# Lessons learned from a multi-million dollar, state-of-the-art distribution automation system upgrade project at California State University Fresno

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## I. INTRODUCTION

This paper will provide insights into the planning, design, and execution of a major campus upgrade project at the California State University in Fresno, California. The project had the objective to replace an aging electrical distribution system with one that delivers a continuous supply of power to all of the campus facilities, regardless of the reliability of the utility feed to the campus. This objective was accomplished by delivering a multi-vendor turnkey automation solution including metal-clad switchgear, padmount switches with voltage and current sensors and motor actuators, transformers, relays, a Remote Terminal Unit (RTU) with Human Machine Interface (HMI), and communication devices. The system can be expanded easily to handle the future plans of the university.

Key elements of the upgraded electrical distribution system are the engineered-to-order Fault Location, Isolation, and Service Restoration (FLISR) and Loss of Voltage (LOV) automation schemes that ensure the continuous supply of power to all campus facilities. The automation equipment, such as relays, RTU, and communication devices, was chosen based on performance, support for open communication protocols like IEC 61850 with GOOSE (Generic Object Oriented System Event) messaging, and best fit for the application.

Another deciding factor for California State University Fresno was the seamless integration of best-in-class products from multiple vendors into one system. This included major milestones such as system engineering and testing, factory acceptance testing, training for operators, and documentation with the ultimate goal to eliminate any issues during the commissioning of the solution.

The intent of this paper is to share lessons learned with other potential end-users and provide helpful insights into issues to consider for distribution system upgrade projects in general.

## II. ABOUT CALIFORNIA STATE UNIVERSITY FRESNO

### A. Quick Facts

Founded in 1911, California State University Fresno (from here on referred to as “Fresno State”) is one of 23 campuses that belong to the California State University system. Since 1956 Fresno State has had its campus at its present location in Fresno, central California. The 388-acre main campus and its 1,011-acre University Farm are located in the northeastern part of the city, about 150 miles off the Pacific Coast, and about 200 miles from San Francisco to the North and Los Angeles to the South. As of fall 2015 Fresno State counted 24,136 enrolled students and 2,334 employees. Academic Schools and Divisions include Jordan College of Agricultural Sciences and Technology, Craig School of Business, and Lyles College of Engineering. The Fresno State Bulldogs athletics program produced famous athletes such as Derek Carr (quarterback for the Oakland Raiders), Paul George (small forward for the Indiana Pacers), and Trent Dilfer (former quarterback for the Tampa Bay Buccaneers).

### B. Challenges with Aging Electrical Infrastructure

The original electrical distribution system at Fresno State was installed when the campus was built in 1956 and had a source voltage of 4,160 volts. Overhead poles and lines carried the distribution network across the campus to supply energy to various areas on campus. About 10 years later, in the mid-1960s, the campus added an additional 12,000 volts underground distribution system which also included a separate circuit for redundancy purposes. The power feed for the entire system was provided by a nearby Pacific Gas and Electric (PG&E) substation. For the following 20-30 years this system served the energy needs of the growing campus well until it reached its capacity limits in the mid-1990s. By that time the campus had grown significantly and therefore created the need to incrementally connect new buildings to the electrical infrastructure. This was done without adding additional circuits to the system but rather using the existing, redundant circuit to supply the new buildings with power. At the time this temporary solution seemed fitting in order to save costs but would prove to be challenging in the future.

