Improved Service Reliability for Rural Electric Customers – Innovative Auto-Restoration Following Loss of Primary Source Interconnection

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***Abstract*—Plumas-Sierra Rural Electric Cooperative (PSREC) has two interconnections with large investor-owned electric utilities. Presently, PSREC normally operates solely connected to the Pacific Gas and Electric (PG&E) system via a radially fed line. This connection to PG&E is subject to service interruption for events on the PG&E line or connecting facility. Loss of this PG&E interconnection drops the entire PSREC customer load. An alternative service interconnection is available with Sierra Pacific Power Company (SPPCo) on another part of the system. However, this alternative source does not have the capacity to carry the entire PSREC customer load.**

In an effort to increase the reliability of PSREC's service to its customers, future enhancements will allow the system to operate with PG&E and SPPCo in parallel, a project PSREC dubbed Marble Live. In addition, PSREC decided to implement an auto-restoration scheme based on scenarios that require PG&E to interrupt service to the PSREC system. In the case of an event on the PG&E line, PSREC will automatically island its system and execute a series of steps to reconnect to PG&E, should conditions permit, or remain disconnected from PG&E and connect to SPPCo after shedding the appropriate amount of load.

This paper describes the system protection and control scheme solution that PSREC incorporated to accomplish a system restoration that satisfies the demands of both PG&E and SPPCo while increasing the reliability of service to PSREC's customers. Audio tone direct transfer trip equipment, IEC 61850 GSSE, also known as UCA GOOSE, messages among geographically diverse locations, and spread-spectrum radio among directional relays provide communication among substations, while the restoration logic resides in communications processors at each substation. The combination of protection elements and communications equipment initiates selective load shedding and restores power from the alternate power source to as many retail customers as possible.

I. Introduction

Plumas-Sierra Rural Electric Cooperative (PSREC), like most other utilities, continues a yearly cycle of upgrades and updates to its ever-changing system. The cooperative, located in rural northeastern California, has been experiencing an increase in its retail customer base as well as developing industrial customers. This recent expansion and a little foresight led PSREC to begin planning the initial stages of major system improvements to ensure continued quality and reliability for its customers. The first of these improvements came in March 2004, when PSREC launched its first SCADA system and incorporated six of its 13 substations into the scheme. This scheme included an HMI that displayed analog values, target status and breaker operation history information, as well as remote breaker control capabilities, and remote engineering access. This new control center provided PSREC with flexibility, a greater sense of system control, and a broader view of its system.

This project, while necessary, simply acted as a stepping stone toward addressing the real need and desire of PSREC: increased system reliability and robustness. As of June 2006, PSREC was being fed solely from Pacific Gas and Electric (PG&E). While this relationship has worked well since the creation of PSREC, PSREC had considered the idea of establishing a permanent connection to its eastern neighbor, Sierra Pacific Power Company (SPPCo). PSREC can connect manually to SPPCo for purposes of carrying load in the event that the PG&E line providing power to PSREC becomes unavailable, but the SPPCo line is not rated to carry the entire PSREC load. The SPPCo line can only service half of PSREC's residential customers.

From PSREC's standpoint, the goal of the new scenario would be to have immediate access to an alternate source of power, should the primary connection be compromised in any way. PSREC needed an automated scheme under which unavailability of the primary source (PG&E) would initiate logic to trip and close breakers, as necessary, to restore power to as many residential customers as possible in the shortest time possible.

A permanent connection to SPPCo would leave PSREC running PG&E and SPPCo in parallel across the PSREC service area. This proposition caused both PG&E and SPPCo some concern from a system stability standpoint. While this paper addresses concerns from each company and relates how PSREC alleviated these concerns, it does not go into detail on the technical side of the system and scenarios that could affect stability.

In this paper, we examine the PSREC system to provide a logistical understanding of how each party is involved. We provide context and background for the decisions regarding the planned system scheme logic and communication meth-

ods. We also discuss PG&E and SPPCo concerns to identify the basic outline around which PSREC plans to form the system logic.

II. PSREC Overview

Located in northeast California, PSREC services a roughly 30 MW load over 1,000 square miles. This service area consists of 13 substations with a mix of residential and industrial customers. For the purposes of this paper, we concern ourselves mainly with two substations within PSREC's system: Quincy and Marble, with a third substation, Beckwourth, also playing a role.

PSREC has no generation, so PG&E feeds PSREC from the west through the PSREC Quincy substation. The Quincy substation steps up the PG&E 60 kV source to 69 kV to feed the PSREC system. As this paper discussed previously, PG&E is the primary source to the PSREC system, so the Quincy substation is a mission-critical substation; any problem that occurs at Quincy will likely affect the rest of the system.

