Implementation of a New Substation Restoration System Using Protective Relays and a Logic Processor

Bernard S. Tatera, Jr.

Pacific Gas & Electric Company
San Francisco, California

Bst1@pge.com

Lawrence C. Gross, Jr.

Relay Application Innovation, Inc.
Pullman, Washington

Larry144@RelayApplication.com

Presented before the

3rd Annual
Western Power Delivery Automation Conference
Spokane, Washington
April 10 – 12, 2001

Implementation of a New Substation Restoration System Using Protective Relays and a Logic Processor

A reclosing system approach that is applicable to remedial action schemes, protection interlocking, load shedding, and other relay logic applications.

INTRODUCTION

During the last three years, three Pacific Gas & Electric substations in the greater San Francisco bay area were studied for the addition of new transformer capacity. In year 1999 the decision was made to expand three distribution substations by adding a third transformer at each location.

The addition of a third transformer required changes in the existing automatic restoration system (automatics) at each of these distribution substations.

The automatics scheme is intended to automatically restore a substation after an unplanned outage such as a fault or loss of power to the substation. Unplanned outages in a distribution substation are typically the result of failed equipment, lightning, or other conditions causing a short circuit in the substation. The automatics scheme is designed to restore power to as much of the station as possible. Transformers are locked out and are not tested after an internal fault.

The automatics system increases system availability, reduces outage time, identifies the failed piece of equipment, and reduces the labor required for system restoration and fault diagnostics.

BACKGROUND

All three substations had an existing automatics scheme consisting of electro-mechanical relays that was not considered suitable for further expansion. To expand the installed system required many additional auxiliary relays and interconnecting wiring. This caused concern about the system testing requirements and the system reliability.

The previous PG&E standard for automatics in a distribution substation has changed over the years from electro-mechanical discrete relays to a programmable logic controller (PLC) based system [1]. The PLC was used in a number of different substation configurations and was capable of expansion by adding additional input and output modules with activation of larger sections of relay ladder logic when additional transformers are added within a substation.

The PLC system for automatics has been used within PG&E since the mid 1980’s. Installation is expensive because the system is a separate, stand alone scheme requiring its own substation design drawings and discrete wiring. Maintenance is expensive because replacement parts of this specialized, limited-use PLC have long lead times and troubleshooting requires a specialized knowledge of the system. Because of these installation and maintenance issues, a new system was desired for the capacity increase of these distribution substations.

The requirement for completing these projects during the year 2000 period led to major portions of the engineering development of this project to be contracted to an outside engineering services firm. The design basis for any selected alternative would be the proven relay ladder logic for automatic reclosing developed and applied by PG&E for use with a PLC.

Three engineering services companies provided proposals for the automatics of the three substations.

PROPOSED AUTOMATIC RECLOSING SYSTEMS

Three proposed systems for automatic reclosing were studied for providing automatic reclosing at the three distribution substations.

1. PLC based system
2. Remote Terminal Unit (RTU) based system
3. Relay Logic Communication (RLC) based system

The three systems were compared and the estimated costs were found to be similar overall, however each option had different percentages in each major project subcomponent. Figure 1 breaks these costs down by percentage for each system type.