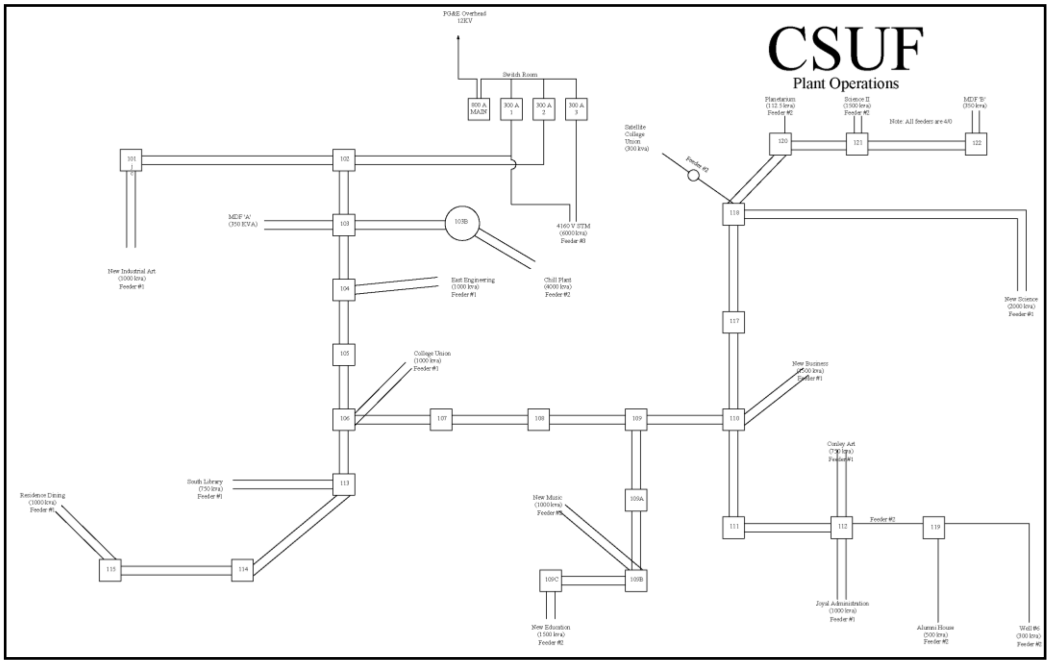


Figure 1: Old 12kV system at Fresno State

In the mid-1990s the electrical distribution system at Fresno State supplied over 60 buildings and was at maximum capacity. Even though the campus was continuously growing and donors were willing to finance new buildings, the university had to decline those offers due to the lack of capacity on their distribution system. Securing donation-based funding for an electrical infrastructure upgrade was difficult. Donors like to see their names on new, shiny buildings rather than donating money to an infrastructure which is mainly underground and nobody can see. The only solution feasible at the time was another temporary workaround which resulted in daisy-chaining new buildings to the power supply of existing buildings with smaller loads. Eventually the PG&E substation providing power to the campus reached its limits; subsequently no additional loads could be connected.

Over the past 15 years the Fresno State on-campus facility management team did their very best to keep the aging electrical distribution system operational but faced more and more challenges as time went on. Major outages, meaning more than half of the entire campus being without power, occurred on a somewhat regular basis every 6 to 12 months and affected daily operations, research projects, and critical loads such as the on-campus dairy farm. Outages lasted anywhere between 8 and 72 hours and were typically caused by failures of aging equipment such as cables, transformers, and switchgear. With no monitoring system or fault current indicators in place, locating a fault in the system to then eventually repair the damage and restore power was difficult and extremely time consuming. Additionally, the electrical distribution system had limited protection capabilities with electromechanical time overcurrent relays protecting the 12kV main and the three 12kV feeders. The relays were set to protect the cables from the distribution circuit breakers to the fused disconnect switches. As buildings were added and daisy-chained to the existing switches, neither the fuse ratings nor the relay coordination studies were adjusted accordingly.

Figure 2: Old 12kV main and feeders breakers with relays

In the event of an outage on campus, the field crew would have to wait for a phone call or other notification from affected parts of the campus to know that an outage had occurred. They would then go out searching the campus, literally looking for smoke to get an idea where the fault was. If there was no smoke visible, they would go to a few locations where they knew they could separate the wiring connections. Once the wiring connections were separated, the field crew would then start checking the power lines to see if they could determine which direction the fault was located. There was no option of re-routing power and supplying critical loads from an alternative source because the second, redundant circuit that was initially designed for this purpose had already been utilized to supply new buildings with power as described above. Operating and maintaining an unpredictable and unreliable system like this was not only challenging and time consuming but also a safety concern for the personnel. Proper training in the operation and maintenance of the old, existing 4,160 volt switchgear was missing mainly due to lack of knowledge transfer over the years. Dangerous situations occurred when the station power batteries failed so that the crew had to manually trip and charge the breakers, or when it would take several attempts to close the 12kV breakers, hoping they would hold up.

On January 1st, 2013 the university's main switch, which powers the entire campus, failed (see Figure 3). This catastrophic event took down both the 4,160 volt and 12,000 volt system which resulted in a campus-wide power outage lasting three days. The failed main switch was so antiquated that it was no longer available from the manufacturer and therefore had to be purchased off of eBay to be replaced as quickly as possible. In addition to other critical loads, the outage affected the Science Building and led to a loss of several years of critical research data. In order to prevent future losses of that nature, Fresno State purchased and installed a 450kW generator to supply emergency backup power for the research projects within the Science Building. However, this was only another temporary measure to increase the system's reliability.

