Case Study – Improving System Performance Using Distribution Network Automation

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***Abstract*—After receiving a U.S. Department of Energy co-funded Smart Grid Investment Grant, Westar Energy implemented an economical and powerful distribution automation (DA) system that includes fully automated fault location, isolation, and service restoration (FLISR) functionality and volt/VAR control. The system described in this paper uses a centralized distribution automation controller (DAC) for automated feeder voltage profile optimization that remains fully functional alongside an FLISR system, which can change the power system topology. Additionally, the DA system provides intelligence and mitigation for miscoordination detection and overload avoidance.**

One of the unique aspects of the DA system is that it is able to translate between various communications protocols. It also interfaces with the existing energy management system and integrates some existing Westar legacy equipment with new equipment and controls. Cellular modems and a secure Ethernet gateway provide secure wireless access to the distributed controls throughout the distribution system. Engineers use this remote access along with event collection to improve settings and system operation.

This paper describes the objectives of implementing the new Westar DA system, characteristics and capabilities of the system, system implementation, system performance during real-world events, and implications for future implementations throughout the Westar territory.

I. Introduction

In 2010, Westar Energy was awarded a U.S. Department of Energy (DOE) co-funded Smart Grid Investment Grant for the SmartStar Lawrence project. The three-year project consisted of installing advanced metering infrastructure, a meter data management system, and distribution automation (DA). Westar Energy is an investor-owned electric utility founded in 1910 that serves approximately 690,000 customers in the eastern portion of Kansas. The company chose Lawrence, Kansas, as the initial location for implementing this technology because of its size and customer base, which includes many student residents, commercial and industrial customers, and educational institutions.

This paper describes how Westar Energy implemented a cost-effective DA system that is now providing a very capable and fully automated fault location, isolation, and service restoration (FLISR) and volt/VAR distribution solution. The system translates between various communications protocols and interfaces with the existing Westar energy management system (EMS). The implemented DA system also integrates some existing Westar legacy equipment. Cellular modems were used for communications to the remote intelligent electronic devices (IEDs) because the system was primarily deployed for system restoration and voltage control, which do not require high-speed communications.

While Lawrence customers are the first to benefit from these new capabilities, experiencing fewer outages and a reduction in outage durations, the company plans to install similar equipment throughout its service territory. Application of a centralized distribution automation controller (DAC) and security gateway hardware at Westar Energy has opened the door to the secure, system-wide deployment of communications devices across the entire Westar territory. The DA system was designed to maximize system effectiveness, allow for improved system awareness, and increase work efficiencies across the company, namely as a result of the new remote access capabilities. The SmartStar Lawrence DA project was a success and has provided valuable experience that will be leveraged as Westar Energy continues to expand DA to other parts of their system.

II. Distribution Automation System Objectives

Westar Energy identified the following objectives that they wanted to achieve through implementing a pilot DA system:

- Increase system reliability [1].
- Reduce outage restoration times.
- Minimize distribution system losses.
- Reduce system loading during peak conditions.
- Improve system operation and understanding.
- Improve service to customers.

To minimize the impact on the distribution system operators, Westar Energy also wanted to pass information from the DA system to the existing EMS so that a separate interface would not be needed. The operators could then use the same system that they were already intimately familiar with operating.

III. Pilot DA System

The DA system was implemented on 24 of the 1,227 circuits across the Westar distribution network. The feeder circuits used reclosers at normally open tie points to interconnect two or more power sources. Additional reclosers were installed throughout the feeder circuits to allow sectionalizing capabilities in the event that permanent faults occur on a line section. Fig. 1 shows some of the distribution circuits, the interconnection switches, and three different substations that can be used as sources for the feeders.

