Distribution Automation Helps Revitalize Community

Ernie Gorrell
Pike Electric Incorporated
(formerly with City of Danville, Department of Power & Light)

James Niemira
S&C Electric Company

Eli Nelson
Schweitzer Engineering Laboratories, Inc.

Presented at the
8th Annual Clemson University Power Systems Conference
Clemson, South Carolina
March 10–13, 2009

Originally presented at the
35th Annual Western Protective Relay Conference, October 2008

Distribution Automation Helps Revitalize Community

Ernie Gorrell, *Pike Electric Incorporated (Formerly with City of Danville, Department of Power & Light)*
James Niemira, *S&C Electric Company*
Eli Nelson, *Schweitzer Engineering Laboratories, Inc.*

***Abstract*—Over the past ten years, the City of Danville has seen the region's core industries, such as tobacco and textiles, close down or move overseas. Understanding the need to develop new jobs in the region, the City of Danville and many other communities sought to draw high-tech and manufacturing companies to the area with a large available work force and pro-business politics. Recognizing the importance of power system reliability to industry, the City of Danville created a new technology district, called Cyber Park, which boasts a cutting-edge electrical distribution system. This paper examines the implementation of this distribution system and the advantages it provides to customers.**

The distribution system eliminates customer outages using high-speed switchgear and advanced relaying in a completely automated system. Power is supplied to Cyber Park in a closed-loop configuration from a local substation. Substation-relayed circuit breakers and underground switchgear utilize communications-assisted, high-speed tripping to detect and isolate faults, allowing the power to reroute around the loop and provide a highly reliable power supply to customers. This paper presents high-speed communications techniques over fiber-optic networks, which allow total clearing times of six cycles or less. Conclusions include the economic benefits of distribution automation projects for utilities and end users.

I. Background

The City of Danville, Virginia, has been providing electric service since 1886 and currently provides electricity, natural gas, water, wastewater, and telecommunications services. Danville Power & Light (DP&L) is a division of Danville Utilities, within the Danville municipal organization.

DP&L is the largest municipal electric utility in Virginia. The city's electric distribution system covers approximately 500 square miles, including the City of Danville and portions of three adjacent counties. The electric system includes 1,800 miles of 12,470/7,200 V distribution lines originating from 16 substations served by 118 miles of 69 kV transmission lines. DP&L serves over 48,200 meters, offering electric rates comparable to utilities serving customers in the neighboring areas of Virginia and North Carolina [1].

The City of Danville has suffered from high unemployment and a loss of tax-based revenue because of their long-established reliance on the textile and tobacco industries. Employment in these industries has declined from 16,000 to a few hundred people over the last 12 years. During this time, the region has faced a serious financial predicament and a decline in the population as these traditional industries disappeared from the area.

Recognizing the challenges the area was facing, a city and county partnership was formed to classify the economic hardships and develop collaborative strategies. Each community government was challenged to develop a precise plan to enhance the region's economic situation. One result of this partnership was Cyber Park, a planned technologies site to assist in stimulating economic growth in the community and provide diversity in the regional manufacturing spectrum.

DP&L was called upon for any contribution that would augment the community development efforts in Cyber Park and the surrounding areas. While exploring different alternatives, it was realized that although the traditional underground distribution system with concrete-encased duct banks protected against dig-ins, it did not protect against other types of service interruptions or failures. The DP&L staff was familiar with high-speed, high-reliability distribution systems and began considering the use of this type of system at Cyber Park as an incentive for economic development. Consequently, the design and deployment of a system was included in the DP&L strategic plan to address service reliability issues in Cyber Park. After evaluating several solutions from various suppliers, the high-speed fault-clearing system was selected, installed, and commissioned in early 2004. Additional customer demand for the reliable power supplied by this system prompted its expansion in 2007 with the addition of new switchgear in the loop. The high-speed fault-clearing system is readily expandable without requiring significant reprogramming or reconfiguration.

