

Case Study: Mobile Protection Unit for Rapid Power Restoration

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Abstract—A mobile protection unit (MPU) implements a minimize-simplify-optimize philosophy to provide a custom designed and manufactured, portable, completely self-contained, fully functional, quickly transportable substation relay enclosure. The unit is designed to meet relay protection and teleprotection communications requirements for a diverse set of applications, permitting the rapid and temporary restoration of transmission facilities or feeders to supply load following a catastrophic event. The MPU utilizes a trailer for rapid deployment and mobility of a functional relay enclosure, including a material supply enclosure and power generator. The relay enclosure incorporates multifunctional protection panels populated with an assortment of microprocessor-based relays, test switches, control switches, and communications equipment that are standard on the Consolidated Edison Company of New York, Inc. (Con Edison) system, thereby permitting easy integration to existing power system protection schemes during an emergency or construction condition.

I. BACKGROUND

Consolidated Edison Company of New York, Inc. (Con Edison) operates one of the most complex and reliable electric power systems in the world.

Con Edison delivers electricity to more than three million customers through a huge transmission and distribution network. The company has built the largest system of underground electric cables in the world to accommodate the congested and densely populated urban area it serves. The system features approximately 94,000 miles of underground cable. Con Edison's nearly 34,000 miles of overhead electric wires complement the underground system.

If a catastrophic event occurs, the destruction of a major transmission facility would result in the loss of the supply to the associated area substations and thus the blackout of the load supplied from the substations. Established substation contingency plans have been prepared to detail the temporary restoration of power facilities to the affected area substations. A critical part of the contingency plans is the restoration of adequate relay protection.

This project was for the design, construction, and procurement of standby relay systems and their enclosures. The major objectives for the standby relay systems include the following:

- Portable.
- Completely self-contained.
- Fully functional.
- Adaptable for various protection schemes.

- Housed for long-term, year-round outdoor environment.
- Quickly transportable without special permits from a long-term storage location to any Con Edison site (New York City and Westchester County).

II. INTRODUCTION

A. Project Justification

A web search for mobile substations provides an extensive list of trailer-mounted options. The standard equipment offerings include transformers, switchgear, circuit breakers, and protection cubicles, normally limited to a single function. In most cases, if a relay enclosure is provided, it is small and offers only limited protection for the primary equipment included on the trailer. For construction contingencies or catastrophic events where existing primary equipment is available but a fully functional substation relay enclosure is needed, few options exist.

Con Edison recognized the need for an innovative method of packaging protection equipment for on-site installation within a limited time to mitigate the loss of any one of a number of selected transmission or distribution substations. The solution was a mobile, modular substation design, which was completely factory assembled, wired, and tested and offered all the necessary accessories of a stationary substation design with versatile protection options for multiple contingencies.

In addition to deployment for catastrophic events, the mobile substation can also serve as a temporary protection option for new construction or renovations.

Microprocessor-based protection devices are flexible in protection, communications, and auxiliary operations. This mobile protection unit (MPU) has the capability of providing functional current differential, step-distance, or diverse piloted protection schemes for a 345 kV ring bus and line feeders or overcurrent/overvoltage and differential protection for a 138 kV/13 kV step-down transformer, as well as instantaneous and time-overcurrent protection for distribution feeders.

B. Minimize-Simplify-Optimize Philosophy

The relay protection for the electrical system of Con Edison incorporates a diverse collection of relay models and manufacturers, which creates a challenge in providing a representative selection in a limited space. The project must balance space constraints with protection requirements for

construction and emergency applications. The New York State and City of New York Departments of Transportation have limits that apply to height, width, length, and weight of vehicles. Working within these limits to avoid special permitting requirements became part of the overall engineering challenge in designing an MPU. Ancillary equipment, such as climate control, batteries, and electrical distribution, limited the space available for protection and communications equipment even further.

To address these challenges, the design of the MPU incorporates a minimize-simplify-optimize philosophy. Equipment design and layout are minimized and simplified, without sacrificing functionality, to optimize the space available. Swing rack relay panels with integrated, rear-facing switchyard termination cabinets (SYTCs) not only free up valuable floor space but facilitate exterior connection access. Forty-slot ac and dc load centers manufactured in a single enclosure with exterior disconnects also streamline the enclosure layout, while offering safety advantages that traditional load centers do not. Sealed nickel cadmium (NiCad) batteries eliminate the need for a hydrogen exhaust fan and offer superior performance under adverse conditions compared with traditional lead-acid batteries.

