

SEPAM™ 49RMS Application Note

Protection for Motor Applications

Class Number 3000

SEPAM 49RMS Protection for Motor Applications

Introduction

Thermal protection of a motor can be accomplished by using various protection elements. ANSI 49 provides over-current protection based on the magnitude of current, both past and present. The SEPAM 49RMS element uses current magnitude to model the heating effect the current has on the motor windings. If a motor is equipped with RTDs (resistance temperature detectors), this information can be used by the 49RMS element.

Motor circuits have two distinct protection requirements; one for the rotor and one for the stator (see Figure 1). The SEPAM 49RMS function was designed to provide maximum protection, while allowing the motor its full capacity to start and run during adverse voltage conditions. The SEPAM 49RMS function has two distinct protection elements (Thermal Rate 1 and Thermal Rate 2; see Figure 1) to match both damage curves of a motor (stator and rotor; see Figure 2). Certain motors run extremely critical loads and must be allowed more acceleration time if the voltage is depressed.

Figure 1: Motor Damage Curve

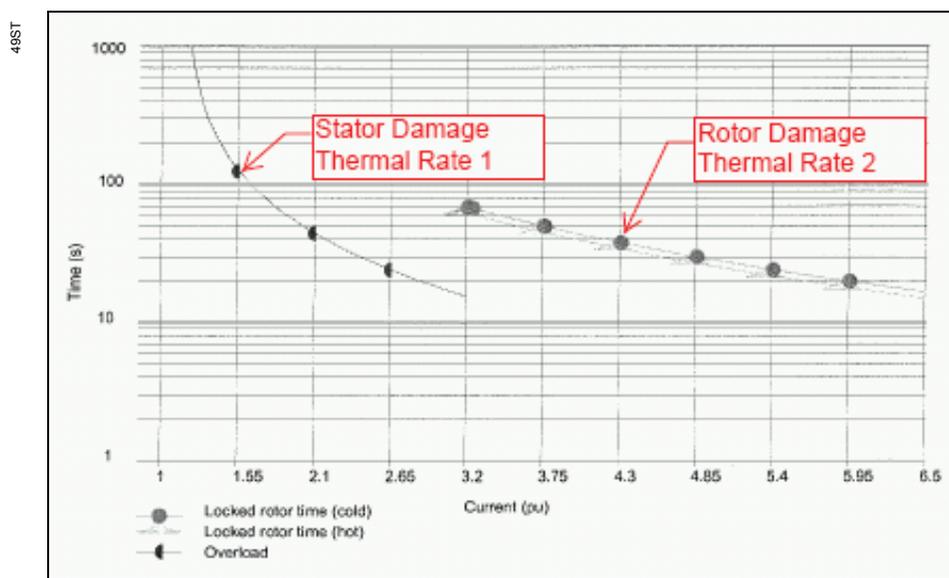
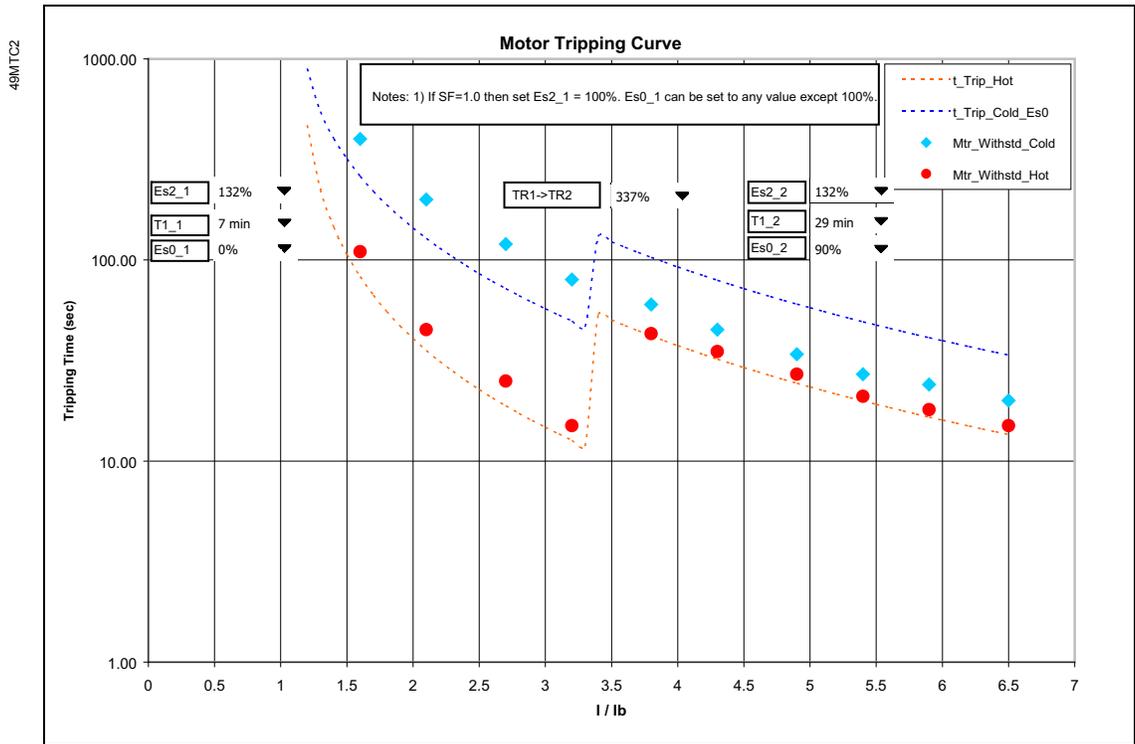


