

Motor Protection Retrofit: A Business Case

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Motor Protection Retrofit: A Business Case

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Abstract—The initial stage of any project is often the business case development. This paper outlines the business case for the motor protection retrofit at a large thermal generation plant. The key protection improvements for this installation are reviewed, including the advantages of the thermal model and the application of the slip-dependent thermal model.

I. INTRODUCTION

Understanding and making use of the technical advantages and other, highly important digital features of microprocessor-based relays can be of great assistance when building a business case. These advantages include improved thermal modeling of motor heating, event reporting, sequential event reporting, motor start reports, motor start trending, motor operating statistics, additional protection features, and additional control functions.

This paper reviews the business case for the replacement of electromechanical thermal-replica 4 kV motor protection and interposing relays at a 2,200 MW thermal power plant. The original motor protection relays are 35 years old, and thus they have surpassed their expected service life, are obsolete, and have limited spare parts. We recognize that the probability of a motor protection failure is low; however, the financial consequences of the outage created by a failure could be extremely high. This financial consequence is related to the equipment damage that may occur because of protection failure and the subsequent purchase of higher-cost generation because of the unavailability of a generator.

The slip-dependent thermal model is reviewed briefly. Through application examples, the improved protection for these motors is detailed, where previously the protection was desensitized to allow for starting.

II. BACKGROUND AND ISSUES

The 4 kV bus shown in Fig. 1 is for Unit 1 of four similar generator unit ancillary systems. The motor protection is required to detect abnormal motor conditions and initiate removal of the motor from service in order to protect the motor from damage. For this thermal generation plant, the critical motors are the standby boiler feed pumps (SBFPs), forced draft fans (FD fans), induced draft fans (ID fans), condenser cooling water (CCW) pumps in the summer, and boiler circulation pumps. If the protection is unavailable or the motor is unavailable for any of these critical motors, the related generator unit will be unavailable or derated until the problem is corrected.

A. Maintenance Schedule and Spare Parts

The existing electromechanical thermal-replica motor protection and interposing relays are well beyond their service life, are obsolete from a manufacturing perspective, and have limited spare parts. The plant requirement for maintenance on this existing equipment is to calibrate and complete functional tests every five years. Historically, the calibration on a single thermal-replica motor protection and interposing relay scheme takes a full day. There are a total of 90 motor protection schemes within the facility.

The new digital relays are self-checking and do not require the same extent of calibration and functional testing. Digital relays are capable of recording and storing event reports, sequential event report data, motor start reports, motor start trending, and motor operating statistics, as well as alarming for self-diagnosed failures. Digital relays are constantly reporting their status. Only functional testing is required after the original in-service commissioning is complete. This functional testing takes less than 30 minutes. The cycle for the digital relay functional testing corresponds to the current NPCC (Northeast Power Coordinating Council) requirements for digital relay reverification.

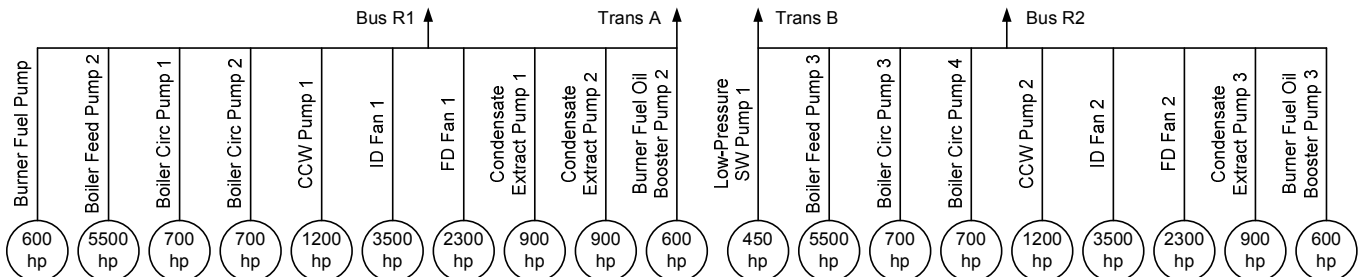


Fig. 1. Unit 1 4.16 kV Simplified Single-Line Diagram

B. Silver Migration

The existing auxiliary relay cases in the motor protection panels have proven to be susceptible to silver migration. Silver migration is the ionic movement of silver between two potentials. The moisture present in the humid air of the thermal plant acts as an electrolyte. The silver transfers from the contacts of an auxiliary relay onto the terminals of its mounting case. When the silver migrates so that two terminals are bridged, protection failures can occur. The plant has recorded several false trips during the past few years. The most recent operation because of silver migration was in February 2007.

