Field Evaluation of Automatic Restart of Essential Motors Using Microprocessor-Based Protective Relays

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FIELD EVALUATION OF AUTOMATIC RESTART OF ESSENTIAL MOTORS USING MICROPROCESSOR-BASED PROTECTIVE RELAYS

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Abstract—Industrial facilities that employ numerous electrical motors for vital functions require either continuous operation, ride through, and/or automatic restart operation for abnormal conditions, such as momentary voltage loss, voltage dips, or other system voltage transients. With large essential motors, it is impractical or not economical to provide an uninterruptible power source. Therefore, the next option to reduce the effects of transient interrupted service is to automatically sense the disturbance and initiate a sequenced restart of the essential motors based on process requirements, motor acceleration characteristics, and power system capabilities. A customized logic algorithm that has been programmed into microprocessor-based motor protection relays, eliminating additional undervoltage, control, timing relays, and wiring associated with traditional schemes, is described in this paper. The algorithm has been simulated during factory and site acceptance tests. This approach offers many user-configurable features that could be used in virtually any microprocessor-based relay protecting a medium-voltage induction motor. Also, the plant essential motors are prioritized into different categories, defining the order in which some essential motors are staggered and restarted together.

Index Terms—Automatic restart logic, ride through, priority timers, voltage sag, microprocessor multifunction protective relaying, digital bits.

I. INTRODUCTION

Industrial facilities are constantly subjected to transient electrical disturbances caused by both internal and external events. Transient voltage disturbances can range from a momentary voltage dip to a complete blackout. Severe voltage dips or temporary voltage loss can cause control relays and magnetically held motor contactors to drop out and subsequently reclose upon restoration of voltage. Uncontrollable restarts (reclosing) of large motors pose at least three major risks:

- Uncontrolled portions of processes being restarted out of sequence.
- Total system voltage collapse due to multiple motors starting simultaneously.
- Motor-load drive train damage due to transient torques created by out-of-synchronism reclosing of system (restored) voltage and the motor residual back electromotive force (EMF) voltage.

One solution to mitigate these risks is to apply programmed ride-through (delayed dropout) and sequenced restart functionalities to motors [1] [2].

This paper describes a sequenced automatic restart logic algorithm programmed in microprocessor-based (µP) relays for medium-voltage induction motor protection that were installed in a large greenfield petrochemical complex. The paper also addresses the validation results obtained during factory acceptance testing. Both ride-through and restart logic programming were applied to only critical medium-voltage induction motors based on process needs (especially the cooling water process), motor load characteristics, motor controller contactor coil pickup/dropout voltages, and power system capabilities. This paper discusses the dynamic motor starting studies performed to ensure the power system was capable of accelerating the restarted critical motors. The dynamic motor starting studies also verified the restarting sequence.

II. TRADITIONAL AUTOMATIC RESTARTING

Traditional (nonprogrammed) ride-through and restart functionalities require undervoltage relays with associated auxiliary control relays and discrete timers. Each motor (or groups of motors) is assigned a priority (or tier) based on its criticality and/or process requirements and has three time settings (27TD1, TD2, and TD3). The ride-through setting is 27TD1. If power system voltage is lost for longer than the 27TD1 setting but recovered before TD2 times out, the motor will be restarted after TD3 times out. Motors in different tiers may have the same 27TD1 and TD2 settings, but TD3 is unique for each tier [3].

