Replacing Electromechanical Relays With Microprocessor Relays to Provide Thermal Protection for Motors

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REPLACING ELECTROMECHANICAL RELAYS WITH MICROPROCESSOR RELAYS TO PROVIDE THERMAL PROTECTION FOR MOTORS

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Abstract—Thermal overload protection is a critical part of any motor protection scheme. Older electromechanical relays provide thermal protection with an inverse-time overcurrent element. Replacing electromechanical relays with modern microprocessor-based relays requires the development of settings for a more sophisticated thermal protection element, such as the first-order thermal model. Additionally, this requires a planned outage to install the new relay and commission the settings. To correctly set the thermal element in a microprocessor-based relay, motor manufacturer data (such as a nameplate, data sheet, and system data) are needed. However, these data are not always available for older motors. This paper describes the settings required for the first-order thermal model and provides case studies from various end users illustrating how settings from existing electromechanical relays were used to develop settings for a microprocessor-based thermal element.

Index Terms—Motor protection, thermal model, motor retrofit, electromechanical motor protection relays, setting motor thermal element

I. INTRODUCTION

During motor starting, typically six times the rated current flows in the motor circuit due to inrush. This can overheat and damage the rotor windings if this inrush condition persists for more than the motor design limit. Similarly, when the motor is running, the current flowing in the stator and rotor circuit results in losses due to the stator and rotor resistances. These losses lead to motor heating. If the temperature in the motor windings exceeds the design temperature of the motor, the useful life of the motor is shortened.

Before microprocessor relays became prevalent, electromechanical time overcurrent or thermal overload relays and resistance temperature detectors (RTDs) were used to provide thermal protection for motors. Many modern microprocessor-based relays use the first-order thermal model to protect motors against thermal overload conditions.

When migrating from conventional electromechanical relays to microprocessor-based relays, it must be understood that these elements are fundamentally different in how they protect motors against thermal damage. The time overcurrent element cannot properly respond to the thermal dynamics of the motor. For example, this element may overtrip for cyclic loads [1]. The first-order thermal model, on the other hand, uses the motor currents to mathematically calculate the motor's temperature in real time and trips the motor when this calculated motor temperature exceeds the thermal trip threshold. Microprocessor relays also provide recording capabilities that can be used to trend motor start data and RTD measurements. This can be used to monitor the performance of the motors and schedule maintenance and repairs [2].

In order to set the thermal overload element in a modern microprocessor relay properly, data, such as a motor manufacturer's data sheet, motor nameplate, or power system data, are required. Only limited data are often available, particularly in cases where the motor has been in service for some time. For example, a motor data sheet may have been lost or misplaced for an existing motor. Another example could be that a motor's nameplate is worn or rendered illegible over a period of time. In those cases, the existing protection settings may be the best source of information about the motor's thermal capability.

The goal of this paper is to share examples of how to use electromechanical settings along with available motor data as the basis for setting the thermal overload element in a modern microprocessor relay.

II. OVERVIEW

A brief overview of the first-order thermal model and general guidance on how to set the first-order thermal model is provided in this section.

A. First-Order Thermal Model

Fig. 1 shows the main components of the first-order thermal model. A brief description is provided in this paper to illustrate the data required to set the thermal elements for the stator and the rotor. Refer to [3] and [4] for a detailed description of the first-order thermal model.

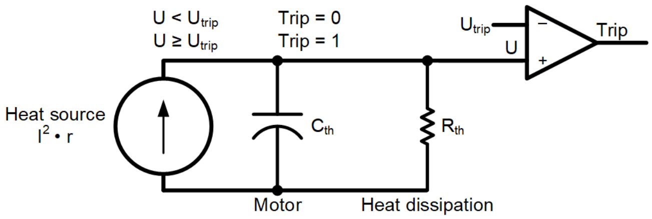

Fig. 1 First-Order Thermal Model [5]

The major components in Fig. 1 are as follows:

1. Heat source: The heat flow from the source is $I^2 \cdot r$ watts or J/s. This includes heating due to the positive-sequence and the negative-sequence currents.
2. Thermal capacitance (C_{th}): This represents the capacity of the motor to store heat from the source. The unit of thermal capacitance is J/°C.
3. Thermal resistance (R_{th}): This represents the heat dissipated by the motor to its surroundings. The unit of thermal resistance is °C/W.
4. Comparator: This compares the calculated per-unit temperature (U) and creates a trip condition when U exceeds the trip threshold (U_{trip}).

The relay calculates the Thermal Capacity Used (TCU) by the motor using (1).

$$TCU = \frac{U}{U_{trip}} \cdot 100\% \quad (1)$$

When the TCU reaches 100 percent, the relay will trip.

The construction of the stator and the rotor are different and so are their thermal characteristics. Therefore, the components of the thermal model differ for the stator and the rotor. These components also vary depending on the state of the motor—starting, running, or stopped. Some microprocessor relays include separate thermal models for the stator and the rotor, which are always active and operate simultaneously to protect the motor.