II. Power System Considerations

Reliable electric service continuity was a clear requirement for Cyber Park, and aesthetic considerations were also paramount. The utility soon decided to use underground distribution to meet these requirements. At first, concrete-encased duct banks were considered to add more reliability than direct-buried cables. The utility staff, however, was aware of a previous deployment of a high-reliability distribution system [2] and began to consider using this technology as a differentiator to aid in attracting business to the technology park.

Concrete encasement of the duct banks would provide a slight advantage in protection from dig-ins but would still result in an outage when faults occurred. Also, a segment of the supply feeders to Cyber Park would still have to be via overhead distribution. Concrete encasement of the underground segments would do nothing to prevent or protect from transient faults on the overhead sections, and service to the loads would be disrupted during reclosing operations on the feeder circuit breaker.

On the other hand, the use of a high-speed fault-clearing system would maintain service continuity to the loads even during and after a fault. This would neutralize the advantage of concrete encasement while providing the further benefit of continuous, real-time monitoring and control. Faults due to causes other than dig-ins would also be protected against. The high-speed fault-clearing system could easily deal with faults on the overhead system. The faulted overhead section could be severed from the remainder of the distribution system during transient faults. Load service would be maintained, and loads would not be disrupted during reclosing operations. If the reclosing was successful, the distribution system would automatically return to normal configuration, prepared for another fault should one occur.

Because of the additional benefits derived from the technological solution, project funds were reallocated. The money saved by eliminating most of the concrete-encased duct banks and using a direct-buried conduit system funded the additional fault interrupters, motor operators, protective relays, communications equipment, and engineering design that comprised the high-speed fault-clearing system.

III. Physical Design Considerations

Two overhead feeders from the Brantly Substation provide the supply to Cyber Park. The overhead feeders dip to the underground system at riser poles just outside the park, while underground cables distribute power within the park. The main feeder loop is normally closed during operation so that the two supply feeders are electrically paralleled, forming a loop network through Cyber Park. Communications-dependent protection schemes are applied to the cable and overhead line sections of the closed-loop distribution back-bone to provide the highly reliable electric service required by the tenants of the park.