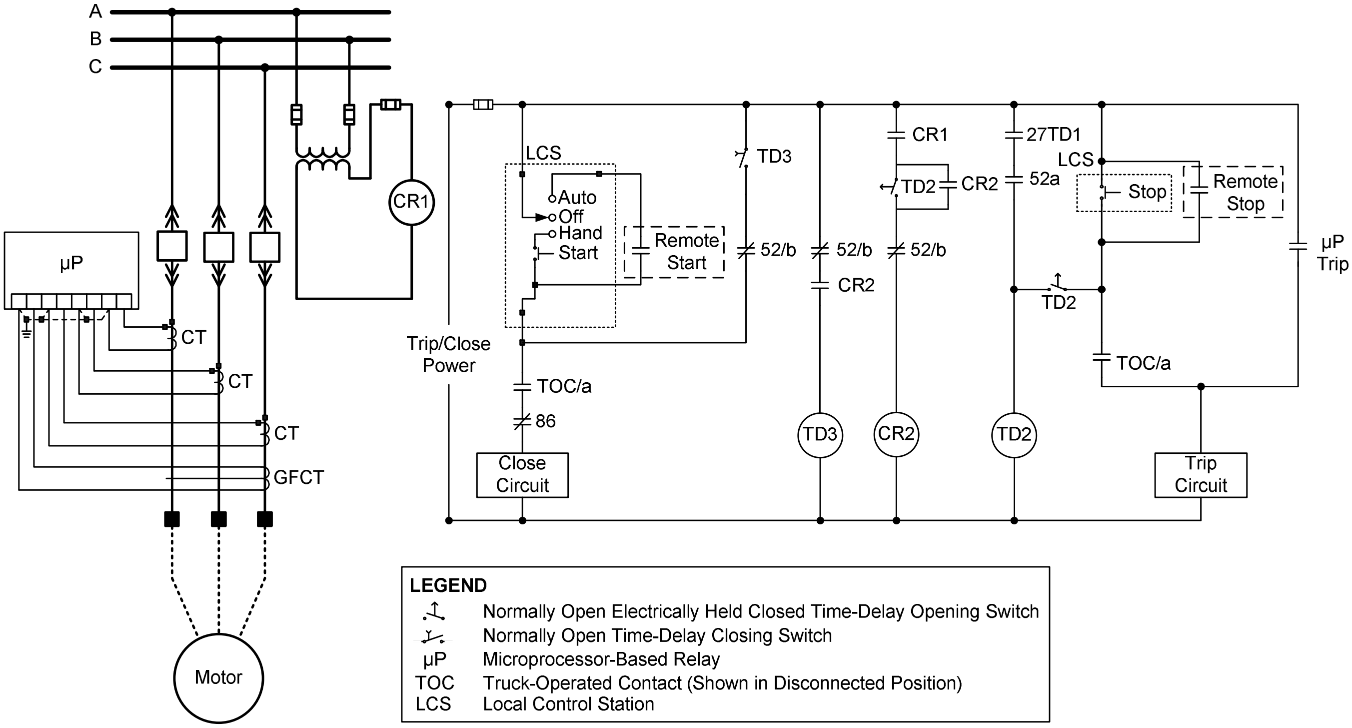

Fig. 1 Schematic Diagram for Traditional Restarting Using Discrete Timers [3]

Fig. 1 shows a basic motor schematic that has ride-through and restart functionalities. The purpose and typical settings for each control relay and timer are the following:

- CR1 is a control relay that is connected to the voltage transformer (VT) to indicate the presence of bus voltage.
- CR2 is another control relay that works with other electrical components in the motor trip or close circuits to provide acceleration functionality.
- 27TD1 is the undervoltage with a time delay setting of the protective relay. This setting prevents tripping of the breaker until 27TD1 times out. 27TD1 provides ride-through functionality and is typically set between 0.2 to 1 second.
- TD2 is an off-delay timer relay. TD2 works in combination with TD3 to provide restart functionality. If the voltage recovers after 27TD1 has timed out but before TD2 times out, the circuit breaker will be tripped and then closed once TD3 times out. TD2 is typically set between 5 and 10 seconds.
- TD3 is an on-delay timer relay that works in combination with TD2 to allow the reclosing of a motor circuit breaker once TD3 times out and if voltage recovers before TD2 times out. Setting TD3 depends on the characteristics and process requirements or priority of each motor.

There are other traditional methods to restart an essential motor as described in [4]. The use of a μP relay that provides motor protection reduces wiring complexity. A μP relay also has built-in voltage detection capability that helps in cost reduction.

III. MOTOR STARTING STUDIES

Dynamic motor starting studies can be performed to calculate the voltage, current, motor slip, and starting times while starting a motor under loaded conditions (e.g., pump, conveyor). Starting a motor may cause disturbances to other loads operating on the bus to which the motor is connected. Starting large motors may cause a serious voltage dip on the buses, causing other motors to slow down.

The motor starting study was performed using computer simulation software and typical motor data [5]. Each motor load was started separately, assuming the rest of the plant was operating under normally loaded conditions. The starting performance of the motor was then evaluated over time (10 to 15 seconds) to study the effect of motor starting on the system voltage. The motor terminal voltage, full load amperes, and slip were calculated over time. The motor terminal voltage must be maintained at 80 percent of the nominal voltage for proper motor operation. Depending upon the process, motors are prioritized for restart from 1 through 7, with 1 being the highest priority and 7 being the lowest priority. A partial one-line diagram is shown in Fig. 2.

Two different operating scenarios were considered when performing the motor starting study for the petrochemical plant. The loading characteristics of the remaining loads in both scenarios were based on the anticipated loading. The local utility was considered as supplying power at a voltage of 1.0 pu for both Scenario 1 and Scenario 2.

