REAL-WORLD APPLICATION

How a Nuclear Power Plant Improved Reliability and Saved on Costs With SEL Dynamic Disturbance and Fault Recording Systems

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Introduction

Electric power utilities are continuously improving their system to meet the North American Electric Reliability Corporation (NERC) PRC-002 standard. The purpose of NERC PRC-002 is to have adequate data available to facilitate analysis of bulk electric system (BES) disturbances. The retrieval of data from intelligent electronic devices (IEDs) or digital fault recorders (DFRs) requires personnel to access field equipment for data collection if the devices are not remotely accessible. To collect data in person, power utilities typically require excessive amounts of labor hours associated with travel, which can also lead to a delay in decision making. Therefore, remotely accessible data can help increase reliability and productivity and can reduce costs.

This white paper describes the application of Schweitzer Engineering Laboratories (SEL) dynamic disturbance and fault clearing technology associated with a utility's nuclear plants and how they benefitted from the SEL solution on costs, convenience, and reliability.

Key Points

NERC STANDARD AND SEL DYNAMIC DISTURBANCE AND FAULT RECORDING SYSTEM

NERC PRC-002-2 defines the requirement needed to facilitate the analysis of disturbances in the power system [1]. The standard states what and how often data should be recorded, including Sequence of Events (SOE) data, Fault Recording (FR) data, and Dynamic Disturbance Recording (DDR) data. The current revision of PRC-002 requires a minimum of 10 days storage of 16 samples per cycle for IED event reports, 30 samples per second of DDRs, and time-stamp accuracy of SOE data within 4 ms.

SEL Dynamic Disturbance and Fault Recording Systems provide the hardware and software for recording and archiving the required disturbance data.

The SEL-3555-2 Real-Time Automation Controller (RTAC) provides SOE, DDR, and DFR. Furthermore, the SEL-3555-2 has features like secure communication, advanced data concentration, high-speed logic processing, flexible engineering access, and protocol conversion capabilities. It contains exe-GUARD® whitelist antivirus technology, which increases cybersecurity and allows only authorized applications to be executed.

The SEL-2240 Axion® is a fully integrated modular input/output (I/O) device. The Axion modules integrate with a main controller like the SEL-3555-2 to provide high-speed deterministic control performance over an EtherCAT® network.

The SEL-2488 Satellite-Synchronized Network Clock is used in the system to provide accurate timing over IRIG-B for SOE record logging. The demodulated IRIG-B from the SEL-2488 output provides time output to within ±100 ns peak accuracy to UTC.

*EtherCAT® is a registered trademark and patented technology, licensed by Beckhoff Automation GmbH, Germany.

	NERC PRC-002-2 Recording Requirements	SEL Dynamic Disturbance and Fault Recording System
Sequence of Events (SOE) Recording	SOE recording should store changes in the circuit-breaker position.	The SEL 3555-2 triggers SOE recording on a user-defined digital status. • Logger stores as many as 30,000 records • SOE accuracy is within 1 ms
Fault Recording (FR)	FR should monitor the following analogs: Logger stores as many as 30,000 records • Phase-to-neutral voltage • Phase currents • Residual or neutral current FR data should include the following in a single record or multiple records: • 2 cycles of pre-trigger data and 30 cycles of same trigger data, or • 2 cycles of pre-trigger data, first 3 cycles of post-trigger, and a final cycle of fault data Fault-recording rate: ≥16 samples per cycle	An SEL-3555-2 configured with Axion modules records the current, voltage, and digital status of up to 60 Axion modules (a maximum of 16 CT/PT SEL-2245 modules can be used on one RTAC). The fault recording capability of the SEL-3555-2 with Axion modules is as follows: • Measurement of phase-to-neutral voltage, phase currents, and neutral currents • Configurable pre-trigger and post-trigger data • User-programmable event report trigger (the SEL-3555-2 generates 1, 2, 4, 8, and 24 kHz fault records formatted in COMTRADE) • Minimum fault-recording rate of 16 samples per cycle