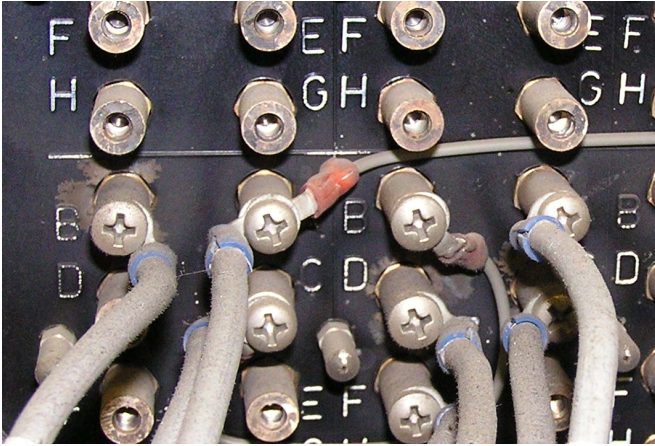


Fig. 2. Auxiliary Relay Case Showing Silver Migration

There is currently an approved base program in place to change out these auxiliary relay cases that are susceptible to silver migration on the generator, 4 kV bus, and transformer protection schemes. The existing schedule includes replacing all of the auxiliary relay cases for the 90 motor protection schemes in the plant. The cost of a new case is approximately \$600 (Canadian), and the time to replace a case is two working days. This auxiliary relay case replacement program is currently scheduled to take place over the next five years. For the 90 motor protection schemes, this translates to 180 days and \$54,000 (Canadian) over the next five years.

The new digital relays have internal timers, internal latches, digital inputs, and enough output contacts so that the auxiliary relays and auxiliary relay cases are no longer required.

C. Digital Recording and Data

The plant currently has no digital fault recording equipment on the 4 kV motors or 4 kV bus. The new digital motor protection relays sample and store analog and digital data. This provides the operating data required to quickly determine what caused a trip without completing all the detailed tests that were required previously to troubleshoot any

motor protection trips. Following a motor protection trip from existing electromechanical protection, it was a requirement to functional test the protection. With the stored digital data from the new digital relays, this is no longer a requirement. The new digital relays also provide motor operating statistics and motor trend reports. These files can be used to provide an early warning regarding changes in motor start current, thermal capacity used during starting, and motor start time. As an example, these types of detailed data can indicate gradually increasing load torque, which could lead to an unwanted rotor trip. Analyzing these types of data can assist with planning motor maintenance schedules and help to avoid unplanned downtime.

D. Thermal Model and Motor Cooling

The existing motor protection relies on operators and operating procedures to determine the correct time between starts and prevent damage to motors caused by frequent multiple motor starts. The new digital relays provide a lockout feature to prevent motor starting until the thermal element calculates that there is enough available thermal capacity to allow a start without tripping. The protection engineer sets the rotor and stator thermal capacity used during starting, and the relay provides a lockout until the motor has cooled to the defined capacity.

E. High-Inertia Loads

The SBFP and the FD fan motors each have starting times considerably longer than their safe stall times. The existing electromechanical thermal-replica protection relays have been desensitized to accommodate the long starting times. The plant had used speed switches in the past, but over time, the speed switches proved to be too unreliable and were retired. The probability of a motor stall is low, but the consequence of a failure is higher. The failure of an FD fan motor would cause a forced derating to half load until the motor was repaired. Repair for this 2,300 hp motor could be one week to three months, depending on the severity of the motor damage. An SBFP motor failure would not result in a unit forced outage as long as the other SBFP for that generator unit is available. If both SBFP motors are unavailable, the generator would be on forced outage until the motor was repaired or a spare unit made available. Repair or replacement of this 5,500 hp motor could be from one week to three months.

The digital relay for this motor protection retrofit calculates the motor slip based on the measured current and voltage. The relay uses the calculated slip to compute the positive- and negative-sequence rotor resistance during the motor start. This calculation of rotor resistance reflects the motor heating during a start and provides for longer acceleration time before tripping than is allowed in the I^2t rotor model.

TABLE I
ALTERNATIVES AND ECONOMIC ANALYSIS (IN CANADIAN DOLLARS)

	Base Case	Alternative 1 (Partial)	Alternative 2 (Delay)	Alternative 3 (Recommended)
Project Cost	104,000	250,000	430,000	400,000
Net Present Value	49,614	137,568	231,530	215,437
Impact on Economic Value		87,954	181,916	165,823

III. ALTERNATIVES AND ECONOMIC ANALYSIS

A. Base Case

The base case considered for this business case is status quo. This plan could lead to the failure of a critical motor (FD fan, boiler feed pump, CCW pump during summer operation, or the boiler circulation pump) that could leave a main unit unavailable or derated for one day to three months, depending on the severity of the failure. Although the risk of a failure is low, the consequences of a failure are high.