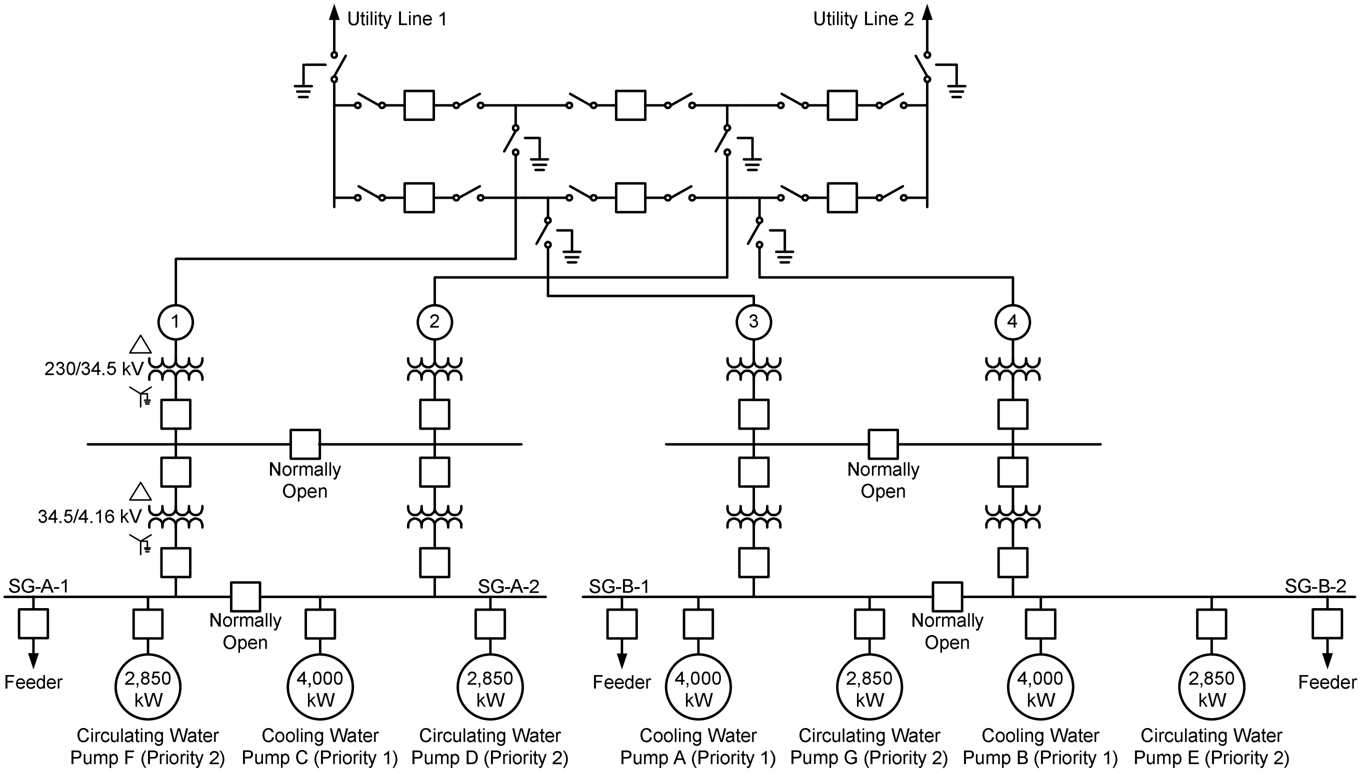

Fig. 2 Partial One-Line Diagram

Scenario 1 was a normal configuration (intact system). All tie breakers were considered to be in their normal operating states (normally closed or normally open). This scenario studies the system performance under normal loading and operating conditions when one transformer feeds each side of the switchgear with the tie breakers in the open positions.

Scenario 2 was a single feed. All the normally open tie circuit breakers were considered closed. This scenario studies a system case similar to the system status following an automatic transfer operation when one of the double-ended switchgear mains is open and the normally open tie breaker is closed.

In Fig. 3 and Fig. 4, a restart simulation curve shows the terminal voltage, motor current, and motor slip versus time for an example motor Pump A (4,000 kW motor) in Scenario 1 and Scenario 2.

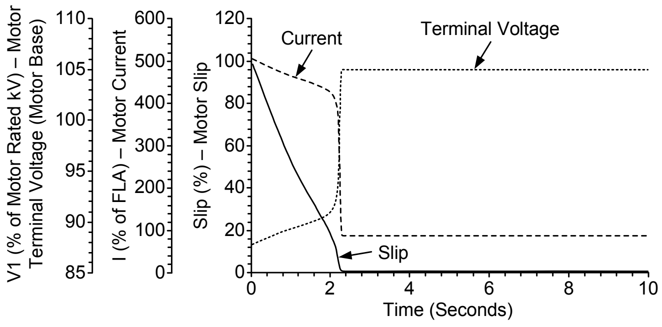

Fig. 3 Scenario 1: Normal Feed

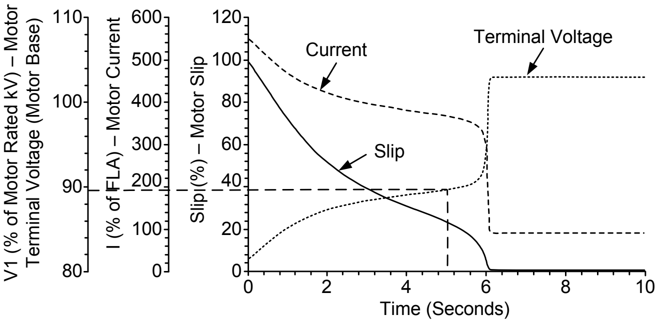

Fig. 4 Scenario 2: Single Feed

It was found from the dynamic motor starting studies that, with the system operating under the conditions defined in Scenario 1, all the static loads and the listed individual motor loads were started without a considerable voltage dip in the system. Starting all the Priority 1 motors together did not cause a considerable voltage drop, so the Priority 2 motors were able to be started 5 seconds later. Based on the study, it can be deduced that the entire static load and the listed individual motors grouped by the seven priorities will return to service within 1 minute after the system voltage has been restored.

With preconditions defined in Scenario 2, starting all the Priority 1 motors simultaneously causes considerable voltage drop on the buses (SG-B-1 and SG-A-2), primarily due to the starting of large motors (4,000 kW). The listed Priority 1 motors are Pump A and Pump B (fed from SG-B-1) and Pump C (fed from SG-A-2). SG-B-1 and SG-B-2 are two sections of double-ended switchgear. Alternating motor restarts between the two sections SG-B-1 and SG-B-2 by starting Pump A and Pump C together and starting motor Pump B after a 4-second delay did not cause any considerable voltage drop. With alternating the motor restarts between the two sections of switchgear, Priority 2 motors were able to be started 5 seconds after starting the first Priority 1 motor. Table I shows the time duration of each event in the case study for successful restart of the motors, with the system operating conditions defined in Scenario 1 and Scenario 2.

TABLE I
SUMMARY OF SELECTED MOTOR RESTART STUDY TIMING

Time Duration	Description
t = 0 seconds	Plant running under normal load and operating conditions
t = 1 second	Total plant power outage
t = 1.15 seconds	Diesel uninterrupted power supply system isolates and serves emergency loads (150 milliseconds after outage)
t = 1.20 seconds	Drop off motors on µP relay (200 milliseconds after outage)
t = 1.30 seconds	Drop off remaining loads (300 milliseconds after outage)
t = 1.50 seconds	Power restored after outage
t = 1.60 seconds	All lumped loads return to service (all static loads return to service immediately)
P1 – t = 6.5 seconds	Priority 1 motors restart (Priority 1 motors Pump A and Pump C programmed priority start timer [PST] for 5 seconds)
P1A – t = 10.5 seconds	Priority 1A motor restarts (Priority 1A motor Pump B programmed PST for 9 seconds)
P2 – t = 11.5 seconds	All Priority 2 motors restart (Priority 2 motors programmed PST for 10 seconds)
P3 – t = 16.5 seconds	All Priority 3 motors restart (Priority 3 motors programmed PST for 15 seconds)
P4 – t = 21.5 seconds	All Priority 4 motors restart (Priority 4 motors programmed PST for 20 seconds)
P5 – t = 26.5 seconds	All Priority 5 motors restart (Priority 5 motors programmed PST for 5 seconds)
P6 – t = 31.5 seconds	All Priority 6 motors restart (Priority 6 motors programmed PST for 30 seconds)
P7 – t = 36.5 seconds	All Priority 7 motors restart (Priority 7 motors programmed PST for 35 seconds)