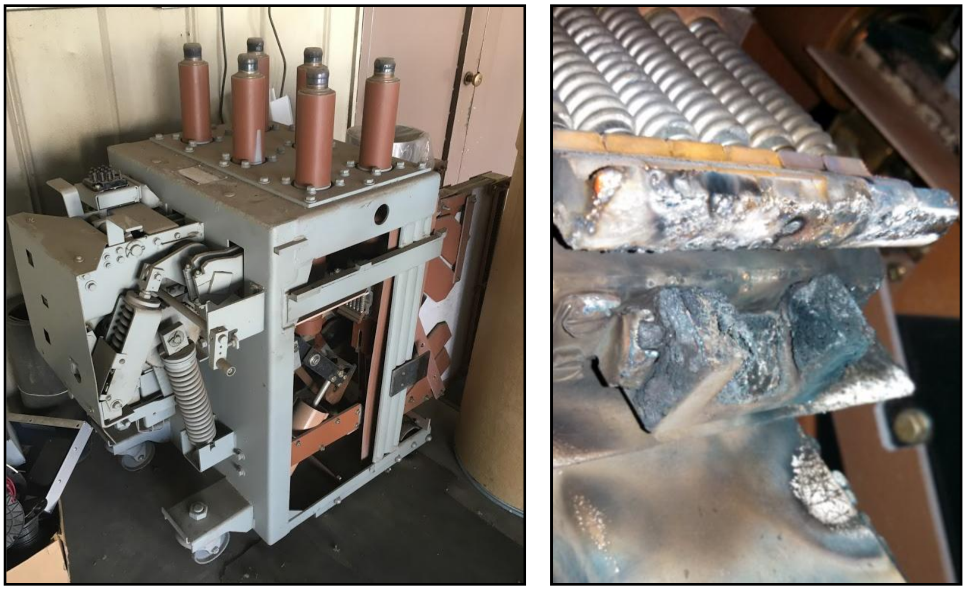

Figure 3: Old main switch with melted contacts

The most recent outage described above and the alarming rate of outages caused by age and fatigue of existing equipment eventually pushed for an upgrade of the over 60 year old electrical infrastructure that was well beyond its lifespan. A reliable and safe to operate electrical distribution system was considered crucial to provide continuous education at Fresno State.

## C. Goals for Upgrade of Electrical Infrastructure

Fresno State had several goals for the upgrade. The two most important goals were to significantly increase the reliability indices, such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) as defined by IEEE 1366, and to substantially improve operator safety. Another very important goal was the implementation of a future-proof solution with the ability to expand the system and accommodate the ongoing campus growth.

Significantly increasing the system reliability required an investment in state-of-the-art equipment including metal-clad switchgear, padmount switches, cables, transformers, and a Supervisory Control And Data Acquisition (SCADA) system. To meet and exceed ANSI and IEEE industry standards, the goals for the new system were to provide best-in-class quality, safety, and reliability with products backed by exceptional service and support. In order to restore power more quickly, achieve the shortest system reconfiguration times in the event of a fault, and improve operator safety, a remote monitoring and control system with a fast and robust communication infrastructure was specified. In addition, it had to be a future-proof, vendor-agnostic platform that supported fiber optic communication over IEC 61850 and that was capable of running Fault Location, Isolation, and Service Restoration (FLISR) and Loss Of Voltage (LOV) automation schemes.

This upgrade project needed to be a turnkey solution which had to be specified, designed, and coordinated by a consulting firm and installed by a contractor. A major milestone for the new system was the testing of every portion including a full factory acceptance test of the automation solution. All vendors and solution providers were asked to work together from the beginning to reduce and/or eliminate any problems during the commissioning of the equipment. With the delivery of the final solution, respective documentation and operator training had to be provided for Fresno State.

# III. STATE-OF-THE-ART DISTRIBUTION AUTOMATION UPGRADE PROJECT

## A. Design and Planning

In March 2014 Fresno State secured $30 million in funds through the California State University (CSU) Capital Improvement Program to upgrade the entire electrical infrastructure with a new 12kV distribution system. The project scope included site preparation, demolition and removal of existing systems, electrical equipment, electrical manholes, duct banks, site utilities, a new main campus switchgear building, and a campus-wide building metering system. Making a project of this magnitude a success required not only thorough planning and design but also a great amount of teamwork among the various parties involved during project execution. The list below includes the major parties and their respective roles in the project, with emphasis on the distribution automation portion.

- Fresno State University, Facility Planning and Plant Operations
  End user; defining overall requirements, providing input on existing infrastructure, making final decision on vendor/manufacturer acceptance
- P2S Engineering, Inc. ("P2S")
  Consulting firm; project specification, design, coordination, vendor/manufacturer evaluation and recommendation
- The Ryan Company, Inc. / Quanta Services Co.
  Contractor; planning, construction, and installation
- Power Systems Testing Co.
  Service provider; testing of cables, terminations, switchgear, and relay settings
- G&W Electric Co. ("G&W")
  Vendor; providing padmount switches, LaZer® automation solution including ABB bay controller relays and RTU
- ABB Inc. ("ABB")
  Vendor; providing metal-clad switchgear, relays, and RTU
- General Electric Co. ("GE")
  General contractor; purchase of ABB metal-clad switchgear

