Implementing Distribution Automation and Protection

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INTRODUCTION

A growing trend of the last few years is for distribution engineers to use protective relays to implement automation solutions. This approach is cost effective because the protective devices already measure system voltages and currents, monitor the status of switches, communicate between devices, and are programmable. This paper provides a case study on several installed systems and provides field data obtained from these installations.

CASE STUDY SYSTEMS

System #1: Normal/Standby Source Transfer Over Optical Fiber

One application is a normal/standby source transfer [1]. In this case, reclosers and recloser controls protect the circuit. Both controls provide standard overcurrent protection and reclosing functions. At each location, the recloser controls monitor the switch status and the voltages at each side of the switch. Each control has communications ports that allow fiber-optic transceivers to communicate between the two controls.

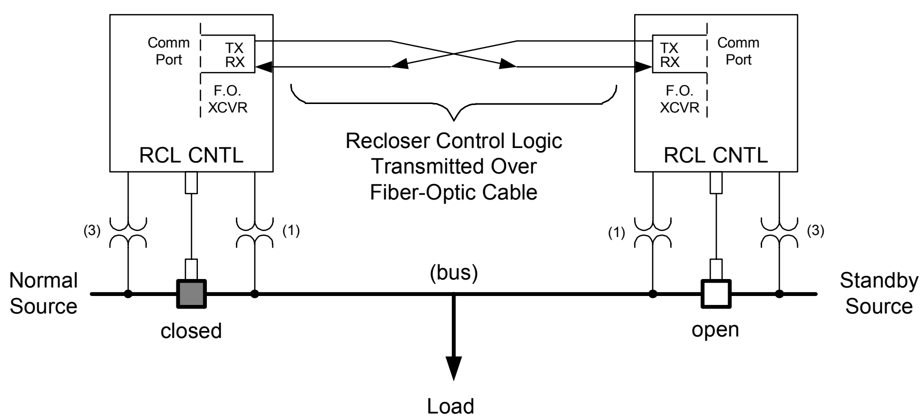

Figure 1 Normal/Standby One Line Diagram

One of the first installations was for a large industrial customer who needed increased service reliability. The two reclosers and controls were separated by one pole span on a distribution circuit. Thus, the cost of installing fiber-optic cable and transceivers was reasonable.

The following describes the operation:

- The controls continuously monitor each phase of voltage magnitude and provide overcurrent protection for the load when the recloser is closed. When any one phase of voltage drops below a preset level on the control designated as the normal source and an overcurrent condition does not exist, the normal-source recloser trips after a settable time delay. The LOW VOLT TRIP message displays on the front panel of the controller to indicate that the normal-source recloser is in an abnormal state.

- After the normal-source recloser trips on a low voltage condition, the standby-source recloser closes after a settable time delay. The LOW VOLT CLOSE message displays to indicate that the standby-source recloser is in an abnormal state.
- When the normal-source voltage returns to a healthy state, the reclose of the normal-source recloser and the trip of the standby-source recloser depend on the sync-close option selected.

  If sync-close supervision is enabled, the normal-source recloser closes after a settable time delay when a sync or dead bus condition exists and, the standby source trips after a settable time delay following the normal-source reclose. Note that the normal-source recloser waits indefinitely for a sync condition before closing.

  If sync-close supervision is disabled, the standby-source recloser trips after a settable time delay when the normal-source line voltage becomes healthy (the load again is temporarily without power) and the normal-source recloser closes after a settable time delay following the trip of the standby-source recloser (restoring power to the load).
- The LOW VOLT TRIP and the LOW VOLT CLOSE display messages reset when each source returns to its prior position and completes the voltage throw-over trip/close cycle.