Marble substation resides on the east side of the PSREC system. Marble stands as the gateway to the SPPCo system. A 60 kV line from Sierra Pacific already runs into the Marble substation. The closing of one normally open breaker would enable SPPCo to feed PSREC. This connection, reserved until now as an emergency tie, along with the PG&E connection at Quincy are our primary areas of interest in discussing the implementation of the remedial action scheme (RAS). Fig. 1 provides a simple one-line diagram that will help us visualize the important elements of the system.

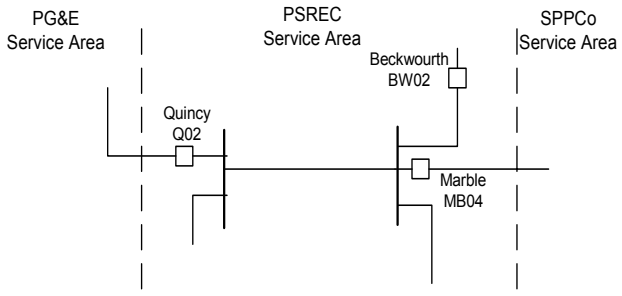

Fig. 1. Simple PSREC One-Line Diagram

Beckwourth substation is at the north side of the PSREC system. While the Beckwourth substation is not an integral part of the PSREC system, it becomes important in terms of the scheme to be implemented. As the paper discusses later, opening of the Beckwourth breaker, BW02, becomes instrumental to successful scheme execution, in the event that the RAS operates.

III. PG&E and SPPCo

Because the PSREC system upgrade will directly impact the systems of PG&E and SPPCo, it is worth noting the concerns of each utility. To satisfy PG&E and SPPCo conditions, PSREC implemented a protection scheme consisting of over-/underfrequency protection, over-/undervoltage protection, overcurrent protection, and loss-of-phase protection. The goal is not only to ensure the safety and reliability of the benefactor's utilities, but also to prevent PSREC from becoming merely a fuse connecting the two control zones.

The main concerns of PG&E centered on the idea that PSREC must disconnect from PG&E should any one of a specific number of events occur within the PG&E system or on the line entering the Quincy substation. More specifically, PG&E required that certain events on its own system would result in a direct transfer trip signal to the Q02 breaker at Quincy, thereby effectively isolating PSREC from PG&E.

Realization of the scenario discussed above would directly impact the SPPCo line entering the Marble substation once the parallel connection is established because the SPPCo line is not rated to carry the entire PSREC load. In the best interests of SPPCo and PSREC, a direct transfer trip signal from PG&E to the Quincy breaker Q02 will cause the breaker protecting the SPPCo source, Marble breaker MB04, to open immediately to avoid an overload on the SPPCo line. MB04 can then close after an appropriate amount of load shedding and various other system conditions are met.

Other details upon which all parties agreed are beyond the scope of this paper. What is important to note, however, is that the PSREC, SPPCo, and PG&E agreement states that unavailability of the PG&E line will cause PSREC to also sever the SPPCo connection, until adequate load has been shed to ensure the SPPCo line will source PSREC within its rated capacity.

IV. System Architecture

Following establishment of a brief description of requirements to which the three parties associated with the project agreed, PSREC began designing the overall effort to incorporate a RAS into its system. At this point, PSREC enlisted the help of engineers at Schweitzer Engineering Laboratories, Inc. to develop the logic and communication scheme. Before the logic could be finalized, there was considerable debate regarding the system architecture and careful consideration of performance needs, available infrastructure, and budget.

With the basic logic set on paper and an overriding philosophy on how to design the system, PSREC then had to choose the method of communication and the protocol that would deliver the information. Most schemes of this nature take advantage of such low-cost, higher-reliability communication solutions as spread-spectrum radios. For one particular function unassociated with the RAS, PSREC did decide on this method of communication. The entire system could have used this communication option if it were not for inherent geographical limitations of such technology. The two main stations involved in the scheme are separated by a distance of only 20 miles, but within these 20 miles lays the beginning of the Sierra Nevada mountain range. Spread-spectrum radios work well only in applications where nothing impedes line of sight, however the same cannot be said when a mountain range exists between the two locations.

There exist a number of other methods PSREC could have used to solve the communication dilemma: dedicated fiber line, power line carrier, and audio tone direct transfer trip. These are all highly reliable, high-speed communication

methods. While such technologies deliver rock-solid performance, they are also considerably expensive. While considering justifications for such expenditure, PSREC decided to analyze the use of an existing, less proven communication system as a cost-saving measure. The obvious question was how adverse an effect a total or partial failure of the communication infrastructure would have on the system should an event occur while communications are unavailable.

The problem was solved by implementing reliable local backup based on conventional protection techniques. As the preceding section described, in the event a communications failure causes the RAS to misoperate, proper setting of undervoltage protection elements to sense a system voltage collapse places the system at minimal risk. PSREC thus considered it acceptable to take advantage of a less proven method of communication, albeit one that was already in place and functioning well for the past year: an Ethernet network supplied and maintained by a commercial service provider.