B. Stator Thermal Model

Fig. 1 is applicable to the stator model during the starting and the running states. The components of the stator thermal model are defined by the following settings in the relay:

1. The overload pickup (OLPU) is the value of current at which the thermal element begins timing to trip.
2. Locked rotor amperes (LRA) is the steady-state current drawn by the motor at rated voltage when the rotor is locked (at standstill). It is typically in per unit of the full-load amperes (FLA) of the motor.
3. Hot stall time (T_{STALL}), also known as the hot locked rotor time, defines the duration for which the motor can draw the starting current (LRA) without incurring damage.
4. The stator running time constant (RTC) determines how much time it takes the stator to reach its rated operating temperature. The higher the RTC value, the longer it takes for the relay to trip on thermal overload conditions and vice versa.

Fig. 2 shows the stator TCU calculated during the start, run, and stop cycle.

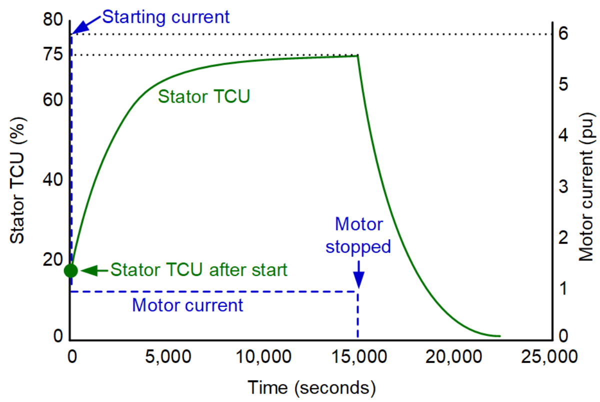

Fig. 2 Variation of the Stator TCU (%) During a Motor Start-Run-Stop Cycle

The motor start lasts for 6 seconds in this example. The 6 pu starting current is a single data point on the graph since the motor start-run-stop cycle lasts for 25,000 seconds while starting takes place in 6 seconds. At the end of the starting process, the stator TCU is low. In this case, it is around 20 percent. The stator TCU continues to increase during the running state until it reaches a steady-state value of around 75 percent. The stator TCU is high during the running state. After the motor is stopped, the TCU begins to decrease until it reaches ambient temperature or a TCU close to 0 percent.

C. Rotor Thermal Model

Fig. 1 is applicable to the rotor model during the running state. Motor starting is an adiabatic (lossless) process, which means that the amount of heat dissipated to its surroundings during the few seconds of motor starting is negligible. Thus, the R_{th} component of the rotor model in Fig. 1 is considered to be infinite during the motor start. Therefore, the rotor's TCU increases rapidly during the motor start. The components of the rotor thermal model are defined by the LRA and T_{STALL} settings in the relay.

Fig. 3 shows the rotor TCU calculated during a start, run, and stop cycle.

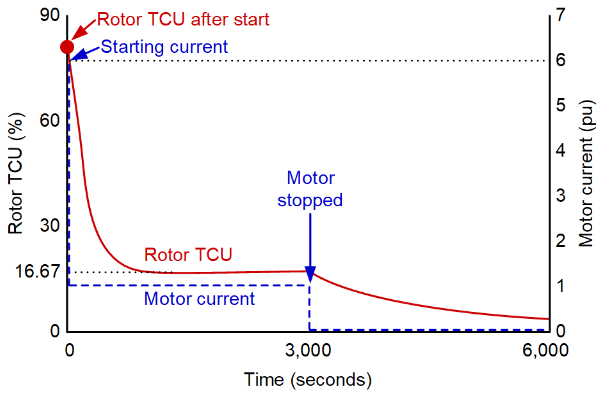

Fig. 3 Variation of the Rotor TCU (%) During a Motor Start-Run-Stop Cycle

The rotor TCU increases rapidly during the motor start. At the end of the starting process, the rotor TCU will be high. The 6 pu starting current is a single data point on the graph since the motor start-run-stop cycle lasts for 6,000 seconds while starting takes place in 6 seconds. In this case, the rotor TCU is equal to 80 percent. As the current decreases from LRA to FLA in the running state, the rotor TCU also begins to decrease to a low value. The rotor TCU in the running state is close to 16.67 percent. When the motor is stopped, the rotor TCU decreases from 16.67 percent until it reaches ambient temperature or a TCU close to 0 percent.

D. Plotting the Stator and Rotor Trip Characteristic

Now that the first-order stator and rotor thermal models have been discussed briefly, we can look at how to plot the trip characteristic for the stator and rotor. The rotor overload protection curve is an $I^2 \cdot t$ characteristic curve in the starting state. Therefore, (2) can be used to plot the relay's rotor trip characteristic, where I is the motor current in multiples of FLA.

$$t = \frac{T_{STALL} \cdot LRA^2}{I^2} \text{seconds} \quad (2)$$

Equation (3) can be used to plot the hot stator trip characteristic [4].

$$t = 60 \cdot RTC \cdot \ln\left(\frac{I^2 - (0.9 \cdot OLPU)^2}{I^2 - OLPU^2}\right) \text{seconds} \quad (3)$$

Fig. 4 shows an example coordination plot of the thermal limit curves of a motor protected by the first-order thermal element against the stator and rotor trip characteristics.

