 2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0\ < 0°}$$

To find the equivalent motor heating current is calculated by:

$$Ieq = \sqrt{I1^2 + K * I2^2}$$

$$\mathbf{Ieq} = \sqrt{2.499927^2 + 3 * 0^2} = 2.499927\ \approx \mathbf{2.5}$$

Our condition,

- ⇨ Ieq > 2Ith
- ⇨ 2.5 > 2.1

In this case, Tau = T2 = 25min

The formula can be given as,

$$t = T1 * \ln\left(\frac{\left(\frac{Ieq}{Ith}\right)^2 - (A)^2}{\left(\frac{Ieq}{Ith}\right)^2 - 1}\right) \textit{in minutes}$$

$$t = 25 * \ln\left(\frac{\left(\frac{2.5}{1.05}\right)^2 - (0.9)^2}{\left(\frac{2.5}{1.05}\right)^2 - 1}\right) \textit{in minutes}$$

$$t = 25 * \ln\left(\frac{5.66893424 - 0.81}{5.66893424 - 1}\right) \ in \ minutes$$

$$t = 25 * \ln(1.040694512) \ in \ minute1D460$$

$$\mathbf{t} = 25 * 0.03988829018 = \mathbf{0.9972072545} \quad \boldsymbol{in\ minutes}$$

$$\mathbf{t} = 0.9972072545 * 60 = \mathbf{59.83243527} \quad \boldsymbol{in\ seconds}$$

CASE 3: CB Open

Injected current is,

Ir = 1.45 <0°

Iy = 1.45 <-120°

Ib = 1.45 <120°

$$\mathrm{Ieq} = \sqrt{(\mathrm{I1}^2 - \mathrm{K.I2}^2)}$$

I1 = Positive sequence current, I2 = Negative sequence current, K = Negative sequence current heating factor

For calculating Positive sequence,

$$\mathrm{I1} = \frac{\mathrm{Ir} + \mathrm{aIy} + \mathrm{a}^2\mathrm{Ib}}{3} \quad , \quad \mathrm{a} = 1 < 120°$$

$$\mathrm{I1} = \frac{1.45 < 0° + 1 < 120° * \ 1.45 < -120° + (1 < 120°)^2 * \ 1.45 < 120°}{3}$$

Convert from polar to rectangular form, real = r.cosθ; imag = r.sinθ;

In our case,

Ir = 1.45; θr = 0°;

Iy = 1.45; θy = -120°;

Ib = 1.45; θb = 120°;

a1 = 1.0; θa = 120°;

a = 1.0 * cos(120) + 1.0 *i* * sin(120)

a = 1.0 * -0.5 + 1.0 *i* * 0.866

a = -0.5 + 0.866 *i*

Ir = 1.45 * cos(0) + 1.45 *i* * sin(0)

Ir = 1.45 * 1 + 0

Ir = 1.45

Iy = 1.45 * cos(-120) + 1.45 *i* * sin(-120)

Iy = 1.45 * -0.5 + 1.45 *i* * -0.866

Iy = -0.725 – 1.2557 *i*

Ib = 1.45 * cos(120) + 1.45 *i* * sin(120)

Ib = 1.45 * -0.5 + 1.45 *i* * 0.866

Ib = -0.725 + 1.2557 *i*

$$\mathrm{I1} = \frac{\{\,1.45 + (-0.5\ +\ i\,0.866) * (-0.725\ - 1.2557\,i)\ +\ (-0.5\ +\ i\,0.866)^2 * (-0.725 + 1.2557\,i)\,\}}{3}$$

$$\mathbf{I1} = \frac{\{\,1.45 + 1.4499\ \ +\ 1.4499\,\}}{3} = \mathbf{1.4499 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2}\ \ ,\ \ \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I1} = \sqrt{1.4499^2 + 0^2} = \mathbf{1.4499}\ , \quad \mathbf{\theta 1} = \tan^{-1}\frac{0}{1.4499} = \mathbf{0}$$

$$\mathbf{I1 = 1.4499 \ \ < 0°}$$

For calculating Negative sequence,

$$\mathrm{I2} = \frac{\mathrm{Ir} + \mathrm{a}^2\mathrm{Iy} + \mathrm{aIb}}{3} \ , \quad \mathrm{a} = 1 < 120°$$

$$\mathrm{I2} = \frac{1.45 < 0° + (1 < 120°)^2 * \ 1.45 < -120° + 1 < 120° * \ 1.45 < 120°}{3}$$

$$\mathrm{I2} = \frac{\{\,1.45 + \ (-0.5\ +\ i\,0.866)^2 * (-0.725\ - 1.2557\,i)\ + (-0.5\ +\ i\,0.866) * (-0.725 + 1.2557\,i)\,\}}{3}$$

$$\mathbf{I2} = \frac{\{\,1.45 - 0.72497 + 1.25565\,i - 0.72494 - 1.2557i\}}{3} = \mathbf{0 + 0i}$$