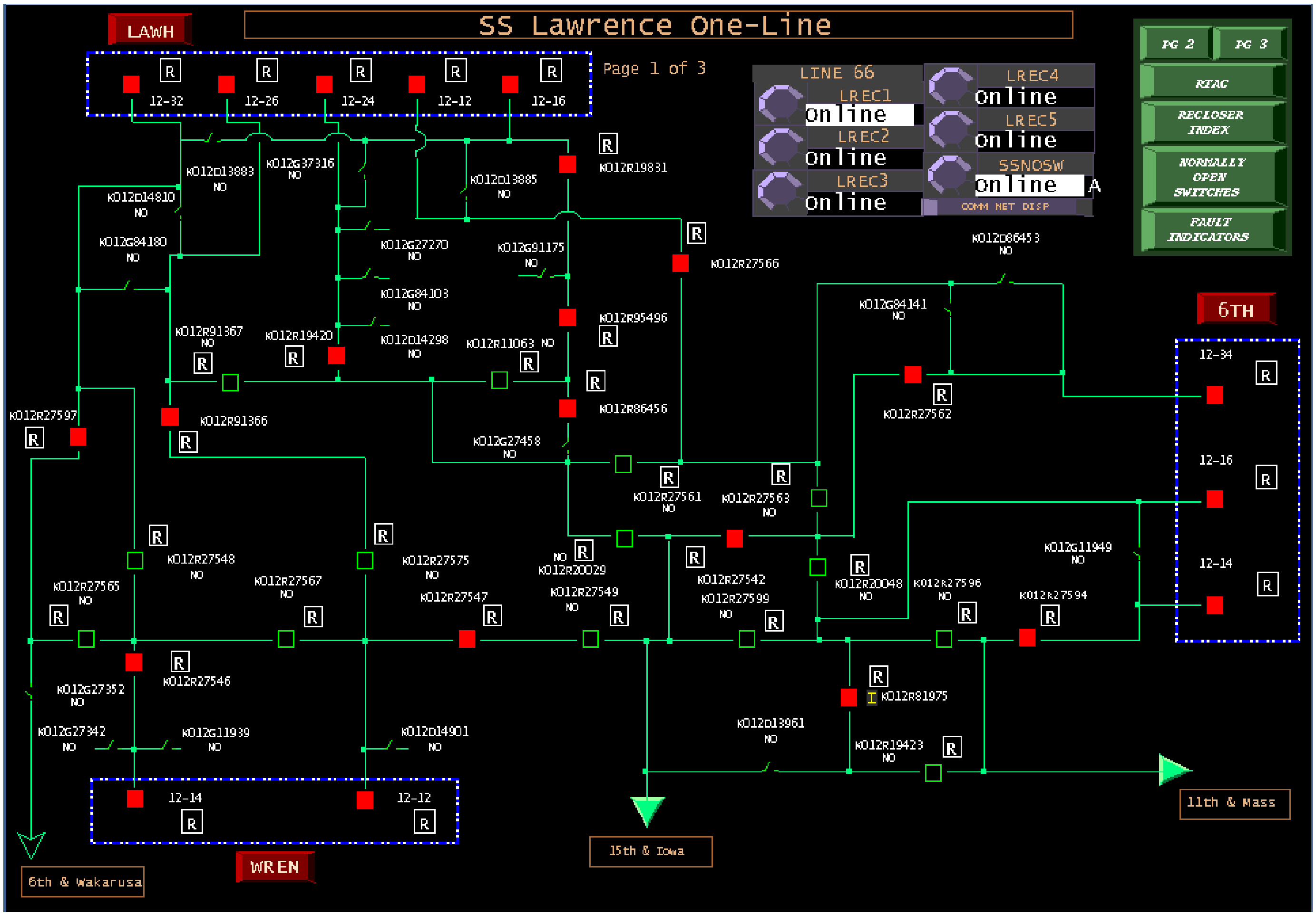

Fig. 1. EMS one-line diagram showing normally open (NO) and normally closed (NC) switch points

The equipment used in the DA system included the following:

- Thirty-three new recloser controls and satellite-synchronized clocks paired with the new reclosers.
- One legacy recloser and recloser control.
- Fifty-three capacitor bank controls retrofitted to existing capacitor banks.
- Ten substation transformer load tap changer (LTC) controls (six of which needed to be upgraded).
- Thirty-nine existing nontelemetered switches.
- Eighty-seven 3G and 4G LTE cellular modems for feeder IED communications and control.
- One DAC, providing centralized system intelligence.
- One Ethernet security gateway, providing comprehensive security measures including automated password management of the IEDs.

Leveraging existing communications and controls, the DAC communicates with the substation transformer LTC controls and protective relays via messages transmitted through the EMS to the substation remote terminal units (RTUs). In order to maintain an awareness of the system configuration and of abnormal system operating conditions, a server-based software solution monitors the Westar outage management system (OMS) and provides the status of the nontelemetered switches in the system to the DAC. Whenever operators change the state of the switches in the OMS, this information is also passed to the DAC.