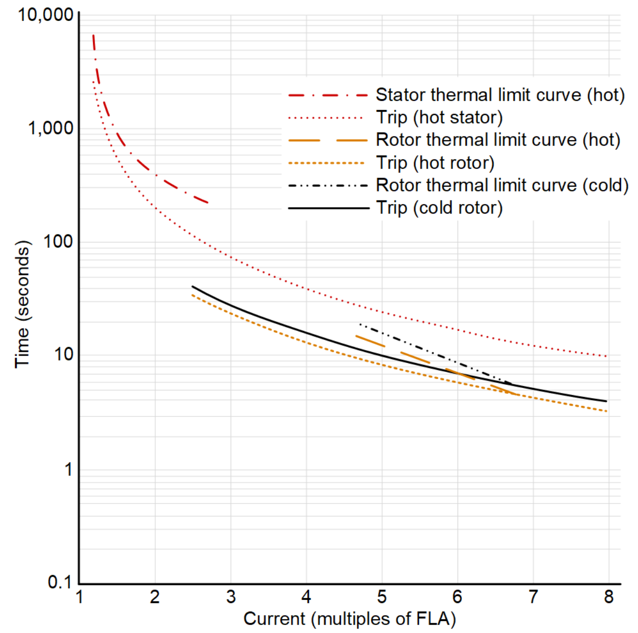

Fig. 4 First-Order Thermal Element Coordination Curves for an Example Motor

E. Reset Characteristics of the Thermal Model

When the motor is stopped, the heat stored in the motor needs time to dissipate to the surroundings. This heat dissipation is represented by the capacitor (C_{th}) discharging through the resistor (R_{th}), as shown in Fig. 5. How fast this heat dissipation occurs depends on the motor design, the cooling method, and the initial temperature of the motor at the time of stopping, as well as the ambient temperature. The microprocessor relays provide settings to help accurately model the motor's reset characteristics.

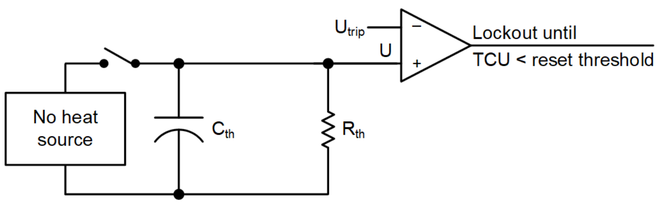

Fig. 5 Stop State of the Thermal Model [5]

Once the motor is stopped, the temperature in the stator and the rotor must decrease enough to ensure that if the motor is started up again, it will not cause the stator or the rotor temperatures to exceed the U_{trip} threshold. Until this temperature is achieved, the motor should be locked out. Some microprocessor relays can prevent a new start until the TCU decreases below a stator and rotor reset threshold setting. These reset thresholds depend on how much thermal capacity is used during a motor start. If the motor start time and RTD measurements are available, [5] shows a process to calculate the reset settings. If these data are not available, the reset thresholds can be set based on the recorded TCU during a motor start. The average value of the start TCU recorded in the last five starts can be used.

III. REPLACING ELECTROMECHANICAL RELAYS WITH MICROPROCESSOR RELAYS

A. Setting the Thermal Model

In order to determine the settings of the first-order rotor and stator thermal models discussed in Section II, the following information about the motor is required at a minimum:

1. Service factor (SF)
2. FLA
3. LRA
4. T_{STALL}

Motor manufacturers usually provide data sheets for new motors that have this information. However, these data sheets are not always available for electromechanical retrofit projects. In such cases, the following steps can be used to develop thermal model settings using the motor nameplate and the existing electromechanical relay settings. Fig. 6 shows an example motor nameplate.

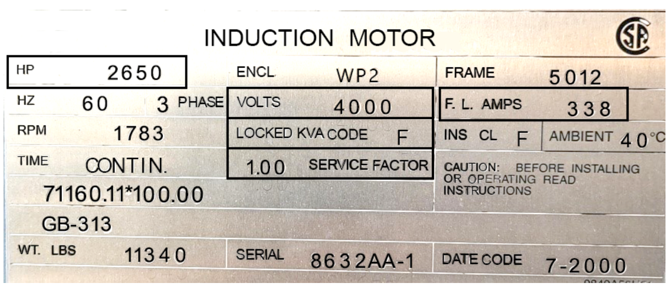

Fig. 6 Motor Nameplate With the Required Information Emphasized

1. OLPU: The pickup can be set equal to the rated SF on the motor nameplate. If the SF is 1.0, the pickup should be set to 1.05 to account for any measurement errors.
2. FLA: The rated full-load current of the motor is available directly on the nameplate.
3. LRA: This value is not always provided on the motor nameplate. Instead, a National Electrical Manufacturers Association (NEMA) design code letter is usually provided, as shown in Fig. 6. This locked kVA code letter defines LRA on a per-horsepower (hp) basis. Table I provides the locked rotor kVA code and the corresponding kVA/hp multiplier [6]. An approximate value of LRA can be calculated using (4), where the kVA/hp multiplier can be obtained from Table I.