Figure 2: Motor Tripping Curve



Default Settings

Figure 3 provides a sample listing of the default settings for Series 40/80 for 49RMS protection using SFT2841 software.

Figure 3: SFT2841 49 RMS Default Settings listed with 49RMS Spreadsheet Variables (Series 40/80)

The screenshot shows the '49RMS: Thermal overload' configuration window. It includes checkboxes for 'On', 'Latching', and 'Trip C.B.', and a 'Measurement origin' dropdown. Two sets of thermal settings are displayed: 'Thermal settings 1' and 'Thermal settings 2'. The parameters for 'Thermal settings 1' are: $Es1_1 = 85\%$, $Es2_1 = 120\%$, $T1_1 = 20\text{ min}$, $T2_1 = 60\text{ min}$, and $Es0_1 = 0\%$. The parameters for 'Thermal settings 2' are: $Es1_2 = 85\%$, $Es2_2 = 120\%$, $T1_2 = 20\text{ min}$, $T2_2 = 60\text{ min}$, and $Es0_2 = 0\%$. A 'TR1->TR2' button is located next to the $Es2_2$ parameter. Other options include 'Negative sequence factor' (Low [2.25]), 'Accounting for ambient temperature' (unchecked), 'Use learned cooling time constant T2' (unchecked), and 'Maximum temperature of machine' (120 °C). 'Apply' and 'Cancel' buttons are at the top right.

Figure 4 provides a sample listing of the default settings for Series 20 for 49RMS protection using SFT2841 software.

Figure 4: SFT2841 49 RMS Default Settings listed with 49RMS Spreadsheet Variables (Series 20)

50/51-1	50/51-2	50N/51N-1	50N/51N-2	38/49T	49RMS	49RMS(#2)	37
Thermal overload							
Element activity		Basic settings (group A)					
<input type="radio"/> Off		Heat rise alarm set point (Es1)	Es1_1	85	%		
<input checked="" type="radio"/> On		Heat rise tripping set point (Es2)	Es2_1	120	%		
		Heating time constant (T1)	T1_1	20	min		
		Cooling time constant (T2)	T2_1	60	min		
Advanced settings							
Negative sequence factor				Low (2,25)			
Initial heat rise value (Es0)		Es0_1	0	%	Accounting for ambient temperature		
Thermal overload blocked by I26		No		<input checked="" type="radio"/> No Maximum temperature of device			
				<input type="radio"/> Yes			
Additional settings (group B)							
Activity		<input checked="" type="radio"/> On		Heat rise alarm set point (Es1)		Es1_2	85 %
				Heat rise tripping set point (Es2)		Es2_2	120 %
Switching between groups A and B				Heating time constant (T1)		T1_2	20 min
Switching mode between A and B		Is		Cooling time constant (T2)		T2_2	60 min
Switching current Is		TR1->TR2	200	% of IB	Initial heat rise value (Es0)		Es0_2
						0 %	