Table 1 Summary of Transfer Conditions

Conditions for Normal-Source Trip on Low Voltage 1. Communication between devices OK 2. Control designated as normal source 3. Other control designated as Standby 4. Transfer scheme enabled 5. Healthy line voltage on Standby 6. Standby recloser open 7. Low voltage on any phase and no overcurrent condition on Normal Source 8. Controls configured properly *Low voltage trip timer starts after all above conditions are satisfied and trips the normal-source recloser when it times out.*	***Conditions for Standby-Source Close on Low Voltage*** 1. Communication between devices OK 2. Control designated as standby source 3. Transfer scheme enabled 4. Normal-source recloser open 5. Normal source tripped on low voltage 6. Healthy line voltage on Standby Source *Low voltage close timer starts after all above conditions are satisfied and closes the standby-source recloser when it times out.*
Conditions for Normal-Source Reclose after Low Voltage Trip 1. Communication between devices OK 2. Control designated as normal source 3. Transfer scheme enabled 4. Control previously tripped on a low voltage condition 5. Healthy line voltage on normal source 6. Standby-source recloser closed, voltage requirements satisfied (sync or dead bus condition) when sync-close supervision is enabled OR Standby source open when sync-close supervision is disabled	***Conditions for Standby-Source Trip after Low Voltage Close*** 1. Communication between devices OK 2. Control designated as standby source 3. Transfer scheme enabled 4. Healthy line voltage on normal source 5. Control previously closed on a low voltage condition 6. Normal-source recloser closed if sync-close supervision is enabled

Each transition has its own timer (normal trip, standby close, etc.). In this system, most of the times were set in the 0.5 to 1 second range, although we will see in System #3 that these times can be reduced to expedite the transfer process.

System #2: Normal/Standby Source Transfer Using Digital Radios

System #2 employs a scheme similar to System #1, except that the communications media is digital point-to-point radios. The engineers elected to use radios because of the cost savings as compared to installing fiber. The key to the successful operation of this transfer scheme is to have good line of sight between the radios at each end. In this particular installation, the reclosers and controls are separated by just over one-half mile. The radios used are unlicensed spread spectrum radios in the 900-960 MHz range.

The recloser controls continuously monitor the integrity of the communications channel. The following screen capture shows a "COMM" report extracted from one of the controls. We can see that the channel has dropped out periodically, but the overall unavailability of the channel is 0.000126. In other words, on average the channel is unavailable for about 10.9 seconds per day. The unavailability of a fiber channel is much lower.

```
=>comm
R1911                         Date: 02/11/03    Time: 14:11:09.437
A0953

FID=SEL-351R-1-R109-V0-Z002002-D20010518       CID=DBB8       BCBFID=R104
Summary for Mirrored Bits channel A
For 02/01/03 13:32:07.511 to 02/11/03 14:11:09.175

    Total failures    256                 Last error  Re-Sync
    Relay Disabled      0
    Data error          9                 Longest Failure     2.117 sec.
    Re-Sync            48
    Underrun          169                 Unavailability  0.000126
    Overrun             0
    Parity error       26
    Framing error       4                 Loop-back     0
    Bad Re-Sync         0

=>
```

The following report, captured by a control from the "normal source," shows the sequence of events record for a successful transfer. We added the "comment" field for clarification and instructional purposes for this paper. In this report, the controller monitors the status of the switch (open or closed), the reclosing function (reset or lockout), the status of the source voltage, the trip and close timers for the transfer scheme, and some of the intermediate variables and communications parameters (TMB3A, TMB1B, etc.) for internal programming.