TABLE I
LOCKED ROTOR CODE AND THE CORRESPONDING KVA/HP MULTIPLIER

Letter Designation	KVA per HP*
A	0–3.15
B	3.15–3.55
C	3.55–4.0
D	4.0–4.5
E	4.5–5.0
F	5.0–5.6
G	5.6–6.3
H	6.3–7.1
J	7.1–8.0
K	8.0–9.0
L	9.0–10.0
M	10.0–11.2
N	11.2–12.5
P	12.5–14.0
R	14.0–16.0
S	16.0–18.0
T	18.0–20.0
U	20.0–22.4
V	22.4 and up

*Generally, the kVA/hp multiplier is calculated as the average of the range corresponding to the code letter. For example, the kVA/hp multiplier for Code F in Fig. 6 is 5.3.

$$LRA = \frac{577 \bullet \text{Rated hp} \bullet \dfrac{\text{kVA}}{\text{hp}}}{\text{Rated voltage} \bullet \text{FLA}} \text{ per unit} \tag{4}$$

The rated voltage, hp, and the FLA of the motor are provided on the nameplate.

4. T_{STALL}: The nameplate does not provide any information about the locked rotor time. If a motor data sheet is available that shows the motor stall time or locked rotor time, that should be used to define T_{STALL}. If this information is not available, assuming that the electromechanical relay is set correctly, the electromechanical relay's time overcurrent element settings can be used to estimate T_{STALL}.

   The following information from the electromechanical relay is required to calculate T_{STALL}:

   - Phase relay type
   - Phase relay tap setting
   - Phase relay time dial

   The overcurrent curve of the electromechanical relay can be obtained using the phase relay type. The overcurrent curve is usually plotted with multiples of pickup on the horizontal axis and time to trip on the vertical axis, as shown in Fig. 7. The LRA can be calculated as a multiple of the pickup (M) using the relay tap settings, as shown in (5), where CTR is the current transformer ratio.

$$M = \frac{LRA \cdot FLA}{CTR \cdot \text{Phase relay tap}} \tag{5}$$

The family of curves corresponding to the relay type, like the one shown in Fig. 7, can be used to identify the trip time corresponding to the M from (5). The trip time obtained will be close to the hot stall time of the motor. If more sensitive protection is desired, then the trip time can be assumed to be the cold stall time. For the more sensitive approach, (6) can be used to calculate T_{STALL}, or the hot stall time. T_{STALL} must be verified using the motor start data, as shown in Section IV.

$$T_{STALL} = \frac{\text{Cold stall time}}{1.2} \tag{6}$$

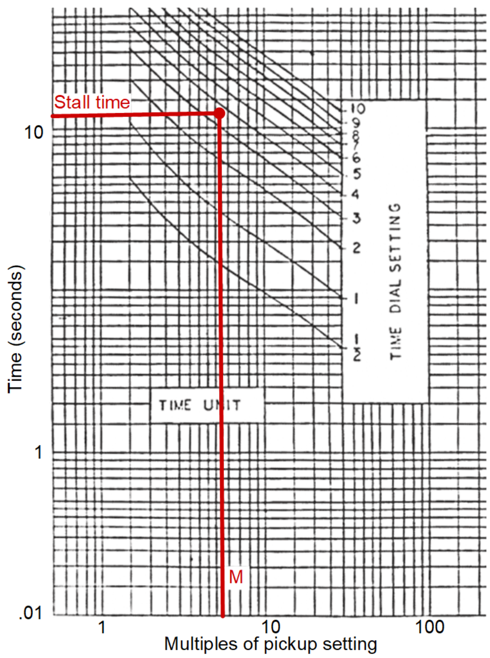

Fig. 7 Determine the Cold Stall Time From the Existing Electromechanical Relay Curve

Once the minimum information required to set the thermal model, namely OLPU, FLA, LRA, and T_{STALL}, is available, the stator RTC value can be calculated using these parameters. Normally, the stator RTC value can be found by coordinating the relay's stator trip curve with the motor's thermal limit curves. For older motor retrofits, the thermal limit curves are usually not available. In this case, the RTC can be automatically calculated by the microprocessor relay using an AUTO setting, as shown in (7).

$$RTC = \frac{1.2 \cdot T_{STALL}}{60 \cdot \ln\left(\frac{LRA^2 - (0.9 \cdot OLPU)^2}{LRA^2 - OLPU^2}\right)} \text{ minutes} \tag{7}$$

This calculation assumes that when the current flowing through the motor is LRA, the time to trip is equal to the cold stall time or $1.2 \cdot T_{STALL}$ from (6). When RTC is set to AUTO, the hot stator trip characteristic overlaps the cold rotor trip characteristic, as shown in Fig. 8.

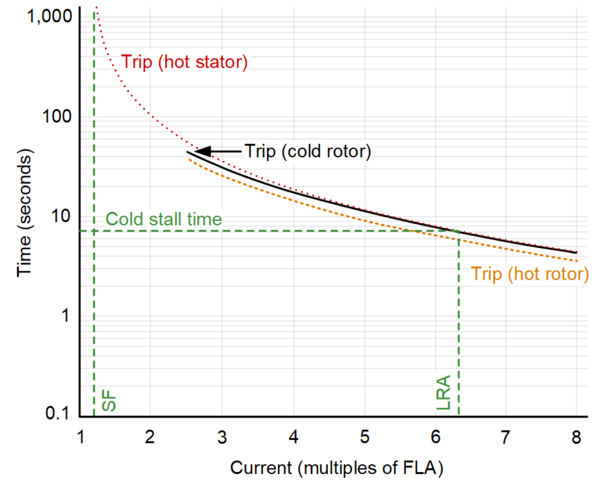

Fig. 8 Thermal Curves for RTC = AUTO

B. Modifying Settings Based on Motor Start Reports

Microprocessor relays can be used to monitor motor start current and time. This recorded information can be used to refine the thermal element settings if these settings were developed with limited information from the motor manufacturer or if the electromechanical relay settings are known to be inaccurate.

