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Application Note

Extending Motor Life with Flexible Thermal Overload Protection - BE1-11*m* Motor Protection System

The largest contributing factor to motor failure is excessive motor heating. That is, life of the motor is shortened if the winding temperatures are allowed to exceed their insulation class levels for a significant amount of time. It is usually assumed that, for every 10°C above the design temperature limit, life of the motor is reduced by a factor of two. Therefore, aggressive application of intelligent thermal motor protection must be implemented to get maximum return on these very large and very critical capital investments. The Basler BE1-11*m* motor protection system, among its many features, has excellent thermal overload protection combined with maximum setting flexibility.

Figure 1 - BE1-11*m*

Thermal Overload Protection

When normal cooling and ambient temperatures are present the temperature of the stator winding is directly related to the stator current, and the running mode thermal overload limit can be stated on a time-current plot as recommended in IEEE 620. Running mode thermal overload can thus be provided by an overcurrent relay 51P that has a time-current characteristic similar to the thermal overload limit. The Minimum Pick Up of this 51P relay element is the continuous overload specification of the motor, i.e. the (Full Load Amps) x (Service Factor) and the characteristic is usually an I2t curve. The time dial setting is chosen to coordinate against the thermal limit and allow short duration overloads predictable from the process analysis. IEEE device number 51 or 49TC (thermal characteristic) may have nearly identical static characteristics but may differ in the dynamic response and, therefore, in their ability to track the motor temperature over time.

A continuously changing thermal response is required to cover the operating diversity of a motor as related to thermal life. A motor has several modes of operation including nominal voltage start, reduced voltage start, acceleration, and nominal- and low-voltage running modes. See Figure 2. Normally, the first two modes are referred to as “locked rotor” and “acceleration”. “Locked rotor” describes that period of time when the rotor has not begun to turn, “acceleration” describes the period when the rotor is coming up to speed, and “running” modes are when the rotor has achieved near synchronous speed. Motor heating occurs during each mode of operation and must be accounted for in the management of motor thermal life.

The thermal element also should be current-based protection that models the thermal capacity of the motor. The model should use negative sequence current in the heating calculation to produce an accurate reproduction of motor heating (motor thermal capacity) during starting (nominal, unbalanced and reduced voltage), acceleration, nominal and reduced voltage running, and stopped modes..

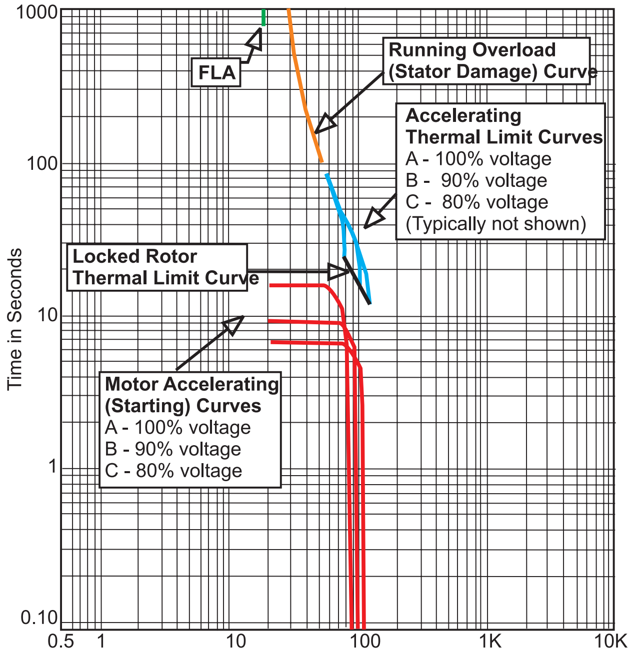

Figure 2 - Typical Start Curve

BE1-11*m* 49TC Thermal Model

The 49TC (Thermal Characteristic) is core protection for managing motor thermal damage. The 49TC element creates a realistic thermal model of the motor by taking into account the load level and negative-sequence (unbalance) current. Thus, the thermal model creates an "equivalent current" , I_{eq} that represents the actual motor dynamics. The thermal model calculation should use equivalent thermal current with unbalance biasing, the selected thermal curve, pickup current, motor cooling constant(s), and RTD biasing based upon measured stator temperature and the hot/cold safe stall ratio.