#	DATE	TIME	ELEMENT	STATE	COMMENT
48	01/28/03	11:41:47.461	59A1	Deasserted	Source Voltage Lost
47	01/28/03	11:41:47.461	TMB3A	Deasserted	
46	01/28/03	11:41:47.461	TMB1B	Asserted	
45	01/28/03	11:41:47.465	SV13	Asserted	Trip Timer Starts
44	01/28/03	11:41:49.466	SV13T	Asserted	Trip Timer Times Out
43	01/28/03	11:41:49.466	TMB5A	Asserted	
42	01/28/03	11:41:49.470	TMB3B	Asserted	
41	01/28/03	11:41:49.474	79LO	Asserted	Control Goes to Lockout State
40	01/28/03	11:41:49.474	79RS	Deasserted	
39	01/28/03	11:41:49.474	TRIP	Asserted	Control Trips
38	01/28/03	11:41:49.474	TMB3B	Deasserted	
37	01/28/03	11:41:49.478	SH2	Asserted	
36	01/28/03	11:41:49.478	SH0	Deasserted	
35	01/28/03	11:41:49.491	52A	Deasserted	Recloser Opens
34	01/28/03	11:41:49.491	TMB4A	Deasserted	
33	01/28/03	11:41:49.503	TMB4B	Asserted	
32	01/28/03	11:41:49.574	TRIP	Deasserted	
31	01/28/03	11:41:51.533	RMB4A	Asserted	Adjacent Recloser Closed
30	01/28/03	11:41:51.537	TMB4B	Deasserted	
29	01/28/03	11:55:38.602	TMB1B	Deasserted	
28	01/28/03	11:55:38.606	59A1	Asserted	Source Voltage OK
27	01/28/03	11:55:38.606	TMB3A	Asserted	
26	01/28/03	11:55:38.681	TMB4B	Asserted	
25	01/28/03	11:55:38.685	SV15	Asserted	Close Timer Starts
24	01/28/03	11:56:12.029	SV15T	Asserted	Close Timer Times Out
23	01/28/03	11:56:12.033	CLOSE	Asserted	Control Closes
22	01/28/03	11:56:12.033	SV13	Deasserted	
21	01/28/03	11:56:12.041	CLOSE	Deasserted	
20	01/28/03	11:56:12.041	52A	Asserted	Recloser Closed
19	01/28/03	11:56:12.041	TMB4A	Asserted	
18	01/28/03	11:56:12.041	TMB4B	Deasserted	
17	01/28/03	11:56:12.045	SV15	Deasserted	
16	01/28/03	11:56:12.200	SV13T	Deasserted	
15	01/28/03	11:56:12.200	TMB5A	Deasserted	
14	01/28/03	11:56:12.212	SV15T	Deasserted	
13	01/28/03	11:56:12.254	RMB4A	Deasserted	Adjacent Recloser Open
12	01/28/03	11:56:22.048	79LO	Deasserted	
11	01/28/03	11:56:22.048	79RS	Asserted	Control Goes to Reset State

System #3: Normal/Standby Fast Transfer With Pad-Mounted Switch

This scheme is again similar to System #1, except that a pad-mounted transfer switch performs switching (see Figure 2) instead of reclosers. The customer needed to reduce the transfer delay to minimize the voltage drop for some critical loads. Therefore, the system design is to transfer the source from loss of voltage on the normal source to application of the standby source voltage in less than 7 cycles.

To achieve the fastest transfer time, all transfer delays (trip normal source, close standby source) are set to zero and some controller settings are optimized to eliminate processing delays.

The scheme employs several fail-safe modes to prevent both switches from being closed or open simultaneously and to provide protection for phase reversals.

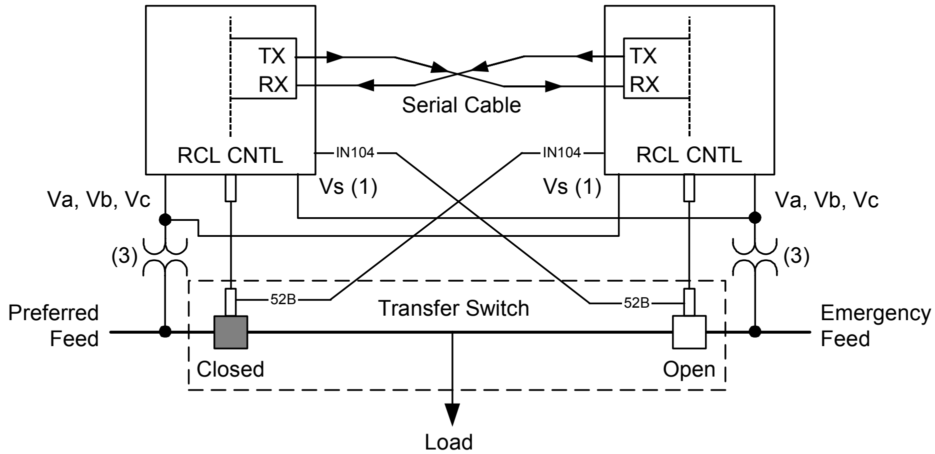

Figure 2 Pad-Mounted Switch One-Line Diagram

Figure 3 shows the validating timing diagram from loss of the preferred source voltage to the emergency source close.