Thermal Replica

At every time step Δt , SEPAM calculates the thermal capacity used (**E**) by the motor, as seen from the formula below:

$$E(t) = E(t - \Delta t) + \left(\frac{I}{I_b}\right)^2 \frac{\Delta t}{T1} - E(t - \Delta t) \frac{\Delta t}{T1}$$

where:

I_b is the full load amperes (FLA) of the motor

T1 is the heating time constant

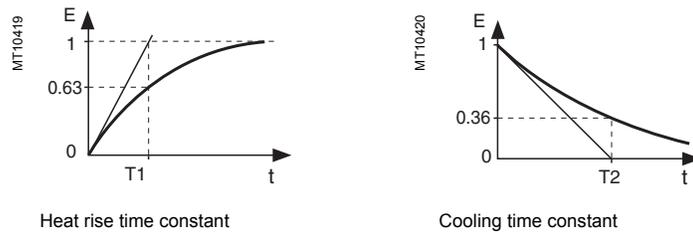
These two parameters are set with the SFT2841 software.

The thermal capacity used

- *increases* due to the copper losses, directly related to I^2 ,
- *decreases* due to the temperature difference between the motor and its environment, directly related to thermal capacity (**E**).

Suppose thermal capacity (**E**) starts at 0 value and the current (**I**) is continuously equal to the FLA (**I_b**). The value of **E** will rise exponentially up to 63% with the time constant **T1**.

Figure 5: Heat Rise and Cooling Time Constants



Suppose the motor has been operated at FLA for a long time. The thermal capacity used is equal to 100%. When the motor is stopped, $I=0$. The thermal capacity used decreases exponentially from 100% to 36% with time constant $T2_1$ (Cooling time constant).

Setting Thermal Rate 1: Es1_1, the Alarm Set Point

Set this alarm value above the maximum continuous operation level.

Example—

If: FLA= 26,
SF=1.15
Max current (based on known or theoretical max load) = 27A

Then: Calculate Es1_1 as follows:
 $Es1_1 = (27/26)^2 = 108\%$ therefore set to 110%,

NOTE: This is an alarm set point that typically does not trip off the motor but notifies an operator of the overload condition. The SFT2841 can be configured to close a non-tripping dry contact (for the power monitoring system).

Setting Thermal Rate 1: Es2_1, the Trip Set Point

The 49RMS element will trip when the thermal capacity used reaches the Es2_1 set point.

Es2_1 and Es2_2 are equal to the square of SF, expressed in %. For example:

- If SF= 1.15 then Es2_1 and Es2_2 = 1.15² = 132
- If SF= 1.00 then Es2_1 and Es2_2 = 1.00² = 100

Sometimes a motor manufacturer will provide heating and cooling time constants. Typically, when this information is supplied, the damage curves are also supplied. If the provided time constant does not protect the provided damage curve, decrease Es2_1 to a value below the SF² until the 49RMS curve protects the damage curve.

Time-Current Characteristic

The tripping time of the 49RMS protection can be shown on a time-current coordination curve as for any over-current protection. However, the 49RMS protection has a hot and a cold curve; the usual over-current protection has only one tripping curve:

- **For a usual over-current protection**, the tripping time is not related to the initial value of the current as long as it is below the set point.
- **For the 49RMS protection**, the initial value of the current, if applied during a long time, will increase the thermal capacity used, **E**, as processed by the relay. The hot/cold determination is based on the present magnitude of E. If E > 50, the motor is considered "hot" and will follow the hot curve. If E < 50, it follows the cold curve.

During actual operation, for a given value of current, the tripping time of the 49RMS protection will be somewhere between the cold and the hot curves, depending on the thermal capacity used by the motor prior to the over-current.

For coordination studies, if a 51 element is not used, the cold curve should have proper selectivity with the upstream relay.