Convert back to polar form,

$$\mathrm{r} = \sqrt{x^2 + y^2}\ , \quad \theta = \tan^{-1}\frac{y}{x}$$

$$\mathbf{I2} = \sqrt{0^2 + 0^2} = \mathbf{0}\ , \quad \mathbf{\theta 2} = \tan^{-1}\frac{0}{0} = \mathbf{0}$$

$$\mathbf{I2 = 0 \ < 0°}$$

To find the equivalent motor heating current is calculated by:

$$\mathrm{Ieq} = \sqrt{\mathrm{I1}^2 + \mathrm{K} * \mathrm{I2}^2}$$

$$\mathbf{Ieq} = \sqrt{1.4499^2 + 3 * 0^2} = 1.4499 \ \approx \mathbf{1.45}$$

Our condition,

In this case, Tau = Tr = 350min

The formula can be given as,

$$t = T1 * \ln\left(\frac{\left(\frac{Ieq}{Ith}\right)^2 - (A)^2}{\left(\frac{Ieq}{Ith}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln\left(\frac{\left(\frac{1.45}{1.05}\right)^2 - (0.9)^2}{\left(\frac{1.45}{1.05}\right)^2 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln\left(\frac{1.9070295 - 0.81}{1.9070295 - 1}\right) \textit{ in minutes}$$

$$t = 350 * \ln(1.209474995) \textit{ in minutes}$$

$$\mathbf{t =} 350 * 0.190186377 = \mathbf{66.56523195} \quad \textbf{\textit{in minutes}}$$

$$\mathbf{t =} 260.09448514 * 60 = \mathbf{3993.913917} \quad \textbf{\textit{in seconds}}$$

P&B RELAY THERMAL OVERLOAD CALCULATION

THERMAL OVERLOAD [P&B]

The Thermal Model protection is arguably the most fundamental feature in any motor protective relay. This is implemented as a software model of the electromechanical overload operation of the heating element and bimetallic coil which became the method of protecting electrical plant.

The Thermal Model protection cannot be switched off, that means even with incorrect settings the relay would try and offer some protection in an overloaded condition.

RELAY SETTING [P&B]

T6x Setting (a)	:	28
Full Load Current	:	20
Hot Cold Ratio (H/C)	:	0.2

THERMAL OVERLOAD CALCULATION [P&B]

Cold Condition

$$t_c = 32.a.\log_e\left(\frac{p^2}{p^2 - 1.05^2}\right)$$

where;

'p' is the multiple of FLC

'a' is the t6x setting

't_c' is the operating time (in seconds)

Running (Hot) Condition

$$t_C = 32.a.\log_e\left(\frac{p^2 - \left(1 - \frac{H}{C}\right)(I_L)^2}{p^2 - 1.05^2}\right)$$

'I_L' is the steady state prior to overload

(If motor is running at FLC $I_L = 1$)

'H/C' is the hot cold ratio expressed as a decimal i.e. 40% = 0.40

The above is the formula for thermal overload.

[COLD CONDITION]

As per the setting, T6x Setting (a) = 28, Full load current = 20A,

For cold condition, By applying the values in the formula and we get,

The trip time @ cold condition,

$$t = 32 \,.\, a \,.\, \ln\left(\frac{p^2}{p^2 - 1.05^2}\right) \text{ in seconds}$$

Consider we are injecting 2 times of the full load current, hence p = 2

$$t = 32 * 28 * \ln\left(\frac{2^2}{2^2 - 1.05^2}\right) \text{ in seconds}$$

$$t = 896 * \ln\left(\frac{4}{4 - 1.1025}\right) \text{ in seconds}$$

$$t = 896 * \ln(1.380500431) \text{ in seconds}$$

$$\mathbf{t} = 896 * 0.3224460646 = \mathbf{288.9116739} \quad \text{in seconds}$$

[HOT CONDITION]

As per the setting, T6x Setting (a) = 28, Full load current = 20A, H/C ratio = 0.2

For cold condition, By applying the values in the formula and we get,

The trip time @ cold condition,

$$t = 32 \,.\, a \,.\, \ln\left(\frac{p^2 - \left(1 - \frac{H}{C}\right)(I_L)^2}{p^2 - 1.05^2}\right) \text{ in seconds}$$

$$I_L = 0.01 * \left\{\left(-0.866666666666667 * \left(\frac{H}{C} * 100 - 80\right)\right) + 17\right\}$$

$$I_L = 0.01 * \{(-0.866666666666667 * (0.2 * 100 - 80)) + 17\}$$

$$I_L = 0.01 * \{(-0.866666666666667 * (20 - 80)) + 17\}$$

$$I_L = 0.6899$$

Consider we are injecting 2 times of the full load current, hence p = 2

$$t = 32 * 28 * \ln\left(\frac{2^2 - (1 - 0.2)(0.6899)^2}{2^2 - 1.05^2}\right) \text{ in seconds}$$

$$t = 32 * 28 * \ln\left(\frac{4 - (1 - 0.2) * 0.47609448}{2^2 - 1.05^2}\right) \text{ in seconds}$$

$$t = 896 * \ln\left(\frac{3.619124416}{4 - 1.1025}\right) \text{ in seconds}$$

$$t = 896 * \ln(1.249050704) \text{ in seconds}$$

$$\mathbf{t} = 896 * 0.2223838263 = \mathbf{199.2559084} \quad \text{ in seconds}$$