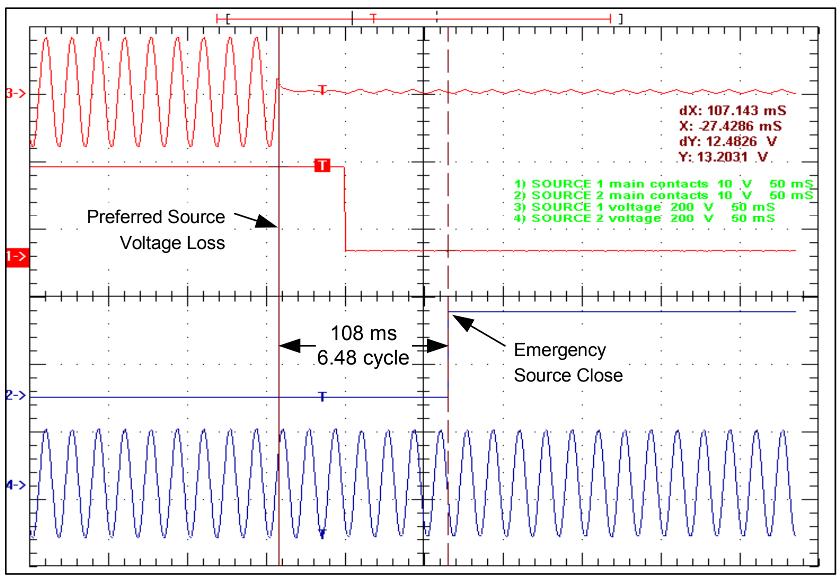

Figure 3 Fast Transfer Scheme Timing Diagram

System #4: Main-Tie-Main Scheme Over Fiber

The scheme shown in Figure 4 is applied on an overhead distribution system in Louisiana. The basic logic and functionality are similar to Systems 1 and 2, except that three switches are being controlled. The interrupters are circuit reclosers, and the protection is provided by nondirectional overcurrent elements in recloser controls. The controls communicate control logic over optical fiber.

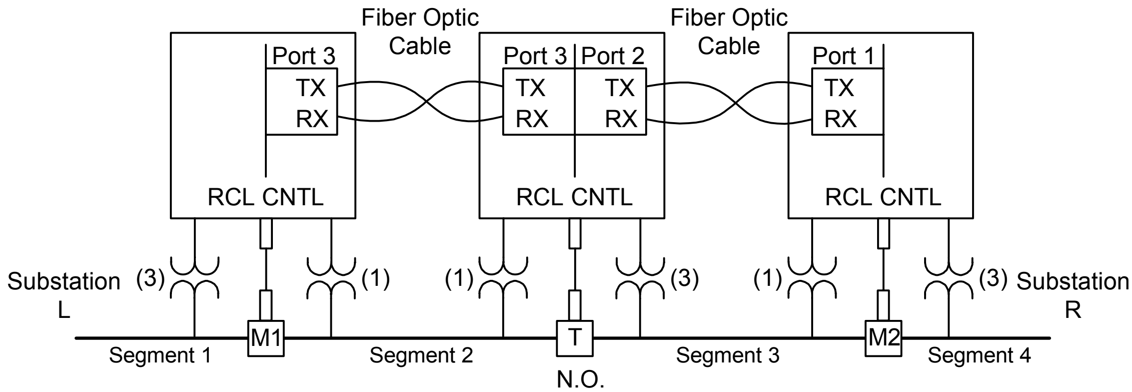

Figure 4 Main-Tie-Main One Line Diagram

On System 4, critical loads on segments 2 and 3 spawned the application of this switching scheme. The utility chose not to feed all four segments from one source for scheme simplicity. However, the system is capable of changing setting groups to accommodate this in the future. The utility has also considered adding reclosers to the switching scheme. The main constraints are the cost of fiber and the desire to maintain simplified settings and operation.

The scheme operation consists of the following:

- If either source (L or R) is lost, the associated main recloser (M1 or M2) opens, and tie recloser (T) closes.
- Two nondirectional overcurrent elements are applied at recloser T. One is activated when fed from source L, the other when fed from source R. To avoid delays, no setting groups are used.
- The sources are momentarily paralleled during return to normal switching.