P2S Engineering specified and designed a 12kV loop feeder distribution system utilizing an ABB arc resistant, metal-clad switchgear lineup located in a new switchgear building and G&W padmount switches distributed across the campus. The design (shown in Figure 4) includes (2) main breakers and (5) sets of A/B breakers to feed (4) active distribution loops and one spare loop for future use. Besides the spare loop, the 12kV main substation also provides room for one more set of A/B breakers for even further system expansion in the future. The (4) active loops incorporate a total number of (32) padmount switches which are divided between the loops and connect (69) facilities across campus as follows:

Feeder loop 1 feeds (26) facilities on the West side of campus and utilizes (12) switches. Feeder loop 2 feeds (17) facilities on the Central/South side of campus and utilizes (7) switches. Feeder loop 3 feeds (24) facilities on the North/East side of campus and utilizes (11) switches. Feeder loop 4 feeds the central plant and the new switchgear building on the North side of campus and utilizes (2) switches. The total number of (32) G&W padmount switches are engineered to order and configured specifically for the application, resulting in a request for (13) 6-way switches, (11) 5-way switches, and (8) 4-way switches.

Responding to the upcoming campus upgrade, PG&E built a new substation and provided a new power feed to the campus in 2015. That required the installation of a 3-way vacuum interrupter switch to connect the new utility feed to the existing and new switchgears, which was especially important during building cutovers to the new 12kV distribution system.

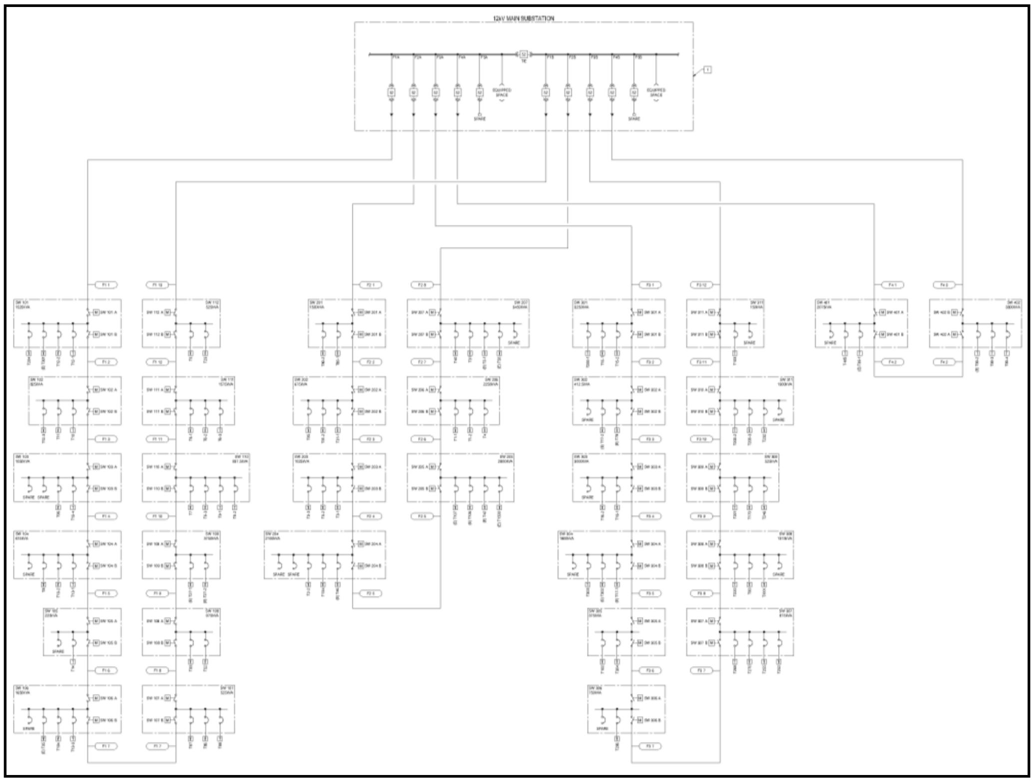

Figure 4: New 12kV loop distribution scheme

The specifications also included the system integration as well as automation hardware and software required for a complete and operational SCADA system. The SCADA system should monitor and control the 12kV loop feeder circuit breakers located in the main switchgear as well as the motor operated load interrupter switches located downstream in the loop feeder padmount switchgear. In addition, the system should monitor the 12kV feeder loops for short circuits and automatically isolate any portion of the feeder upon detection of a fault and reconfigure the loop to restore power to the portion of the loop unaffected by the fault. The system should also monitor the status of the 12kV switchgear breakers, the 12kV padmount switchgear fault interrupters, and the switchgear building auxiliary equipment such as DC power supply and sump pump alarms. This best-in-class loop automation solution will allow Fresno State to monitor and control the entire system remotely from one central location while communicating with the new switchgear and padmount switches.