C. Project Objectives and Design Considerations

Mobile equipment needs to be maneuverable, reliable, safe to operate, and easily deployed in adverse circumstances.

In order to meet the application needs of Con Edison, the MPU needed to be quickly transportable, without special permits or lengthy mobilization time, to any Con Edison site in their New York City and Westchester County coverage areas. Once deployed, the MPU must be easily connected and configured for specific protection functions. To this end, the MPU is designed with all required equipment mounted on a 40 ft trailer.

The main relay enclosure is weatherproof and fully conditioned, suitable for use in all conditions. A battery system in the relay enclosure, kept on charge during storage for immediate availability, provides dc power. The relay panels are equipped and wired to cover various protection schemes, from three-terminal transmission line teleprotection applications to transformer and bus protection scenarios. All yard connections are made in the rear terminations section of the panels via exterior access doors. No internal wiring changes are required for different protection applications. Communications channels can be conveniently configured using fiber patch panels in each relay panel; additional communications cables are not required.

A separate trailer-mounted 208/120 V diesel generator with a fuel tank sized for more than 48 hours of run time provides ac power when station service power is not immediately available. The generator is equipped with a sound-attenuating enclosure to limit noise pollution and provide a safe working environment for on-site personnel.

The rear container provides convenient storage for wire and tools or a weatherproof work area. The storage container can be modified, as required, by field technicians.

III. MOBILE PROTECTION UNIT

A. Main Relay Enclosure

The main relay enclosure is a modified International Organization for Standardization (ISO) shipping container (commonly used for cargo shipment) with external dimensions of 8 ft wide by 9 ft tall by 20 ft long. All the amenities and functionality of a standard stationary relay enclosure are included in the reduced footprint. Fig. 1 provides an internal layout of the equipment.