The starting current, voltage, rotor TCU, and start time are recorded in a motor start report. An example of a motor start report is provided, as shown in Fig. 9.

# Starts	52
Start Time (s)	3.1
Start TCU (%)	84
MaxCurrent (A)	50
MinVoltage (V)	193
MSR_REF Number	10000

CYCLE	IA (A)	IB (A)	IC (A)	IN (A)	VAB (V)	VBC (V)	VCA (V)	ROTOR TCU (%)
5.00	50	43	35	0	193	199	201	66.8
10.00	46	44	35	0	195	197	200	68.0
15.00	45	37	42	0	197	201	197	69.0
20.00	36	40	37	0	199	198	200	70.0
25.00	35	37	37	0	200	199	200	70.8
30.00	34	35	35	0	200	200	200	71.7
35.00	32	32	33	0	201	201	201	72.4
40.00	32	31	31	0	202	203	202	73.1
45.00	32	31	30	0	202	203	203	73.7
50.00	32	32	31	0	203	203	203	74.3
55.00	32	32	31	0	203	203	203	75.0
60.00	30	32	31	0	204	204	204	75.5
65.00	35	34	33	0	202	203	203	76.2

Fig. 9 Motor Start Report

Once the motor has been started around five times with normal load, the LRA value can be set to the average maximum start current in per unit of FLA. Additionally, the T_{STALL} time can be compared to the average start time of the motor. T_{STALL} can be set to the average start time plus an additional margin of 3 seconds for induction motors. The margin can be reduced to 2 seconds for synchronous motors [4].

Even in cases where complete information is available to set the thermal element, recording these values can help identify issues with the motor, such as mechanical problems, as shown in [2]. These data can be used to perform proactive maintenance, as shown in [7].

C. Physical Replacement

When retrofitting electromechanical motor relays, it is common to use one of the following two types of CT configurations.

One configuration is to use three phase CTs and one core-balance CT, as shown in Fig. 10. In this case, there are four electromechanical relays; three relays are providing phase overcurrent protection, one for each of the three phases, and one relay is providing residual ground overcurrent protection. All four relays can be replaced by a single microprocessor relay. The CT wiring circuits do not change significantly. Fig. 10 shows the sample wiring for this case with three phase CTs and one core-balance CT.

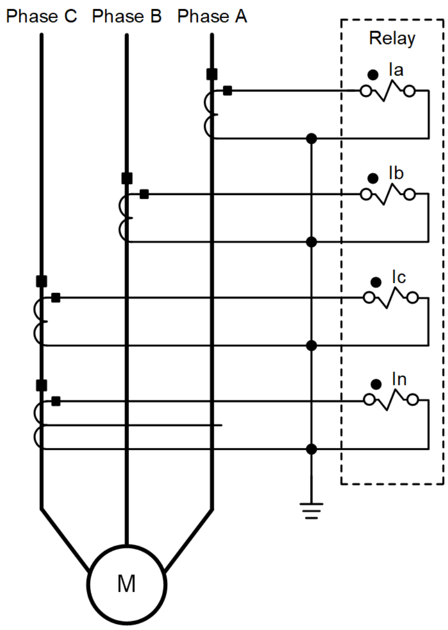

Fig. 10 Sample Wiring for a Microprocessor Relay With Three Phase CTs and One Core-Balance CT

The second configuration is to use two phase CTs and one core-balance CT, as shown in Fig. 11. This installation is typical of high-resistance grounded systems with a core-balance CT. This was done to reduce the number of phase CTs and phase relays required to protect each motor. In this case, three electromechanical relays can be replaced by a single microprocessor relay.

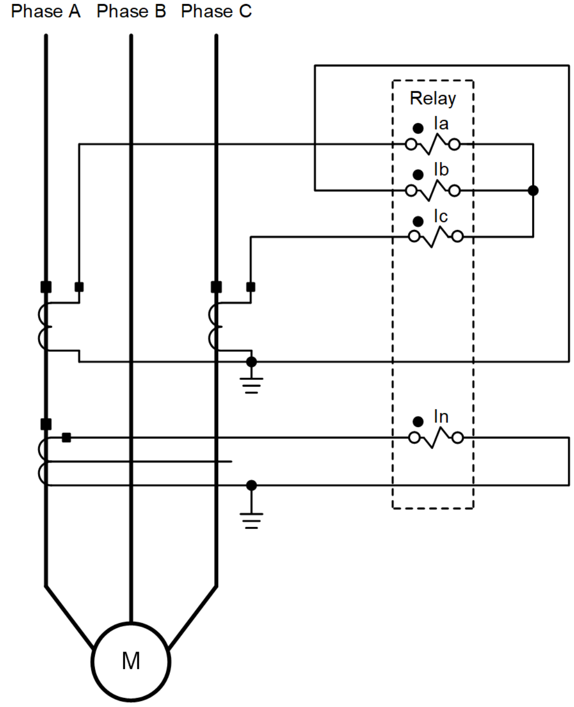

Fig. 11 Sample Wiring for a Microprocessor Relay With Two Phase CTs and One Core-Balance CT