Dynamic Disturbance Recording (DDR)	DDR should monitor the following rms quantities: • Phase-to-neutral voltage • Positive-sequence voltage • Phase-to-phase voltage • Phase currents • Three-phase real and reactive power • Frequency DDR should continuously record and store data with trigger record lengths of 3 minutes. DDR should collect with an input sampling rate of at least 960 samples per second 16 samples per cycle) and an output recording rate of at least 30 measurements per second.	The SEL-3555-2 generates synchronized phasor measurements in IEEE C37.118 format on all analog channels. The 3555-2 with Axion modules include the following capabilities: • Measuring phase-to-neutral voltage, phase currents, and frequency (SEL-3555-2 only) • Calculating three-phase real and reactive power • Continuous archiving • Storing trigger record lengths of at least 3 minutes, based on sample rate and length of events (ranges from 3 to 36 minutes) • Calculating rms quantities at 960 samples per second (1, 2, 4, 8, and 24 kHz are available for user to define) • Storing rms values at a rate of at least 30 measurements per second continuously (as many as 60 measurements per second are available)
Time Synchronization	• Should be able to synchronize to Coordinated Universal Time (UTC) with or without local time offset • Requires clock accuracy within ±2 ms of UTC	The SEL-3555-2 provides • IRIG-B with 250 ns accuracy • Precision Time Protocol (PTP) communications
Data Storage	The data repository must provide enough nonvolatile memory for storage and the following: • At least 10 days of SOE records, fault records, and DDR files must be provided • If requested, files must be provided to the U.S. Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), or the regional reliability organization within 30 days • Sequential Events Recorder (SER) data should be available in ASCII comma-separated value (CSV) format, and FR and DDR files in COMTRADE format • The naming convention must follow IEEE C37.232-2011A	The SEL-3555-2 is the data storage device and has the following capabilities: • As much as 250 GB of data storage and supports a redundant array of independent disks (RAID) • Storage of at least 10 days of records and files (up to several months of storage) • Up to 10,000 COMTRADE events following IEC 60255-24:2013, IEC 60255-24:2013, and IEEE C37.111-2013 formats • Generated file naming convention that follows IEEE C37.232-2011A

Table 1—Simplified NERC PRC-002-2 Disturbance Monitoring and Reporting Requirements

SEL Dynamic Disturbance and Fault Recording System Updated on the Utility Nuclear Power Plant

The utility upgraded their DFR devices with the SEL-3555-2 as the main controller integrated with the Axion module, which is directly connected to the current transformer / potential transformer (CT/PT) for data collection and recording along with SEL-2488 for time synchronization. Figure 1 shows an overview of the simplified SEL Dynamic Disturbance and Fault Recording system. The system hardware includes the following:

- SEL-3555-2 RTAC with web-based human-machine interface (HMI)
- SEL-2488 clock
- 10-slot SEL-2242 Chassis/Backplane and modules, which include
  - Slot A: Power Coupler
  - Slot B: Digital Output Module
  - Slot C: AC Protection Module
  - Slot D: AC Protection Module
  - Slot E: AC Protection Module
  - Slot F: AC Protection Module
  - Slot G: AC Protection Module
  - Slot H: AC Protection Module
  - Slot I: Spare for future expansion
  - Slot J: Spare for future expansion

The system software includes the following:

- acSELerator RTAC® SEL-5033 Software for setting up the RTAC and Axion modules.
- acSELerator Diagram Builder™ SEL-5035 Software for setting up the RTAC HMI.
- SEL-5601-2 synchroWAVe® Event Software for viewing COMTRADE data.

*The Axion AC Protection Module includes three CTs with isolated returns and three PTs for measuring ac signals.

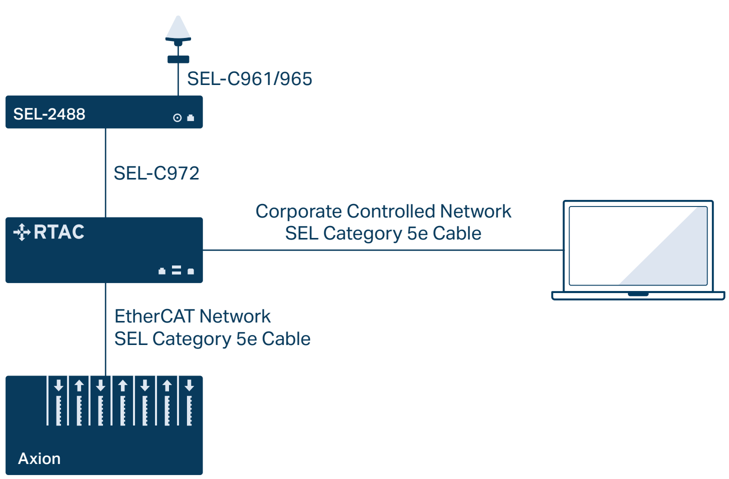

Figure 1—Overview of the Simplified SEL Dynamic Disturbance and Fault Recording System

SOE data that are recorded by the RTAC are inherently time-stamped digital information that may include alarms, security events, errors, module changes, etc. [2], and can be downloaded as a CSV file.