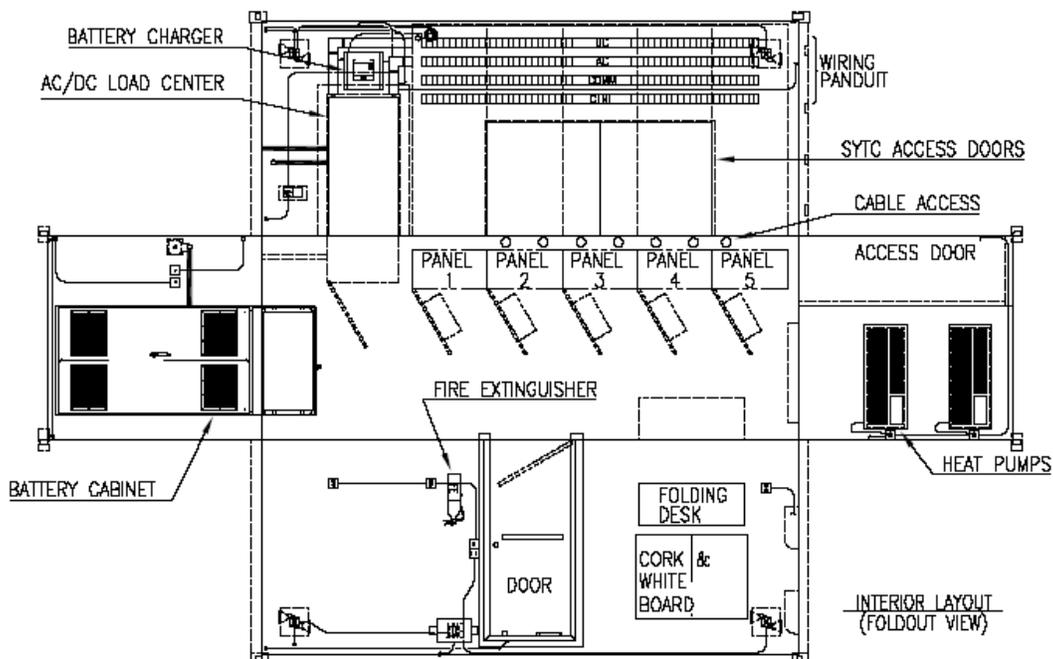


Fig. 1. Internal Layout Plan for Main Relay Enclosure

The ac/dc load center is built into the exterior wall to provide dual access: interior for ac and dc distribution panels and exterior for main disconnects and lugs. Fig. 2 displays a typical dc distribution panel at the top and ac distribution panel at the bottom. In the event of an electrical short in the relay panels (dc) or enclosure wiring (ac), exterior access to the main disconnects allows power to be safely disconnected without exposing personnel to risk (see Fig. 3). Furthermore, exterior access to the main lugs allows easy connection to station power at the bottom of the load center (not shown), and a removable doghouse provides weather protection. Lugs and main circuit breakers are available for primary (Source 1) and auxiliary (Source 2) ac and dc power sources. Mechanical interlocks between the circuit breakers prohibit accidental paralleling of sources.



Fig. 2. Load Center/Internal – AC/DC Distribution Panels



Fig. 3. Load Center/External – Dual AC/DC Source Disconnects

When station power is not available, the trailer-mounted 208/120 Vac, 10 kW generator provides power to the ac load center via a permanently wired, external 100 A receptacle. The generator is equipped with a double-walled base tank sized for more than 48 hours of run time at full load. Additionally, the double-walled base tank allows safe road travel without draining the fuel. Generator alarms are wired to the SYTC for connection to station monitoring equipment. If both station power and the standby generator are unavailable, an exterior weatherproof plug is available for connecting a portable generator.

A 71 Ah, 125 Vdc NiCad battery system is installed for dc power. The batteries are mounted in a two-tier, two-step rack in a National Electrical Manufacturers Association (NEMA) 12 rated cabinet. The batteries are tied and braced to the rack for stability during road travel, and the cabinet protects individual cells from accidental damage from unsecured objects. DC cables between batteries are disconnected during transport for safety. NiCad batteries have two distinct advantages over lead-acid batteries in a mobile application. The lack of significant hydrogen outgassing eliminates the need for exhaust fans or hydrogen sensors. Additionally, the extended operating temperature range of NiCad batteries (0° to 100°F) allows the MPU to be operational even when ac power and enclosure conditioning systems are not available. A battery charger is mounted above the ac/dc load center for easy access, viewing, and heat discharge.

The modified ISO container provides three methods of access. A single-person door in the long wall provides entry for personnel. Removable stairs are provided and stored in the storage container. Fig. 4 shows exterior double doors on the opposite long wall, which provide access to the rear SYTC sections of Relay Panel 2, Panel 3, and Panel 4. A detachable weather hood is provided for extended access. Terminal blocks are mounted within reach of the ground, and a portable stepping platform is provided for additional reach, if required. Seven 4-inch conduit sleeves are mounted in the floor for routing yard cables to the SYTC. Sleeves utilize removable caps to provide weatherproof integrity during transport. Wire mesh cable pulling sleeves can be utilized to secure yard cable jackets at the enclosure entry point. This allows the jacket to be removed inside the enclosure and the wiring fastened to the appropriate terminal block without any strain. Cribbing or piers are required for off-loading conditions or usage at ground level to maintain access to the underside SYTC wire conduit sleeves. A third full-sized access door on the short wall adjacent to the storage container provides access for the removal of entire relay panels.