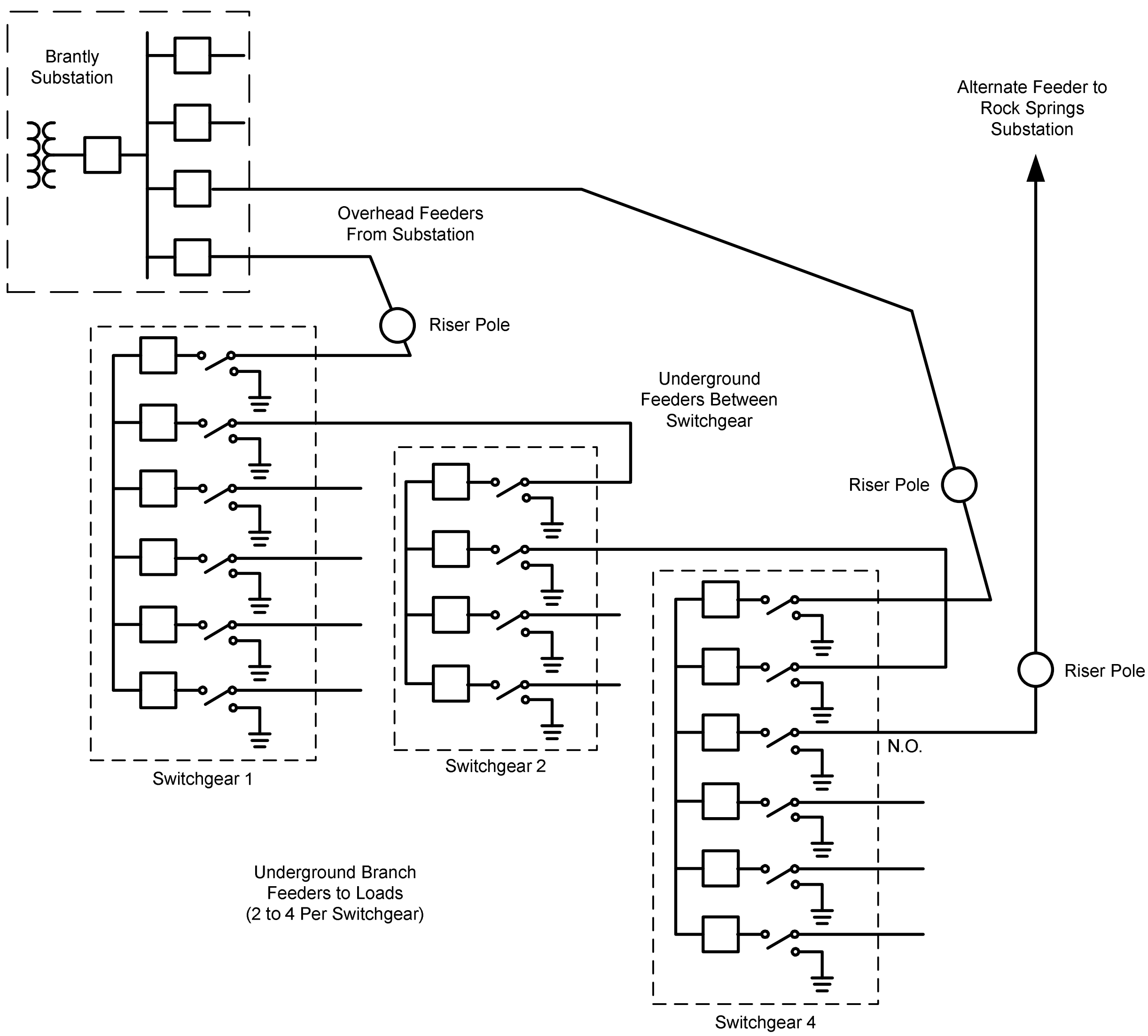

Fig. 1. One-line diagram of the Cyber Park system

Aesthetic considerations aided the decision to select subsurface mounted switchgear with a small, above-grade mounted control cabinet. The larger high-voltage compartment is mounted in a vault, the top of which is at grade level. The control cabinet houses the relays, communications equipment, battery and charger, and switch motor operator controls. Equipment in the control cabinet is designed to operate properly throughout the extremes of expected temperatures without the need for air conditioning equipment. The underground switchgear used for primary distribution has vacuum fault interrupters in a sealed SF6-filled tank for reduced dielectric clearances, making it possible to fit up to six fault interrupter ways in a single tank of small and manageable size. Each switchgear is like a miniature switching substation, with two incoming feeders for supply and feed-through to the next switchgear and up to four load feeders. The switchgear includes a three-position disconnect switch in series with each vacuum fault interrupter. The switch, which is closed during normal operation, can be opened to provide a visible isolating gap or placed in a visible ground position to facilitate cable repairs and other maintenance operations without the need to move the high-voltage elbows.

A robust communications system is required to achieve the high-speed, communications-assisted fault clearing. A fiber-optic multiplexer with redundant ring-optic topology was selected. Conduit for the fiber link was included while installing the high-voltage cables, so the additional cost for fiber installation was minimal.

Fig. 2. Direct-buried conduit for fiber link and high-voltage cables

IV. System Design Goals

The overarching goal of the Cyber Park distribution system design was to serve the connected loads with a reliable, fault-tolerant system. When faults occur, they should be automatically isolated, while maintaining uninterrupted service to the loads. Where temporary faults might be expected, as on the overhead sections, automatic circuit reclosing should be attempted, but without disrupting the sensitive loads at Cyber Park.

To achieve these goals, several high-speed fault clearing schemes were implemented, some of which have proprietary features. Communications-dependent tripping is a key element in the high-speed tripping schemes. Also, to the extent possible, the hardware and relay settings were standardized. The necessary application-specific modifications were made for the Cyber Park installation by using previously completed projects as a starting point for the design. Standardized, design-facilitated performance testing of completed switchgear and controls in the factory simplified and expedited field commissioning and startup testing. It also simplifies event report analysis once the system is deployed.