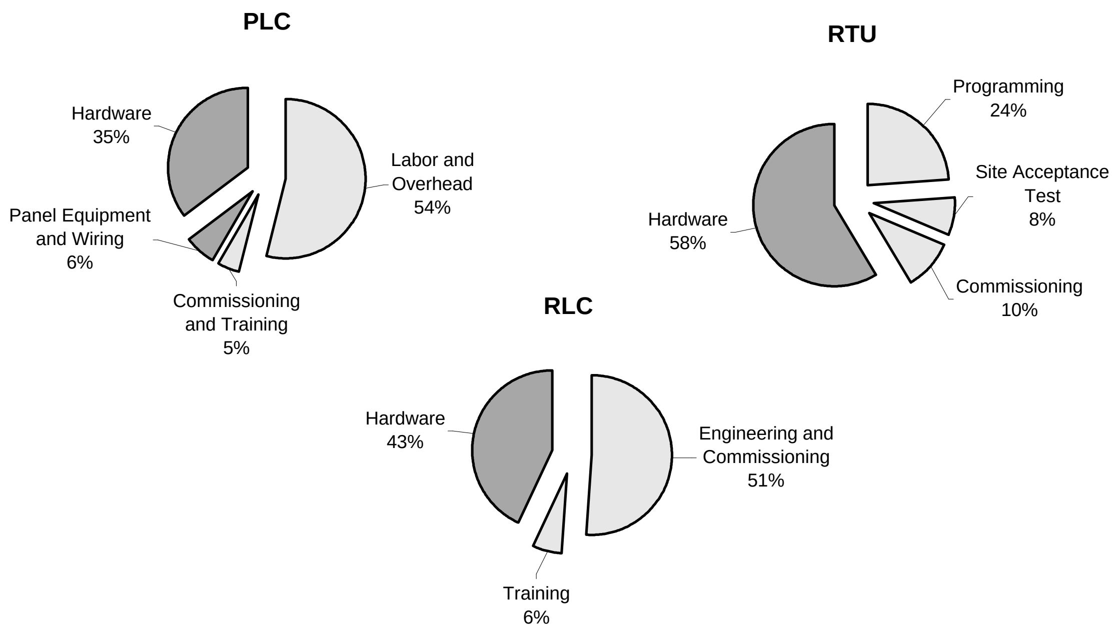

Figure 1: Cost Breakdown for Each Proposed System

The three systems were compared in terms of benefits with an overall evaluation suggesting that the RLC proposal had greater benefits in the area of flexibility and reliability.

Table 1: Benefits of Each Proposed System

PLC Benefits	RTU Benefits	RLC Benefits
Proven logic for a variety of commonly used substation configurations	Simple to provide recloser control and status to SCADA system	Higher Reliability than PLC based system
		Enhanced system monitoring
		Simplified testing
		Improvement of logic for automatic restoration
		Reduction of costs by elimination of bus potential devices, and less wiring
		Flexibility for future changes, additions or modifications
		Distributed Sync Check Logic

RELAY LOGIC COMMUNICATION (RLC) SYSTEM, THE SELECTED ALTERNATIVE

Overview

The selected system consists of multiple microprocessor relays and a protection logic processor (PLP). The relays provide the reclosing control and logic for each switch. The protection logic processor communicates data from one relay to the others for interlocking purposes. This system is called a Relay Logic Communication (RLC) System.

Each microprocessor relay is star connected to the PLP through two serial EIA-232 communication ports.

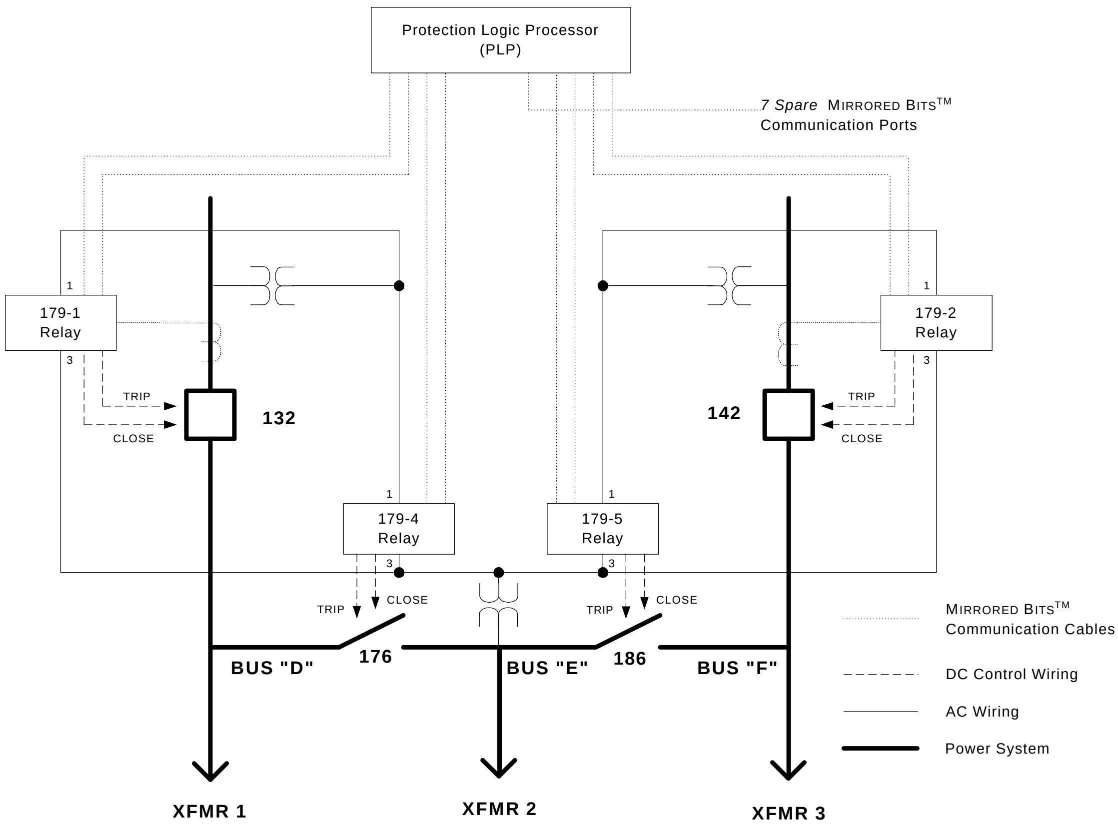

Figure 2: RLC System Overview

Each relay is connected to the power system through line-side potential transformers and optional current transformers. Each relay directly monitors the line potentials, however the presence or absence of potential on each bus section is determined by the line potentials plus the status of circuit breakers and bus sectionalizing switches. Figure 2 gives an overview of the system showing the communication connections, AC connections, and trip and close control.