In addition to those typical SCADA functions, the automation solution had to include advanced automation schemes such as FLISR and LOV to ensure the continuous supply of power to all campus facilities. The entire solution had to be fully redundant to achieve the goal of providing the highest level of reliability. A full factory acceptance test including the relays and screens for the Human Machine Interface (HMI) was required after the initial design and engineering and before the actual commissioning of the automation solution. This ensured that all requirements defined by Fresno State and P2S were met and that problems during the installation on site were minimized.

Another significant part of the design included the Ethernet communication infrastructure as the backbone for the automation solution. The specification called for a multi-mode fiber optic ring communicating IEC 61850, which is recognized as one of the best communication systems in the industry.

The planned time frame for this project was less than two years, with construction beginning in January 2015 and project completion planned for September 2016. This upgrade is the first of its kind within the California State University system and is serving as a point of reference for similar campus upgrades in California and other parts of the country.

## B. Execution and Delivery

Infrastructure

Executing such a large, complex project takes a well-coordinated team to make it a success. During project execution the majority of the existing electrical infrastructure on campus had to remain in place to keep the campus powered. This made construction and installation challenging and required detailed planning ahead of time. Major parts of the construction included a new 12kV main switchgear building with cable vault, (60) medium voltage manholes, and (100) concrete pads for transformers and switches. The installation portion of the project included a 12kV metal-clad switchgear lineup by ABB with (12) circuit breakers and (12) ABB REF615 feeder protection relays providing the control and protection for each circuit breaker. The installation included (4) distribution loops connected via underground cables, (32) padmount switches by G&W, which are SF6 insulated and rated for 15kV and 25kA, (68) 12kV building transformers by ABB, and over (60) low voltage switchboards by GE. Approximately 44,000 feet of trenching and backfill were required to install the new underground electrical lines and connect all transformers and switches.

Figure 5: New 12kV switchgear building

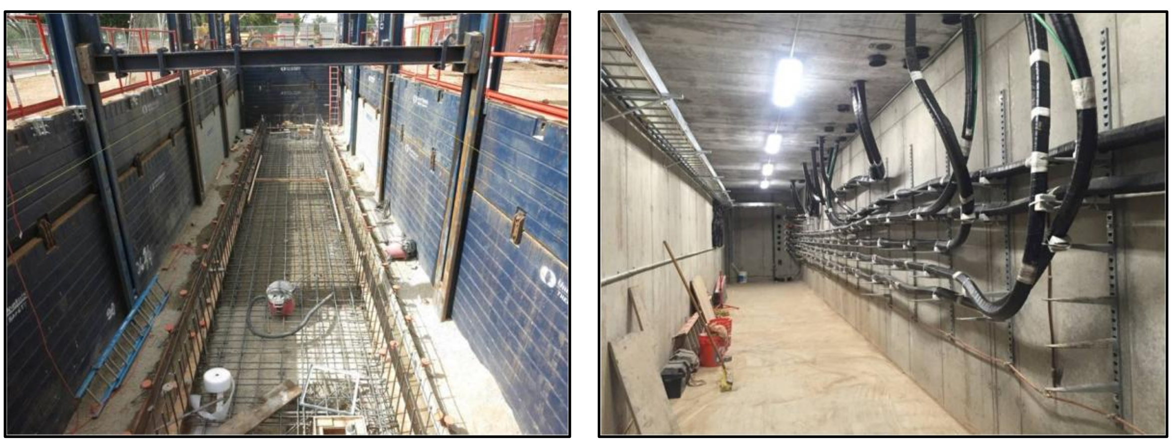

Figure 6: Cable vault below new switchgear building

Figure 7: SF6 insulated 6-way padmount switch

Every padmount switch is equipped with a low voltage control cabinet that is mounted on the side of the switch enclosure. The cabinet houses (1) ABB REC670 bay controller relay, several Secucontrol test switches, (2) batteries for control power backup, (1) iS5 iES10GF Ethernet switch, and (1) fiber optic termination panel. The ABB relay provides feeder protection for the padmount building transformers fed from the switch and controls the motor operators for incoming and outgoing loop feeders. Each REC670 relay is wired to various components of the respective switch: 3-phase internal current transformers (CTs) on the load and source ways, voltage sensing bushings and motor actuators on the source ways, and a low pressure warning device for SF6 gas pressure status supervision. An ABB power transformer (PT) is connected to the two source ways on the primary side and to the low voltage control cabinet on the secondary side providing 120 VAC control power. The iES10GF Ethernet switch in each control cabinet is connected to the REC670 control relay via a fiber optic Ethernet cable. The Ethernet cable connects to a second iES10GF Ethernet switch located in the switchgear control building to complete the communication loop. The ABB REC670 bay controller relay was chosen based on performance. It has the ability to monitor and control all ways of a 6-way switch with one single device and includes the native implementation of IEC 61850 communication.