V. Relay Protection Schemes

Two source feeder ways of each switchgear unit serve the main backbone and are controlled by multifunction, microprocessor-based relays equipped with SEL Mirrored Bits® communications technology. Mirrored Bits communications works independently of other communications channels to create a point-to-point connection that allows high-speed, high-reliability protection schemes. The remaining switchgear feeder ways serve the load loops. There may be one to four load ways in addition to the two feeder ways. The Cyber Park project includes a switchgear unit with three relay-controlled "main" fault interrupters. The third relay-controlled way provides for future connection to a third source feeder from the Rock Springs Substation. The third main fault interrupter can also be configured for nondirectional overcurrent tripping, allowing a single spare unit to serve for any of the various configurations deployed [3].

A. *Branch Feeder Protection*

Fault protection on the load ways is controlled by a dedicated-purpose, nondirectional overcurrent relay that is self-powered from the CT circuit, including the charging of tripping capacitors—no external power supply is required for clearing faults on the load ways. The relay is programmable with a variety of time-current characteristic (TCC) curves to satisfy coordination requirements with upstream and downstream devices.

B. *Main Backbone Feeder Protection*

The protective relays on the main feeder backbone include four communications ports. One port is reserved for local interrogation. The remaining ports are connected to the multiplexer; two ports are dedicated to the protection schemes using Mirrored Bits communications, and one port is used for supervisory control and data acquisition (SCADA) access. The SCADA system allows for remote monitoring and control of the switchgear, and the protective relays have sufficient inputs and outputs so a separate remote terminal unit (RTU) is not needed.

A fiber-optic multiplexer system is used to provide communications for the relay protection schemes and SCADA access. The protection channels provide a virtual point-to-point communications connection between the two relays at opposite ends of the main feeder segment. The relays exchange bits of information for permissive tripping, trip blocking, direct transfer trip, and reclosing permission. The SCADA channels provide virtual point-to-point connections between each relay and the SCADA master station.

The protection schemes applied to the main backbone include permissive overreaching transfer trip (POTT), directional comparison blocking (DCB), and several backup protective and control functions. The high-speed, communications-dependent protection schemes will clear faults on the main backbone feeders within a maximum of six cycles, including fault interrupter arcing time. Fault detection and tripping occur in four cycles or less, and two cycles are allowed for fault interrupter clearing time. The programmed protection schemes are as follows:

- POTT schemes
- DCB schemes
- Backup overreaching POTT/DCB schemes
- Live-line closing onto overhead lines (for the overhead line sections)
- Switchgear bus fault protection
- Breaker failure protection

1) Permissive Overreaching Transfer Trip

The POTT scheme is only operable in the closed-loop, normal system configuration because current infeed is required at both ends of a feeder segment. This scheme also requires good communications in order to operate. If a fault occurs on a segment of the feeder backbone, directional protection elements at both ends of the line will operate. Because of the relative polarity of the CT and potential indication connections, the forward direction is designated as "into the switchgear from the line," and the reverse direction is "into the line from the switchgear." The POTT scheme uses reverse-looking (into the line) phase and ground directional elements at each end of the line. If a fault is detected into the line, the relay transmits a "key" or permissive trip signal to the remote terminal and prepares to trip if it should receive permission from the remote terminal. Thus, if both terminals of the feeder segment simultaneously detect a fault into that segment, they will both trip. Upon tripping, a direct transfer trip signal is sent to the remote terminal as well.