DFR data are fault event reports based on a digital bit status change in the RTAC, such as breaker open or close. The trigger can also be an analog change, such as a drop in voltage beyond a defined threshold. The RTAC captures all waveforms associated with a recording group configured with the Axion modules, and it provides a complete snapshot for a given event that can be downloaded as a single COMTRADE file.

The DDR feature in the RTAC continuously records analog and digital data for at least 15 days and stores the data in COMTRADE format, which can be analyzed by SYNCHROWAVE Event for disturbances.

How the Utility Benefited From the Data Collected

This section discusses an example of the utility's experience with the SEL dynamic disturbance and fault recording technology in their nuclear plant. It includes the remote fault data collection and how the utility used this data for troubleshooting and event analysis.

Within the first year of the installation, the utility experienced two trips on their 500 kV line, which caused their downstream 480 V motor starters to drop out and their process control relays to de-energize. This required them to understand the unexpected behavior and determine the root cause to eliminate these kinds of unexpected trips in the future. To achieve this, they remotely downloaded all the transient data from all incoming power sources for evaluation. While power was not lost to any customers, the RTAC DFR triggered events based on the voltage sags.

Figure 2 shows a simplified one-line diagram of the system. There is a 500 kV ring bus with circuit breakers forming a ring with isolators on both sides of each breaker feeding the 4 kV/480 V station loads. The Axion fault recorder monitors the main generator voltage and current, and the voltage of the incoming 4 kV power sources to the station. The DFR recorder is set to trigger events based on voltage sag transients affecting the 4 kV plant loads and the main generator.

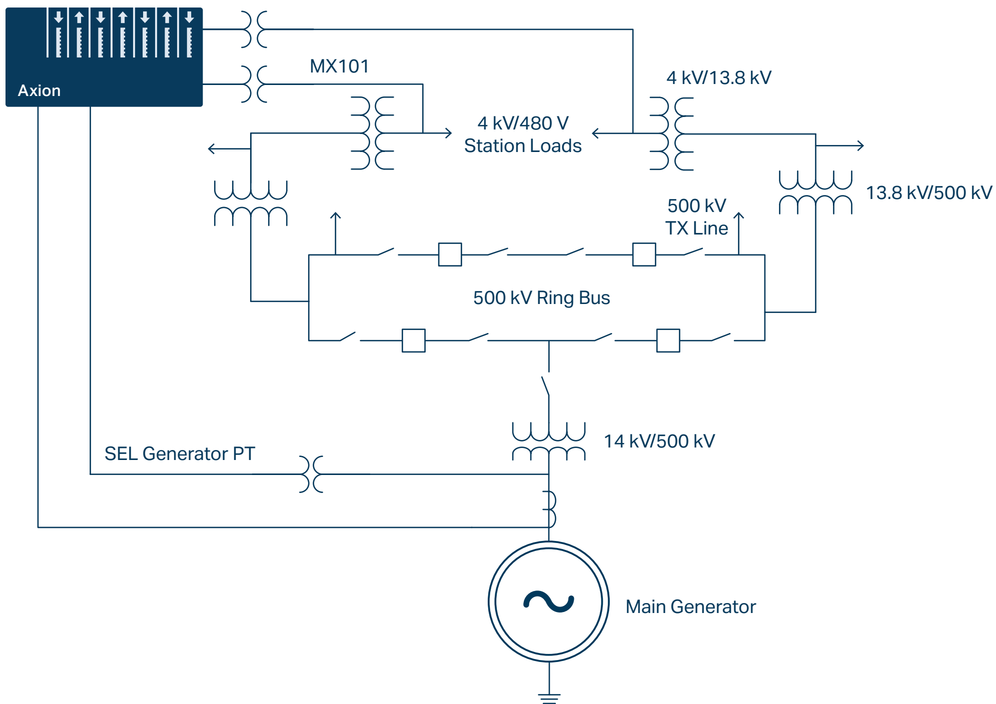

Figure 2—Simplified General One-Line Diagram With Axion Unit

On the 500 kV line, one fault occurred on Phase A of the transmission line, and on the consecutive day, another fault on Phase B occurred at the same location. Figure 3 shows the location of the two faults on the transmission line recorded by Axion input MX101 on the 4 kV side.