Cold Curve Equation

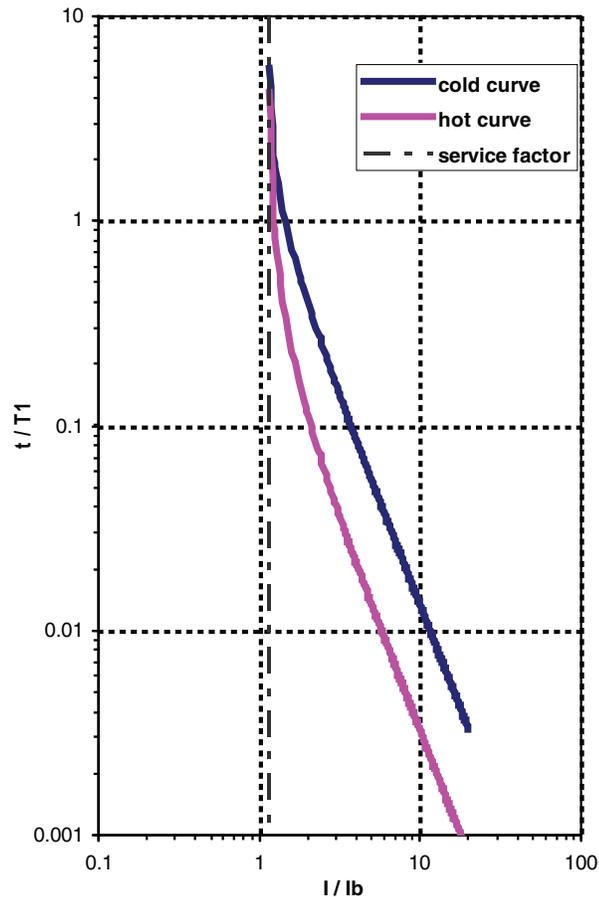
$$\frac{t}{T1} = Ln \left(\frac{\left(\frac{I}{Ib} \right)^2}{\left(\frac{I}{Ib} \right)^2 - Es2} \right)$$

Hot Curve Equation

$$\frac{t}{T1} = Ln \left(\frac{\left(\frac{I}{Ib} \right)^2 - 1}{\left(\frac{I}{Ib} \right)^2 - Es2} \right)$$

Refer to Figure 6 for a graphical representation.

Figure 6: Graphical Representation of Hot and Cold Curves



Setting Thermal Rate 1: T1_1 Time Constant

T1_1 should be set to protect the motor damage curve supplied by the motor manufacture in the same manner as an over current relay curve is set to protect the transformer damage curve. While "T1" is technically a time constant, it behaves much like a 50/51 "time dial."

The following tools can be used:

- SKM PowerTools® CAPTOR Program
- 49RMS Spreadsheet on www.PowerLogic.com

On an old motor (common in retrofit situations), the stall time may need to be estimated if no data is available. **It should first be stated that no motor can be properly protected without having the thermal damage curves.** If these values do not exist, motor protection is an "educated guess."

Sometimes a motor manufacture will provide heating and cooling time constants. Typically when this information is supplied, the damage curves are also supplied. If the provided time constant does not protect the provided damage curve, decrease Es2_1 **to a value below the SF²** until the 49RMS curve protects the damage curve.

Specific Case when SF = 1

SF = 1 means that the motor cannot accept more than 100% thermal capacity used. In this case the motor horsepower should have been determined based on some level of margin (so the normal load is below rated FLA). When E=100%, a trip will occur. When the SF=1, Es0 cannot be equal to 100%.

Setting Thermal Rate 1: T2_1

The following methods should be used to determine T2:

1. Motor manufacture recommendation.
2. "Learned" based on Motor RTD feedback (SFT2841 software setting; see next section).
3. If no other data is available, begin with $T2_1 = 3 \times T1_1$ and monitor to validate.

Automatic Setting for T2_1, the Cooling Time Constant

If the motor has stator RTDs, the relay can measure the cooling time constant T2. Accuracy is better if ambient temperature is measured also.