System #5: Automatic Load Restoration for Causeway Bridge

The 24-mile Lake Ponchartrain Causeway crosses the largest inland body of water in Louisiana. The Causeway has twin two-lane spans that about 30,000 vehicles use on the average workday.

The bridge, operated by the Greater New Orleans Expressway Commission (GNOEC), received a major upgrade in electrical and other services over the past few years to power drawbridge operation, mobile phone towers, toll facilities, and a series of variable message warning signs to be installed along the bridge (see Figure 5).

Part of this upgrade was to add eleven fault interrupting switchgear units spaced at two to three mile intervals on the 24.9 kV feeder along the bridge. Each switchgear unit has three to five motor operated switches, two of which are used as sources (the remainder are loads). Protective relays control the source switches. The relays monitor the current in the three-phase current transformers (CTs), the status of the two switches in the switchgear, and transmit and receive information from the upstream and downstream relays over optical fiber. Power to support the entire bridge load is available from two different utility sources: one from the south, the other from the north.

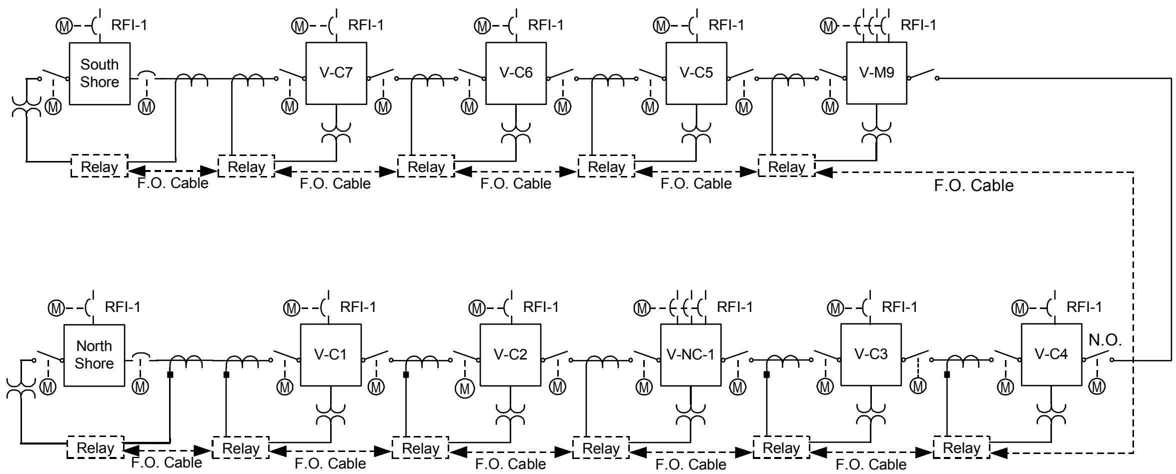

Figure 5 One-Line Diagram of the Bridge Electrical System

In the event of a loss of source from one side or the other, the basic specification calls for power restoration within ten seconds. The design concept is that at no time will the system operate in a closed loop.

The scheme was designed to use the north and south shore switches for fault interrupting, and the remaining switches to sectionalize and restore load. This approach requires closing into faults during the restoration process. However, the fault currents are small, ranging from about 300 to 600 Amps, so closing into faults during the switching process is seen as a small concession to maintain scheme simplicity. Non-directional overcurrent elements are applied at each relay for fault detection and communicated to the adjacent relays. Each relay monitors the status of the two source switches in its own switchgear and transmits and receives the status of the nearest upstream and downstream switch. In addition, the following information is communicated or "passed through" to all devices, upstream and downstream:

- Status of North Shore Breaker
- Overvoltage (Healthy Voltage) from North Shore Source
- Status of South Shore Breaker
- Overvoltage (Healthy Voltage) from South Shore Source
- Status of Normally Open Tie Point

The scheme operation consists of the following:

For a loss of source (north or south): Provided no faults are detected on the line and the remote source is available (healthy voltage and breaker closed), the lost source breaker opens and the normally open tie switch closes.