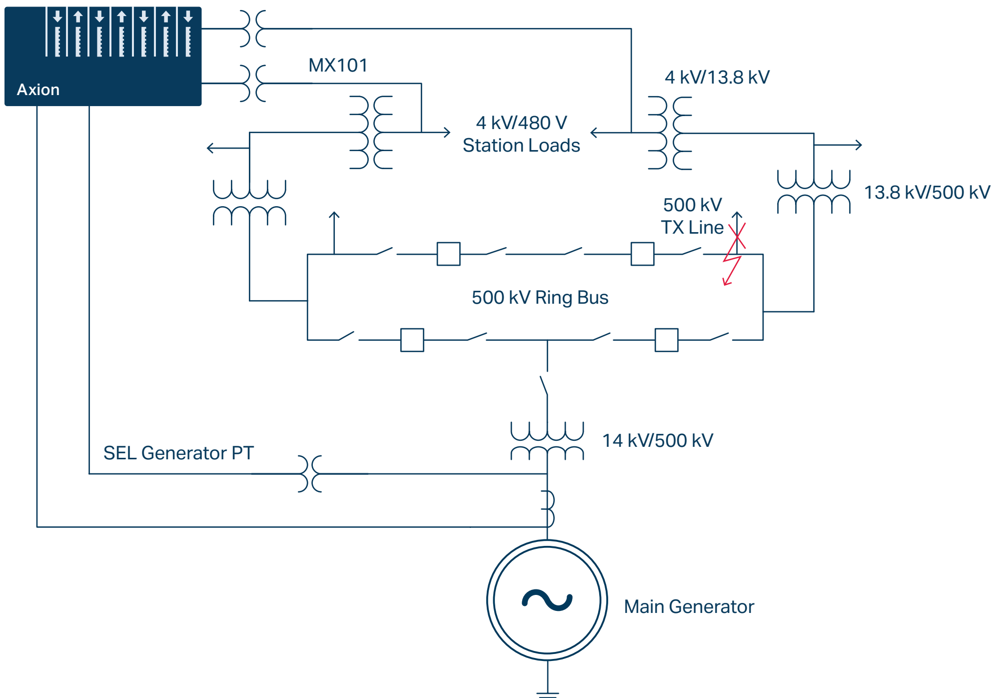

Figure 3—Fault Event Line

To analyze the events, the engineers downloaded the DFR information remotely through the SEL 3555-2 RTAC web interface under the File Manager section, as shown in Figure 4.

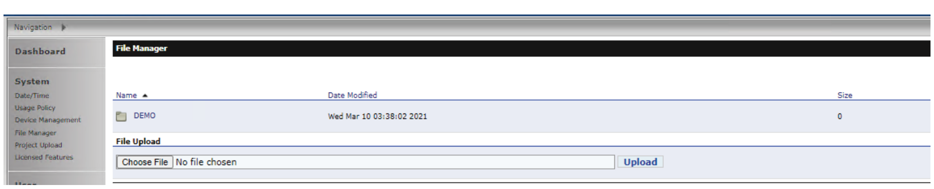

Figure 4—RTAC Web Interface for Event Retrieval

The following are the two events that occurred at the nuclear plant system, including background information.

Event One

A momentary ground fault occurred on Phase A of the 500 kV transmission line on the first day of the weekend. The fault was cleared in approximately 50 ms by the transmission line protection relays, and the reclosing scheme restored the line. The voltage sag occurred in one of the 4 kV station buses for 54.5 ms due to the fault on the transmission line. Figure 5 shows the sag with the voltage signal and its magnitude (RMS value) at the time of the fault that is recorded by the Axion in the COMTRADE event using SYNCHROWAVE Event.