Having decided to rely on Ethernet communication, PSREC next needed to choose the protocol that would allow it the best performance for the situation. For obvious economic reasons, it was also important that PSREC make use of existing equipment and service agreements already in use at the PSREC substations.

Given the existing equipment already in use at each substation involved, PSREC needed to consider several factors as well as the following philosophies in developing the system architecture:

- Minimize communication between substations
- Keep logic as centralized as possible
- Design logic to execute for a finite period of time and then exit with no pending control commands
- Enhance system security

We will consider each bullet point in order. With the inherent uncertainties of the service provider-based Ethernet communication, designing the scheme with the fewest number of data transmissions over the network becomes a top priority. Limiting the number of transmissions initiated throughout the RAS operation is undoubtedly the best policy. One simple way to ensure minimal network data transfer is to centralize the logic within one specific IED or relay such that this IED makes all necessary decisions and then issues controls as required. Most real-world implementations will most likely involve scenarios where the logic in its entirety cannot reside in one IED. There should be reasonable efforts, however, to accommodate this ideology whenever possible. Moreover, when the logic asserts, it is also important that, regardless of outcome, the logic terminates after a given time. This is to say that, should something within the logic not operate according to plan, there should never be a standing trip or close remaining on the breakers involved in the scheme. After a given time, the logic must become inert and incapable of performing any preexisting control function. Taking the above design ideologies into account, we developed three choices with which we could implement our logic for the RAS scheme.

1. Performing the logic within the relays executing the controls.
2. Performing the logic within communications processors (CPs) that reside within each station and issue controls to the affected relays.
3. Performing the logic within the SCADA system.

Looking at these options separately, it became obvious that the second option was best. To perform the logic within the relays would have required that the protective relays involved in the process be upgraded with more capable communications. To perform the logic within the SCADA system would work but would also provide the slowest performance.

When diagramming the logic and the communication path, we saw that centralizing the logic within the CPs was the most efficient method. In our discussions and reviews, we noticed that the CPs acted as the main hub of information. It therefore made the most sense to use CPs to perform the logic and store the information internally rather than wait for relays to perform the logic and transmit results back to the CP.

Revisiting our decisions to this point, we chose Ethernet as the means of communication and CPs as the hardware performing the communication. Given these two decisions, one final important decision remains. What protocol should be used to communicate over Ethernet?

Given the application, the appropriate protocol seemed to require nothing more than transmitting status between the CPs and then relying on the CPs to issue the appropriate controls based on the status received. IEC 61850 GSSE messaging seemed the perfect choice. Not only was this protocol designed specifically to transmit binary state information; it was also designed as a high-speed device-to-device message.

V. IEC 61850 GSSE Messaging Overview

For background on the evolution of IEC 61850 GSSE messaging, or GSSE messaging, we begin with its parent, Utility Communication Architecture (UCA). A simple overview can provide context to those unfamiliar with the standard. UCA began in the early 1990s as a way for utilities to combine and consolidate communications among their various autonomous departments. Ideally, those within one department could collect, interpret, and analyze data in the same manner as those in another department. Operations, metering, and distribution, for example, could all use the same communications. Shared communications was to create a sense of uniformity throughout a system and, in theory, prove to be a cost-effective alternative to integrating several protocols throughout the system.

In creating the standard, UCA architects determined that they wanted to implement high-speed (4 ms) direct messaging of state-change information from one device to several devices. To meet such a stringent self-imposed timing requirement, UCA architects developed multicast messages. Simply stated, the UCA architects' solution was to broadcast to the entire network a message that all devices could receive, provided that the receiving devices subscribed to the particular sending device and its message.

Refer to Fig. 2 for further illustration of the concept. Each device has outgoing messages that it will broadcast when the state of the element assigned to the message changes. When,

for example, the 52A contact changes state in Device1, Device1 broadcasts Msg1 to the network. Msg1 contains information that the 52A contact has changed to either a high or low state. Once Device1 broadcasts the message, all devices that subscribed to Device1: Msg1 (both devices in Fig. 2) can use the information in the message as needed.

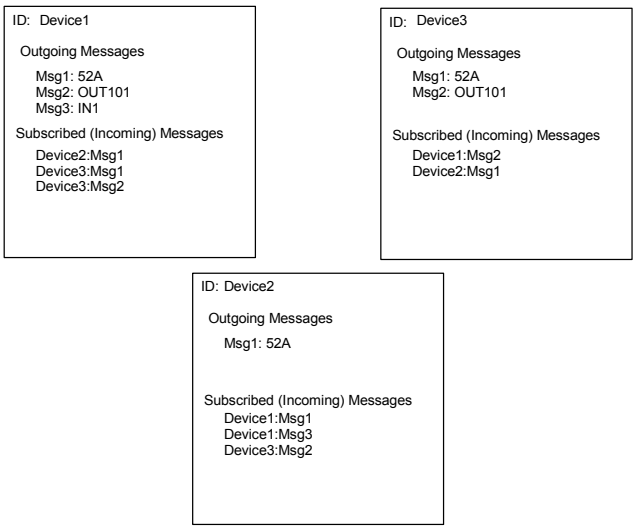

Fig. 2. GSSE Device Publisher/Subscriber Illustration

Device1 broadcasts the change of state periodically, where the time between the initial broadcast of the message and subsequent rebroadcasts is based upon a decaying exponential function. Device1 broadcasts the message (the state change) several times within the first second of the initial state change and then broadcasts the message less and less as time progresses. Fig. 3 displays a screen capture from a network analyzer tool of a GSSE message transmission.