The maintenance time required for calibrating, troubleshooting, and testing these 35-year-old motor protection schemes will only continue to increase as they continue to age.

This option will still cost \$104,000 (Canadian) over the next five years while the auxiliary relay cases are replaced per an existing program. Because it is not practical or possible to replace all the auxiliary cases at once, nuisance motor tripping may be an issue because of the silver migration. All costs associated with this alternative are avoided by upgrading all of the 4 kV motor protection schemes.

B. Alternative 1: Upgrade 4 kV Motor Protection on Critical Motors Only

This option would address the spare parts availability, system reliability problems, and the silver migration issue on half of the motor protection schemes. This alternative would introduce two separate technologies for the 4 kV motor protection, which is not recommended. The auxiliary relay cases on the motor protection schemes that are not changed will still have to be replaced as scheduled. As the original 35-year-old motor protection schemes left on the noncritical motors age further (much beyond their expected service life),

more failures will occur. Although these failures will not affect the availability of a generator unit, motor protection failures could cause costly motor damage and will eventually require upgrading the relays.

C. Alternative 2: Delay Work One Year

Delaying the project will not immediately address the spare parts availability and system reliability. The frequency of motor protection calibration and troubleshooting to verify proper operation will only increase as the equipment continues to age. Similar to the base case, delaying the project will increase the probability of a forced outage or equipment damage. The likelihood of nuisance tripping because of silver migration only increases with time.

D. Alternative 3: Upgrade 4 kV Motor Protection

The recommended and accepted proposal is to replace all existing 4 kV motor protection relays and the auxiliary relay cases with new digital relays that meet the motor protection requirements.

The new protective relays provide the following:

- Protection for motors with start times longer than their safe stall time.
- Thermal lockout for multiple start protection.
- Improved protection for motors previously protected with 51 elements.
- Data acquisition and troubleshooting using the digital data stored in the relay.

The photos in Fig. 3 show the installation of the digital relays. Installation costs were kept to a minimum by taking advantage of existing wiring. The photos show that generally only internal panel wiring required modification.



Fig. 3. Motor Protection Retrofit

IV. MOTOR STARTING AND CALCULATING MOTOR SLIP

Most digital motor protection relays calculate the heating in the motor by measuring the current. The relay calculates the heating in terms of thermal capacity. The thermal capacity is defined where 0 percent is completely cooled and 100 percent is the limit threshold. The thermal capacity is accumulated based on measured current so that during motor starting, the protection is essentially an I^2t element, with the maximum starting time limited by the hot motor safe stall time. Problems arise when starting motors with high-inertia loads, as the time required to start the motor may approach or even exceed the hot safe stall time [1].

The relay used for this retrofit uses a thermal model that calculates motor slip during start. During the start of an induction motor, the rotor resistance changes from a high locked rotor value to a low running value. This motor protection relay uses voltage and current to calculate the slip-dependent rotor resistance that enables the calculation of rotor temperature while it varies during a motor start. The details of this thermal model can be reviewed in [2].

In summary, four quantities are required by the slip-dependent thermal model in order to calculate the locked rotor resistance and rotor resistance at rated speed. These four

quantities are the locked rotor torque (LRQ), the locked rotor current in per unit (I_L), the full-load speed ($FL\omega$), and the synchronous speed ($Syn\omega$).

The locked rotor resistance R_M is calculated directly from LRQ in per unit of rated torque and the locked rotor current in per-unit current.

$$\text{Locked Rotor Resistance} \quad R_M = \frac{LRQ}{I_L^2} \quad (1)$$

The rotor resistance at rated speed R_N is calculated directly from $FL\omega$ and $Syn\omega$. The rotor resistance at rated speed is the motor full-load slip (FLS).

$$\text{Rotor Resistance at Rated Speed} \quad R_N = 1 - \frac{FL\omega}{Syn\omega} \quad (2)$$

At the instant of motor starting, the relay calculates the motor resistance by sampling the positive-sequence voltage $V_1(cyc)$ and the positive-sequence current $I_1(cyc)$ at a selected initial cycle. The real part of this impedance is the initial motor resistance R_p .

$$\text{Initial Motor Resistance} \quad R_p = \text{real} \left(\frac{V_1(cyc)}{I_1(cyc)} \right) \quad (3)$$

Now, with a sampled value for R_p and the locked rotor resistance R_M , the stator resistance can be calculated, where $A = 1.2$, a constant shown in [2].