The equivalent thermal current, I_{eq}, follows:

$$I_{eq} = I\sqrt{1 + k\left(\frac{I_2}{I_1}\right)^2}$$

where:

I_{eq} = equivalent thermal current in pu (unit of thermal pickup current)
I = maximum phase current in pu
I_1 = positive sequence fundamental component of current in pu
I_2 = negative sequence fundamental component of current in pu
k = constant to determine additional heating caused by negative sequence current in pu

The factor k is a user setting. With k set to 8, the formula gives a derating factor closely matching the NEMA MG-1 derating factor (from voltage unbalance). A larger k makes the estimation of equivalent current, Ieq, more conservative because it adds more heating to the model. Because voltage sensing is not always available, the ratio of negative sequence to positive sequence current (I2/I1) is used primarily instead of voltage unbalance.

Thermal Curves - Standard, IEC, and User

The 49TC element includes Standard (North American) and IEC curves with appropriate settings for loading, cooling constants, and stall times. See Figure 3 for thermal characteristic settings.

For special applications, the motor relay offers User Curves with separate locked rotor and overload curves for differing starting voltages if the application requires this flexibility. See Figure 4.

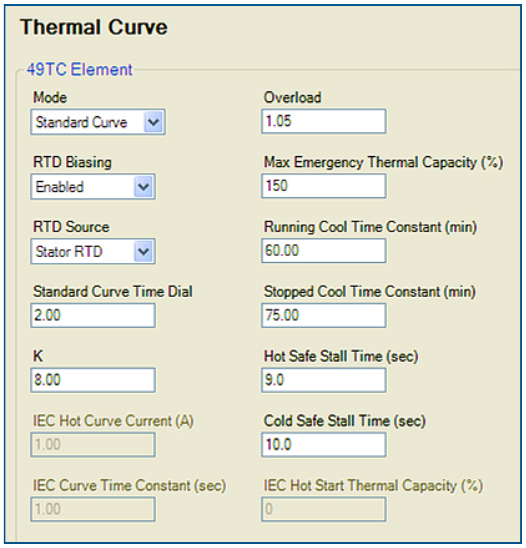

Figure 3 - Thermal Model Element Configuration in BE1-11*m* BESTCOMS*Plus*®

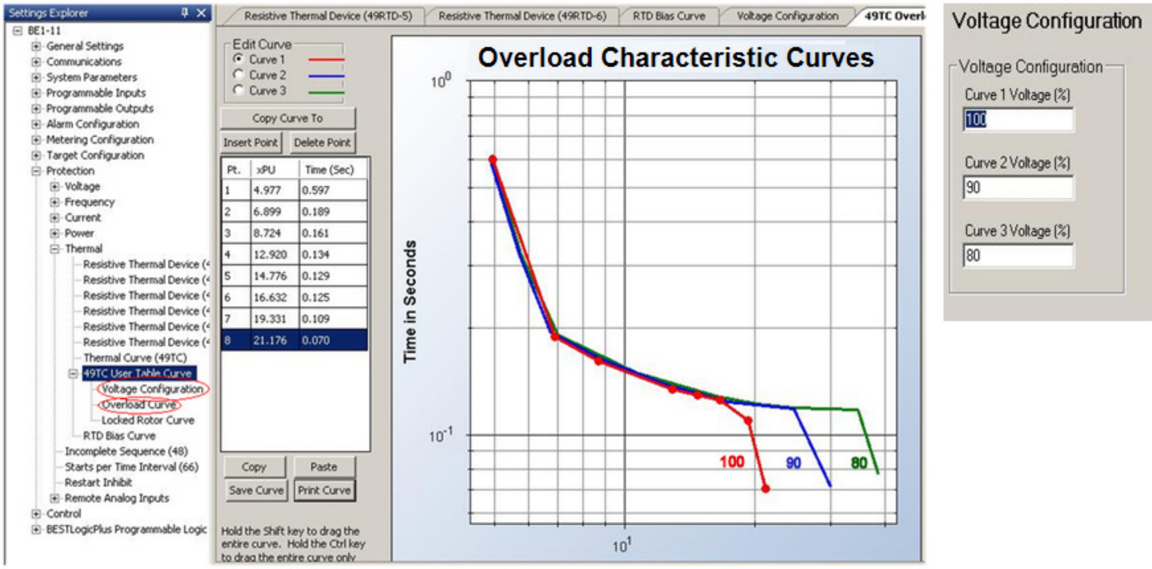

Figure 4 - User-Programmed Overload Table Curve

Thermal Setting Flexibility

The Basler BE1-11*m* thermal model implementation has two unique features. One is the ability to tailor the 49 thermal model with the "overload" setting. The range of this setting is 0.9-1.2 times the service factor times the full load current. (See Figure 3.) Using this setting allows for fine tuning the thermal model for lightly or heavily loaded applications.

Another unique setting is the ability to set the thermal capacity at which the motor will perform an emergency start. This setting, "Max Emergency Thermal Capacity", allows the user to perform an emergency start at any set thermal capacity, thus keeping vital processes running. Once emergency start is initiated, the thermal model adjusts to keep the motor protected as the motor cools into the nominal thermal range.