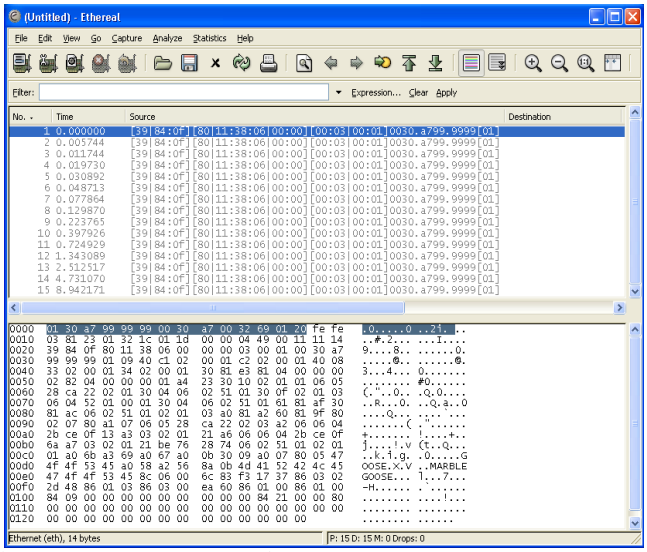

Fig. 3. GSSE Message Network Capture

As we can see in Fig. 3, the initial message is broadcast (at time 0.000000 under the "Time" column in the upper half of the screen capture) and, within the second, broadcasts an additional 10 times before trailing off. This flood of messages is attempting to deal with the fact that recipient(s) do not send an acknowledgment of successful message receipt back to the sender. As part of the operating characteristics of GSSE messaging, sending devices retransmit messages in the absence of an acknowledgment from a receiving device.

After reviewing PSREC's network configuration, an interesting setback involving limitations of PSREC Ethernet network configuration was discovered. While the Marble, Quincy, and Beckwourth substations are networked together, they are configured as part of a wide-area network (WAN) connected via a leased line frame relay service with routers used to split the network into multiple segments. At the same time, the UCA/IEC GOOSE message was not originally intended to work within a WAN environment, and was supposed to be contained within the substation local area network. More specifically, GSSE messaging is not inherently capable of being broadcast over a WAN. Messages are transmitted on layer 2 of the OSI stack and are therefore not routable. Considering that the network, as was configured, cannot use GSSE messages, PSREC had the following options.

- Reconfigure the network to accommodate the needs of GSSE messages.
- Replace GSSE messages with a different means of communication.

In order for the network to be modified to enable the passing of GSSE messages from station to station, PSREC would need to upgrade the networking equipment within each substation to include a router with Layer 2 Tunnel Protocol (L2TP), Generic Routing Encapsulation (GRE) or a similar tunneling protocol capable of transmitting Layer 2 messages.

L2TP is an offshoot of PPTP (Microsoft®) and L2F (Cisco®) protocols and is widely used in the creation of virtual private networks (VPNs). As the name implies, L2TP is nothing more than a protocol that allows routers to create a tunnel across a wide area network. More specifically, once the tunnel is created L2TP passes layer 2 (application layer) packets between the endpoints of the tunnel, which enables the transmission of GSSE messages.

The benefits associated with PSREC reconfiguring for a network upgrade was two-fold. Not only would they be getting the speed benefits of using GSSE messaging for their RAS, but would also be introducing a major upgrade to the security of their SCADA system in the form of a VPN. It is important to note a distinct difference and tradeoffs between privately owned communication infrastructure and the use of a commercial service provider. Each approach has its inherent set of advantages/challenges that must be properly understood in order to meet particular system objectives. In small installations, the commercial system provider approach will often be more cost effective and may provide lower cost of ownership (lower system maintenance and faster time of repair), but will often be associated with clear demarcation of responsibility (inability to modify the core network device settings in order to accommodate special needs), service level agreements (inability to give priority to special types of traffic), and the need to provide additional layers of security (security perimeter) necessary to prevent all unauthorized access attempts.

PSREC recognized the importance and value of upgrading the substation network to accommodate an intersubstation

VPN and implementing L2TP technology to permit the use of GSSE messaging.