$$\text{Stator Resistance} \quad R_S = R_p - \frac{R_M}{A} \quad (4)$$

The slip, shown in (6), is a function of the changing motor input resistance, shown in (5), the previously calculated locked rotor resistance R_M , the rotor resistance at rated speed R_N , and the stator resistance R_S . The motor input resistance is measured and updated every processing interval. The motor slip is calculated every 2 cycles.

$$\text{Motor Resistance} \quad R = \text{real} \left(\frac{V_i}{I_i} \right) \quad (5)$$

$$\text{Motor Slip} \quad S = \frac{R_N}{A(R - R_S) - (R_M - R_N)} \quad (6)$$

$$\text{Positive-Sequence Rotor Resistance} \quad R_i = (R_M - R_N)S + R_N \quad (7)$$

A comparison of the standard I^2t starting element, which assumes a constant rotor resistance, with the slip-dependent starting element shows that the slip-dependent model simply includes the slip-dependent rotor resistance in the heat source of the thermal model [2] [3].

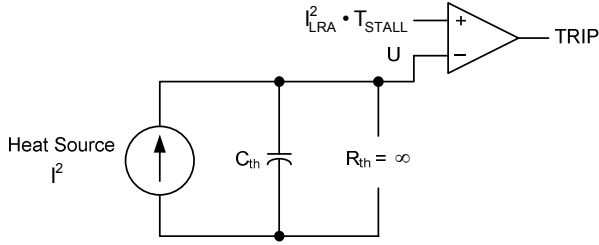


Fig. 4. Rotor I^2t Starting Element

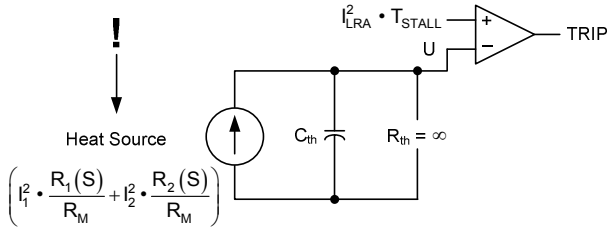


Fig. 5. Slip-Dependent Starting Element

Note that the thermal resistance of the rotor during starting is infinity. Starting transfers a large amount of heat to the rotor bars. The time to start is much smaller than the motor thermal time constants. The conclusion is that the heat transferred to the rotor will not begin to transfer to the surroundings until after the starting process is complete.

A. Example 1: 5,500 hp Standby Boiler Feed Pump

The following data were available for this 5,500 hp, 4 kV motor:

- Full-load amperes (FLA) = 685 A
- Locked rotor current = $4.82 \cdot \text{FLA}$
- Service factor (SF) = 1.05
- Revolutions per minute (rpm) at rated load (rated speed) = $n_r = 3,565$ rpm
- $\text{LRQ} = 0.96 \cdot \text{rated torque}$
- Safe stall time = 5.3 seconds @ 100 percent rated voltage
- Safe stall time = 6.8 seconds @ 90 percent rated voltage
- Safe stall time = 9.0 seconds @ 80 percent rated voltage
- Voltage = 4,000 V

This information provided most of the data required to calculate the settings for the digital relay. FLA was set to 685 A. The setting for locked rotor current was increased from $4.82 \cdot \text{FLA}$ to $5.5 \cdot \text{FLA}$ (an increase of roughly 300 A) as suggested by the company that rebarred the rotor to a larger style rotor bar. The stator was not modified. SF was set to 1.05 as per the motor ratings. FLS was calculated as: $(\text{FLS} = 1 - n_r/n_s)$ ($\text{FLS} = 1 - 3565/3600 = 0.0097$). The hot safe stall time was set conservatively at 9.0 seconds.

The following settings were applied to the relay:

```
RID      := UNIT 4 SBFP2
TID      := 4-532-CB-A5
CTRL     := 800    FLAL := 685.0    E2SPEED := N    CTRN    := 100
PTR      := 35.00  VNOM := 4160    DELTA_Y := WYE  SINGLEV := N
E49MOTOR:= Y      FLS  := 0.0097  LRQ    := 0.96  49RSTP := 91
SF       := 1.05  LRAL := 5.5     LRTHOT1 := 9.0  RTCL   := AUTO
```

Fig. 6 is the motor start report for this 5,500 hp SBFP. The traces show the motor current, terminal voltage, rotor temperature in per unit of the trip value or thermal capacity, and slip.