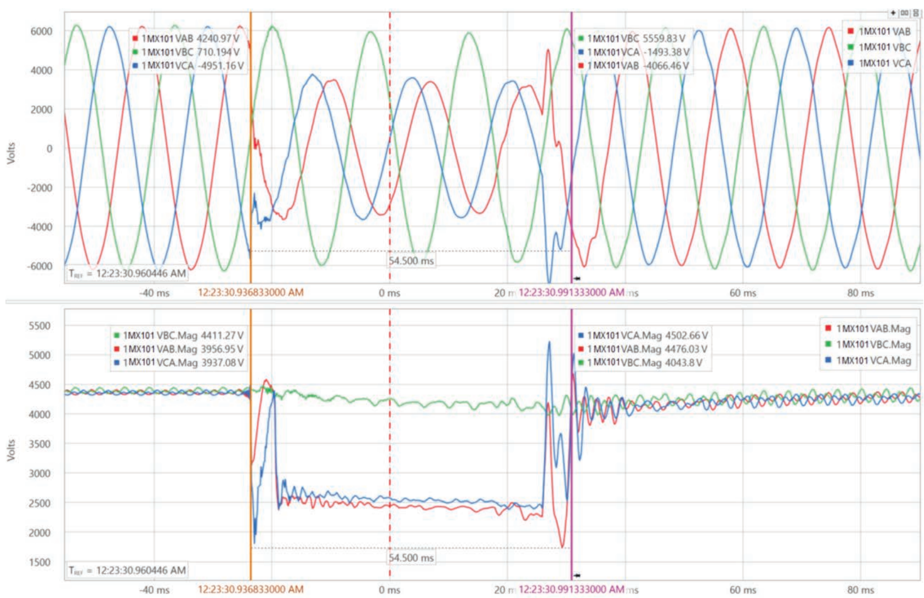

Figure 5—Event One

Event Two

The following day, a ground fault occurred on Phase B of the same 500 kV transmission line. The fault was again cleared in approximately 50 ms by the transmission line protection relays, and the reclosing scheme restored the line. The voltage sag occurred in one of the 4 kV station buses for 52.25 ms due to the fault on the transmission line. Figure 6 shows the sag with the voltage signal and its magnitude (RMS value) at the time of the fault that is recorded by the Axion in the COMTRADE event using SYNCHROWAVE Event.

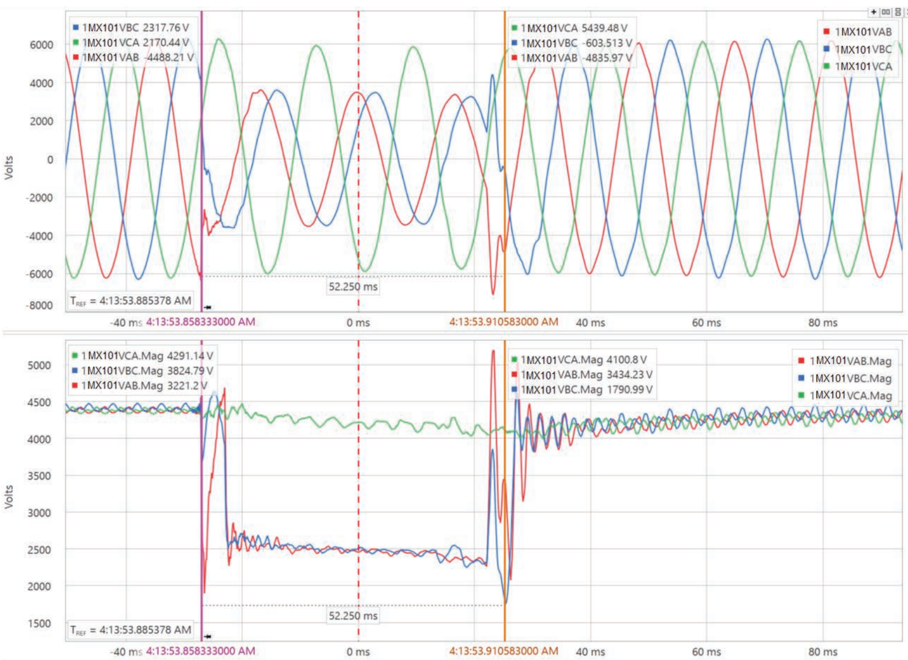

Figure 6—Event Two

Both transmission line faults caused multiple 480 V unbalanced plant motors to trip offline. Operators manually restarted all motors to keep the balance of plant systems in service, and the plant connected to the grid. To understand the cause of motor trips, the engineers downloaded the DFR information remotely through the SEL 3555-2 RTAC web interface and used SYNCHROWAVE Event for analysis, as shown in Figure 5 and Figure 6. The DFR data shows that the switchyard faults caused an approximate 50 percent dip in voltage on the station's 4 kV and 480 V buses for approximately 50 ms. Each 480 V motor that tripped during the voltage dip are maintained in service using normally energized starters and control relays that drop out when supply voltage is less than 70 percent. By evaluating these two events, the utility confirmed that system voltage dropped below the minimum coil voltage for the 480 V system starters and the system performed as expected.