DC inputs and outputs on each relay are used to monitor switch status and to control the breaker/switch tripping and closing. The relays contain the majority of the reclosing logic. Each relay needs information from other relays to make proper reclosing decisions. The relays transmit and receive up to 16 bits of data to and from the PLP. Eight bits are communicated on serial port 1 and eight bits are communicated on serial port 2. Note that Figure 2 shows two separate communication channels for each relay.

Logic

The PLP gathers information from all relays on the system, its DC inputs, and any information it receives from the communication processor. The PLP then processes the logic and consolidates the data for transmission to multiple relays. All PLP communication ports are updated, and processed within the same processing interval (typically 4 ms). The process of moving data from one relay to another, including processing time by the PLP is approximately one cycle. With the received PLP information, and the internal logic of the relay, a proper automatic reclosing decision is made. Figure 3 shows a partial logic diagram of the relay reclose logic. The logic uses information from hardwired inputs (i.e. IN201), Mirrored Bits™ communication channels, and AC measurements (i.e. VA).

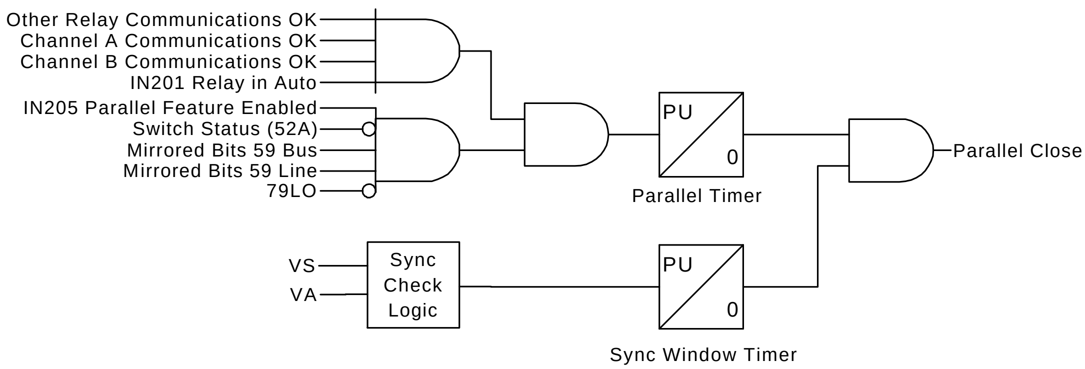

Figure 3: Example Reclose Logic (Partial Parallel Logic Shown)

Data Collection

A data collection device (communication processor) is used for testing and directly interrogating the relays. The communication processor is the interface for the computer that runs the functional tests of the system using a virtual test panel and allows communication to any device in the automatics system. It is not required for the automatics system operation, and if one of these communication links fails, or the communication processor fails, the automatics system operation is unaffected.

EIA-232 to EIA-485 converters are used since the two EIA-232 ports on the relays are used for communication to the PLP and the remaining EIA-485 port on each relay is used for standard ASCII communications to the communication processor.