However, PSREC was also interested in a temporary solution that could be implemented immediately. As the Marble Live project neared completion, PSREC decided that employing a temporary solution would allow the project to progress while giving them the flexibility to upgrade the network as part of the next stage of the project. As such, the SCADA system was chosen to host the RAS in the interim. By using the SCADA system, PSREC would be able to implement and test the developed RAS logic immediately and proceed with the rest of the project as planned. While the SCADA-implemented RAS will not operate as quickly as the GSSE message-based RAS, it is an effective temporary alternate for the GSSE-based scheme.

VI. Ethernet and Mission-Critical Goals

Ethernet communications have improved constantly over the years to meet consumer-driven demands. Such refinement and greater predictability have resulted in large part from the development of several enhancements, including the following:

- Gigabit port speeds
- Collision-free traffic operation
- Traffic prioritization
- Traffic segregation

While this list is by no means inclusive of every Ethernet enhancement, it offers a glimpse into how Ethernet is becoming more predictable, faster, and more reliable. These recent enhancements go largely unnoticed by the common user. Further explanation of just one previously listed enhancement, traffic prioritization, is beneficial in visualizing how these enhancements have improved Ethernet performance.

IEEE specification 802.1p has implemented traffic prioritization, whereby compliant switches within a network can prioritize traffic under eight categories of urgency. IEEE 802.1p is a subset of the IEEE 802.1Q standard that deals with virtual local area network (VLAN) tagging (another recent Ethernet enhancement, segregation, but beyond the scope of this paper). Fig. 4 shows an Ethernet frame with an IEEE 802.1Q tag. Note the TPID and TCI blocks; these are the two blocks that concern IEEE 802.1p specification.

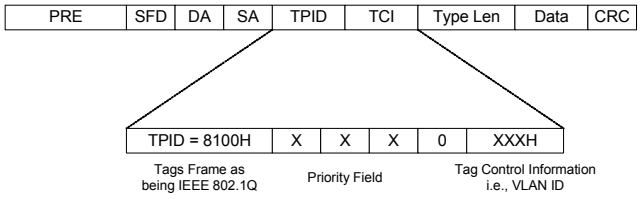

Fig. 4. IEEE 802.1Q Ethernet Header

To provide an idea of the speed at which Ethernet using IEEE 802.1p prioritization can send messages, we can do a few rough calculations to obtain a worst-case scenario. In the case of PSREC, we consider that a high-priority transmission, in this case a GSSE message, will pass through two network switches, each with an approximate latency of 10 μs. We assume worst case that an Ethernet frame is in the process of being transmitted when the GSSE message arrives. An Ethernet frame of maximum size (1526 bytes) at 100 Mbps equals a delay of about 122 μs before the next message can be processed. Assume also, for the sake of argument, that there are already 10 pending high-priority messages in queue. A typical GSSE message is 300 bytes, which works out to 24 μs per message. Table 1 sums up the delays and latencies.

TABLE I
MESSAGE TIME WORST-CASE SCENARIO ESTIMATE

Switch 1 latency	10 μs
Switch 2 latency	10 μs
Frame in progress	122 μs
Pending high priority messages	240 μs
GSSE message in question	24 μs
Total	406 μs

From this estimate we see that, even in somewhat extreme circumstances, the GSSE packet in question still gets transmitted in less than half a millisecond. This demonstrates that, compared to traditional Ethernet methods, in which the GSSE message is exposed to collisions (hub-based designs) or must wait its turn in a single queue (switch-based design without priority tagging), we can now assign importance to network traffic and ensure transmission of critical information as soon as it becomes available. Additional versatility can be made available through use of the Virtual LAN (VLAN) enhancements present in the IEC 61850 GSSE implementation.

VII. The Scheme

The basic scheme was fairly simple and took the following form:

1. Quincy receives transfer trip signal, trips breaker Q02
2. Marble receives indication of transfer trip at Quincy, opens breaker MB04
3. Scheme waits five minutes for Quincy to restore
4. If Quincy restores, logic ends (MB04 must be closed manually)
5. If Quincy does not restore, Beckwourth receives indication and opens BW02 to shed the necessary load
6. Marble receives indication that BW02 is open and closes MB04 to restore the remaining load

Intermixed with this basic logic are several layers of system checks. These verify that potential exists at certain points within the system and not at others, that breakers are still closed, etc. The checks help ensure that the system is available at each step of the process. To illustrate how we used GSSE messaging to accomplish these checks, we focus on the Marble substation, where the majority of the action occurs.

Before we examine the logic behind the operations at the Marble substation, we first look at how the communications processor uses scheme information and from where the information comes. Fig. 5 shows the GSSE subscription information.