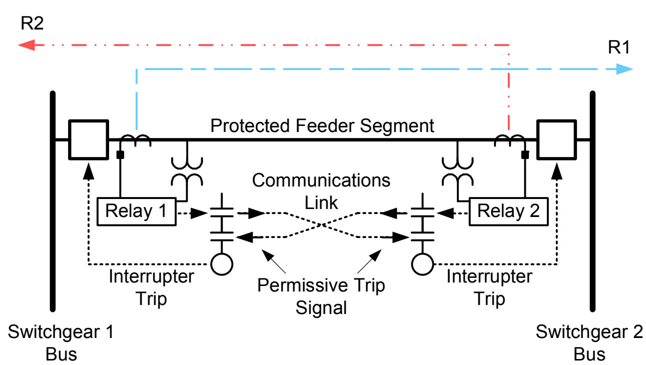

Fig. 3. Example of POTT scheme tripping logic

Because faults on the overhead section are more common due to exposure to weather and wildlife, the POTT scheme on the overhead feeder segment is slightly modified. When a fault in the overhead feeder section is detected, Cyber Park is isolated from the faulted feeder by tripping the first switchgear unit adjacent to the riser pole supplying the underground distribution loop. Power remains to all loads in the park by feeding around the loop from the remaining good feeder. The substation feeder breaker is allowed to clear the overhead line fault with a conventional time-overcurrent delayed trip and automatic circuit reclosing scheme. If power is successfully restored to the overhead segment, a live-line closing scheme activates the motor-operated disconnect at the underground switchgear to restore the loop to normal configuration. For the overhead line feeder sections, a short, three-cycle time delay is included in the POTT scheme to allow time for load-side fuses to operate, avoiding unnecessary operation of the feeder backbone fault interrupters.

2) Directional Comparison Blocking

The DCB scheme is used simultaneously with the POTT scheme. The DCB scheme uses reverse-direction fault detection elements for tripping and opposite directional elements for blocking the trip of a source-side interrupter. The DCB scheme is operational when the power system is configured as two radial feeders (i.e., with an open point along the loop) as well as when the loop is closed, because only one source of fault current is required. The directional tripping elements are set to pick up with a three-cycle time delay to allow generation, transmission, and processing of the blocking signal transmitted by forward elements (i.e., detecting fault current flow out of the line) at the remote end of the feeder segment. If a fault is detected into the line, and a blocking signal from the remote end is not received within the three-cycle coordinating time delay, the fault interrupter is tripped. The direct transfer trip is issued to the remote terminal, assuming the communications channel is healthy.

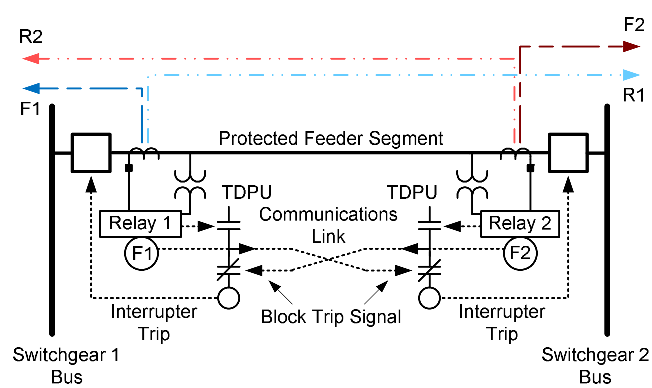

Fig. 4. Example of DCB scheme tripping logic

The DCB scheme is enabled for 30 cycles after loss of communications and is then disabled. Thus, loss of communications simultaneous with a fault occurrence will still allow tripping. After 30 cycles, tripping is blocked by default.

3) Backup Overreaching POTT/DCB

To account for the possibility of a completely out-of-commission switchgear unit (e.g., due to a traffic accident), backup protection is provided by an overreaching POTT/DCB scheme. This scheme works similarly to the primary POTT and DCB schemes, except the partner terminal is at the switchgear beyond the next one on the feeder, overreaching an intervening switchgear unit. For the overreaching schemes, an inverse-time overcurrent delay element, which coordinates with the load feeder protection of the intervening switchgear, supervises the directional tripping elements to delay a response until load feeder protection has had an opportunity to operate. Direct transfer trip of the overreaching remote terminal is not initiated on the backup schemes.

