On the Road to Intelligent Distribution Automation

Duke takes the road less traveled and arrives at a new level of distribution automation.

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DUKE ENERGY-CAROLINAS HAS EMBARKED ON A MAJOR INITIATIVE TO IMPROVE THE VISIBILITY AND CONTROL OF ITS DISTRIBUTION SYSTEM. Known as the Remote Operation and Access to the Distribution System (ROADS) project, this initiative will provide Duke’s power delivery organization with remote access to intelligent electronic devices (IEDs) within distribution substations and out on the feeders they serve.

As part of the ROADS project, Duke (Charlotte, North Carolina, U.S.) is automating three distribution substations. The ROADS Distribution Automation (RDA) system will provide continuous remote monitoring of the power apparatus at these substations. In addition, the RDA facilities at one of the substations includes a highly sophisticated Integrated Volt/Var Control (IVVC) function that monitors and controls the operation of one transformer load tap changer (LTC), three voltage regulators and five switched capacitor banks to reduce losses and improve the feeder voltage profile.

LAYING A SOLID FOUNDATION

In recent years, Duke has replaced many of its electromechanical protective relays with IEDs (Fig. 1). With the implementation of ROADS, Duke is more fully tapping the wealth of information and other advanced capabilities of these IEDs. Duke’s engineers have been able to retrieve fault event data and station trouble alarms from these IEDs via dial-up telephone lines. Recently, Duke has begun using its corporate data warehouse to monitor some continuous loading information and device status data.

A similar situation exists on the distribution feeders. Duke has deployed line-capacitor-bank controller IEDs along with voltage-regulator controller IEDs. These are stand-alone de-
FIG. 1. Existing Protective Relay Panels. Duke has invested heavily in protective relay IEDs in many of its distribution substations. This photo shows a typical relay panel.

PAVING A NEW ROAD TO THE FUTURE

The RDA project included the procurement and implementation of a substation integration and automation system to enable Duke to better utilize its IEDs.

The scope of this project included:

- Master station equipment. This equipment, installed at Duke’s general office in Charlotte, includes a master station server, engineering workstation, feeder communications server, and facilities for connecting these devices to Duke’s substation communication network as well as its corporate network. One unique feature of the RDA master station is that the system does not include any dispatcher workstations; Duke personnel access the system using web browser software and “remote desktop” facilities running on existing desktop PCs (Fig. 2).

- System software. Major system software components include basic SCADA functions for remote monitoring and general processing, and advanced distribution application software, which performs the distribution network applica-

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Fig. 2. RDA Master Station. Duke’s unique architecture is designed for unmanned operation. Users access system information via existing desktop PCs running web browser software.

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cilities transmit substation data to the RDA master station and the corporate data warehouse over a hybrid communication network. Unlicensed spread-spectrum radio (900 MHz) delivers substation data to a hub on Duke’s optical-fiber wide area network (WAN), which then forwards the data to the RDA master station. Communication with feeder devices is han-
dled by commercial digital cell phone facilities. The communication protocol for all master station communications is DNP3 over TCP/IP (DNPi).

ALARM E-MAIL/PAGING SYSTEM

The ROADS DA system is designed for unmanned operation, because the operation and control of Duke's distribution system is primarily controlled by a mobile workforce rather than by control center personnel. When a critical alarm condition occurs, the RDA system delivers an e-mail message using Simple Network Mail Protocol (SNMP) to Duke's e-mail server, which, in turn, forwards appropriate e-mail and paging messages to the responsible party.

The RDA system allows Duke to specify who should receive the alarm based on a variety of criteria, including substation name, equipment type (circuit breaker, transformer) and type of alarm (feeder outage, maintenance alert).

NON-OPERATIONAL DATA ACCESS

Duke's relay engineers must be able to remotely acquire fault event information (including waveform data files), view settings and monitor relay health. To support this requirement, the RDA system uses a second serial port, configured for the relay manufacturer’s standard protocol, on each relay IED. The RDA system engineering workstation, running the relay manufacturer’s standard software, uses the RDA substation communication network for secure and reliable communications with the individual substation IEDs. “Remote Desktop,” a standard Microsoft Windows application, enables...
Authorized and authenticated personnel to interrogate and download non-operational data from individual relayIEDs via the engineering workstation using existing desktop PCs. In the future, Duke plans to extend this capability to other IEDs.

**DATA WAREHOUSE INTERFACE**

Duke uses its corporate data warehouse as a means of managing historical information about power-system conditions. Over the years, this system has proved to be an effective data-warehousing tool. Hence, Duke decided early in the RDA project to use it to store and provide access to the wealth of new information acquired from distribution substations and feeders.