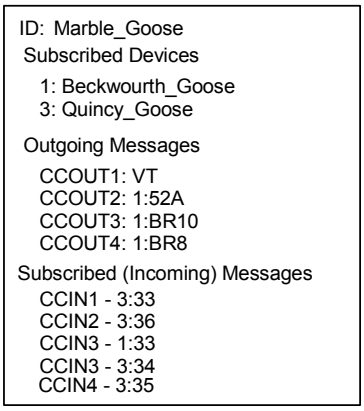

Fig. 5. Marble Station GSSE Subscription

The Marble communications processor is labeled as Marble_Goose and it subscribes to GOOSE messages from device 1: Beckwourth_Goose and device 3: Quincy_Goose. We explain later the importance of distinguishing the devices as 1 and 3. The Marble CP is broadcasting GOOSE messages based on state changes of four points: CCOUT1 through CCOUT4. CCOUT1 through CCOUT4 are internal identifiers for the devices and correspond to the standard nomenclature of UserST bits 33 through 36 (Note: UserST bits are the standard identifiers within the UCA standard for user-assignable status bits). Table 2 shows the relationship.

TABLE II
USERST BIT TABLE

Device Label	**UserST Bit**
CCOUT1	33
CCOUT2	34
CCOUT3	35
…	…

The UserST bit label is 32 greater than its corresponding CCOUT label, because the first 32 UserST bits are reserved for predefined functions. UserST bits 33-xxx are open for use as any function. In the case of the Marble substation, CCOUT1 (UserST Bit 33) is defined as the timer variable V within the device. Any time that this timer variable changes state, CCOUT issues a new flood of messages to the network, similar to that captured in Fig. 3, to inform any subscribed devices of this change of state. Likewise, the 52A contact of the device on port one of the CP and breaker bits 8 and 10 of the same device trigger similar messages for changes of state.

The subscribed messages portion of a GSSE message defines incoming messages (CCINs). Marble subscribes to GSSE messages from two devices based on the state change of points. These five points provide the information in Table 3 to the Marble communications processor:

TABLE III
CCIN ASSIGNMENTS

3:33 (CCIN1)	Quincy TT Signal
3:36 (CCIN2)	Quincy Q02 52A
1:33 (CCIN3)	Beckwourth MB04 52A
3:34 (CCIN4)	Quincy CP IN1
3:35 (CCIN5)	Quincy CP IN2

Whenever the above elements change state within their respective devices, the devices are programmed to broadcast the state change of that signal. The Marble CP is subscribed to receive these signals and uses these signals in its own logic. The following text explains in detail the operation of the Marble communications processor.

When the Marble CP detects that the Quincy TT signal, via CCIN1, changes state to high, the CP issues a trip command to breaker MB04 and starts a 6-minute timer (timer Y) and a 5-minute timer (timer V). Timer Y acts as an overall time limit for the logic to perform its programmed functions. After this timer expires, the logic resets and clears any standing trip or close still asserted in the system but unable to operate because of a system malfunction. Timer V acts as a delay to provide Quincy breaker Q02 a chance to reclose. Should conditions permit and Q02 recloses, the logic eventually times out. Any further action is disabled, and Marble breaker MB04 must be restored manually. If Q02 does not reclose after 5 minutes, the timer V, acting as a pickup timer, asserts and changes state. VT, in turn, as presented in Fig. 5, maps to CCOUT1 in the Marble CP. We thus make use of GSSE messaging again. Assertion of timer V acts as a signal to the Beckwourth station CP that the RAS scheme is in process and has reached the point where it must shed load before Marble can close back in and restore the remaining system. Notification that the timer has gone to a high state triggers the Beckwourth CP to issue an open command to breaker BW02.

From Fig. 5 and Table 3, we can see that Marble is subscribed to receive GSSE messages concerning the state of Beckwourth breaker BW02. Through use of this information, the Marble CP can determine when BW02 is open and whether it is safe to close MB04 and pick up the remaining load. Once the scheme has run its course, BW02 opens, and MB04 closes to pick up the remaining load, the Quincy line must be reestablished manually when it becomes available.

While the above description is not all inclusive of the entire scheme, it serves to display the effectiveness of using GSSE messaging. The logic went through several iterations and modifications, but eventually led to a design that satisfied all parties involved.

VIII. TESTING AND VALIDATION

In the interim period, while PSREC is planning their network upgrade, which will accommodate VPN-based security enhancements, and will be able to transmit GSSE messages between the substations, RAS functionality was implemented within the SCADA system. SCADA is configured to receive, (by exception polling), all of the necessary indications. The

SCADA system therefore became the central point of logic for the RAS. On the condition that certain values change state, the SCADA server runs script and sends the appropriate control function.

For example, when PG&E sends a transfer trip signal to the Quincy substation, the substation CP will detect this input. The input changes state, and the SCADA master polls this input during the next polling session. When the SCADA system detects that this input has asserted high, it is configured to automatically run a script that sends an open command to the Marble breaker MB04. While this solution does not match the speed of the GSSE message solution, it reacts quickly enough to make it a suitable temporary replacement for the GSSE message solution.

This solution was implemented and replaced all GSSE messages originally intended for the remedial action scheme with status points to the SCADA system and scripts within the SCADA server that initiated commands to the appropriate relays.

Following RAS modification, the system was tested. After a thorough test of the scheme under several different scenarios, PSREC was confident it had created a system that functioned exactly as needed. While the method by which the scheme operated is only a temporary solution, the modification necessary to compensate for the shortcomings of current communication system topology was successful.