4) Live-Line Closing

A temporary fault will cause the underground switchgear unit to trip according to the protection schemes described previously. On the overhead line sections of the circuit, it is possible that the fault may be transient in nature, caused by weather or wildlife contact. To allow for recovery from a temporary fault, the substation feeder circuit breaker is allowed to go through a conventional time-overcurrent delayed trip and automatic circuit reclosing sequence after the faulted feeder is isolated from Cyber Park by tripping the first underground fault interrupter next to the riser pole. After a preset time delay has elapsed, the live-line closing scheme allows the underground switchgear to reclose, provided that the voltage on the overhead feeder has been restored and indication of successful reclosing by the substation feeder breaker is received over the communications link. To allow for line maintenance, the live-line closing feature can be disabled through the switchgear control front-panel Local/Remote switch or through SCADA. Lockout of the substation circuit breaker, operation of the switchgear bus fault protection scheme, or operation of the breaker failure scheme will also disable the live-line closing.

5) Bus Fault Protection

In the unlikely event of an internal fault in the switchgear unit, the feeder line section is programmed to trip and lock out if a fault has been detected into the switchgear bus on one of the main backbone feeders, and the fault is not detected leaving the switchgear on the adjacent line. This scheme also provides backup for the load-way fault protection. The fault detection of the bus fault scheme uses a time-overcurrent delay to coordinate with load feeder line protection. Direct transfer trip of adjacent switchgear is initiated to isolate the feeder segments supplying the faulted switchgear, except direct transfer trip is not issued from the underground switchgear to the substation feeder circuit breaker for the overhead line sections of the circuit. Operation of this scheme disables the live-line closing scheme.

6) Breaker Failure Protection

The fault interrupters of the underground distribution switchgear will typically clear a fault within two cycles after a trip. If the relay has issued a trip, but the fault is still present beyond nine cycles, the breaker failure scheme operates. The breaker failure scheme is used to trip and lock out all other main feeder interrupters in the switchgear. Remote terminals of underground feeder segments are also tripped through direct transfer trip. Operation of this scheme disables the live-line closing.

VI. System Testing

To ensure the system would perform as expected, the protection schemes and communications network were tested at the switchgear manufacturer. Testing included simulating the Cyber Park power system with computer-controlled relay test sets and connecting all of the communications channels through multiplexers, just as the system would be installed on-site. Faults were simulated throughout the system to ensure proper operation, and spare relays were programmed to simulate substation breakers in order to fully exercise the protection schemes and coordination. Post-installation testing was also performed before the system was energized [4].

Fig. 5. Factory testing of protection schemes and communications

VII. Conclusion

The system has been in service more than four years and has operated correctly in response to faults on any part of the system. Highly reliable power provided by a high-speed fault-clearing system offers many benefits to the end user. High-tech and manufacturing companies located in Cyber Park see improvements in their processes and a reduction in downtime related to power disruptions. Industrial and commercial customers acknowledge this advantage and choose to locate where electric power is more reliable. Using modern distribution relays and switchgear to their fullest is the key to distribution automation.

Fig. 6. High-speed fault-clearing system installed at Cyber Park

The Institute for Advanced Learning and Research, a collaborative effort of Virginia Tech, Averett University, and Danville Community College, initially anchored Cyber Park in 2004. Shortly afterward, Cyber Park became home to

Danville Community College's new Regional Center for Applied Technology and Training. Since that time, there has been explosive growth in development for the City of Danville. The following is a partial listing of new businesses that have moved to the Danville area [5].