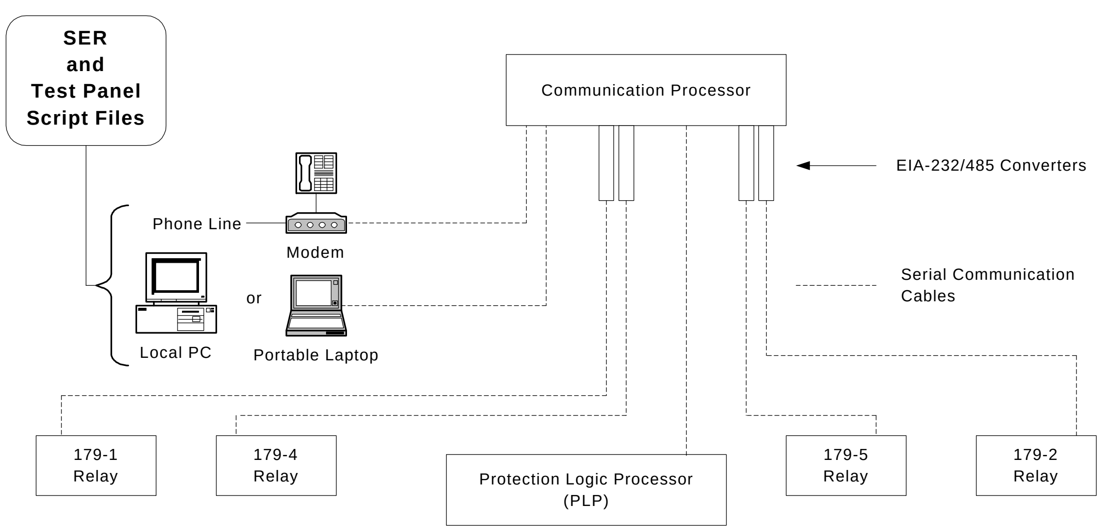

Figure 4: RLC System Interrogation and Testing Interface Block Diagram

Testing

Testing of the system required proving the wiring, the logic, and the devices. Almost all testing must be completed while the station is in operation.

The existing PG&E PLC design used a test panel that routed outputs to "pseudo" switches, lights, and alarms, to simulate the station operation. This allowed testing the logic and timer settings of the system and the operation of the PLC or discrete electro-mechanical relays. All wiring and operation of the primary devices (breakers, switches, potential transformers, etc.) require a station clearance to test.

The selected design also allows testing the RLC system logic while in a "pseudo" output mode.

The "pseudo" output mode consists of looping the control outputs back to the inputs of the relay via another output that is activated while in the test mode. This "pseudo" output connection allows testing of the overall system without having to exercise breakers or de-energize in service power equipment to do actual testing. While in test mode the breaker status is simulated. No actual control signals are sent to the breaker while in test mode, but the relay changes the state of a latched bit every time the breaker is tripped or closed. This allows testing of the scheme logic.

Because the system outputs are routed to inputs while in test mode, the new RLC system simplifies the testing process. These inputs are monitored by the system via interrogation by a computer terminal program and do not require dedicated monitoring using a separate physical device.

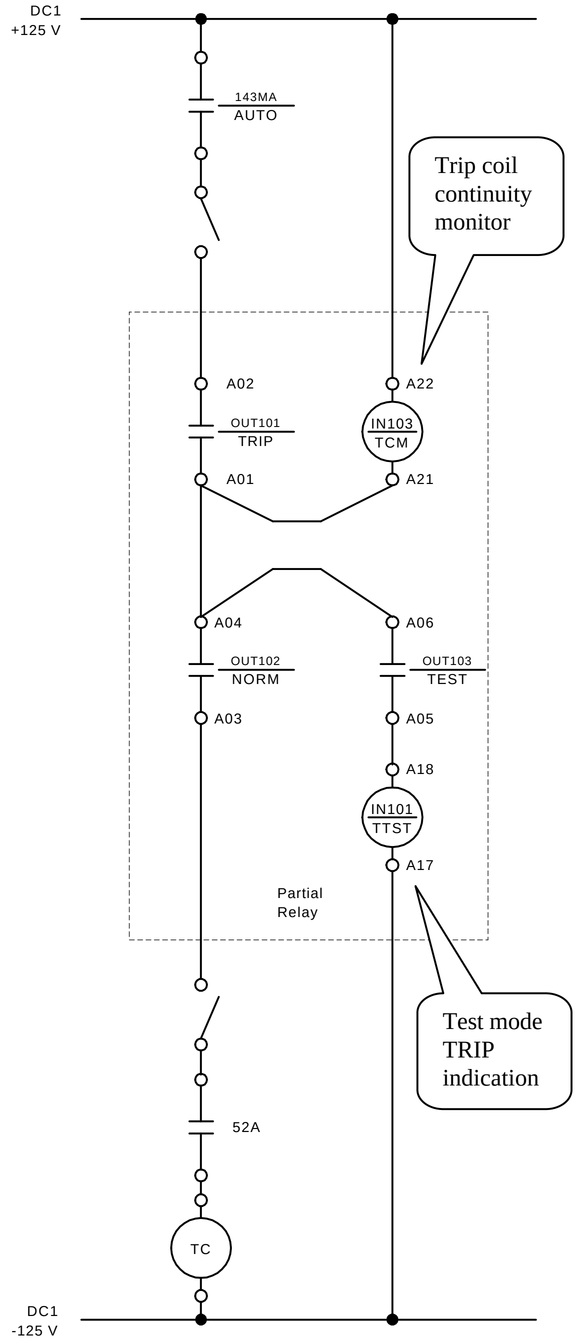

Figure 5: RLC System Simplified DC Schematic (Test Mode I/O)

Virtual Test Panel

The "Virtual Test Panel" to test the system consists of running simple programs called scripts that operate through the programmable terminal emulation program. They send pre-defined commands to the PLP, communication processor, and relays, and then parse the information that is sent back to the terminal as a response to the initiated command. These scripts automatically toggle bits within the relay and initiate relay monitoring commands.