The data warehouse interfaces directly to the substation data concentrators using separate channels on the substation communication network. This approach enables Duke to utilize the existing data concentrator database and DNP3 mapping for the data warehouse interface, thereby avoiding separate databases and point mapping structures for data warehouse applications.

**INTEGRATED VOLT-VAR CONTROL**

One of Duke’s key objectives for this project was to determine the benefits of an RDA-controlled Volt-VAR application.
tion versus the present method of Volt-VAR control that uses stand-alone IEDs. The expectation is that Duke can realize a significant reduction in electrical losses by maintaining optimal voltage profiles and reactive power flows on its feeders. To address this objective, the RDA system at Duke’s Pebble Creek Substation includes a sophisticated IVVC application function.

Simply stated, the IVVC application will determine, every few minutes, optimal tap positions for LTCs and voltage regulators, and the optimal positions (on or off) for all switched capacitor banks in the substation and out on the feeders. Once the optimal positions are determined, IVVC will automatically execute the recommended control actions via remote control (Fig. 4).

Following are significant highlights of Duke’s IVVC application:

● The application uses a three-phase, unbalanced powerflow model of the distribution feeders and the associated substation. The substation model includes full representation of the substation LTC transformer and two-stage substation capacitor banks.

● The feeder model includes representation of distribution transformer excitation characteristics. These losses vary with the square of feeder voltage, so proper modeling of distribution transformer characteristics is an important consideration.

● IVVC feeder models were created by converting existing electrical models from Duke’s feeder analysis package. This proved to be a very effective mechanism for building IVVC feeder models as well as geographically correct dynamic feeder maps for displaying program results. For the small number of feeders included in this initiative, the use of existing, fully verified models from the feeder analysis program was ideal. Duke does recognize that widespread implementation of IVVC will require that feeder models be built and maintained using its geographic information system.

● Real-time measurements acquired from IEDs located in the substation and out on the feeders are used to fine-tune the calculated power flow results. This ensures that calculated values match actual feeder measurements wherever available.

● IVVC control actions are implemented by transmitting control commands (on/off command or desired tap position) to the local controller IEDs associated with each IVVC device.

● The application uses a fail-safe design to ensure that failures in communication facilities and other IVVC equipment do not result in the execution of undesirable control actions. IVVC will operate correctly (and safely) in the event of a single component failure. If multiple failures occur or the feeder is reconfigured for any reason (making the model incorrect), the IVVC application will be automatically disabled and all Volt/VAR controller IEDs will revert to their original autonomous operation.
The IVVC application uses a linear programming optimization algorithm to determine the changes to LTC and the voltage regulator tap positions and capacitor bank position that will best meet the desired objective without violating feeder electrical constraints. For Duke, the desired objective used (problem formulation) is loss minimization.

LESSONS LEARNED

Duke’s project team learned many lessons during this implementation project. But none has hit home harder than the enormous amount of effort needed to implement and test DNP3 and Modbus IED interfaces. The process is far from “plug and play.” Development and confirmation of IED point lists and templates have been a tremendous burden on Duke’s project personnel.

Developing meaningful IED test scenarios in the factory has also been a major challenge. Some IEDs cannot be thoroughly tested by simulating the associated power apparatus (LTC transformer) in the factory, even if sophisticated test equipment are used.

Problems with communication interfaces to existing in-service IEDs were discovered by Duke during system installation. Some existing relay IEDs did not have the latest firmware to support standard protocols used by the RDA system. In addition, communication ports on some of the in-service IEDs did not work once the RDA system began polling the device, and these IEDs had to be replaced.

Electric utilities contemplating similar projects should anticipate having similar difficulties and allow for these problems in project budgeting and scheduling.

RESULTS TO DATE

Duke recently completed installing and commissioning the RDA system, and all equipment and software are currently operating and providing IED data in support of the ROADS vision. The IVVC application function is running, and Duke engineers are evaluating the performance and results of this application to determine whether a business case exists for expanding the concept to other substations and circuits. Early results are promising.

If the business case indicates that further RDA system deployment is economically justified, Duke may expand the
RDA concept to other substations and circuits. Future efforts may include:

- Providing remote monitoring at other Duke distribution substations
- Implementing control of substation devices, such as feeder circuit breakers
- Implementing remote monitoring and control of line switching devices out on the distribution feeders, including automatic fault location, isolation, and restoration
- Extending IVVC to additional feeders.
- Investigating the use of RDA substation and circuit data for external systems such as outage management and equipment maintenance planning.

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