TABLE I
NEW DANVILLE BUSINESSES

Date	Business Name	Description
Feb 05	Yorktowne Cabinetry, Inc.	Manufacturer of semi-custom cabinets
Apr 05	TWM Cabling Solutions, Inc.	Manufacturer of cable assemblies
Apr 05	Essel Propack	Manufacturer of laminated and plastic tubes
Jan 06	Telvista Service	Inbound technical support
Feb 06	Piedmont Precision Machine Co.	Manufacturer of components and machines
Feb 06	Unarco	Manufacture and repair of shopping carts
Apr 06	Armet Armored Vehicles	Manufacturer of armored vehicles
May 06	Arista Tubes	Manufacturer of extruded plastic tubes
Oct 06	Swedwood	Manufacturer of furniture
Jun 07	Horizontech, Inc.	Data processing
Feb 08	Com.40 Ltd.	Manufacturer of mattresses and furniture
Feb 08	Advanced Vehicle Research Center	Research off-road and alternative fuel vehicles
Jun 08	Infinity Global Packaging	Specialty goods packaging
Jun 08	CBN Secure Technologies, Inc.	Manufacturer of driver's licenses and identification cards

The list is substantiating evidence of the City of Danville's success in attracting new businesses to the area. Some of these customers are choosing to locate in Cyber Park, and all are providing new revenue sources for DP&L. The City of Danville's investment in economic development and distribution automation is paying off with renewed opportunities for their residents.

VIII. REFERENCES

[1] Danville Utilities. Available: http://www.danvilleutilities.com.

[2] J. Appleyard, D. Myers, and J. Niemira, "Innovations in Use of Microprocessor Relays and Controls for Improved Reliability on the Distribution System," in *IEEE/Power Engineering Society Transmission and Distribution Conference and Exposition,* 2001.

[3] P. Kalv and J. Niemira, "Bolstering Economic Development Through Distribution Automation," proceedings of the DistribuTECH Conference and Exhibition, Tampa, FL, February 2006.

[4] "City promotes economic development with high-reliability electric power," *Utility Automation & Engineering T&D.* Available: http://uaelp.pennnet.com/Articles/Article_Display.cfm?ARTICLE_ID=237179&p=22.

[5] City of Danville: News and Announcements. Available: http://www.danville-va.gov/news.asp?menuid=4090.

IX. BIOGRAPHIES

Ernie Gorrell is a senior project engineer for Pike Electric Incorporated. He has over 30 years of engineering and operation experience with electric transmission and distribution substations. Mr. Gorrell has performed protective relay and control design, testing, and substation commissioning. He is a member of IEEE. Mr. Gorrell earned an Associate of Science in Electronic Engineering from Jefferson Technical College in Steubenville, Ohio and a Bachelors of Science in Engineering Technology, majoring in electric engineering with a minor in mechanical engineering, from Old Dominion University in Norfolk, Virginia.

James K. Niemira, P.E., is a principal engineer at S&C Electric Company in the power systems services division. He has over 20 years of professional experience in the electric power industry. Mr. Niemira has done design work, field startup, and commissioning of wind farm substations and testing of distribution switchgear and controls. He is closely involved in distribution system protection and automation projects involving S&C's high-speed fault clearing system equipment. Mr. Niemira has authored and coauthored numerous papers and magazine articles dealing with power system protection, control, and automation and presented at industry meetings, such as DistribuTECH, Western Protective Relay Conference, Midwest Cogeneration, and Minnesota Power Systems Conference. He is a Senior Member of the IEEE, active in the IEEE Power and Energy Society, and serving as the chairman of the PES Chicago Chapter. He participates regularly in the IEEE/PES Power System Relay Committee meetings. Mr. Niemira earned a Master of Engineering in electric power engineering from Rensselaer Polytechnic Institute in Troy, New York, and a BSEE from the University of Missouri at Rolla. He is a licensed Professional Engineer, presently maintaining licenses in Illinois, North Carolina, and South Carolina.

Eli J. Nelson is a marketing engineer at Schweitzer Engineering Laboratories, Inc. (SEL). Mr. Nelson has primary responsibility for distribution relaying and control products and supports SEL activities in North America and around the world. He is a member of the IEEE since 2002 and a member of the IEEE Power & Energy Society. Mr. Nelson earned a BSEE from Washington State University in Pullman, Washington.