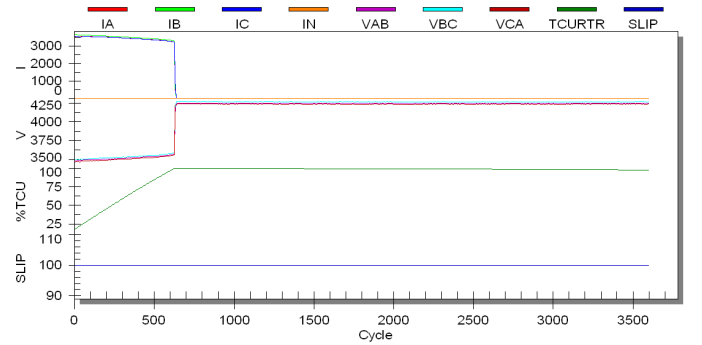


Fig. 6. SBFP Motor Start Report, $\text{LRQ} = 0.96$

Fig. 6 shows that the slip remained at 1.0 for the entire start. Because of the high-inertia load, the motor start time is longer than the hot safe stall time, and the thermal capacity reaches 100 percent. When the calculated slip exceeds 1, the relay assigns a slip of 1 and calculates the temperature rise using the high locked rotor resistance. Following a review of the motor start data, the motor manufacturer suggested a revised LRQ of 0.7 per unit of rated torque and a hot safe stall time of 6.5 seconds.

The following settings were applied to the relay:

```
RID      := UNIT 4 SBFP2
TID      := 4-532-CB-A5
CTR1     := 800   FLA1 := 685.0   E2SPEED := N   CTRN := 100
PTR      := 35.00 VNOM := 4160   DELTA_Y := WYE  SINGLEV := N
E4MOTOR  := Y     FLS  := 0.0097 LRQ   := 0.70  49RSTP := 91
SF       := 1.05  LRAL := 5.5    LRTHOT1 := 8.0  RTC1  := AUTO
```

The applied settings used a hot safe stall time that was more conservative than suggested at 8.0 seconds. Fig. 7 is the start report for the revised settings. During the 11-second start, the rotor temperature reaches 75 percent of the maximum allowed temperature. The revised LRQ quantity results in a new stored constant for locked rotor resistance R_M (1) and also results in a revised calculated value for R_S (4). The stator resistance R_S is dependent on R_M and R_P , as per (3). The relay measures and calculates R_S during every start.

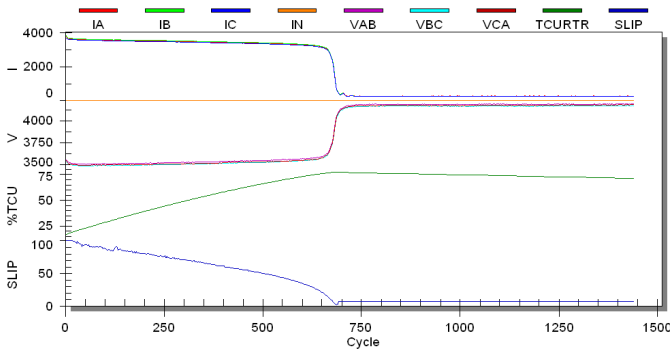


Fig. 7. SBFP Motor Start Report, LRQ = 0.7, Start 1

The motor was started twice more with LRQ at 0.7 and the hot safe stall time at 8.0 seconds. Fig. 8 is a motor start report for Start 3 of the 5,500 hp SBFP with the revised settings. Note that on this repeated start, the traces show the normal motor current and relay terminal voltage. However, in this case, the calculated slip remains at 1 for an extended time. The rotor resistance remains at R_M for this time, and the thermal capacity reaches 100 percent.

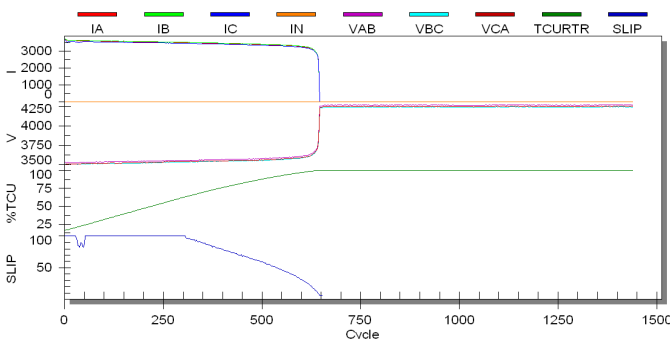


Fig. 8. SBFP Motor Start Report, LRQ = 0.7, Start 3

A detailed examination of the digital data provided by the relay shows that although the current and voltages are as expected for motor starting, there is a variation in the positive-sequence voltage $V_1(\text{cyc})$ and the positive-sequence current $I_1(\text{cyc})$. Fig. 9 shows a plot of the resulting varying starting resistance over the first 8 cycles of the motor start.