As shown in Fig. 11, the nonpolarity ends of two phase CTs, Phase A and Phase C, are connected to the polarity end of the Phase B relay coil. The current through the Phase B relay coil is the negative sum of the Phase A and Phase C currents, as shown in (8), for 1-per-unit balanced currents with ABC phase rotation. This is represented in the phasor diagram shown in Fig. 12.

$$\begin{aligned} I_{b\ relay} &= -(I_{a\ relay} + I_{c\ relay}) \\ &= -(1\angle 0 + 1\angle 120) = 1\angle -120 \text{ pu} \end{aligned} \quad (8)$$

This assumption works if $I_{a\_relay} + I_{b\_relay} + I_{c\_relay} = 0$. The sum of the three phase currents is equal to the ground current. In a high-resistance grounded system, the ground current is limited to a low value (less than 10 A), which minimizes the error due to the missing CT.

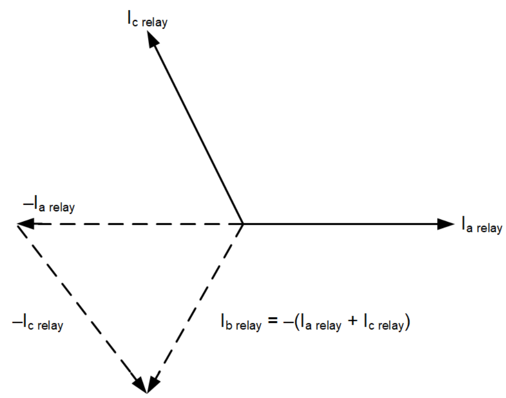

Fig. 12 Calculated B-Phasor

To provide adequate protection against ground faults with only two phase CTs, a core-balance CT is required, as shown in Fig. 11. An instantaneous ground overcurrent element (50G) can be set to provide sensitive ground fault protection.

The disadvantage of this configuration is that any CT errors, such as CT saturation, affect the phase CT measurements and the calculated Phase B current. Whenever possible, a third CT should be added to measure Phase B current. This ensures that the relay is able to measure all three phases directly and can calculate accurate values of positive- and negative-sequence current, which are used by the first-order thermal model to estimate the TCU.

IV. MOTOR PROTECTION EXAMPLES

A. Example 1: 4,160 V, 1,500 HP Synchronous Motor

In this example, thermal element settings are developed using the motor nameplate information and the plant's archives shown in Table II. The 1,500 hp synchronous motor considered in this example had three phase CTs and one core-balance CT. It was originally protected by several electromechanical relays providing instantaneous phase and residual ground overcurrent protection and inverse-time overcurrent protection. A multifunction microprocessor-based relay can replace all these electromechanical relays. Fig. 13 shows a single-line drawing of the 1,500 hp motor.

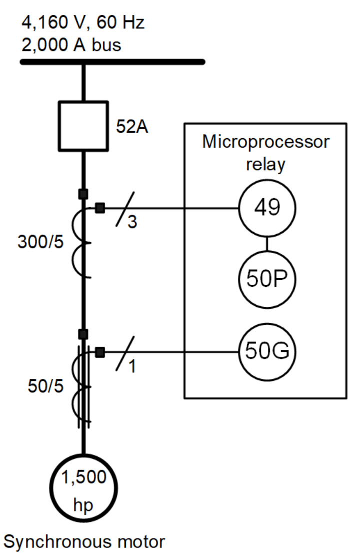

Fig. 13 Single-Line Drawing of the 1,500 HP Motor Protected by the Microprocessor Relay

The information required from the motor nameplate to set the thermal element is shown in Fig. 14.

Fig. 14 Motor Nameplate for Example 1

TABLE II
EXAMPLE 1: AVAILABLE INFORMATION

From Motor Nameplate	From Plant Archives
FLA = 162 A	SF = 1.15
HP = 1,500	Cold Stall Time = 8 s
Voltage = 4,160 V	—
Locked KVA Code = F	—

Using Table II, the thermal element in the microprocessor relay can be configured as follows:

1. The plant archives state that SF equals 1.15. The OLPU setting can be set equal to the rated SF of the motor at 1.15.
2. The nameplate provides the FLA as 162 A, and the locked kVA code is F. Using the information provided in Table I and (4), the LRA can be calculated as follows. The kVA/hp multiplier for Code F is between 5 and 5.6. An average value of 5.3 can be used as the kVA/hp multiplier. Using (4), the approximate LRA value can be calculated, as shown in (9).

$$\text{LRA} = \frac{577 \bullet 1{,}500 \bullet 5.3}{4{,}160 \bullet 162} = 6.8 \text{ pu} \tag{9}$$

3. T_{STALL}: The plant archives document provides the cold locked rotor time, also known as the cold stall time, as 8 seconds. Using (6), T_{STALL} is calculated at 6.67 seconds, as shown in (10).

$$T_{STALL} = \frac{8}{1.2} = 6.67 \text{ seconds} \tag{10}$$

4. Since the motor's thermal limit curves are not available and the RTC value is not provided in the motor data sheet, the RTC can be set to AUTO. In this case, using (7), the relay calculates the RTC value as 23.9 minutes, as shown in (11).

$$\text{RTC} = \frac{1.2 \bullet 6.67}{60 \bullet \ln\left(\dfrac{6.8^2 - (0.9 \bullet 1.15)^2}{6.8^2 - 1.15^2}\right)} = 23.9 \text{ minutes} \tag{11}$$

Using both the cold stall time and T_{STALL} values in (2), the cold and hot rotor thermal trip characteristics, respectively, are plotted as shown in Fig. 15. Fig. 15

also shows the microprocessor relay's hot stator thermal overload protection curve plotted using (3).