The BE1-11*m* thermal model is unique in that the user is not limited by FLA · SF (full load current times service factor) for determining motor operation. You can bias the thermal model with the Overload setting to account for both high-load, hot running applications and low-load, cool running applications. (See Figure 3.)

Emergency Start

Providing optimum thermal and fault protection for a motor without restricting the operational requirements is a balance between accurate thermal modeling and flexible operational setting. For example, many motor protection products block motor start when a specified thermal limit has been exceeded. However, process requirements may force the user to bypass the block start which resets the stored thermal information to zero in other manufacturers' products. This ignores the previous thermal information, as the motor is forced to run beyond its thermal limits and is not an accurate representation for managing motor thermal life.

If we think of the thermal capability of the motor as a bucket and the level of water in the bucket as thermal capacity consumed in the emergency start case just described, the bucket would be emptied when the motor block is bypassed and restarted. In the Basler BE1-11*m*, instead of emptying the bucket, the bucket is made larger (expanded) and continues to accumulate accurate thermal data that will aid in overall motor thermal life management. The model continues protecting the motor as it cools into the nominal thermal range.

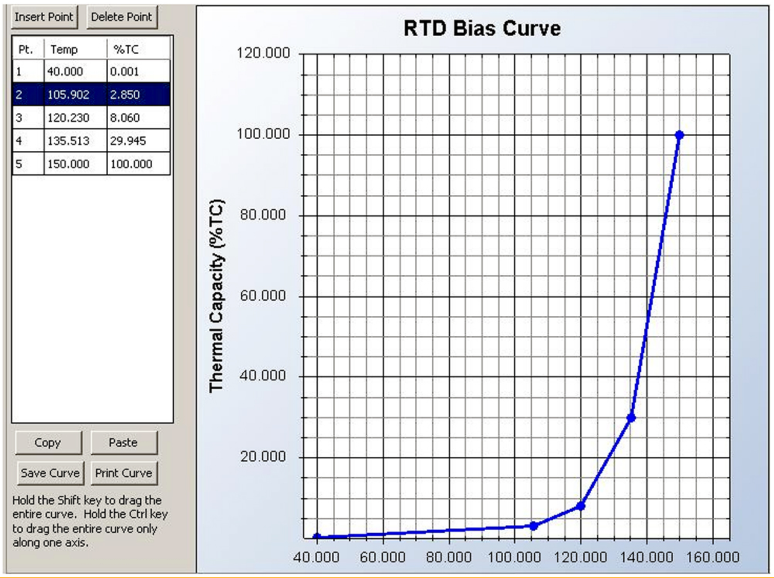

Figure 5 - Multi-point RTD Biasing Modifies Thermal Model at High Operating Temperatures

Thermal Model Biasing

You can bias the thermal model based on RTD values. This is done to provide protection in conditions of abnormal cooling. This can include conditions of blocking cooling supply and abnormally high ambient temperatures. The BE1-11*m* provides multiple bias points for accurate thermal modification, as seen in Figure 5. Motors typically are cooled by means of a rotor mounted fan blade that forces air through the motor frame while the motor is running. Thermal limits and temperature rise are based on this cooling functioning as designed with a known level of ambient air temperature. If normal cooling is not available, the motor may operate warmer than can be predicted by current alone. RTDs monitoring the stator temperatures can provide biasing to improve the thermal capacity being calculated by the 49TC model.