Figure 8: Switch control cabinet with relay, test switches, Ethernet switch, and batteries

The switchgear control building houses the 12kV metal-clad switchgear with the (12) ABB REF615 feeder relays which are all connected to a SEL-2730M managed Ethernet switch. Besides the switchgear the control building also houses (2) 19” wide control cabinet racks with (2) redundant ABB RTU560, (4) iES10GF Ethernet switches (one for each loop), (1) iS5 iES28GF managed Ethernet switch, (1) SEL-3555 computer, (1) 19” touch screen, and (2) redundant, uninterruptible power supplies (UPS) with battery backup. The iES28GF managed Ethernet switch connects to the (4) iES10GF Ethernet switches (one for each loop) and therefore to the complete fiber optical loop and every switch across campus. The switch is also connected to the SEL-2730M managed Ethernet switch in the metal-clad switchgear and the redundant RTU560. The ABB RTU560 acts as a data concentrator and Human Machine Interface (HMI) for all four existing loops and all future loops. It ties the automation solution together and is programmed to provide visualization, monitoring, and control of the new electrical infrastructure for Fresno State. Hardwired alarm contacts are terminated at the RTU560 which include two sets of sump pumps in the switchgear building vault and two battery charger alarms for the batteries supplying emergency power to the switchgear building. The status contacts of the switchgear tie breaker are also picked up by the RTU560. The SEL-3555 computer is used to access and display the RTU560 HMI via the touch screen. A separate desktop computer, located outside the switchgear control building, is connected to RTU560 to display the HMI remotely.

Figure 9: 12kV metal-clad switchgear lineup and control cabinet racks in switchgear control building

Automation

The key element in achieving the safety and reliability goals was G&W’s best-in-class, engineered-to-order LaZer® automation solution that not only encompasses G&W padmount switches but also ABB relays and RTUs, an SEL computer, and iS5 Ethernet switches. It is designed as an open loop scheme with the logic programmed into each REC670 relay to increase the speed of FLISR and LOV. The REC670 communicates to and coordinates with the programmed REF615 substation breaker relays. All relays are communicating through multi-mode Ethernet fiber cables using IEC 61850 communications with Generic Object Oriented Substation Events (GOOSE) messaging protocol. The benefits of this communication architecture are Ethernet speed, flexibility of network configuration for future expansion, and centralized engineering access to the relays. For improved reliability, the REC670 relays at the padmount switches are utilizing a ring topology network to communicate. That ensures rerouting of communication traffic around the ring to restore communications with the adjacent switch if a communication path is lost between switches. If an additional issue arises that prevents a switch from communicating with its adjacent switch, the system is able to compensate. It does this by using information being communicated by the second adjacent switch to facilitate the automation response.

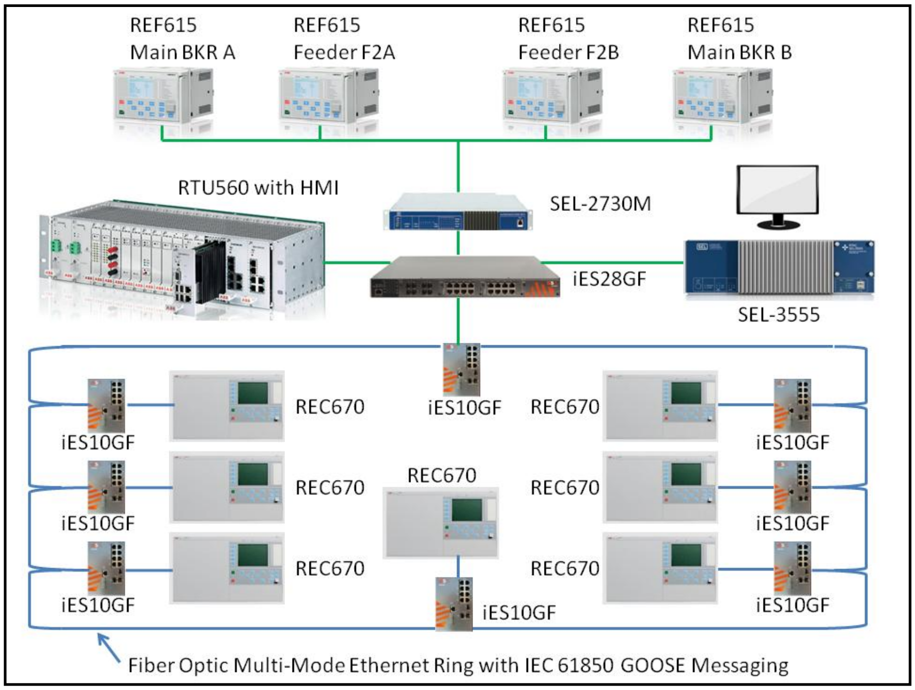


Figure 10: 12kV communications diagram for loop 2 (loops 1, 3, and 4 are similar)