Based on the motor starting studies performed, it was concluded that the Priority 1 motors must be reaccelerated by alternating the motor restart between the two sections of switchgear. The PST defines when the motor has to be restarted and is set to (P • 5) seconds, where *P* is the priority number of the motor. In this example, it is set to 5 seconds for the relays protecting motors Pump A and Pump C. The PST on the relay protecting motor Pump B is set to 9 seconds. The PSTs for the other priority motors are defined in a similar manner, as shown in Table I.

IV. VOLTAGE DIP RIDE THROUGH

A voltage dip can be characterized as a loss of supply voltage as low as zero for a duration of time and can occur when the plant is connected to or disconnected from the supply for a few seconds. Causes of voltage dips include the temporary loss of supply for a short duration due to automatic reclose and switching from one supply to another, short circuits on the supply or utility side, the start of large direct online induction motors, or power swings.

When the supply to a plant is disconnected, the motors generate back EMF and the voltage will not instantaneously fall to zero. With inherent inertial energy stored in the rotor, the motor can continue to drive its load, decelerating slowly (as shown in Fig. 5 and Fig. 6) if a short power interruption occurs. Per IEEE C37.96, induction motors can remain online or ride through during voltage dips that last for 0 to 15 cycles (60 Hz base) [6]. For the example considered, 12 cycles or 0.2 seconds was used as the ride-though time.

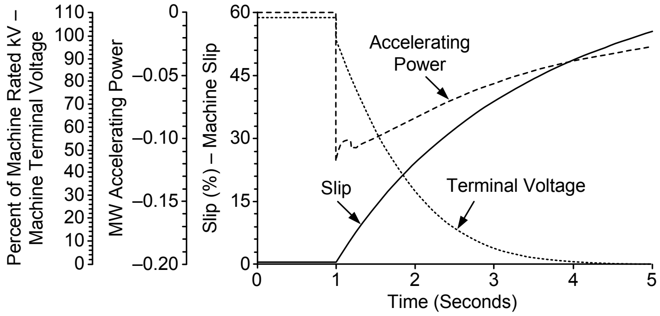

Fig. 5 Motor Spin Down for a 149 kW, 480 V Induction Motor Simulation

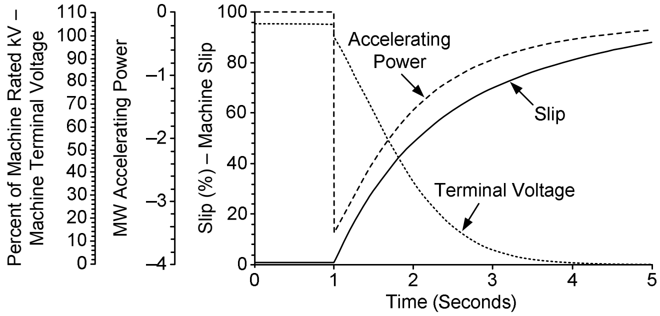

Fig. 6 Motor Spin Down for a 4,000 kW, 4,160 V Induction Motor Simulation

A. Open Transition Automatic Bus Transfer Scheme Associated With Ride Through

Each double-ended main-tie-main switchgear bus below 34.5 kV in the plant is equipped with an open transition automatic bus transfer scheme (ATS) that senses low voltage or a loss of voltage on the supply and subsequently opens the unhealthy supply breaker and closes the bus-tie breaker so that both sides of the double-ended bus receive power from the healthy supply breaker. Although not part of the ride-through scheme, the ATS is similar in that it energizes a motor bus that has been previously disconnected from its power source. In induction machines, there is a possibility of developing damaging high-transient torques (2 to 20 times rated torque); hence, the automatic open transition ride through should not be used. The ATS scheme must have a time delay prior to closure of the bus-tie breaker so that the motor back EMFs on the unhealthy bus are allowed to spin down to 21 percent (1.5 motor open-circuit alternating time constants) of the system voltage before the motors are reconnected to the bus via a tie breaker closure [7].

B. Power Circuit Breaker-Fed Motor Inherent Closed Transition Ride-Through Capability

The medium-voltage power circuit breaker maintains the system voltage for the motors during low voltage or a loss of system voltage (for interruptions greater than 12 cycles, the motor is tripped by the µP relay) and thus inherently provides a closed transition ride-through scheme, which does not produce transient torques. Power circuit breakers are latched contact devices, unlike contactors, which are magnetically held by the system voltage.

C. Contactor-Fed Motor Inherent Limited Closed Transition Ride-Through Capability

Contactor-fed low- and medium-voltage motors have inherent limited closed transition ride-through capabilities provided by the magnetic characteristics of the motor starter contactor coils in the form of coil dropout time and dropout voltages, which vary among various sized contactors. Typically, the low- and medium-voltage contactor coils will remain closed for voltage dips down to 50 percent of rated system voltage for 1 to 6 cycles (16.67 to 100 milliseconds) for low-voltage motors and up to 18 cycles (300 milliseconds) for medium-voltage motors due to contactor dropout time.

V. IMPLEMENTATION OF AUTOMATIC RESTART USING A µP PROTECTIVE RELAY

Microprocessor-based protective relays have built-in voltage detection and can be used to sense the voltage dips and trip the motor in an undervoltage condition caused by a momentary power loss. After an undervoltage trip, the relays can restart.