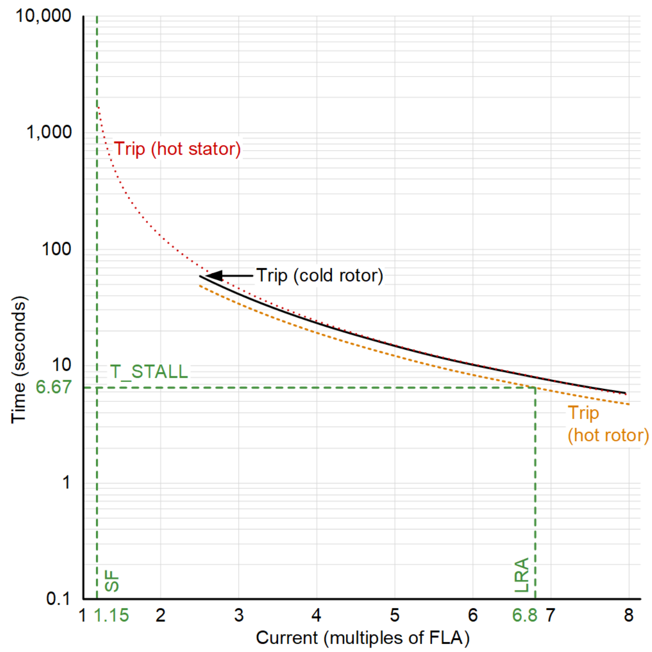

Fig. 15 Trip Characteristics for Example 1

5. The settings calculated in (9) and (10) should be modified based on motor start records. The start times for the last four starts for this motor were available in the plant archives and are shown in Table III.

TABLE III
EXAMPLE 1: MOTOR START RECORDS

Motor Start Number	Start Time (Seconds)
1	4.06
2	4.83
3	5.06
4	4.13

The average starting time is 4.52, and adding a 2-second margin would result in a T_{STALL} setting of 6.52 seconds. This is close to the T_{STALL} value of 6.67 seconds calculated in (10). Once the microprocessor relay records motor current during the starting process, the LRA setting can be adjusted to provide adequate protection. The average of the maximum currents from the last five starts should be used to modify this setting.

B. Example 2: 460 V, 100 HP Product Pump Motor

In this example, thermal element settings are developed for a 100 hp product pump motor. This motor had two phase CTs and one core-balance CT and was protected by three electromechanical relays: two phase time overcurrent relays and one residual ground overcurrent relay. Fig. 16 shows a single-line drawing of the motor. The motor data sheet was not available. The electromechanical relay settings and trip curves were documented in a settings sheet. The FLA and SF of the motor, along with the locked rotor kVA code, were obtained from the motor's nameplate shown in Fig. 17. This available information about the motor and the electromechanical relay settings is summarized in Table IV.

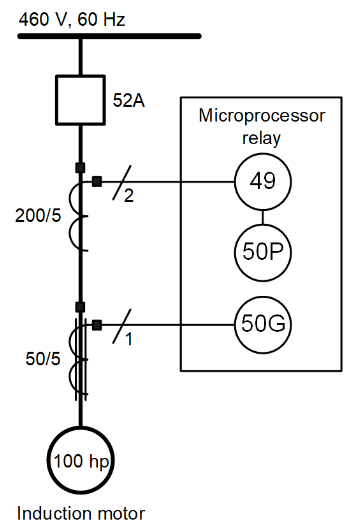

Fig. 16 Single-Line Drawing of the 100 HP Motor Protected by the Microprocessor Relay

Fig. 17 Motor Nameplate for Example 2

TABLE IV
EXAMPLE 2: AVAILABLE INFORMATION

From Nameplate	From Settings Sheet
SF = 1.15	Phase Relay Trip Curves = Available, Shown in Fig. 18
FLA = 118 A	Phase Relay Tap = 5.6
HP = 100	Phase Relay Time Dial = 1.5
Voltage = 460 V	—
Locked KVA Code = G	—

1. The nameplate shows that SF equals 1.15. The OLPU setting can be set equal to the rated SF of the motor at 1.15.
2. The motor nameplate shows that the FLA is 118 A and the motor's kVA code is G. Using the information provided in Table IV and (4), the LRA can be calculated as follows.

   The kVA/hp range for Code G is between 5.6 and 6.3, as shown in Table I, so an average value of 5.9 can be used as the kVA/hp multiplier. Using this value in

(4), the approximate LRA value is 6.27 pu, as shown in (12).

$$LRA = \frac{577 \cdot 100 \cdot 5.9}{460 \cdot 118} = 6.27 \text{ pu} \quad (12)$$

3. T_{STALL}: The motor nameplate does not provide any information about the stall time. Therefore, this value must be calculated from the electromechanical relay settings provided in Table IV as follows. First, the LRA value is converted to multiples of pickup (M) using (5), as shown in (13).

$$M = \frac{6.27 \cdot 118}{\left(\frac{200}{5}\right) \cdot 5.6} = 3.3 \quad (13)$$

The electromechanical relay's trip curves are shown in Fig. 18.