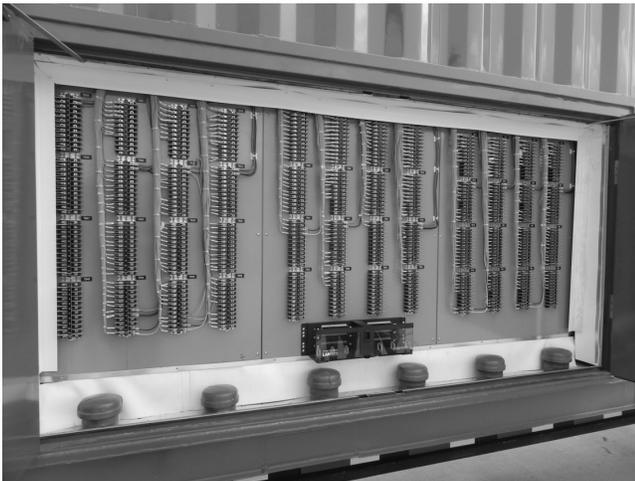


Fig. 4. External Access to SYTC

The exterior walls, floor, and ceiling of the container are fully insulated and fire rated for 1 hour. The underside of the relay enclosure floor utilizes a one-piece galvanized steel sheet to provide road and storage weatherproofing. Dual-redundant heat pump units provide heating and air conditioning for operation in all weather conditions. The units currently utilize manual temperature programming and have the capability of automated temperature and humidity control, if required at some future date. The container interior is outfitted with a folding table and stool for drawing review or setting up a laptop computer. Wall-mounted file holders store the enclosure and relay panel documentation. Four exterior flood lights, one on each corner of the enclosure, provide exterior work light for nighttime deployment. Safety equipment, such as a fire extinguisher and portable eyewash bottle, is securely mounted to the walls for safe travel. A ceiling-mounted smoke detector, along with a door intrusion alarm, is wired to the SYTC for connection to station monitoring equipment.

B. Relay Panels

The MPU provides five protection and control panels that include three switchyard termination panels. A side access panel is provided in the event that a relay panel needs to be changed. Four horizontal Panduits are mounted to the upper rear of each panel to facilitate routing of communications (copper and fiber), ac and dc power, and control wiring. Panel 1 and Panel 2 are wired to the rear SYTC of Panel 2, Panel 3 to the rear of Panel 3, and Panel 4 and Panel 5 to the rear of Panel 4, as shown in Fig. 5. The wiring configuration reduces space requirements by eliminating the need for an external cable tray, allowing the use of switchboard wiring in lieu of jacketed cable.



Fig. 5. Protection Panel SYTC Rear View

The protection and control panels are a swing rack design, which allows them to be mounted against the enclosure wall. This saves at least 4 ft of floor space in the rear of the panels, without sacrificing accessibility. The door of each panel is a 19-inch rack. The doors swing open past 90 degrees, allowing full access to relay and internal panel wiring. Each panel has an internal light and receptacle for testing or commissioning.

Relaying is microprocessor-based, utilizing a diverse selection of Con Edison standard manufacturers and model numbers. Additional interchangeable modules are provided for maximum protection scheme versatility. Nineteen-inch rack-mount drawers built into the relay panels provide convenient storage for extra modules. When used for transmission protection applications, relay diversity ensures a match for the

remote terminals. AC sensing and dc control circuits are wired to the SYTC for easy connection to yard cables. All sensing circuits are utilized, and spare control circuitry is wired to provide maximum versatility. Microprocessor-based relaying provides the capability of having multiple protection schemes with preprogrammed logic, multiple input monitoring, multiple output tripping, and diverse communications. Test switches are utilized to provide isolation of all currents, voltages, inputs, and outputs for connections between the yard and the relay enclosure. See Fig. 6 for a view of the Panel 1 through Panel 5 layout.



Fig. 6. Protection Panels 1 Through 5 Front View

Panel 1 and Panel 5 are equipped with multiplexers for standard Con Edison communications schemes. Internal relay-to-multiplexer fiber connections are prewired and easily configured via fiber patch panels in each protection panel. Panel-to-panel fibers are routed through the rear communications Panduit, and all configuration options are accounted for. Any changes in communications wiring can be accomplished at the individual patch panels. For example, fiber connections for relays in Panel 2 are installed to the multiplexers in Panel 1 and Panel 5. Selection of which multiplexer to use is made by connecting the relay to the appropriate port in the Panel 2 fiber patch panel. External yard connections to the multiplexers or individual relays are made via a fiber patch panel in the rear SYTC of Panel 3. As for the internal connections, all possible configurations are accounted for and can be selected by choosing the appropriate port in the patch panel. Each panel incorporates line current differential relays with distance and overcurrent backup protection. In addition, the relays facilitate three-terminal protection schemes and numerous other communications-assisted protection scenarios.

Panel 2 and Panel 4 are equipped with line current differential and line distance protection relaying. Each incorporates a full range of backup protection methodologies, in addition to differential, distance, and overcurrent protection.

Panel 3 is equipped for transformer and bus protection. The relaying provides protection for diverse transformer sizes and configurations with a capability of five three-phase current inputs providing differential, overcurrent, voltage, and frequency protection.