A. Protocol Conversion

Several communications protocols were implemented across the DA system, including DNP3, Modbus®, and other open protocols. The protocols were selected either because of legacy equipment limitations or to provide the desired IED functionality. In turn, the DAC acts as a multiprotocol interface to all of the IEDs, allowing them to participate as peers in a unified, holistic system. Additionally, the DAC provides port routing functionality for remote access capabilities using various proprietary software interfaces. This allows a mix of new and legacy IEDs as well as controllers from different equipment manufacturers to be used, thus minimizing the installation time and the cost associated with implementing the system.

B. Wireless Communications

Westar Energy chose to leverage cellular technology for a number of reasons. Because the automation system was primarily deployed for system restoration and voltage control, high-speed communications were not required. All protection functions are performed locally within the IEDs, so the loss of communications is acceptable, although not desirable. It was also recognized that the design, deployment, and maintainability of a company-owned communications system would require a significant capital investment and would result in long-term operation and maintenance expenses. However, there would be the advantage of no recurring carrier charges. This type of deployment would also stress the technical workforce at Westar Energy, both in the present and in the future. Planned obsolescence would also need to be factored into the system and would require another capital-intense system upgrade of the communications network in the future. Moreover, performance of cellular communications has been evaluated by Westar Energy and others (refer to [2]) and was found to be adequate for the new DA system.

The initial setup of the cellular modems and antennas proved to be a challenge. However, making an adjustment to the antenna placement by moving each antenna from underneath the control cabinet to a mounting bracket higher on the pole improved the quality of cellular service. The initial Ethernet and serial settings for the modems also took some time to troubleshoot, and time was needed to develop standardized settings for various IEDs. The DA engineers worked closely with the Westar information technology (IT) groups and the cellular network providers to configure the communications backhaul properly.

Cellular communications allowed Westar Energy to minimize deployment times because there was no back-end infrastructure to build and maintain. Although there were ongoing data charges, data rate plans were negotiated with the cellular providers, which offset the costs that would have been associated with a company-owned system. Other benefits are that the cellular network is continually being built to incorporate new technologies that increase data throughput rates and decrease costs of data plans. Westar Energy is confident that the move to cellular technology was the correct decision.

Another critical aspect of successfully implementing the communications system for the DA system was that the DA engineers worked with the IT groups, including IT security, when designing and implementing the system. Through a collaborative effort, a secure communications system was implemented using cellular as well as serial and Ethernet communications.

IV. DA System Implementation

Westar Energy implemented the DA system in two phases, starting with the FLISR capability (Phase 1) and then adding volt/VAR control capability (Phase 2). This method allowed the reclosers to be installed initially (see Fig. 2), later followed by the replacement of capacitor bank controls and LTC integration. The initial DAC programming was provided by the DAC manufacturer. FLISR and volt/VAR programming were included by creating a system model and configuring standard DA libraries for the Westar distribution system. Human-machine interface (HMI) displays were also developed for use during commissioning and testing.

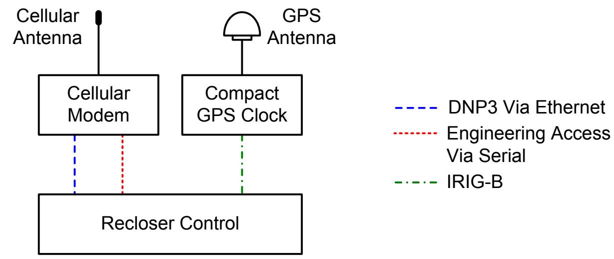

Fig. 2. Typical recloser cabinet with a Global Positioning System (GPS) satellite clock and a 3G or 4G LTE cellular modem

Remote interactive training was provided so that engineers at Westar Energy would be proficient at maintaining and implementing changes to the system to accommodate additional IEDs or feeder circuits in the future. Westar engineers further developed and implemented features in the system to aid with routine system monitoring and operations, including the deployment of automated password management, remote IED management capabilities, automated Short Message Service (SMS) and email routines, and additional HMIs. Additionally, the involvement of operations groups in the implementation and the provision of training were essential to operator understanding and acceptance of autonomous, closed-loop system operation.