IX. Results

The results obtained from the temporary system were less impressive than preliminary results from the same scheme communicating with IEC 61850 GSSE messaging. To show the benefits of both communication methods, we juxtaposed results from the actual system implementation using the SCADA system with those of the test results from a GSSE messaging scheme over a basic LAN setup in a lab environment.

Fig. 6 shows the results of a GSSE messaging test. The test included two CPs, each connected to a relay, networked together on a LAN. The process begins with remote bit 1 being set to a logical one. This triggers transmission of a GSSE message to the other CP, which sets the relay remote bit 1 to a logical 0. This in turn causes broadcast of another GSSE message, which sets remote bit 1 in the first relay to a logical 0. The cycle then repeats, with GSSE messages toggling remote bit 1 on each relay.

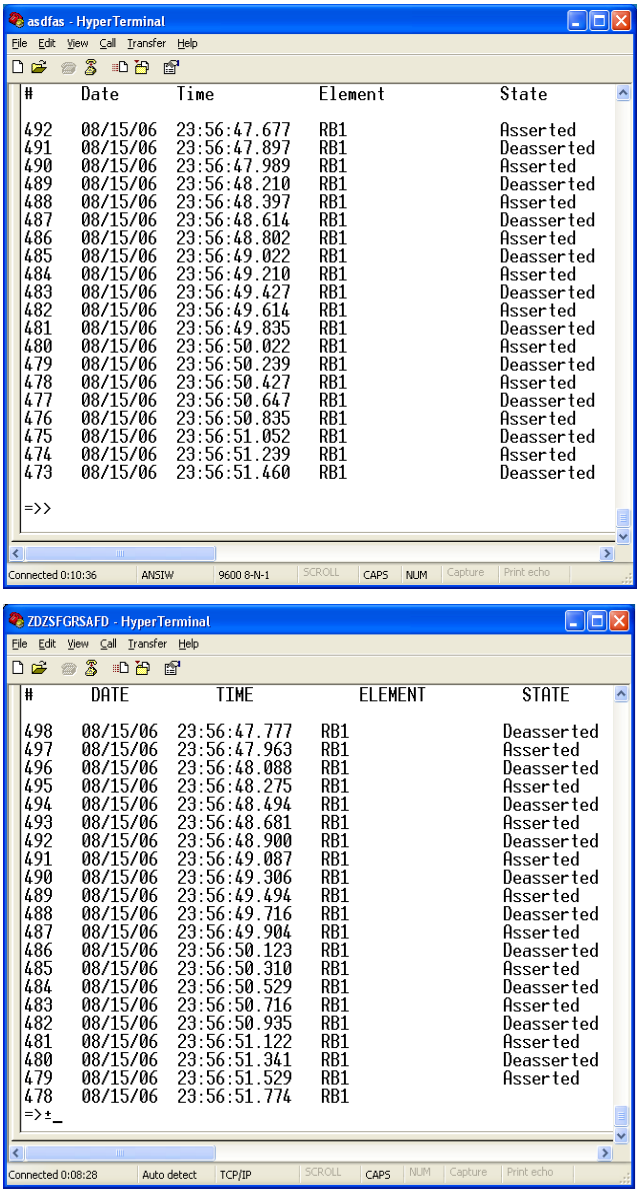

Fig. 6. GSSE Message Time Test

Beginning with the first screen capture, if we look at event 492, we see that RB1 asserted at 23:56:47.677. The first CP issued the GSSE message at this time, and the second CP, upon receiving this message, issued a command to its associated relay at 23:56:47.777. Setting remote bit 1 to a logical zero in the second relay causes rebroadcast of the GSSE message the first CP received. The first CP then issues a zero to remote bit 1 for its relay, and the cycle continues. This creates a cyclic repetition effect illustrated in the Fig. 6 screen captures. If we examine the above figure closely, we can see that response time from relay to relay averages about 100 ms. This is the time it takes for the system to detect a state change and broadcast a message, for a CP to receive the message and issue a control to a relay, and for the relay to detect the state change from the issued control.

Fig. 7 shows the speed of the implemented logic using the SCADA system to detect a change of state and issue a control.