For a fault (example: on North Shore portion of the line): The North Shore breaker trips. Since all of the switches have overcurrent detection, the switches closest to the fault are open. Then, the North Shore breaker closes by control action. Since it is possible the fault was in the switch itself or between the CTs and the switch, this would reenergize the fault. The North Shore breaker trips again and the next upstream switch opens. This process continues until the fault clears. Then, the normally open tie closes to restore power to all but the faulted portion of the feeder.

One set of CTs is installed at every switchgear located on the source side of the switchgear. Thus, depending on the fault location, it could take a maximum of four reclose attempts from the shore breaker to completely restore load (worst case: system fed from South Shore, fault occurs between the CT and switch at M9). Again, the decision to use this scheme was a tradeoff between a few extra reclose attempts and simplicity.

The scheme operated correctly during Hurricane Isidore in late 2002 when the South Shore feed was lost. However, minutes later, the North Shore feed was also lost. Not even a good transfer scheme could solve that problem.

System #6: International Drive Automation and Protection

In the year 2000, a project to upgrade the reliability of the distribution system in the International Drive area just south of Orlando, Florida, was completed. The local utility, Florida Power Corporation, installed: dozens of pad-mounted fault interrupting switchgear units; thousands of feet of underground feeder cable; thousands of feet of fiber-optic cable; and a complete digital fiber multiplexed communications system (Figure 6). This upgrade provided a tremendous improvement in the protection, control, and automation of the system [2].

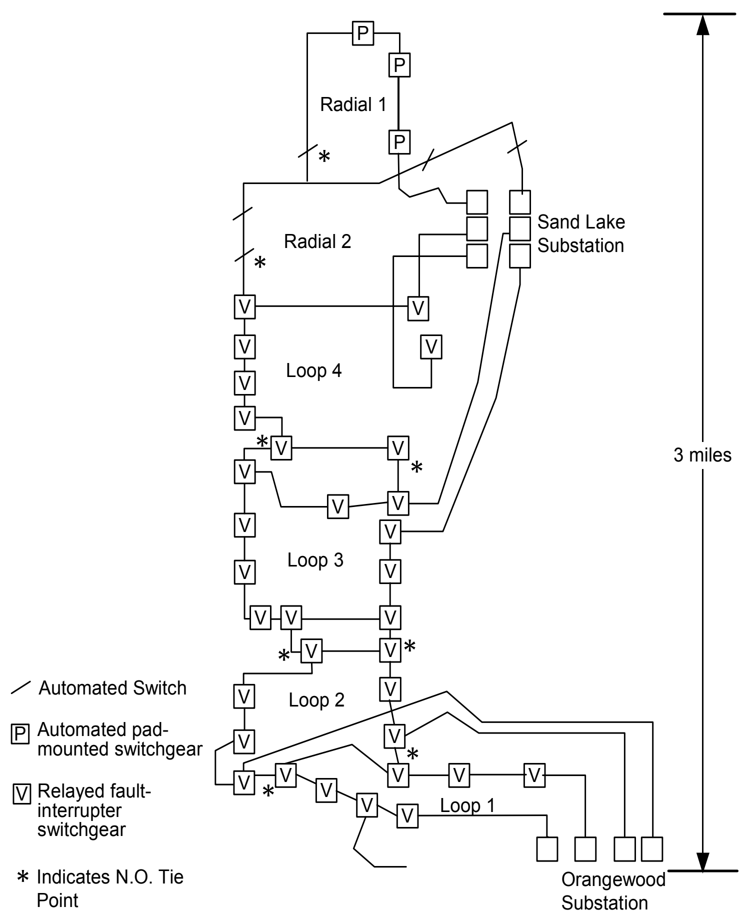

Figure 6 I Drive System One-Line Diagram

Although there are many aspects of the project that are quite remarkable, one of the main innovations is that the underground system operates as a closed loop. As such, the protection is treated more like a transmission system than a traditional distribution system. Some protection schemes include directional overcurrent relays in a permissive overreaching transfer trip scheme, directional comparison blocking, breaker failure protection, and bus fault protection.

The relays applied for protection also perform an automatic source transfer. This scheme protects against the loss of a substation bus at Orangewood Substation. In short, the transfer switches Loop 1 and Loop 2 if either of these two loops should lose its normal source.