Test scripts were designed to automatically measure the integrity of all hardwired inputs, output contacts, and AC connections. Figure 6 shows a terminal window and the results of a test that checked the hardwired relay inputs.

Additional test scripts were developed to simulate system logic and timing, and run fault and various situational operation scenarios for the substation automatics.

With various pre-defined fault conditions, the only action required by the technician completing the test is to simply click on the desired function button and follow the instructions. Most scripts are fully automatic and require no operator intervention after the script is started. Figure 6 shows button windows that were pre-programmed to execute corresponding script programs. The major action is simply to verify that the correct relay action occurred by review of the sequence of event record from the PLP as shown in Figure 7.

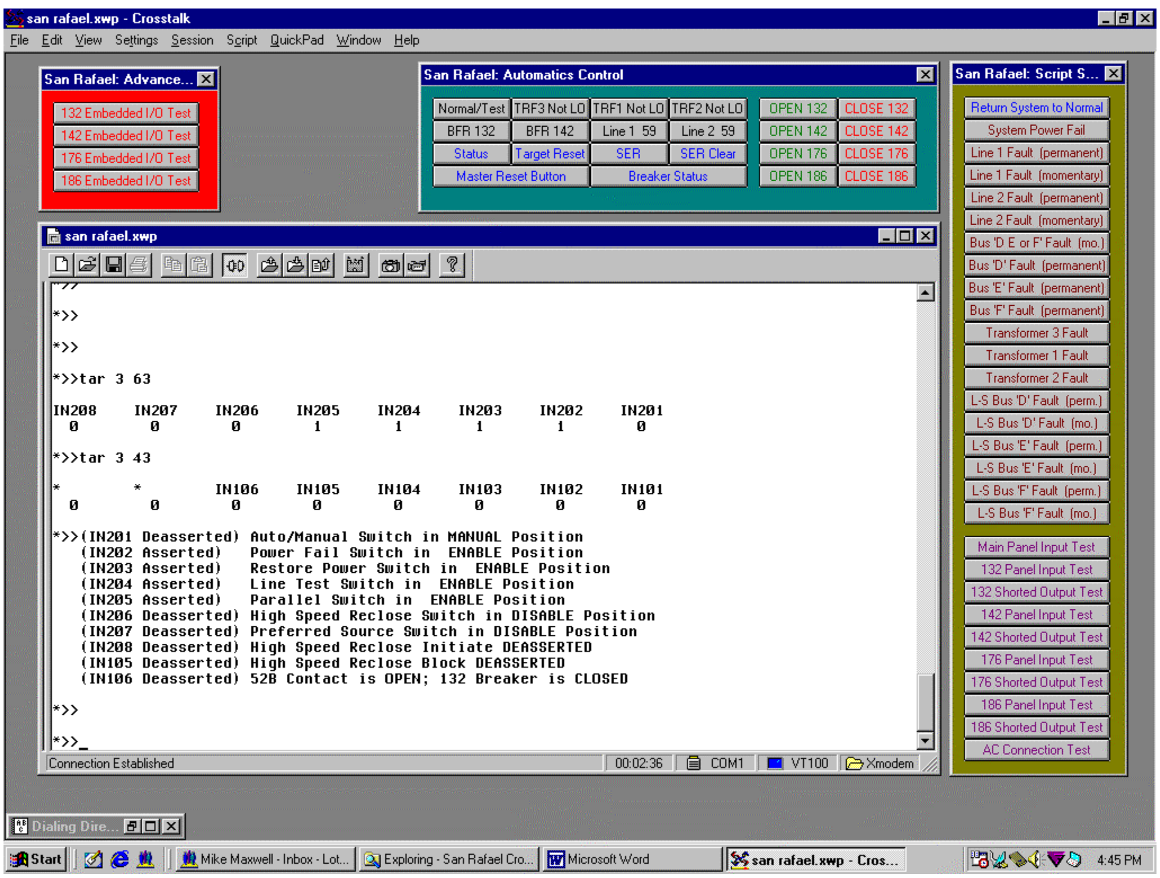

Figure 6: Example Terminal Screen Showing Test Script Buttons

Troubleshooting

The PLP and the relays store sequence of event records (SER). The SER settings of the PLP control what data is recorded. The data included inputs and outputs of the PLP and key logic bits sent by the relay to the PLP. The SER should look identical for each scenario that is repeated. If these are recorded during commissioning, an actual operation report is easily compared to the test. An example SER is shown in Figure 7. This SER shows the two line breakers tripping and the complete restoration of the station after a simulated bus fault occurred. Refer to Figure 1 for a single line of the station.