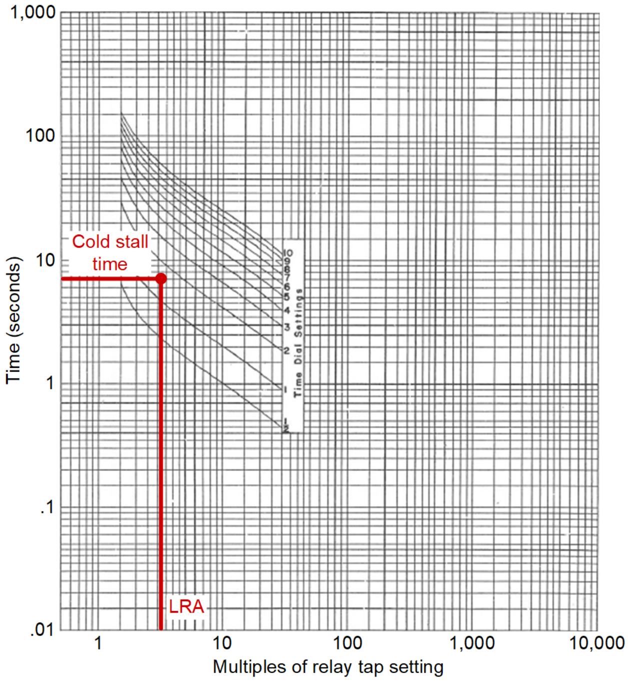

Fig. 18 Using an Electromechanical Relay Curve to Determine the Cold Stall Time

The trip curve with the time dial of 1.5 lies in between the two trip curves with the time dials of 1 and 2. As shown in Fig. 18, the cold stall time for M = 3.3 on the 1.5 time dial curve corresponds to a time of 7 seconds. Using (6), T_{STALL} is calculated at 5.83 seconds, as shown in (14).

$$T_{STALL} = \frac{7}{1.2} = 5.83 \text{ seconds} \quad (14)$$

4. Since the motor's thermal limit curves are not available, the RTC can be set to AUTO. In this case, using (7), the relay calculates the RTC value as equal to 17.7 minutes, as shown in (15).

$$RTC = \frac{1.2 \cdot 5.83}{60 \cdot \ln\left(\frac{6.27^2 - (0.9 \cdot 1.15)^2}{6.27^2 - (1.15)^2}\right)} = 17.7 \text{ minutes} \quad (15)$$

Fig. 19 shows the plot of the microprocessor relay's hot stator and rotor thermal overload protection curves for this example using (2) and (3).

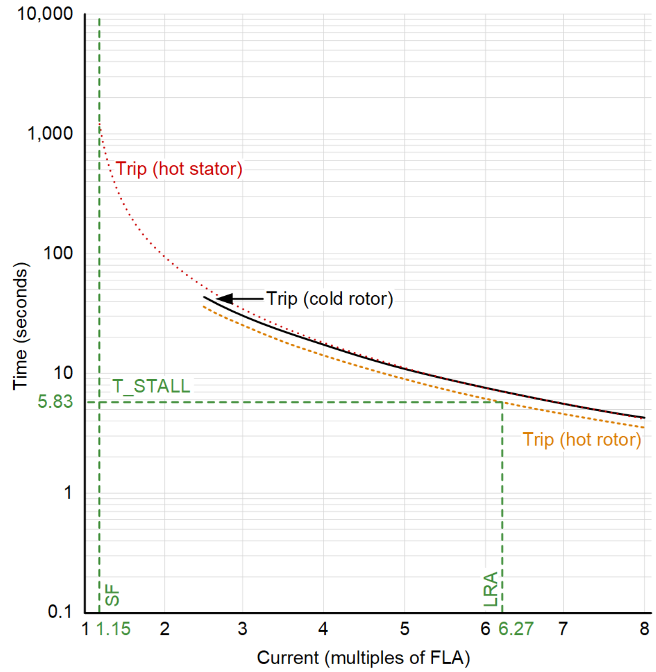

Fig. 19 Trip Characteristics for Example 2

V. CONCLUSIONS

Microprocessor motor protection relays feature advanced thermal models, such as the first-order thermal model, that perform better than electromechanical relays. However, these thermal overload elements in modern microprocessor relays often require motor data to set them optimally. When such data are limited or unavailable, the existing electromechanical relay settings can be used to update the settings in a microprocessor relay. Two real-world examples have been shared to illustrate how electromechanical relay settings can be translated to calculate the microprocessor relay settings.

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VII. APPENDIX A

A list of key variable names along with their description is provided as follows, in order of appearance:

RTD	Resistance temperature detector.
TCU	Thermal capacity used.
OLPU	Overload pickup.
LRA	Locked rotor amperes.
FLA	Full-load amperes.
T_{STALL}	Hot locked rotor time.
RTC	Running time constant.
SF	Service factor.
CTR	CT ratio.

VIII. VITAE

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