C. Trailer

New York City Department of Transportation requirements limit the overall trailer dimensions to 40 ft long by 8 ft wide. Larger sizes require special permits for travel on city streets. The substation yard clearance requirements of Con Edison limit the height to 12.5 ft. The MPU uses a special trailer with low-profile wheels to meet the height clearance requirements. In addition, it provides easy access to the front door and SYTC access doors. Dolly legs allow separation from the tractor and leveling control. See Fig. 7 for a side view.



Fig. 7. Completed Trailer View

Both the main relay control unit and the storage container utilize four industrial twist locks (ISO locking mechanisms) to facilitate easy separation from the trailer for longer duration use. Separation can be achieved with the use of an appropriately sized overhead crane or forklift.

Four grounding lugs are mechanically attached to the trailer and the 4/0 copper grounding loop. All units, including the trailer, are mechanically attached at two points to the ground loop. Multiple grounding lugs allow easy redundant connection to the substation grounding mat, regardless of trailer orientation. The Con Edison standard is to connect a minimum of two trailer ground lugs to the substation grounding grid.

D. Storage Container

The storage container is a modified ISO container and currently houses the relay enclosure portable access stairs and portable SYTC stepping platform. It provides operators with a self-contained shop or storage facility. Wire, cable, and tools necessary for yard connections and MPU deployment can be stockpiled in the storage container, or it can be outfitted with a work bench for a weatherproof shop. Double, full-height doors provide access for storage of oversized equipment. Twist locks allow the storage container to easily be separated and

lifted off the trailer via a forklift for placement at ground level, facilitating easy and continuous usage during mobilization and demobilization.

IV. TESTING

The relays in the MPU are factory acceptance tested, and the relay alarms are monitored during storage. The versatility of microprocessor-based relaying and flexibility of fiber communications connections ensure a high degree of functionality at the time of need.

The relay panel wiring incorporates designs from various Con Edison substations. Functional testing of protection and facility equipment is performed at the factory prior to delivery of the MPU. Factory acceptance testing verifies the enclosure and protective panel wiring and functionality. Secondary current and potential and I/O signals are injected and monitored at the SYTC. This confirms wiring and communications links between points of external contact and protective relays, as well as proper relay operation. Because multiple protection schemes are accounted for in the panel wiring to the SYTC, field alterations during deployment are not required. All wiring changes and new connections are made at the SYTC; therefore, retesting of the relay panel wiring is not required.

Protective relay settings vary depending on specific project requirements, but standard settings and logic can be developed and tested ahead of time to cover different protection schemes. Only the specific protection set points and possibly minor logic modifications are required at the time of deployment. Incorporating protective relays consistent with existing Con Edison protection systems ensures a minimum of difficulties with implementing, testing, and troubleshooting protection schemes.

The relay alarms are wired to the SYTC for external monitoring. Maintaining power to the protective relays and monitoring the self-test alarms during storage ensures that issues are noticed before mobilization, not during on-site commissioning.

With thorough preparation and planning, on-site commissioning is limited to verification of yard connections and site- and job-specific relay settings.

V. TRAINING AND MAINTENANCE

Proper training for personnel is essential for effective use of the MPU. Furthermore, preventative maintenance is an absolute necessity. Adherence to manufacturer-recommended equipment maintenance schedules ensures correct operation at the time of need.

Operational training is provided for all personnel who may be involved in the MPU deployment. Training covers the use and maintenance of the relay panels and review of possible connection options. Detailed drawings are included in the wall-mounted file holders for easy reference.

Training also covers the use and maintenance of enclosure equipment, such as the standby generator, battery system, and

heat pumps. This equipment is essential to the proper operation of the MPU. Operation and maintenance manuals for all equipment are provided in the wall-mounted folders. Full enclosure drawings are also included.

Mobilization and storage of the MPU are critical operations. Operational training includes review and practice of the procedures. Checklists are also provided to ensure proper safety and operational measures are taken during project deployment, when time is critical and steps can be overlooked. Proper storage procedures ensure that equipment is ready for the next use.

VI. CONCLUSION

The MPU is designed to meet all foreseeable system emergency and maintenance protective relaying requirements. As the unit is implemented in the field, experience will provide additional improvements and efficiencies that will be incorporated into the design to minimize outage and restoration times.