V. DA System Capabilities

A. *FLISR Capabilities*

The Phase 1 portion of implementing the Westar DA system provided centralized automated controls that perform autonomous FLISR activities. The DAC provided the following features as part of the FLISR functionality:

- Loss-of-source detection.
- Open-phase detection.
- Miscoordination detection and mitigation, which provides operator notification and sectionalizes the correct portion of the system with the fault.
- Overload mitigation and load shedding, which smartly selects an alternate source with available capacity, shifts sources if loading increases beyond the limits, or sheds load if no alternate sources with capacity are available.

B. *Volt/VAR Capabilities*

In Phase 2, automation and control for voltage and reactive power flow were implemented. Example results are shown in Fig. 3. Volt/VAR control can be used to achieve several different goals, as discussed in [3]. The Phase 2 implementation used the same centralized system DAC and feeder information as Phase 1, but it added control of voltage regulators, capacitor banks, and substation transformer LTC controls to the system model. This simplified the effort of adding volt/VAR control while allowing both capabilities to operate as an integrated system. A benefit of implementing the system in this manner was that even after system reconfiguration, volt/VAR capabilities can still be performed on the reconfigured system, as described in [4].

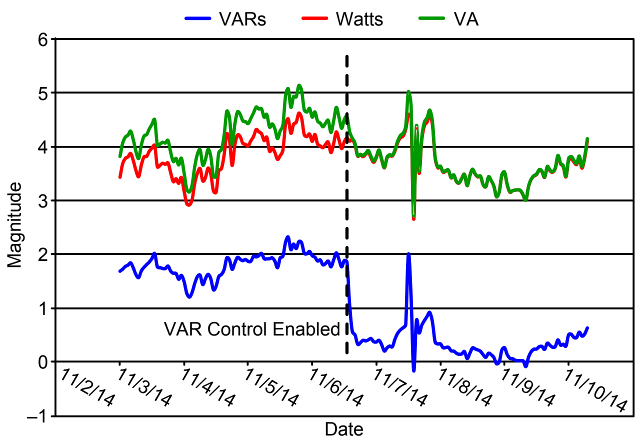

Fig. 3. Results of an automated capacitor bank control on one of the feeders

Volt/VAR features provided by the DAC included the following:

- Minimized VAR flow (i.e., system losses).
- Flattened voltage profile across feeders, allowing for feeder voltage reductions while not exceeding the minimum voltage limits to end-use customers.
- Feeder voltage reductions, which resulted in reduced energy consumption during peak demand (dependent on load characteristics). This is also known as conservation voltage reduction (CVR).
- Flexible operator control modes, which do as follows:
  - Optimize voltage on the feeder.
  - Optimize power factor (PF) on the feeder.
  - Optimize PF on the substation bus.
  - Demand response for peak load reduction.
  - Optimize the VAR set point on the primary side of the transformer for transmission VAR support.

C. *Remote Engineering Access*

A benefit of having secure communications to the substation and feeder devices is that it enables remote engineering access. Engineers are now able to retrieve and change IED settings as well as pull event data (Sequential Event Recorder [SER] reports and oscillography) from devices on a feeder circuit. This facilitates faster event analysis as well as helps to refine settings for improved system operation and protection. Westar Energy has also implemented automated password management using the secure Ethernet gateway to facilitate changing passwords in accordance with North American Electric Reliability Corporation Critical Infrastructure Protection (NERC CIP) requirements. Automated password management allows complex passwords to be changed in all of the remote IEDs periodically or on demand as required. Lastly, the DAC was configured with automated SMS text and email messaging routines for configured alarms and events, alerting operators or engineers to system issues that require attention.

VI. The DA System in Action

On November 10, 2014, a failed ground wire located on the primary line between the substation breaker and the first downstream recloser failed and caused the circuit to lockout. The DAC opened the first recloser to isolate the fault and closed a normally open recloser to pick up 894 customers from an alternate feeder source in less than two minutes. In addition, the DA system has been used to identify a sympathetic fault on a feeder in the automation scheme. As a result of the remote data collection capabilities provided by the system, Westar engineers were able to identify a location upstream of a faulted line section where conductors were slapping together on account of the magnetic fields associated with high fault current levels. It is believed that similar intelligence can be designed into the system so that this process of fault identification can be automated in the coming years.