Undervoltage protection (27M) for motors should perform two main protection functions:

- Provide backup to the current actuated overload relays (49) for transient undervoltage conditions, which cause an increase in the motor running current and thus provide unnecessary thermal heating of the stator coils.
- Provide protection to the motor from sustained system undervoltage conditions, which are not severe enough to cause overload currents for a 49 trip, but over time can thermally degrade the stator insulation systems.

The motors used in this project are rated to operate continuously at ±10 percent (90 to 110 percent) of rated nameplate voltage and can start the load at 70 to 80 percent rated motor voltage and maintain 10 percent acceleration torque throughout the start period. In addition, the 27M undervoltage relay setting should not cause nuisance tripping due to system voltage dips during the start of the motor under consideration, other motors, or even distant faults that would depress the motor bus voltage.

The µP relay has two undervoltage relay elements, 27P1 and 27P2. 27P1 is configured for a conservative value of 65 percent (nominal value is 50 percent) of the motor rated voltage and a 0.2-second delay. 27P2 is configured for 92 percent of rated voltage with a 20-second delay (considering the cable impedance to the motor, note that the voltage is not measured at the motor terminals). A delay of 20 seconds was chosen because some large motors can start at 70 to 80 percent of the rated voltage. The 27P2 delay was set longer than the longest motor start time (from computer simulation, it is 15 seconds, so 1.2 • 15 + safety margin 2 seconds = 20 seconds) to prevent nuisance tripping and allow successful motor restarts. For additional protection, the number of starts per hour and the time between starts can be programmed in the relay.

Fig. 7 shows a schematic diagram of automatically restarting the motors using a µP protective relay. OUT101 is used for a protective trip for abnormal and fault conditions. OUT302 is used for an undervoltage trip, and OUT304 is used for automatic restart. OUT302 is programmed to trip on undervoltage conditions based on the two levels of undervoltage pickup settings, as described in the previous paragraph.