The open loop LaZer® automation solution considers different scenarios (described in detail below) and responds appropriately to automatically restore power. Each of the (4) feeder loops has a designated open point which means that one switch in each loop has one of its two source ways in a normally open position. The entire system is fed via the new PG&E utility source and the metal-clad switchgear which incorporates a normally open tie breaker.

Upon loss of utility power or a fault condition, the appropriate upstream main circuit breaker will open and the respective REF615 feeder relay will send a signal to the appropriate REC670 relays in the loop to start FLISR. Local and remote control of the motor actuators that control the source ways are realized via a single local/remote button on the REC670 relay in the control cabinet on each padmount switch. This enables either remote or local control of one source way motor actuator at a time. In addition, each REC670 relay has an auto mode button to enable or disable the programmed FLISR/LOV schemes and therefore automatically open or close source ways.

After recognizing a loss of voltage due to loss of utility power, the REF615 feeder relays at the head end of each loop use peer-to-peer communication to accomplish an automatic source transfer scheme. If both sources are closed and one is considered dead while the other is considered live, a delay timer will start. After this delay timer expires the dead source will open and then send a close command to the switch in the respective loop directly downstream from it. This close command will continue to be passed downstream from switch to switch until it reaches a way that is open. If the REC670 relay for the respective switch with the open way has the auto mode enabled and a live source on the other side, it will automatically send a close command to restore power to the dead half of the loop.

In the event of a Fresno State internal system fault, the REC670 control relays in each loop use peer-to-peer communication to help determine the location of a faulted section. After detecting fault current, the respective loop feeder breaker in the metal-clad switchgear will first interrupt the fault. As soon as the fault is cleared, the REC670 relays will use the pre-fault information to determine which source way furthest downstream saw the fault condition. This switch will be first to open the respective source way, utilizing the motor operator. After the source way opens, the relay will send an open command to the REC670 controlling the switch on the opposite end of the line to isolate the line. At the same time it will send a close command to the REC670 located in the opposite direction of the faulted line (upstream). This command will be passed until it reaches the first switch that has an open source way, which should be the loop feeder breaker that initially interrupted the fault. The switch will then close if it has a live source on the other side. Once the switch on the opposite end of the faulted line is open, it will also send a close command in the opposite direction of the faulted line (downstream). This close command will then be passed until it reaches the first open switch, which should be the tie breaker. The tie breaker will then close if it has live source on the other side of the line. The REC670 controlled load ways are time-coordinated with the REF615 controlled feeder breakers so that only the fault interrupters on the load ways trip for a switch internal load fault. This will prevent a FLISR operation for a faulted load way.