Another benefit that has been realized by the addition of reclosers and recloser controls to the DA system is the reduction in customer interruptions, even without FLISR system interaction. As of November 2014, the reclosers have eliminated approximately 333,000 customer minutes interrupted (CMI).

Additionally, by using the centralized DAC for volt/VAR control along with the capacitor banks spread throughout the Westar system, the voltage profile along feeders has been flattened, improving the power quality delivered to customers as well as reducing energy consumption.

VII. Conclusion

The Lawrence area is already realizing the benefits of the new Westar DA system, which is improving reliability and power quality for customers. The system provides FLISR functionality as well as automation and control for voltage and reactive power flow. It also provides some powerful, advanced features like miscoordination detection and mitigation as well as volt/VAR control even when the system has been reconfigured.

Because the DAC uses industry-standard protocols and because existing and new equipment controls could be integrated and used together, the installation time and costs associated with the project were reduced. Furthermore, using these same standard protocols enabled the DA system to interface with the existing EMS and OMS, helping the operators become more comfortable with the new system.

Westar Energy used 3G and 4G cellular communications to implement control and access to the remote devices. By using cellular communications, Westar Energy was able to leverage the available infrastructure and cellular modems without having to install their own wireless system. This reduced their upfront costs and allowed for faster deployment of the system. Adding a secure Ethernet gateway to the system provided additional security because it allows for virtual private network (VPN) access and password management for all of their remote IEDs.

The new Westar DA system is reducing operating costs and improving system reliability and operating efficiency, all while improving customer satisfaction. This provides a win-win solution for both Westar Energy and their customers. Westar Energy plans to expand their use of DA based on this highly successful pilot system.

VIII. Acknowledgment

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X. Biographies

Aaron Smith, PE, is the Manager of Distribution Automation at Westar Energy in Topeka, Kansas. He has 13 years of industry experience in power system design, planning, operations, automation, tariff administration, and compliance. Aaron earned an executive MBA from the University of Nebraska-Omaha in 2012. He also received an MSEE from Kansas State University in 2011 and a BSEE from the University of Missouri-Rolla (now Missouri University of Science and Technology) in 2002. He is a member of IEEE and a registered professional engineer in the states of Oklahoma and Nebraska.

Mike Watson, PE, is the Director of Asset Strategy at Westar Energy. He has over 25 years of utility industry experience. Mike received his BSEET from Oklahoma State University in 1988 and spent the first 10 years of his career in power system design and systems engineering in the nuclear environment. The following 15 years of his career have been focused on various aspects of the electric distribution field, including power system design and planning, operations, power quality impacts, and system automation. He holds professional engineering licensure in the state of Oklahoma.

Jeff Hauber, PE, is a Senior Engineer in the Distribution Automation group at Westar Energy. He received a BSEE from the University of Kansas in 2005. He started at Westar Energy as a Distribution Engineer with responsibilities including planning, coordination, design, power quality, and reliability. He began working in the Distribution Automation group in 2013. He is a professional engineer in Kansas and a member of IEEE.

Clayton Stubbs is a Distribution Automation Engineer at Westar Energy in Topeka, Kansas. He received a B.S. in electrical engineering from Kansas State University in 2012. Clayton began working for Westar Energy in 2011 as an intern and became a full-time employee upon graduation. He is a member of IEEE and received his Intern Engineer Certificate in the state of Kansas.

Bill Flerchinger is a marketing manager at Schweitzer Engineering Laboratories, Inc. Bill completed a master's certificate in transmission and distribution from Gonzaga University in 2010. He received his M.S. in engineering management and a B.S. in electrical engineering from Washington State University in 1993 and 1987, respectively. He is a member of IEEE.

Dennis Haes is a senior engineer in the engineering services division of Schweitzer Engineering Laboratories, Inc. He has over 20 years of experience with substation automation and 13 years of electric utility operations experience with a large utility. Dennis obtained his B.S. in electrical engineering from New Mexico State University. He is a member of IEEE.

Will Allen received a BSEE from the University of Alberta in 1993. He has experience in the fields of industrial control systems and power system automation. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2000 as an automation engineer and served for several years as an integration application engineer. Will presently serves as a senior engineer in the SEL engineering services division. He is a member of IEEE and a professional engineer in the Canadian provinces of Alberta and Ontario and in the state of Washington.

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