	Asserted	Deasserted	Bit	
23:50:18.491	---	Bkr 2 52A	R1P3	Breaker 132 and 142 trip
23:50:18.495	---	Bkr 2 79RS	R8P3	
23:50:18.535	---	Bkr 1 52A	R1P1	
23:50:18.535	Bus D Restore Permission	---	T2P1	
23:50:18.535	Bus F Restore Permission	---	T2P3	
23:50:18.539	---	Bkr 1 79RS	R8P1	
23:50:23.647	---	CS 5 52A	R1P9	Switch 176 and 186 power fail trip
23:50:23.647	Bus E Restore Permission	---	T2P9	
23:50:23.647	Bus F Restore Permission	---	T5P9	
23:50:23.655	---	CS 4 52A	R1P7	
23:50:23.655	Bus E Restore Permission	---	T2P7	
23:50:23.655	Bus D Restore Permission	---	T5P7	
23:50:28.563	Bus D Tested	---	T6P7	Breaker 132 closes to restore bus D
23:50:28.635	Bkr 1 52A	---	R1P1	
23:50:28.635	---	Bus D Restore Permission	T2P1	
23:50:28.635	---	Bus D Restore Permission	T5P7	
23:50:28.659	---	CS 4 79RS	R8P7	
23:50:33.563	Bus F Tested	---	T6P9	Breaker 142 closes to restore bus F
23:50:33.775	Bkr 2 52A	---	R1P3	
23:50:33.775	---	Bus F Restore Permission	T2P3	
23:50:33.775	---	Bus F Restore Permission	T5P9	
23:50:33.799	---	CS 5 79RS	R8P9	
23:50:48.807	Bus E Tested By Adjacent	---	T3P4	Switch 186 closes to restore bus E (3.5 sec close time)
23:50:48.807	Bus E Tested	---	T3P7	
23:50:52.343	CS 5 52A	---	R1P9	
23:50:52.343	---	Bus E Restore Permission	T2P9	
23:50:52.343	---	Bus E Restore Permission	T2P7	
23:51:15.815	CS 4 52A	---	R1P7	Switch 176 closes to parallel bus D and E
23:51:15.815	Bus D Tested	---	T3P1	
23:51:15.815	Bus F Tested	---	T3P3	
23:51:15.815	Bus E Tested	---	T3P9	
23:51:48.667	---	Bus F Tested	T3P3	Station is completely restored. All relays time to a reset.
23:51:48.667	---	Bus E Tested	T3P9	
23:51:48.667	---	Bus D Tested	T6P7	
23:51:48.691	Bkr 1 79RS	---	R8P1	
23:51:53.823	---	Bus F Tested	T6P9	
23:51:53.847	Bkr 2 79RS	---	R8P3	
23:52:12.372	---	Bus D Tested	T3P1	
23:52:12.372	---	Bus E Tested By Adjacent	T3P4	
23:52:12.372	---	Bus E Tested	T3P7	
23:52:12.401	CS 5 79RS	---	R8P9	
23:52:35.865	CS 4 79RS	---	R8P7	

Figure 7: Example SER of a Full Station Restoration After a Momentary Bus Fault

If an unusual misoperation occurs that cannot be diagnosed from the PLP report, further data is available. Each relay SER is available, and they are time synchronized by connections to the communication processor.

Because the PLP and relays are connected through the communication processor, all SER reports are available remotely through a modem.

With simple maintenance clearances, a technician could attempt to repeat the scenario using the SER reports as a reference to set up the condition. While in test mode the scenario is run and new SER records are generated. A comparison of the SER records helps reveal the trouble.

After the testing is complete and the problem is corrected, the system is returned to normal operation.

Security

Two scenarios threaten the security of any automatics system and they usually occur during testing:

1. Individual devices lose connections and/or communication with each other.
2. A physical contact fails.

Test Mode to Normal mode Transition

Some system failures or conditions would cause misoperations while in Normal mode. The RLC system detects these conditions and latches the system in Test mode. This prevents a transition to Normal mode for these abnormal system output conditions.

Loss of Communication

At any time, if any of the automatics system relays lose communication with the PLP, an alarm is generated and the reclosing status is changed to MANUAL at all relays. The relay that lost communication will revert all data that should come from the PLP to the default bit status of the relay. The default condition is defined by the relay port settings.

Failed Contact

The RLC detects if a contact fails closed while in test mode. It knows the contact is failed because while in test mode the output contacts are routed through monitored inputs. If the input remains asserted even though the contact is told to open, the RLC system knows the contact is failed.