Orangewood Substation has two buses with a tie circuit breaker; the bus tie automatically closes if one transformer is lost at the station. One bus supplies Loop 1, the other bus, Loop 2. In the event that the system loses one transformer at the substation, the tie automatically throws-over to restore service to both loops.

However, in the case of a bus fault, the bus differential operates to initiate clearing the fault and there is no source to the loop supplied by the faulted bus. In this case, the switchgear connecting to the next loop detects the loss of source on both of its two normally-closed feeder positions. After a time delay to coordinate with the substation throw-over, the tie-feeder closes (provided voltage is present on the alternate source).

Figure 7 illustrates the control logic. The scheme is interlocked to prevent closing when the occurrence of a fault causes loss of voltage. If the alternate source is also unavailable, no closing occurs. The return of good voltage to the normal feeders resets the scheme. System operators can open the automatically closed interrupter manually or through SCADA. This scheme is implemented in four 3-feeder switchgear units that connect Loop 1 to Loop 2. For proper scheme operation, the normally open points as shown in Figure 5 must be maintained. This automatic transfer scheme is not implemented on Loops 3 and 4 because the Sand Lake Substation uses a breaker-and-a-half scheme to provide protection against loss of a substation bus or transformer.

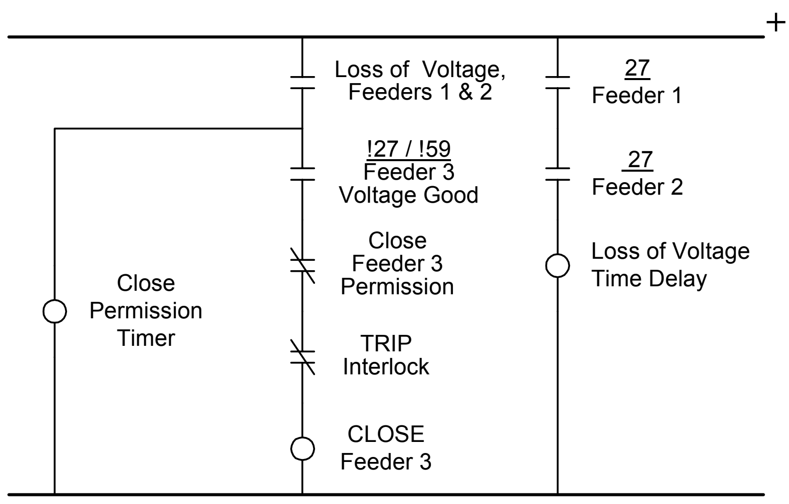

Figure 7 Control Circuit Representation of Automatic Source Transfer Logic

System #7: Power Plant Source Transfer Scheme

This transfer scheme is being applied at a power plant. As we can see in Figure 8, there are two 2400 V Generator Auxiliary Buses, connected by a normally closed Breaker 2. The buses are normally supplied from the generator auxiliary transformer. This transfer scheme was put in place to automatically switch the source over to the house service (fed by a separate transformer).