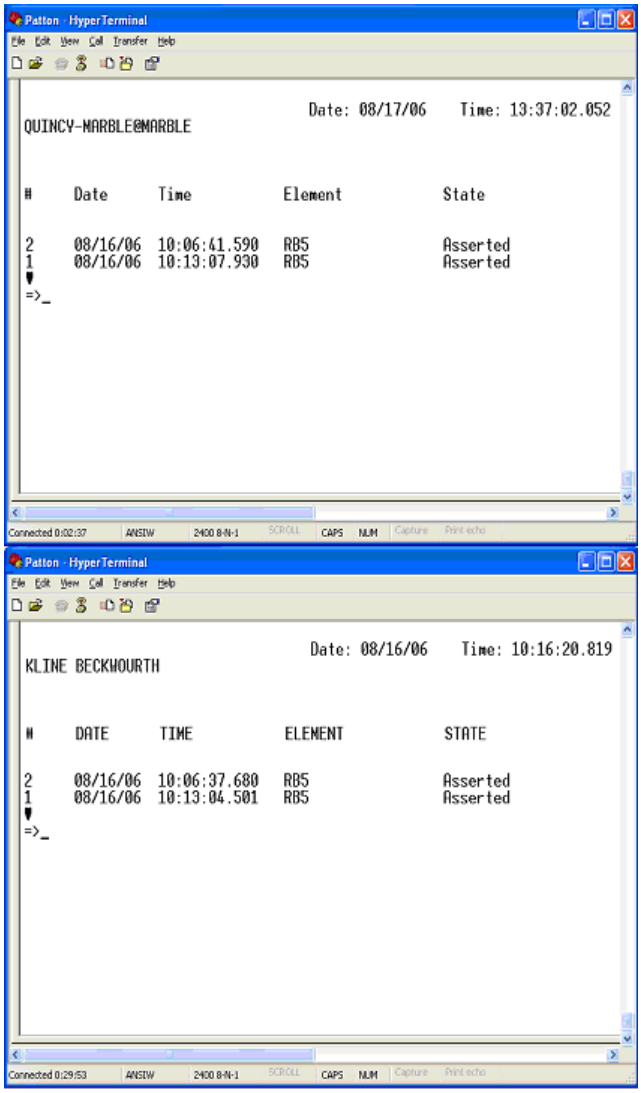

Fig. 7. SCADA Time Test

In this test, we set a remote bit in a relay, and when this change of state occurs, it causes a script to be run in the SCADA server that issues a control to another relay setting a corresponding remote bit. Both points were included in the SER for each relay, giving us an accurate time stamp of the event. As we can see, the SCADA system reacts much more slowly to the situation. Looking at event one and two on both screen captures above, a 3.5–4 second delay exists from the time remote bit 5 at Beckwourth substation is asserted to the time the SCADA system detects this change of state and issues a command to assert remote bit 5 at Marble substation. However, PSREC was still satisfied with the result and decided that using the SCADA system to implement the logic was an acceptable, albeit slower-speed alternative.

X. Conclusions

The first phase of a project to provide PSREC with a system restoration scheme that satisfied both PG&E and SPPCo and increased reliability of service to PSREC customers was successfully completed by implementing a communication based Remedial Action Scheme. The scheme was further backed up with a conventional protection system offering reliable local backup based on locally measured voltage / current quantities. The SCADA-server based solution is expected to serve as a temporary solution and will remain in place until the new routers capable of providing VPN security enhancements and L2TP can be installed in each station. While the upgrade to the network was not originally planned, PSREC realized that it serves multiple purposes: the ability to run the RAS using the quicker IEC 61850 GSSE messaging as well as increasing the overall security of the substation network.

XI. References

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XII. Biographies

James W. Rice graduated from Cal State Northridge in 1975 with a Bachelor of Science Degree. After graduation he spent the next 13 years as Captain of Engine Companies and Helicopter Operations for the local Fire Department. He went to work for Plumas-Sierra Rural Electric Cooperative 19 years ago as a Meter Reader and has progressed to Manager of Technical Services in charge of the Meter Department and Substations.

Samuel H. Fulford earned an Associate degree in Electrical Engineering Technology from Southern Technical Institute, Marietta, Georgia, a BSEE with honors from Florida Atlantic University, Boca Raton, Florida, and an MSEE (power emphasis) from the University of South Florida, Tampa, Florida. He began his career at Florida Power and Light Company, Juno Beach, Florida, as a relay technician in System Relay Operations. He then held various other positions at FPL, including Lauderdale Plant system protection field supervisor, assistant area system protection manager with the Eastern Division System Protection Group, relay design principal engineer in Power System Engineering, protection and control engineering supervisor, and principal engineer in Transmission Operations. Mr. Fulford joined Schweitzer Engineering Laboratories, Inc. as a Protection Services Department supervisor in 2001. He presently supervises department engineers and projects, specifies and designs protection and control panels, prepares technical proposals, bids, and contracts, performs fault studies, calculates and validates customer relay settings, and provides both customer training and technical assistance. He is a member of IEEE and is a registered professional engineer in Florida, Washington, and Alberta, Canada.

Nicholas C. Seeley graduated from the University of Akron in 2002 with a B.S. degree in Electrical Engineering. After graduation, Nick began working at American Electric Power in Columbus, Ohio, for the Station Projects Engineering group where he focused on substation design work. In June 2004, Nick was hired at Schweitzer Engineering Laboratories, Inc. in the Systems and Services Division as an Automation Engineer where he has been involved in the development, design, implementation, and commissioning of numerous automation-based projects.

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