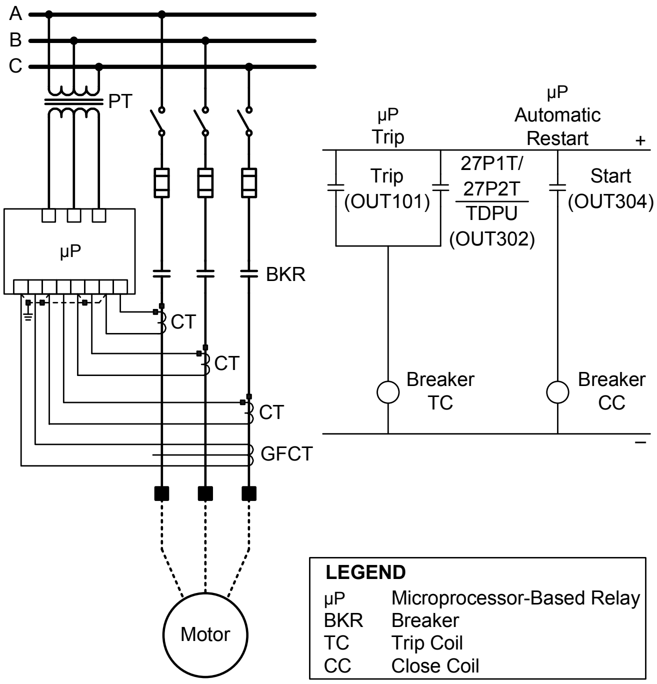

Fig. 7 Schematic Diagram for Restarting Using a µP Protective Relay

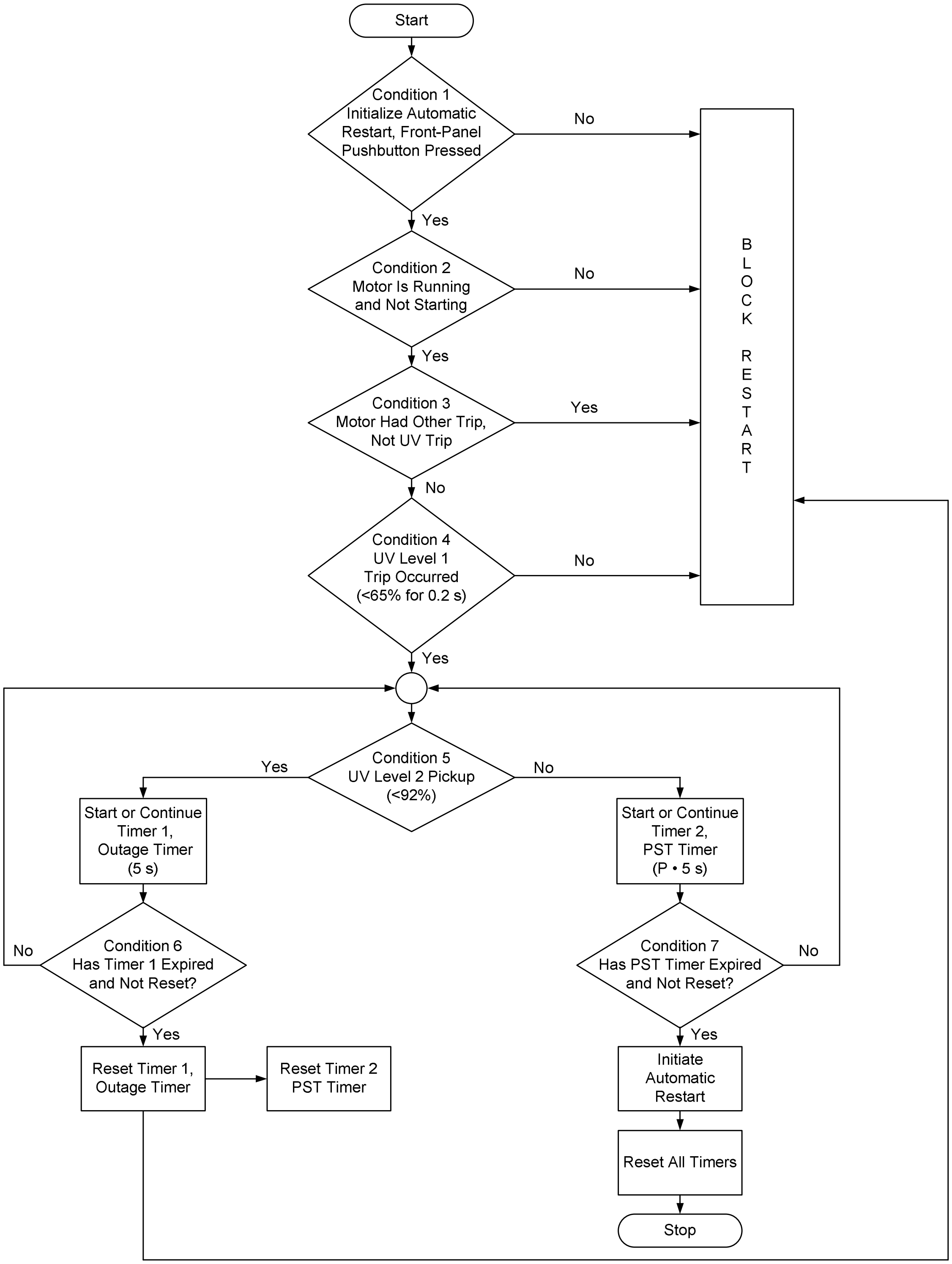

Fig. 8 Automatic Restart Logic Flow Chart (Simplified Version)

The logic is programmed into the µP relay, and the automatic restart function is implemented using the output OUT304 to start the induction motor. The automatic restart function is the combination logic of several conditional functions, as shown in Fig. 8. It is enabled when the front-panel pushbutton is activated (Condition 1), the motor is running and not starting (Condition 2), and the motor has tripped because of an undervoltage (UV) trip (Condition 3). Once the Condition 5 UV Level 2 element is picked up (when the voltage is less than 92 percent), the outage timer is started (preset for 5 seconds). If the voltage does not return to normal levels before the outage timer expires, the timer is reset and the restart is inhibited. Once Condition 4 is detected (undervoltage trips at less than 65 percent for 0.2 seconds) and provided the voltage is restored (greater than 92 percent) within 5 seconds of an undervoltage condition, the PST timer is started (preset for 5 seconds). Upon the PST timer expiring and when the voltage has returned to nominal values (greater than 92 percent), the contact OUT304 is closed to restart the motor. If the voltage does not return to the nominal values upon the PST timer expiring, the motor restart is inhibited. If any of the conditions shown in Fig. 8 are not met, the automatic restart logic is not initiated. The UV level, PST, and outage time are defined by the user and can be modified based on the process requirements. A detailed explanation of the automatic restart logic is provided in the appendix of this paper.

VI. FIELD AND SIMULATION VERIFICATION RESULT

This automatic restart logic was implemented in µP protective relays and tested in the field successfully. The voltage dips were simulated using test sets during the factory acceptance testing. The automatic restart function of the motor is enabled via the pushbutton on the relay front panel. The motor is in the running condition during the initiation of the undervoltage trip. The voltage is reduced less than 65 percent of nominal voltage (motor rated voltage) for more than 0.2 seconds and brought back to more than 92 percent of nominal voltage within the 5-second OUT304 assertion, initiating an automatic restart of the motor.

This is also confirmed in the time-stamped event report generated by the relay, as shown in Fig. 9. An undervoltage condition was sensed for more than 200 milliseconds, and the relay issued a trip signal to the breaker. After approximately 1 second, the relay identified that the motor was stopped, which confirmed the voltage decay. When voltage returned to nominal after 2 seconds, the undervoltage trip was removed, initiating automatic restart, and the breaker feeding the motor was closed after 5 seconds because the motors were Priority 1.

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IED-µP                                      Date: 09/17/2009    Time: 12:15:25
CB-D504AA