RTD Alarming and Tripping

In addition to biasing, RTDs can provide alarming and tripping. In severe failure of cooling or bearings, the motor temperature can rise to damaging levels while the current remains below overload levels. In this case, the RTD must be used to provide the needed protection. The BE1-11*m* has the necessary RTD elements available to be able to provide alarm and trip set points for stator, bearing and ambient RTDs.

The recommended setting for alarm temperature level for the stator RTD is the sum of the maximum ambient, plus 10 degrees hotspot allowance, plus the full load temperature rise. This value should be below the insulation class rating. The trip level can be as high as 50°C above the class rating if the process is critical, because the loss of motor life from occasional short overload periods is insignificant. Setting the trip temperature at the insulation class limit is a conservative setting.

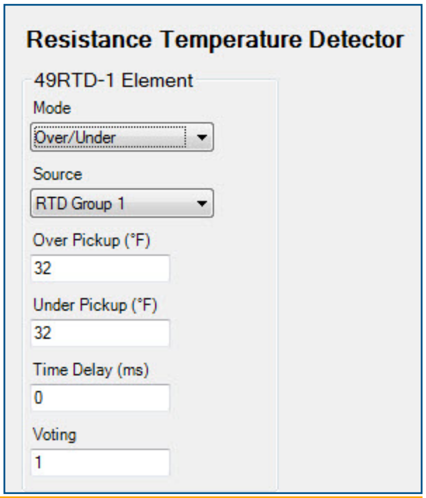

Figure 6 - RTD Screen

RTD Voting

Another advantage of using the BE1-11*m* for motor protection is the inclusion of RTD voting. RTD voting forces agreement (two or more RTDs must agree) in overtemperature situations, and avoiding false trips. You can set the number of RTDs that must concur before a trip is issued, thus avoiding the situation where a bad RTD can stop a correctly functioning motor. See Figure 6.

User Generated Overload Curve

There are applications, such as high inertia starts, that result in motor starting currents that can encroach on the thermal damage curves. Flexible table curves such as those found in the BE1-11*m* allow the user to create custom curves that accommodate successful motor starting without sacrificing protection. Also, the starting thermal damage curve (locked rotor and acceleration) and the running thermal damage curves rarely fit together smoothly, requiring user settable curves with flexible setting features. Discontinuity of thermal curves can be created with a single point in one of the BE1-11*m* table curves. During the period of discontinuity, the longer of the two trip times is used to reduce the chance of nuisance tripping during motor starts.

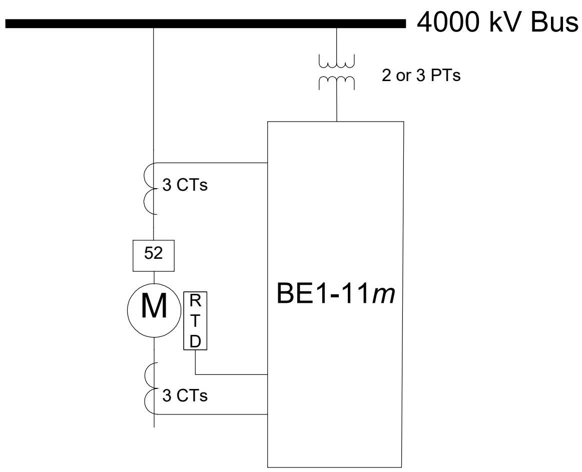

Figure 7 - One-line drawing showing percentage restrained differential calculations for a 2,900 HP motor

For More Information

Visit www.basler.com and download more information on the BE1-11*m* Motor Protection System. Example calculations for a 2,900 HP motor, including percentage restrained differential, can be found in the Settings Calculation Examples chapter of the BE1-11*m* instruction manual. (See Figure 7).

You also can download bulletins on the other members of the BE1-11 family of relays and other Application Notes on the web site.

To discuss your specific application, consult the Basler factory at (618) 654-2341..

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