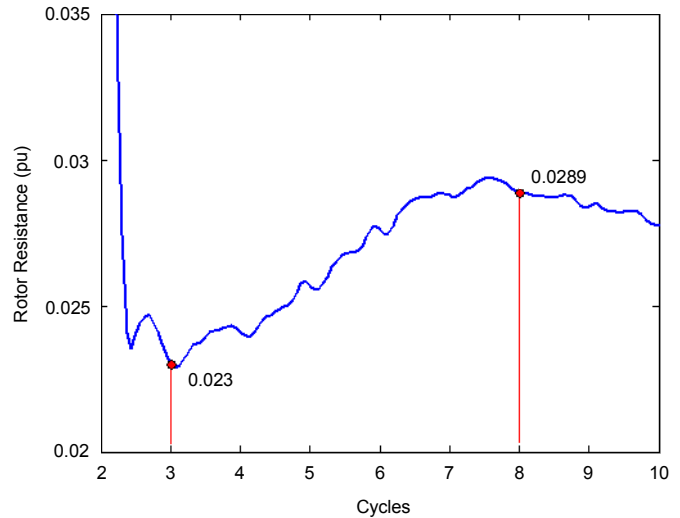


Fig. 9. Varying Starting Resistance During Start 3

During the first few cycles of starting, the rotor resistance is at its initial value R_M , and the slip S is 1.0. Thus, the stator resistance R_S can be determined using the initial measured resistance R_P in (4). The initial cycle at which R_P is measured is not critical when the initial resistance remains constant after a 1- or 2-cycle settling time. This is not the case for this 5,500 hp SBFP, as seen in Fig. 9. To account for this varying starting resistance, the relay software was modified to select the minimum value of R_P over the first few cycles.

Fig. 10 shows a motor start report for this 5,500 hp SBFP with no new settings changes and relay software that is selecting the minimum value of R_P over the first few cycles. The traces show the motor current, relay terminal voltage, rotor temperature in per unit of the trip value or thermal capacity, and slip. This motor start report shows that as the slip decreases, the calculated rotor resistance is decreasing as the motor accelerates. During the 11-second start, the rotor temperature reaches 89.5 percent of the maximum allowed temperature, while the motor takes a full 3 seconds more than the hot safe stall time of 8 seconds to successfully start.

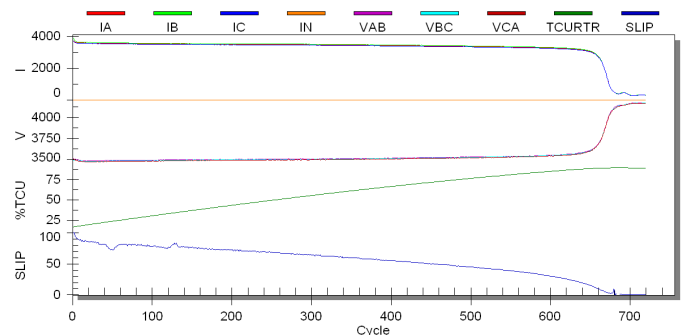


Fig. 10. SBFP Motor Start Report, August 2009

B. Example 2: 2,300 hp Forced Draft Fan

The following data were available for this 2,300 hp, 4 kV motor:

- FLA = 295 A
- Locked rotor current = $5.6 \cdot \text{FLA}$
- SF = 1.0
- RPM at rated load (rated speed) = $n_r = 1,190$ rpm
- LRQ = $0.80 \cdot \text{rated torque}$
- Hot safe stall time = 9.0 seconds
- Voltage = 4,000 V

This information provided the data required to calculate the settings for the digital relay. FLA was set to 295 A. Following the analysis of digital data provided by the relay from an initial motor start, the setting for locked rotor current was increased from $5.6 \cdot \text{FLA}$ to $6.8 \cdot \text{FLA}$. SF was set to 1.05 to provide a small margin above rated conditions. The SF settings affect the stator overload model but do not affect the rotor model. FLS was calculated as: $(\text{FLS} = 1 - n_r/n_s)$ ($\text{FLS} = 1 - 1190/1200 = 0.0083$). The safe stall time was only increased slightly to 9.5 seconds.

The following settings were applied to the relay:

```
RID      := UNIT 3 FD FAN 2
TID      := 3-532-CB-B10
CTR1     := 450   FLA1    := 295.0   E2SPEED := N     CTRN     := 100
PTR      := 35.00  VNOM   := 4160   DELTA_Y := WYE   SINGLEV  := N
E49MOTOR:= Y      FLS     := 0.0083  LRQ      := 0.80  49RSTP  := 90
SF        := 1.05  LRA1    := 6.8    LRTHOT1  := 9.5   RTC1     := AUTO
TCAPU    := OFF   TCSTART := 90     TCLRNEN  := N    COOLTIME := 124
```

Fig. 11 is a motor start report for this 2,300 hp FD fan. The traces show the motor current, voltage measured at the relay, calculated thermal capacity, and slip. The actual motor acceleration time is shown to be about 750 cycles, or 12.5 seconds. The thermal capacity used is reaching 82.8 percent. This start time of 12.5 seconds is 3 seconds greater than the hot safe stall time. This motor start report shows that as the slip decreases, the calculated rotor resistance is decreasing as the motor accelerates. The rotor temperature is not a linear relationship, and this FD fan with a hot safe stall time of 9.5 seconds can take 12.5 seconds or more to start without premature motor trips.