VII. BIOGRAPHIES

Ralph Mazzatto received his BS in Electrical Engineering in 1965 and his MS in Electrical Engineering in 1968 from Pratt Institute, Brooklyn, NY. He was a member of Eta Kappa Nu, the Electrical Engineering Honor Society. He started his career with Con Edison in 1965 as a cadet engineer in training. In 1967, Mr. Mazzatto was promoted to the project engineer responsible for development of electronic and electromechanical test equipment for field applications. In 1974, he was promoted to section manager in protective systems testing, responsible for the installation and periodic maintenance of protective relaying systems in Brooklyn, Queens, and Staten Island substations. In 1984, Mr. Mazzatto moved to system operations where, as associate chief district operator, he was the direct supervisor of the Manhattan, Bronx, and Westchester district and transmission operators. In 1991, he returned to protective systems testing as the section manager responsible for the installation and periodic maintenance of protective relays and systems in Brooklyn and Queens transmission and area substations. In 1995, Mr. Mazzatto moved to central substations where, as area manager, he was responsible for the operations and maintenance of Queens Central 138 kV and 345 kV substations. In 1997, he moved to his present position of technical specialist in central engineering. As a recognized authority, Mr. Mazzatto provides expert technical support for design, application, installation, and testing of protective relaying in the company's transmission substations. He serves as a member of the New York ISO System Protection Advisory Subcommittee. Mr. Mazzatto is a Senior Member of the IEEE, an active member of the IEEE PES Society serving as the PES Chapter Representative for Region 1, and a member of the New York JT Chapter Executive Committee (ExCom).

Margaret Leschuk received her BS in Electrical and Computer Engineering from Lafayette College, Easton, PA, in 2003 and her MBA in Finance and Management of Operations and IT from the Stern School of Business, New York University in 2009. She started her career with Con Edison in 2003 as a member of the Growth Opportunities in Leadership Development (GOLD) program. After completing the program in 2004, Ms. Leschuk took a permanent position as an associate engineer in the long-range planning section of transmission planning, which involved performing detailed load flow analysis of the Con Edison transmission system. In 2005, she was promoted to engineer within transmission planning and took on the first formal long-range transmission plan for Con Edison. In the summer of 2007, Ms. Leschuk worked as the executive summer support engineer for central operations, which involved providing dedicated and continuous executive support for substation, transmission, and distribution system conditions throughout the summer peak period to the chief executive officer (CEO) and president of Con Edison. In 2008, she was promoted to senior planning analyst in the substation operations planning department, where she schedules equipment outages for the northern region and acts as program manager for various capital projects.

Richard Glass is currently receiving his education in electrical and structural engineering from Virginia Western Community College. He started his career with Couvrette Building Systems as an AutoCAD® operator, designing modular buildings and kiosks for the banking industry. Mr. Glass started at VFP, Inc. in 2000 as a design engineer. He designed custom concrete and fiberglass-coated wood shelters for the cellular industry. Mr. Glass advanced to senior designer/project engineer, with his primary focus being custom modular and mobile control houses for electrical substations. He has 16 years of experience in structural and electrical design for the modular building industry.

Robert (Bob) Brown, Jr. received his BS in Electrical Engineering from Kansas State University, Manhattan, KS, in 1986. He started his career with Nebraska Public Power in 1986 as a substation engineer and progressed into protection and control engineering. Mr. Brown started at Schweitzer Engineering Laboratories, Inc. in 2000 as a protection engineer and project manager. He is a primary customer contact, responsible for designing protection and control panels, engineering relay settings, providing answers to customer technical questions, and providing technical training. Mr. Brown was promoted to senior engineer (protection) and is responsible for providing protection services to the power system industry, providing turnkey control enclosures, and implementing engineering, procurement, and construction projects. He has over 25 years experience in power system protection, power system construction and maintenance, distribution system engineering, substation design and commissioning, protection integration, and technical training. Mr. Brown is an IEEE member and a registered professional engineer in the state of Washington, as well as ten additional states.

David Schmidt received his BS in Physics from Vanderbilt University, Nashville, TN, in 2000. He started his career with Wick Fisher White Consulting Engineers in 2002, designing electrical systems for commercial buildings. Mr. Schmidt started at Schweitzer Engineering Laboratories, Inc. in 2009 as an electrical engineer and project manager for drop-in control building projects. He is responsible for designing protection and control panels, engineering relay settings, providing answers to customer technical questions, and providing technical training.