The nuclear power plant has a common maintenance group that services multiple locations across the service area. Prior to the SEL recorder installation, typically a security-controlled laptop and qualified technician would have to be scheduled or called in to work overtime to collect the data.

This can add significant delay (as many as several days) because to evaluate plant conditions the technician must select a day to travel, drive for hours to the plant, download the records, and forward them to engineering for evaluation.

With the SEL recorder installed, the engineering team was able to remotely download the data without any significant delay. Having the data immediately available enabled quick confirmation that the grid transients had caused the system trips, which supported a faster restoration of plant systems. The remote connectivity to the SEL recorders and the advanced event analysis software reduced event response time from several days to a few hours.

The utility is currently taking action to improve the voltage ride-through capability of critical 480 V motor control circuits, and they are using the DFR data to establish minimum voltage requirements.

Additional Data Recorded by the DDR

The SEL-3555-2 RTAC can be configured not only to capture fault data but also to record normal loading trends using the DDR technology. The plant uses this technology to monitor voltages and currents at the 14 kV main generator, which is collected from PTs and CTs using the Axion modules shown in Figure 2.

The nuclear power plant received a spurious voltage unbalance alarm on their main generator. The purpose of the alarm is to detect a loss-of-voltage signal from the generator PTs (i.e., blown PT fuse alarm). The alarm could also occur if something caused an undervoltage condition on the main generator, such as a ground fault. The alarm condition immediately cleared, and the alarm self-reset.

The utility needed to determine if the spurious alarm indicated a momentary ground condition on the main generator that cleared prior to the ground protection trip or if the alarm circuit was faulty. The generator had previous operating experience when momentary ground conditions resulted in voltage unbalance alarms and subsequent generator trips. Because of this previous experience, it was critical to verify that voltage on the generator was stable during the time the alarm occurred. Otherwise, the PT circuits would need to be instrumented to capture future alarms, or the generator would need to be removed from service for troubleshooting.

To perform this verification, the DDR data was pulled from the SEL-3555-2 RTAC web interface and reviewed using SYNCHROWAVE Event. The DDR data showed that there were not any voltage deviations on the generator that would indicate a ground condition. This information provided justification for keeping the generator in service and for scheduling offline troubleshooting of the PT and alarm circuit during the next scheduled generator outage. Figure 7 shows the healthy primary voltage on the 14 kV main generator.

Figure 7—Main Generator Voltage Trend Using the DDR

With the DDR data available, within two hours the data collection and engineering review was done to determine that no ground condition existed. The nuclear power plant was able to avoid online troubleshooting of energized circuits that feed protective relays, which would have posed a risk to generation and personal safety.

Conclusion

The SEL Dynamic Disturbance and Fault Recording System meets and exceeds the requirements of NERC Standard PRC-002-2 (December 15, 2014 version). By implementing this technology, fault records and disturbance data were readily available to the utility, which helped facilitate faster plant restoration. After one year of runtime with an SEL DFR/DDR system installed, the utility has saved approximately 90 percent in maintenance resources responding to alarms and system transients monitored by the recorder. Applying the SEL solution has made power safer, more reliable, and more economical on their nuclear power plant system.

References

[1] NERC Standard PRC-002-2 – Disturbance Monitoring and Reporting Requirements. Available: https://www.nerc.com/pa/Stand/Reliability%20Standards/PRC-002-2.pdf.

[2] "SEL Dynamic Disturbance and Fault Recording Systems." Available: https://selinc.com/api/download/122510/.

Further Reading

I. West, "Capture Vital Substation Data Using the SEL Digital Fault Recording (DFR) System," SEL Application Note (AN2021-04), 2021. Available: selinc.com.

Biographies

Phoebe Loh, received her BS in electrical engineering from Drexel University in 2015 and MS in information systems engineering and management from Harrisburg University of Science and Technology in 2020. Since 2017, she has worked at Schweitzer Engineering Laboratories, Inc. (SEL) as an automation application engineer in sales and customer service, supporting various customers on SEL technologies and products. Prior to working at SEL, she had two years of industrial control system (ICS) experience in different industrial segments.

Tanvi Varshney, received her BS in electrical and electronics engineering from Uttar Pradesh Technical University, India, in 2012. She received her MS in electrical engineering from Drexel University in 2016. She joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2016 and currently works as a protection application engineer in King of Prussia, Pennsylvania. She is a member of IEEE.

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