Follow these steps to set the function:

1. Connect the stator RTDs to the inputs 1, 2 and 3 of the MET1482 module number 1. At least one stator RTD must be connected to input 1.
2. Go to the **SEPAM hardware** menu of SFT2841.
3. Set MET1482 module number 1 for "motor/generator" use.
4. If available, connect the ambient temperature sensor to input 8 of the MET1482 module number 1.
5. Select the "accounting for ambient temperature" option in the 49RMS menu of the SFT2841.

A new value for T2_1 is estimated after each heating/cooling sequence. It is displayed on the front panel of the SEPAM unit and in SFT2841 software when connected. It can also be accessed through the communication interface.

The T2_1 setting of the thermal image protection can be automatically updated each time a new value for the cooling time constant is made available. For that purpose, select the "use learned cooling time constant T2" option in the 49RMS menu of SFT2841 software.

The evolution of the measured value of the cooling time constant is of interest for predictive maintenance.

Setting Thermal Rate 1: Es0_1

This setting is to protect cold stator damage curve provided by the motor manufacture.

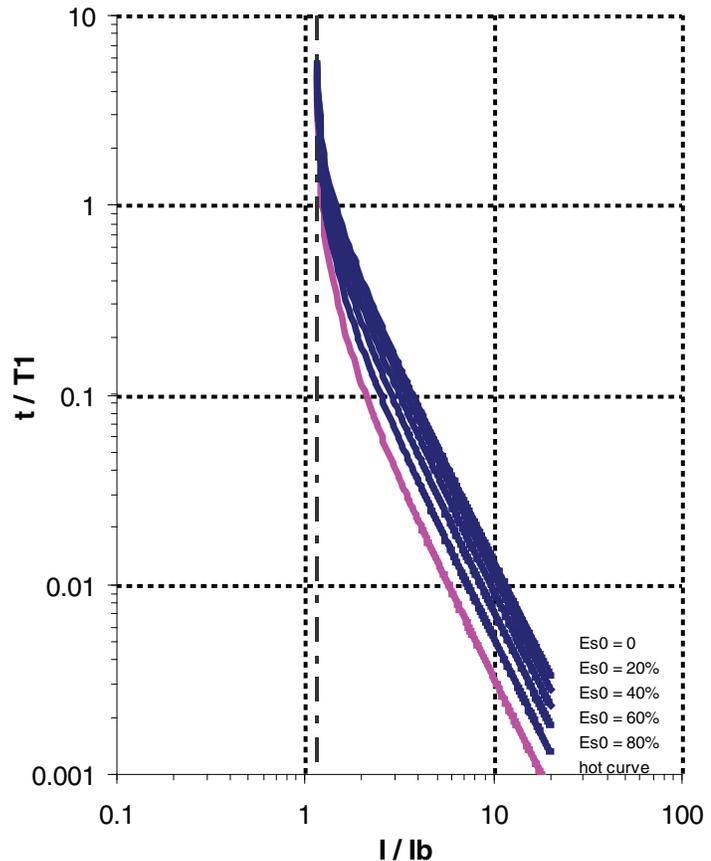
Set to 0% if a cold curve is not supplied. If a cold curve is supplied, adjust as necessary (using the spreadsheet tool) to protect cold curve.

The impact on the thermal model of the motor is that the thermal capacity used by the motor cannot decrease below the setting of Es0_1.

From a mathematical point of view, the equation of the cold curve becomes:

$$\frac{t}{T1} = Ln \left(\frac{\left(\frac{I}{Ib}\right)^2 - Es0}{\left(\frac{I}{Ib}\right)^2 - Es2} \right)$$

Figure 7: t/T1 with varying Es0



Effect of Thermal Rate 1, Es0_1 Setting on Starts per Hour (66)

Motor manufactures also provide information about how many times a motor can be started hot and cold during a specified period of time. Typically the time period is one hour. SEPAM uses the 49RMS element settings to determine if a motor is in a hot state or cold state. If the calculated E (Thermal Capacity) is 50% or greater, the motor is considered hot. If the calculated E (Thermal Capacity) is less than 50%, the motor is considered cold. The relay uses user-determined values or default 49RMS settings to perform this calculation (even when the 49RMS element is turned off). The default Es0_1 is 0%. If Es0_1 is set to 50% or greater, the motor is always considered hot. The starts-per-hour then are limited to the number of hot starts that are programmed into the element. Keep this in mind when setting Es0_1 > 50%. Typically this value is set to 0% or a small value and does not affect the starts-per-hour (66) function.