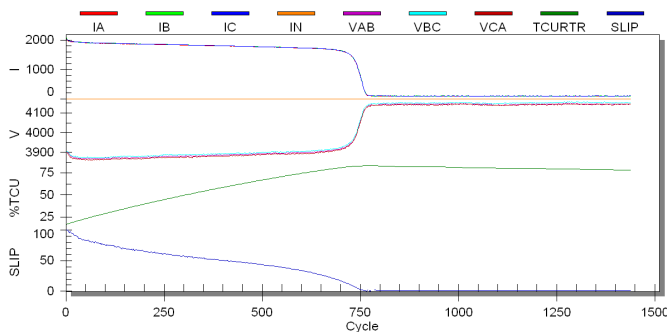


Fig. 11. Motor Start Report for Unit 3 FD Fan 2

The relay offers supervision to prevent motor starting until the motor thermal capacity has enough available starting capacity. The relay setting $\text{TCSTART} = 90$ is a start inhibit level where the rotor thermal capacity required to start the motor is less than TCSTART .

When the motor is stopped, there is no longer any current flowing. The time required to cool the motor to a preset thermal limit is dependent on the thermal capacity at the time the motor was stopped, the thermal capacity reset setting, and the cooling time constant. The following defines the lockout time where COOLTIME is a relay setting and $\% \text{TC}_{\text{RESET}}$ is equal to 100 minus TCSTART .

$$\text{Lockout Time } T_{\text{LOCKOUT}} = \frac{\text{COOLTIME}}{3} \cdot \ln \left(\frac{\% \text{TC}}{\% \text{TC}_{\text{RESET}}} \right) \quad (8)$$

The motor manufacturer may provide cooling parameters for a stopped motor in the form of either a cooling time constant or a cooling time. When the manufacturer provides the actual cooling time for the stopped motor, this time can be used directly for the relay stopped cooling time. The relay stopped cooling time (COOLTIME) is the cooling time constant multiplied by 3. When the cooling time constant is not provided by the motor manufacturer, the following equation can be used to calculate cooling time.

Cooling Time Constant

$$\text{RTC} = \frac{(\text{TD} + 0.2) \cdot \text{LRTHOT}}{60 \cdot \ln \left(\frac{\text{LRA}^2 - (0.9 \cdot \text{SF})^2}{\text{LRA}^2 - (\text{SF})^2} \right)} \text{ minutes} \quad (9)$$

Using the relay settings for this 2,300 hp FD fan, the cooling time constant can be calculated.

Cooling Time Constant

$$\text{RTC} = 41.03 = \frac{(1.0 + 0.2) \cdot 9.5}{60 \cdot \ln \left(\frac{6.8^2 - (0.9 \cdot 1.05)^2}{6.8^2 - (1.05)^2} \right)} \text{ minutes} \quad (10)$$

The data provided for this 2,300 hp motor did not include the cooling time constant, so a setting of $\text{RTC} \cdot 3 = 124$ was applied to the relay.

This motor protection relay has been in service for a few months, so there are additional reports available from the relay. One is the motor operating report shown in Fig. 12. This report verifies the consistency of the starting data over multiple starts. The report continues to accumulate the data shown until it is cleared manually.

From this report, we can see that the motor has been started 46 times since April 11, 2009, and the average thermal capacity used (TCU) is 82.5 percent with a peak of 100.4 percent. Over these 46 starts, the start time has an average of 12.8 seconds with a peak or maximum start time of 14.1 seconds.

This motor operating report also includes trip and alarm data. The report shows two locked rotor trips. These trips occurred following a maintenance outage. On return to service, the secondary fuses were not replaced, and thus the relay terminal voltage stayed at zero for two attempted motor starts. Following restoration of the fuses, the motor was started successfully. The fact that the secondary fuses were not installed during a start attempt is confirmed by the minimum start voltage (Min Start V) peak being shown as 0.0 V.