FID = R303-VO-Z003003-D20081124                                 CID – B521

#    DATE         TIME            ELEMENT              STATE
27   09/17/2009   12:15:16.912    27P2                 Asserted
26   09/17/2009   12:15:16.921    27P1                 Asserted
25   09/17/2009   12:15:16.921    LOP                  Asserted
24   09/17/2009   12:15:17.125    UNDER_VOL_TRIP       PICKUP
23   09/17/2009   12:15:17.125    OUT302               Asserted
22   09/17/2009   12:15:17.129    LT03                 Asserted
21   09/17/2009   12:15:17.158    IN101                Deasserted
20   09/17/2009   12:15:17.179    IN303                Asserted
19   09/17/2009   12:15:17.229    IN102                Asserted
18   09/17/2009   12:15:17.770    LOP                  Deasserted
17   09/17/2009   12:15:18.091    MOTOR_RUNNING        ENDS
16   09/17/2009   12:15:18.091    MOTOR_STOPPED        BEGINS
15   09/17/2009   12:15:18.095    LT02                 Asserted
14   09/17/2009   12:15:18.271    UNDER_VOL_TRIP       DROPOUT
13   09/17/2009   12:15:18.271    27P1                 Deasserted
12   09/17/2009   12:15:18.275    27P2                 Deasserted
11   09/17/2009   12:15:18.771    OUT302               Deasserted
10   09/17/2009   12:15:22.134    SV07T                Asserted
9    09/17/2009   12:15:22.134    LT03                 Deasserted
8    09/17/2009   12:15:22.139    START                Asserted
7    09/17/2009   12:15:22.143    OUT304               Asserted
6    09/17/2009   12:15:22.222    IN101                Asserted
5    09/17/2009   12:15:22.230    IN303                Deasserted
4    09/17/2009   12:15:22.234    IN102                Deasserted
3    09/17/2009   12:15:22.239    SV07T                Deasserted
2    09/17/2009   12:15:22.643    START                Deasserted
1    09/17/2009   12:15:22.647    OUT304               Deasserted
= >>
```

Fig. 9 Time-Stamped Event Report

Similar test scenarios, as shown in Table II, were also verified.

TABLE II
TEST SCENARIOS

Test Scenario	Result
Voltage was dropped less than 92% and greater than 65% of nominal and then brought back within 5 seconds	No undervoltage trip and restart occurred
Voltage was dropped less than 92% for more than 5 seconds	There was an undervoltage trip, but no restart occurred because the simulated outage was greater than 5 seconds

Computer simulations were used to analyze transient stability for ride through and restarting for momentary loss or low voltage. Fig. 10 shows the ride through for 150 milliseconds (chosen arbitrarily for the simulation). From this, it is inferred that in a momentary loss of supply for a short duration (as low as 150 milliseconds), the terminal voltage of the motor drops to 80 percent of rated voltage and transient oscillation damps out within 65 milliseconds. Hence, the motors fed by contactors or circuit breakers can sustain a 200-millisecond ride through. Fig. 11 shows the restarting of the largest motor and that the motor reaccelerates as expected transients damp out in less than 1 second. It is also clear that the motor restart occurs only after the motor voltage completely decays.

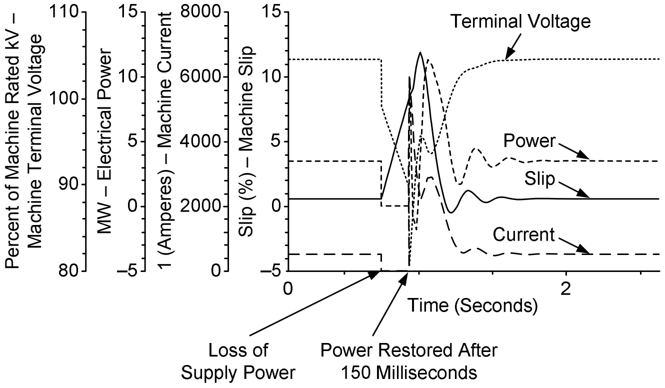

Fig. 10 Ride-Through Simulation

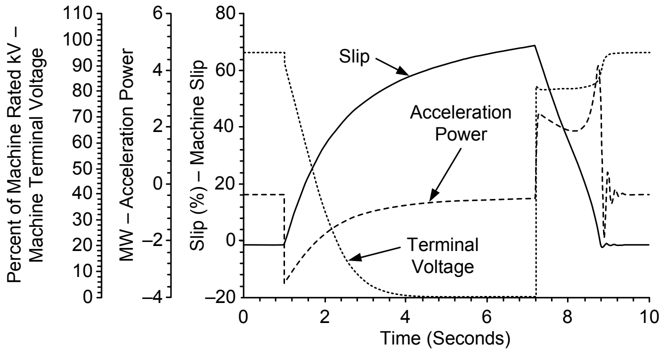

Fig. 11 Restart Simulation

VII. CONCLUSION

A user-created, digital logic-based algorithm for automatic restarting of plant essential motors has been implemented in µP motor protection schemes and verified in the field. There is no need for any additional external control circuitry, but additional controls from supervisory control and data acquisition (SCADA) or other remote process controls can be accommodated in the future. Use of this scheme in the motor protection system allows for recording or logging of motor restart events, oscillograph data, and conditions. Dynamic motor starting studies can be performed to ensure a stable plant power system when motors are restarted. Motor restart studies aid in determining the priority starting times and effects of staggered restart. This algorithm can be customized for virtually any motor or load combination, with motor restart priority being customized by the user.

VIII. APPENDIX

The logic diagram for an automatic restart is shown in Fig. A-1.

Output OUT304 := START is controlled by the START digital bit. The internal logic is shown in Fig. A-2.

If the TRIP digital bit is not asserted, the µP relay asserts the START digital bit in response to any of the following conditions:

- Start motor signal is received from logic control equation STREQ, which is used in this case.