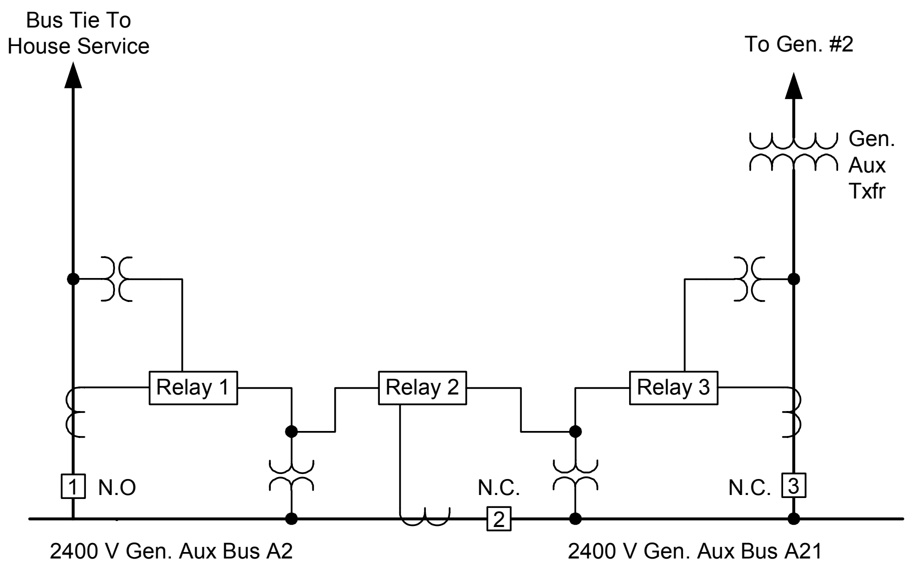

Figure 8 Power Plant Source Transfer Scheme One-Line Diagram

The following are operating characteristics of the scheme:

- Operators enable or disable the automatic transfer scheme through the plant Distributed Control System (DCS). After the operators send a signal, the relays check breaker and voltage status and then activate the scheme. Provided all of the voltage sources are healthy, Breaker 1 is open and Breakers 2 and 3 are closed.
- Transfer occurs if the Generator Auxiliary source voltage drops below a preset pickup OR Breaker 3 opens.
- At this time, the automatic transfer scheme is only implemented from the generator auxiliary supply to the house service supply. Restoration to normal is done manually for simplicity.
- The scheme includes two delays. The initial undervoltage sensing uses a 30-cycle delay for security. The scheme adds a 60-cycle delay before closing the alternate supply (Breaker 1) to allow the motors to coast down and ensure a “dead” bus. The optimum transfer time is 1.5 seconds or less to keep from asserting a downstream transfer scheme on a 480 V bus (fed from the 2400 V bus, operates in about 2 seconds).

Refinements made during the design process and start-up include the following:

- The output from the DCS system was initially thought to be a pulsed output and then changed to a maintained output. The relays could handle either, but appropriate settings changes needed to be made.
- In the initial design, the transfer occurred only on a loss of healthy voltage from the generator auxiliary bus. However, a new excitation system kept the generator voltage high much longer than the previous system (on the order of minutes). Thus, transfer now occurs for any operation of Breaker 3 or the loss of healthy voltage.
- During testing, engineers learned that even after the normal source opens, the voltage stayed above the pickup setting (about 85%) on the 2400 V bus to delay transfer and additional 1.5 seconds (3 sec total—too long for this scheme). As a result, we are examining the possibility of raising the voltage threshold or minimizing delays, or a combination of both.

CONCLUSIONS

1. Many utility and industrial users are applying protection and automation using the same protective devices because of the economics and capabilities of the devices.
2. The design of the scheme depends on: the criticality of the load; the time in which the load needs to be restored; the physical distance between the switches; the type of switches applied; and other factors, including cost.
3. Fiber optics is the preferred communications media because of reliability and speed. In addition, direct metallic connections can be used for devices in the same location and point-to-point radios are a cost-effective alternative when a clear line of sight is available.

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[2] Fairman, J.R., Zimmerman, K., Gregory, J.W., and Niemira, J.K., "International Drive Distribution Automation and Protection," *Proceedings of the 26th Annual Western Protective Relay Conference*, Spokane, WA, October 24-26, 2000. <http://www.selinc.com/ techpprs/6114.pdf > (6 Mar. 2003)

BIOGRAPHIES

Mike Collum, P.E. started working with Schweitzer Engineering Laboratories, Inc. in 1997 as a field application engineer. He is currently the Regional Service Manager for the Southeast out of Tupelo, Mississippi. For 11 years prior to joining SEL, he was director of planning and protection for South Mississippi Electric Power Association. Mike graduated from Mississippi State University with a BSEE degree. He is a registered professional engineer in the State of Mississippi.

Karl Zimmerman is a Regional Service Manager with Schweitzer Engineering Labs in Belleville, Illinois. His work includes providing application support and technical training for protective relays.

He is an active member of the IEEE Power System Relaying Committee and is the Chairman of Working Group D-2 on fault locating.

Karl received his BSEE degree at the University of Illinois at Urbana-Champaign and has over 20 years of experience in the area of system protection. He has spoken at many technical conferences and has authored several papers and application guides on protective relaying.

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