Benefits of RLC system

Table 2: Summary of RLC System Benefits

RLC Benefits
Higher Reliability than PLC based system
Enhanced system monitoring
Simplified testing
Improvement of logic for automatic restoration
Reduction of costs by elimination of bus potential devices, and less wiring
Flexibility for future changes, additions or modifications
Distributed sync check logic

Higher Reliability

A higher reliability than PLC based system exists for the following reasons. First, the RLC system uses less wiring and fewer electro-mechanical auxiliary relays. Second, the RLC system is continuously self-monitored [2]. Alarms are generated for component failures within the relays or when loss of communication occurs between devices. Lastly, the substation hardened and tested relay platform is the basis of the system. A more technical evaluation of similar systems was performed and documented in reference [3].

Enhanced System Monitoring

The RLC system provides enhanced system monitoring by the continuous continuity checks of Trip and Close breaker coils during normal conditions [4]. In addition the individual relays monitor the trip and close contact status while the RLC system is in the test mode. Finally the breaker status and feature switch conditions are available from the relays and can be provided to the SCADA system via a DNP 3.0 port on the communication processor.

Simplified Testing

The RLC system provides simplified testing by allowing the technician to put the entire system into test mode. This allows testing of feature interoperability and decreases the risk of undesired tripping. The RLC system will check relay output contacts for lack of outputs prior to switching from test to normal mode. For aid of troubleshooting a programmable sequence of events log is available to record all system and logic changes and present them in a time stamped SER log.

Improved Reclosing Logic

The use of the relay platform with all its relay elements results in improved logic for automatic restoration. The major benefit is the provision of a power fail feature with current supervision. The power fail feature is the detection of loss of potential and the automatic tripping of the switch. This feature isolates each bus section in the case of a widespread outage. With the RLC design, power fail tripping will not occur if current is flowing through the breaker. This prevents undesired power fail tripping during abnormal loss of potential conditions (possibly due to blown PT fuse or removal of potential sources from relay inputs). This improved logic is normally not available from discrete reclosers without current inputs.

Cost Reduction

The RLC system provides a reduction of total costs when compared to a PLC system due to less wiring and pre-programmed testing sequences for the RLC system. In addition, when the RLC system logic was developed, a further reduction of costs is available by the elimination of bus potential devices. The RLC system logic only requires that the potential from the transmission line sources be necessary. This eliminates the need for single-phase bus potentials typically used for automatic reclosing.

Flexibility

The RLC system provides flexibility for future changes, additions, or modification by using a relay platform with multifunction capability. The typical microprocessor relay is capable of metering, protection and control. The selection of the relay as the monitoring device allows under-voltage, under-frequency or current elements to supervise automatic reclosing logic. Data transfer to the SCADA system is also available when programmed through a DNP 3.0 capable serial port.

Distributed Sync Check Logic

The RLC system provides a distribution of synchronism checking elements because each relay includes a sync check function with multiple programmable sync windows and sync timer parameters. This duplication and programmability provides greater control and flexibility and allows sync parameters for each breaker or switch to be assigned independently.

SCHEDULE

When there is a compressed schedule or limited engineering resources within the utility, there is a trend for electric utilities to consider turnkey engineering projects. Utilities are becoming less interested in choosing each individual system and system supplier. Rather they are now determining their system needs, communicating their needs to a supplier and relying on that supplier to provide the system necessary to meet those needs.

With a move to a contracted solution, the most important element is to define the utility expectations of the system. A successful project will have the construction and engineering staffs participate early in the development cycle so that construction testing and system performance issues are addressed in the concept stage. This clear definition of system requirements allowed the proposed system to be completed within the required schedule.

Table 3: Actual Project Timeline

Date	Project Event
September 1, 1999	Start of selection process of new automatic reclosing system for three PG&E distribution substations to be energized during year 2000. Proposals from three vendors were reviewed.
October 1999	Selection of new automatic reclosing system – RLC. Start concept design review. Input, output, and alarm point requirements are developed with I/O points assigned to relays.
January 5, 2000	Concept design complete by selected contracted engineering services staff. PG&E reviews concept design for final approval.
February 9, 2000	Design report for San Rafael substation complete and concept review meeting held with PG&E Construction, Engineering, and System Protection Staff. Relay logic and drawings for San Rafael substation are reviewed.
March 1, 2000	Proof of concept test completed at the vendor's site with staging of proposed relay and communication devices connected for San Rafael system. PG&E Construction and System Protection personnel are on site to observe testing.
April 25-27, 2000	Training at PG&E training facility for Operations, Maintenance, Construction, Protection, and Engineering groups using a simulator panel with relays and logic processor.
May 2000	First PG&E transformer capacity project tested and commissioned - San Rafael Substation.

TRAINING

Training on the new system was scheduled between the installation and commissioning of the system. The training was directed to three different audiences.