- Emergency restart signal is received from logic control equation EMRSTR. Here, EMRSTR is 0.
- Start motor signal (STR) is received from the front panel or serial ports.

The START digital bit remains asserted for 0.5 seconds, unless the µP relay trips. If the µP relay trips before the 0.5-second timer expires, the µP relay resets the timer, clearing the START digital bit.

The Boolean equations for the logic shown in Fig. A-1 are the following:

STREQ := NOT TRIP AND LT01 AND LT02 AND SV07T AND NOT 27P2
SET01:= PB01_PUL AND NOT LT01
RST01:= PB01_PUL AND LT01
SET02:= F_TRIG RUNNING
RST02:= R_TRIG STARTING
SET03:= R_TRIG 27P1T
RST03:= SV06T OR SV07T

STREQ asserts only when an automatic motor restart is initiated. The function of latch LT01 is to enable or disable the automatic restart function of the motor in the µP relay. This logic allows the latch bit LT01 to be toggled on and off by pressing Pushbutton 1 on the face of the µP relay [8]. Latch LT02 is used to determine that the motor is in running condition and has not been started yet.

The STARTING digital bit asserts when the motor is starting, and the RUNNING digital bit asserts when the motor is running. LT02 is set at the falling-edge trigger of the RUNNING digital bit and reset at the rising-edge trigger of the STARTING digital bit. The latch bit LT03 is the ride-through timer latch that starts on the undervoltage trip condition. Considering that the bus transferring will take 3 to 5 seconds, user setting SV06PU defines a momentary outage time window of 5 seconds. User setting SV07PU includes PST, which is defined by the process. The 27P1T digital bit is the definite-time-delayed undervoltage element that triggers the automatic restart. The 27P2 digital bit is used to determine if the voltage has recovered.

When the voltage drops to the 27P1 setting and remains below 27P1 for at least 27P1D seconds, the motor trips via output OUT302 and timer SV07 (PST) is started. If the voltage does not return before the SV06PU (outage time) timer expires, then the system resets and no restart is performed. If the voltage returns to above 27P2 before SV06PU (5 seconds) expires, then the SV07PU (PST) timer is allowed to time out, initiating an automatic restart. The voltage must return to above the 27P2 setting (92 percent) within 5 seconds before the µP relay allows a restart. Every motor can be set with the same or different duration timers, as needed. In general, the PST is set with SV07T, so any automatic restart time delay is possible. Therefore, SV07PU is set at (P • 5) seconds, and SV07DO is set to 0.1 seconds in order to hold the pickup for 0.1 second from dropping out. Along with these latch conditions (LT01, LT02, and SV07T), the automatic restart part of the STREQ digital bit is supervised by the trip and undervoltage alarm 27P2.

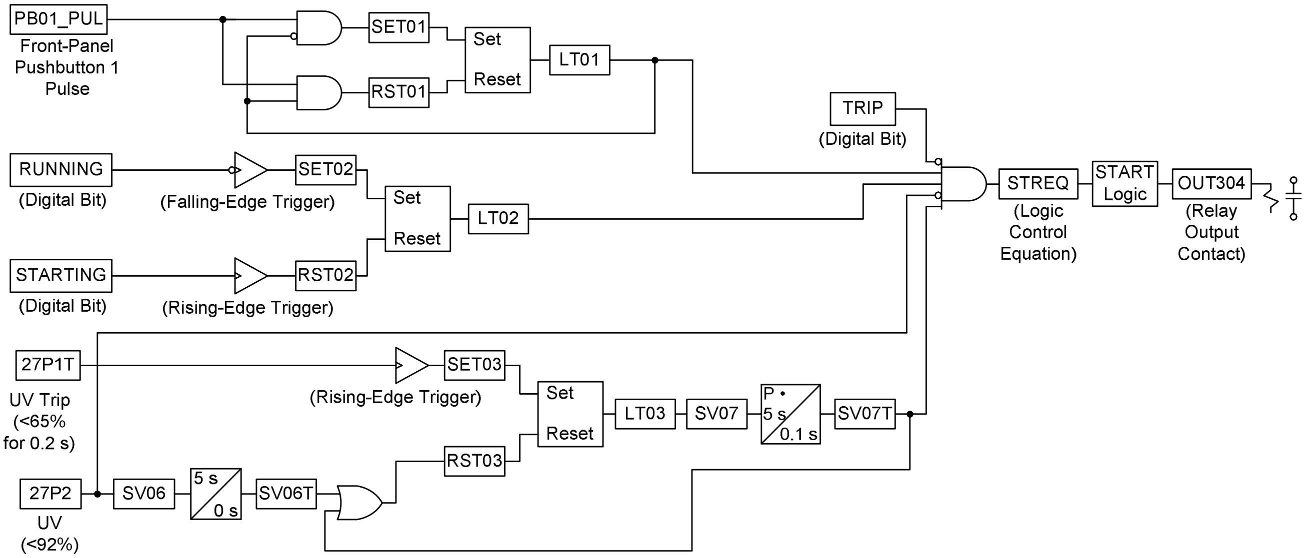

Fig. A-1 Logic Diagram for Automatic Restart Programmed in the µP Relay

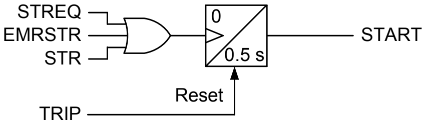

Fig. A-2 START Logic

IX. REFERENCES

[1] V. Popescu and L. Oprea, “Optimized Reacceleration of the Motor Load in a Large Industrial Power System,” proceedings of the 12th IEEE Mediterranean Electrotechnical Conference, Dubrovnik, Croatia, May 2004, pp. 947–950.

[2] M. H. J. Bollen, “The Influence of Motor Reacceleration on Voltage Sags,” *IEEE Transactions on Industry Applications*, Vol. 31, No. 4, July/August 1995, pp. 667–674.

[3] *IEEE Graphic Symbols for Electrical and Electronics Diagrams*, IEEE 315-1975 (Reaffirmed 1993), 1975.

[4] R. A. Hanna, P. Bulmer, and R. Kohistani, “Minimizing Refinery Upset During Power Interruptions Using PLC Control,” 39th Annual Petroleum and Chemical Industry Conference, San Antonio, TX, September 1992, pp. 185–195.

[5] L. R. Manio, K. Kameda, J. J. Dai, H. Iki, K. Katayama, and Y. Uriu, “Sequential Motor Dynamic Acceleration and Re-Acceleration Simulations: Comparison of ETAP® and EMTP-RV® Software,” International Conference of Power Systems Transients, Kyoto, Japan, June 2009. Available: http://www.ipst.org/techpapers/2009/papers/92.pdf.

[6] *IEEE Guide for AC Motor Protection*, IEEE C37.96-2000, 2000.

[7] *Motors and Generators*, ANSI/NEMA MG 1-2003, August 2003.

[8] J. J. Novak and R. D. Kirby, “Better, Faster, and More Economical Integrated Protective Relaying and Control Using Digital Bits and Logic,” *IEEE Transactions on Industry Applications*, Vol. 46, Issue 4, July/August 2010, pp. 1281–1294.

X. VITAE

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