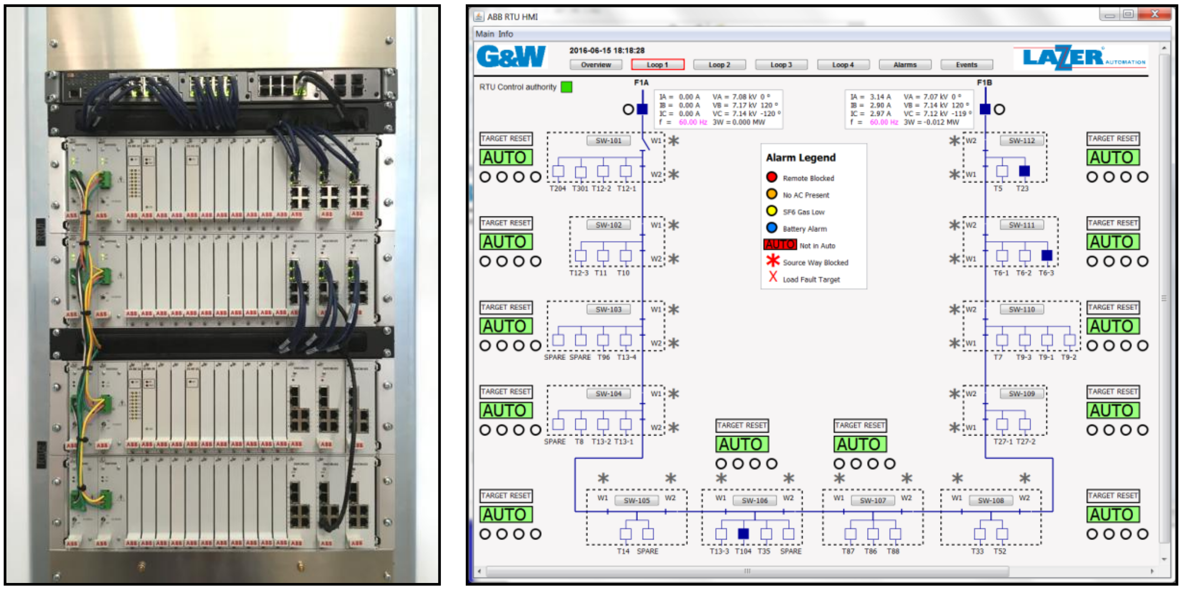


Figure 11: Redundant RTU560 with HMI for remote monitoring and control

Factory Acceptance Test (FAT)

Prior to approving shipment, Fresno State, P2S Engineering and The Ryan Company visited G&W's facility in Bolingbrook, IL for a Factory Acceptance Test (FAT) of the LaZer® automation solution. The FAT was beneficial for all parties involved to witness a test of the complete system functionality, trying to "break" it, as well as implementing enhancements to the automation schemes. Following the commissioning, Fresno State was provided with not only documentation and training on the LaZer® automation solution but also a (3) year parts and performance warranty.

Figure 12: Factory Acceptance Test for complete automation solution

## IV. LESSONS LEARNED

Throughout all phases of the upgrade project there have been lessons learned that can be applied to any future upgrade projects involving switchgear and automation. The lessons learned are different for the various parties involved but one common theme is that it takes great teamwork to be successful. The coordination with and the cooperation between Fresno State, consultants, design engineers, contractors, vendors/manufacturers, and all other involved parties is of utmost importance. That is especially true for the final project milestones: commissioning and start-up. It requires detailed planning very early in the project for those last milestones to ensure that Fresno State received a solution that met the specification/requirements and was delivered and placed in service on time. The coordination of testing requirements, commissioning efforts, and training content between each equipment manufacturer and the end-user is important. The project specifications sometimes do not cover all expectations of the end-user which can result in additional work that is outside the original scope and that will cost additional time and money. Therefore it was important to discuss and review the specifications together with Fresno State early during the planning phase and discover gaps between the specification and expectations.

One example of coordination involves the requirement for construction drawings with respective dimensions for the padmount switches and transformers. The switches and transformers have a long lead time, which requires careful planning and partnership with construction teams to plan their work. Before doing groundwork and pouring concrete, the bolt-down locations on the concrete pads and the placement of the control cabinets on the outside of the switch have to be determined. The control cabinets are mounted on the side of the switch which means that there has to be a certain clearance considered in between two switches, allowing operators to open the control cabinet. This is necessary to operate relays locally and to make use of the test switches if needed. Pouring the concrete pads ahead of time without knowing the exact bolt down locations might result in misfits and gaps and the need to redo the concrete.

Lessons learned with regards to cooperation involve commissioning and testing of the automation solution. During commissioning of the padmount switches it was common practice to energize switches and/or loops one at a time. For the relays in the control cabinet of each switch to operate, control power needs to be supplied to the control cabinet. That power is normally supplied by the PT connected to the switch but if the switch is not energized yet, an external generator is needed as a power supply. The challenge for testing the automation schemes is that the system at a minimum needs all relays in one loop to be operable. For that to be the case either a number of portable generators need to be available on site or the respective loop needs to be energized before starting commissioning and testing. This requires cooperation with the local construction company. Furthermore cooperation with a local testing company is required to inject currents and voltages to the system via a test set to simulate faults and LOV and ultimately ensure that the automation schemes perform as required. Another example is the communication of relay protection settings, IP addresses, and other automation related information with Fresno State. This information needs to be prepared first and then reviewed by Fresno State before being submitted to the contractor. It is important to complete these steps in a timely manner so that all information is available during commissioning.

After everything is commissioned, energized, and tested, the operators need to be trained on the new system. That involves operating switches, understanding how the automation works, and performing several other tests for training purposes. Doing so will affect those facilities already connected to the new electrical infrastructure and cause partial outages on campus. In order to avoid additional outages, it is important to schedule the cutovers from the old infrastructure to the new one appropriately and include the described training into the schedule for switching over facilities on campus. Scheduling and completing the cutovers is challenging as this has to be done in a phased approach, where the campus is functioning on two separate distribution systems right until the last building cutover. Doing so will result in a very compressed schedule for outage work due to the power needs of each building on campus and won’t leave much room to schedule additional outage times for training purposes.

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## VI. AUTHORS


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