Setting Thermal Rate 2

On a new installation it should be feasible to obtain the hot/cold stator and rotor damage curves (see Figure 1). On motors that have been in operation for some time, this may not be possible.

The following settings are the same as Thermal Rate 1:

- $Es2_1 = Es2_2$
- $T2_1 = T2_2$

$Es0_2$ should be set to protect the cold rotor damage curve (provided by the motor manufacture) using coordination software (an example is SKM PowerTools® for Windows™) or the Thermal Overload Excel spreadsheet (www.PowerLogic.com). If you have not been given a cold rotor damage curve, set $Es0_2 = 100\%$.

Set $T1_2$ to protect the hot rotor damage curve (or at least the hot stall time or, worst case, an estimate of the hot stall time).

$Es1_2$ should be set to 300%. Since no real alarming capability for the timing is necessary to protect the rotor damage curve, this value is set at the maximum allowable value of 300%.

The Transition Current (TR1->TR2) setting should be made to optimize protection for the last supplied damage point of the stator and the first damage point of the rotor. If a curve is not available, set this to 200% for Reduced Voltage (RV) applications and 300% for Full Voltage (FV) applications.

Negative Sequence Current

Negative sequence currents directly affect the heating of the rotor. ANSI C37.96 states in part:

“A small-voltage unbalance produces a large negative-sequence current flow in either a synchronous or induction motor. The per unit (pu) negative-sequence impedance of either motor is approximately equal to the reciprocal of the rated voltage pu locked-rotor current. [For example, when] a motor has a locked-rotor current [of six times the rated value], it has a negative-sequence impedance of approximately 0.167 pu on the motor-rated input [kVA] base. When voltages having 0.05 pu negative-sequence component are applied to the motor, negative-sequence currents of 0.30 pu flow in the windings. Thus, a 5% voltage unbalance produces a stator negative-sequence current of 30% of full-load current. The severity of this condition is indicated by the fact that with this extra current, the motor may experience a 40% to 50% increase in temperature rise.”

Negative sequence heating can be taken into account by the thermal image protection by increasing the current, I_{eq} , processed by the thermal image:

$$I_{eq}^2 = I_{ph}^2 + K \cdot I_2^2$$

where:

I_{ph} is the largest phase current

I_2 is the negative sequence current

K is a setting factor

K can be set to 0, 2.25, 4.5, or 9.

With a typical setting $K=4.5$, a negative sequence of 0.3 p.u. will increase the thermal capacity used by a ratio of $4.5 \cdot 0.3^2 = 40\%$.

Ambient Temperature

General and special-purpose motors and industrial control equipment are rated for use in a maximum ambient environment of 40 °C (104°F). When this value of the ambient temperature is exceeded, the thermal capacity used of the motor is increased by a ratio f_a :

$$f_a = \frac{T_{max} - 40^{\circ}\text{C}}{T_{max} - T_{ambient}}$$

where:

T_{max} is the maximum temperature of the windings, according to the insulation class.

The thermal image protection can take into account the ratio f_a :

1. Connect the ambient temperature sensor to input 8 of the MET1482 module number 1 and select the “accounting for ambient temperature” option in the 49RMS menu of the SFT2841 software.
2. Set the “maximum temperature of machine” (T_{max}) in the 49RMS menu of the SFT2841 software.

NOTE: The protection will never allow values above 1 for the f_a ratio. This means, the thermal capacity used, as calculated by the thermal model, can be increased due to excessive ambient environment but never reduced.

Summary

To summarize:

- No motor can be properly protected without having thermal damage curves.
- Use both Thermal Rate 1 and 2 to provide proper protection of stator and rotor damage curves.
- The setting procedure should be thought of as “curve fitting” two, independent curves, one for the stator (Thermal Rate 1) and one for the rotor (Thermal Rate 2) to protect each damage curve.

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