UNIT 3 FD FAN 2
3-532-CB-B10

Date: 08/05/2009 Time: 13:49:57
Time Source: Internal

Operating History (elapsed time in ddd:hh:mm)

Last Reset Date	04/11/2009
Last Reset Time	04:50:45
Running Time	30:02:04
Stopped Time	> 84:20:17
Time Running (%)	26.2
Total MWhr (MWhr)	197.9
Number of Starts	46
Emergency Starts	0

Avg/Peak Data

	AVERAGE	PEAK
Start Time (s)	12.8	14.1
Max Start I (A)	1977.7	2041.0
Min Start V (V)	3696.2	0.0
Start %TCU	82.5	100.4
Running %TCU	10.1	20.7
Running Cur (A)	104.1	631.6
Running kw	274.7	2084.4
Running kVARin	694.5	2281.6
Running kVARout	0.0	151.3
Running kVA	747.8	3090.4

Trip/Alarm Data

	ALARMS	TRIPS
Overload	0	0
Locked Rotor	0	2
Undercurrent	0	0
Jam	0	0
Current Imbal	0	0
Overcurrent	0	0
Ground Fault	0	0
Speed Switch	0	0
Undervoltage	0	0
Overvoltage	0	0
Underpower	0	0
Power Factor	0	0
Reactive Power	0	0
Phase Reversal	0	0
Underfrequency	0	0
Overfrequency	0	0
Start Timer	0	0
Remote Trip	0	0
Other Trips	0	0
Total	0	2

Fig. 12. Motor Operating Report for Unit 3 FD Fan 2

An additional report was gathered showing refined start data over one-month intervals. The motor start trend report captures up to eighteen 30-day averages of the motor start information. This motor start trend report in Fig. 13 shows 42 starts over a 106-day period. The motor start report was cleared on 04/21/2009, while the motor operating report was reset on 04/11/2009. There were four motor starts between these two dates.

The Unit 3 FD Fan 2 motor protection relay has been in service for more than four months. This motor start trend report shows consistent start data in terms of average starting time and thermal capacity used for the motor. The starting conditions are clearly very consistent for this Unit 3 FD Fan 2; otherwise, there would have been more variation in the percent thermal capacity. An increase in percent thermal capacity over time could indicate a gradually increasing load torque.

UNIT 3 FD FAN 2 3-532-CB-B10				Date: 08/05/2009 Time: 13:50:08 Time Source: Internal		
Record Number	Began on Date	Number of Starts	Start Time (s)	Start %TCU	Max Start I (A)	Min Start V (V)
1	07/20/2009	0	---	---	---	---
2	06/20/2009	2	12.8	81	1980	3884
3	05/21/2009	21	12.7	81	1975	3861
4	04/21/2009	20	13.0	82	1980	3864
5	---	---	---	---	---	---
6	---	---	---	---	---	---
7	---	---	---	---	---	---
8	---	---	---	---	---	---
9	---	---	---	---	---	---
10	---	---	---	---	---	---
11	---	---	---	---	---	---
12	---	---	---	---	---	---
13	---	---	---	---	---	---
14	---	---	---	---	---	---
15	---	---	---	---	---	---
16	---	---	---	---	---	---
17	---	---	---	---	---	---
18	---	---	---	---	---	---

Fig. 13. Motor Start Trend Report for Unit 3 FD Fan 2

V. CONCLUSIONS

Motor protection at this plant has been enhanced with the use of digital relays. The slip-dependent thermal model protects the motors while allowing for long acceleration times. The digital relay provides supervision to prevent motor starting until the motor thermal capacity has enough available starting capacity and to prevent damage to motors caused by frequent multiple motor starts. The motor start reports and monthly trend data in the relays can be used to monitor changing starting conditions. The event reports and motor start reports provide data that can be used to enhance the settings and improve the motor protection as well as confirm a valid protection operation without the need to complete a full protection reverification.

Replacement of the existing 4 kV motor protection relays and the auxiliary relay cases with new digital relays provides the following benefits:

- Ensures reliable protection for the motors.
- Removes the safety hazard associated with a catastrophic failure of a large piece of rotating equipment.
- Reduces the risk associated with equipment failure and silver migration-induced trips.
- Eliminates the maintenance time spent calibrating each relay.
- Removes the need to replace auxiliary relay cases.

VI. REFERENCES

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- [3] S. E. Zocholl, AC Motor Protection, Schweitzer Engineering Laboratories, Inc., 2003.

VII. BIOGRAPHIES

Kyle Craig received his BEng in electrical engineering from Carleton University, Ottawa, Canada, in 2004 and his MEng in electrical power engineering from the University of Waterloo, Waterloo, Canada, in 2009. He joined Ontario Power Generation in 2004 as a grad engineer trainee at Lennox GS in Kingston, Ontario. In 2005, he became a thermal station engineer at Lennox GS with a focus on project management and protective relaying. He has been registered as a Professional Engineer in Ontario since 2009.

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