The first session was directed to protection engineers and substation engineers regarding the settings, setup of the system, and how to confirm testing and system operations.

A second session was directed to the operating department responsible for the three new substations. Operator training included capabilities of the system, and how to read and interpret the relay alarms and targets. The training also covered a description of operation for the three automatic reclosing systems.

Lastly, a training session targeted to the local maintenance group regarding system alarms, inputs and outputs, and troubleshooting and event retrieval was completed.

FUTURE EXPANSION

One of the criteria for the new system was future expansion. Could a new system meet existing requirements and be expanded for future applications. The RLC system provided many opportunities for expansion:

- The system can add more relay terminals.
- Only about 65% of the PLP logic is used.
- The system could connect multiple PLPs.
- The system could cross station boundaries and incorporate multiple stations using a communication channel.
- The relay protection logic is available for power system protection functions.
- Additional lights, alarms, and input functions are available using an optional I/O device.
- An HMI could be developed to match standard company HMIs for the virtual test panel.

CONCLUSIONS

PG&E, in order to improve reliability and reduce costs, considered a new approach to their proven PLC automatic substation restoration system. Because of project time constraints engineering service companies were asked to propose solutions. A PLC, an RTU, and the new RLC system were considered. The RLC system was chosen.

1. Installation costs were reduced.
2. Maintenance costs were reduced.
3. The system reliability was increased.
4. The projects met schedule.
5. The testing functionality was maintained and improved.
6. The system monitoring was improved.
7. Troubleshooting was simplified.
8. The system has future expansion capabilities.

For Further Consideration

Because of the success of this system, it should also be considered for other applications. Some possible applications include but are not limited to the following:

- Remedial Action Schemes
- Load Shedding Schemes
- Protection Interlocking Schemes
- Consolidating SCADA, Protection, and Substation Automation

References

[1] Farajollah Soudi, Edward A.Taylor, "Reclosing Practices – Pacific Gas & Electric Company," Proceedings of the 19th Annual Western Protective Relay Conference, Spokane, WA., October 20-22, 1992

[2] John J. Kumm, Edmund O. Schweitzer, III, and Daqing Hou, "Assessing the Effectiveness of Self-tests and Other Monitoring Means in Protective Relays" PEA Relay Committee Spring Meeting, Matamoras, PA, May 25-26, 1995.

[3] David J. Dolezilek, "Choosing between Communications Processors, RTUs, and PLCs as Substation Automation Controllers" Schweitzer Engineering Laboratories, Inc. white paper, October 17, 2000.

[4] Jeff Roberts, Armando Guzman, and Larry Gross, "Making Trip Circuit Monitor Logic with SELOGIC™ Control Equations" Schweitzer Engineering Laboratories, Inc. Application Guide, AG96-08, 1996.

BIOGRAPHIES

Bernard S. Tatera , Jr., P.E.

Bernard received his B.S. degree in Electrical Engineering in 1986 from California Polytechnic State University San Luis Obispo, CA and a M.S. degree in Electrical Engineering from Santa Clara University, CA in 1995. He started his career with PG&E in 1986 and has held various positions including Protection Engineer, Senior Protection Engineer, Supervising Protection Engineer and Senior Automation Engineer. From 1993 to 1997 Bernard worked for the Sacramento Municipal Utility District, Energy Operations department in the area of System Protection and Control. His recent assignments since his return to PG&E in 1997 have included the testing and programming of Substation Automation projects and he now works as a Consulting Engineer in the System Automation group of PG&E. Bernard is a Registered Professional engineer in the State of California and is a member of IEEE Power Engineering Society.

Lawrence C. Gross, Jr., P.E.

Larry received his B.S. degree in Electrical Engineering from Washington State University in 1992. He worked for Pacific Gas & Electric Company from 1992 until 1995 as a Transmission System Protection Engineer. Larry joined Schweitzer Engineering Laboratories, Inc. (SEL) in 1995 as an Application Engineer. He provided technical training and technical support for customers. Assigned to development teams, he wrote instruction manuals, directional element functional tests, and differential relay acceptance tests. In 1997, Larry started the engineering services department at SEL providing specialized project support to consultants and utilities. Most recently, Larry founded Relay Application Innovation, Inc. to provide electric power system protection applications, analysis, and training. He has performed services for a relay manufacturer, utilities, and design consultants. Larry has written several application guides and a technical paper about power system protection, monitoring, and control. He is co-author of a patent that is pending regarding protection against slow circuit breaker closures while synchronizing a generator. As a representative of SEL, he served on the Executive Board for the Advisory Council of the Electrical and Computer Science department of Washington State University. Larry is a registered Professional Engineer in the states of Washington and California, and is a member of the IEEE Power Engineering Society.