Self-Healing Circuits at Southern California Edison

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***Abstract*-- Southern California Edison has been investigating and demonstrating self-healing distribution circuit technologies for many years. Initial work resulted in the installation of automated mid-point switches that sense loss of voltage on most urban distribution circuits. The next generation of this system was demonstrated on the Circuit of the Future. This system uses fault interrupting switches throughout the circuit that communicate with each other using fiber-optic cables. This arrangement allows the protection system to identify the faulted circuit section and isolate it before the substation breaker trips. The latest demonstration of self-healing circuits is being designed for implementation on the Irvine Smart Grid Demonstration project. This self-healing circuit variation places fault interrupting switches on the distribution circuit with communications being accomplished with low-latency radios. Again, the faulted section of the circuit is isolated before the substation breaker is tripped. Two radial circuits are also looped so that when the faulted section of the circuit is tripped, all other sections of the circuit stay energized.**

***Index Terms*—Power system protection, power system faults, power system restoration, wireless communications.**

I. Introduction

MOST of Southern California Edison's (SCE) distribution circuits are configured as radial feeders out of distribution substations. These circuits have multiple tie switches that can be used to pick up load from adjacent distribution feeder. In the early 1990's, SCE started implementing self-healing circuits involving the use of automated midpoint and tie switches to shorten circuit outages for customers. The second version of self-healing circuits was on SCE's Circuit of the Future where fault interrupting switches connected by fiber optic communications cables allow the isolation of only a portion of the circuit to reduce customer outages. The most recent version of self-healing circuits is being implemented on the Irvine Smart Grid Demonstration project. This system again uses fault interrupting switches, but replaces fiber optic communications with wireless radios for passing information between switches. Results of this latest system will dictate what will be implemented in future stages of self-healing circuits at SCE.

II. SCE's Existing Self-healing Circuit System

In the late 1980's SCE was involved in the development of a frequency hopping, spread-spectrum radio system. In the early 1990's this system started to be used for operation of distribution circuit mid-point and tie switches. These radios had the ability to run some simple logic internally, so could be used as a controller for the switches with remote communications abilities to system operators.

SCE's existing self-healing circuit automation system uses a single automated mid-point switch as indicated in Fig. 1. When a fault occurs the substation breaker opens and then recloses after 15 seconds. If the fault is still present, the substation breaker reopens and stays open. When the midpoint switch sees the loss of voltage for more than 30 seconds, it opens. At 55 seconds after the initial fault, the substation breaker closes for a second time. If the fault is in the first half of the circuit the substation breaker trips, locks out, and the second half of the circuit is restored by the operator through the use of an automated tie switch. If the fault is in the second half of the circuit, the substation breaker closes which restores the first half of the circuit. This method of automation gets many customers back in service quickly, but still causes several operations of the substation breaker and interrupts all customers on the circuit.

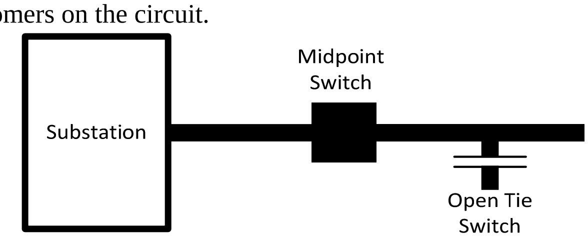

Fig. 1. Existing self-healing circuit configuration

This scheme for quickly restoring customers has been implemented on more than half of SCE's 4600 distribution circuits. While this system was responsible for significant reductions in customer minutes of interruption, it still needlessly interrupts more customers than necessary. SCE's Circuit of the Future self-healing concept was designed to improve on the existing system.

III. Self-healing on SCE's Circuit of the Future

The SCE Circuit of the Future effort began in late 2003

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with the initial conceptual design effort [1]. The circuit was constructed and put into operation on August 14, 2007. It is located north of San Bernardino, CA and served out of SCE's Shandin Substation. This 12-kV circuit serves approximately 1,500 customers and is composed of both overhead and underground construction. There are also adjacent circuits that can be used as backup following faults.

The Circuit of the Future self-healing automation system utilizes vacuum fault interrupters located along the circuit to limit the number of customers affected by a fault. Depending on the fault location, the substation breaker might not even trip. Through the use of fast communications over fiber optics, the fault location can be determined and the proper fault interrupting switches opened automatically. With knowledge of circuit loadings at the time of the faults, ties to other circuits can be closed to restore all customers except the faulted section. This automation scheme can limit outage time and increase reliability for customers. Fig. 2 shows the general arrangement of the Circuit of the Future and its protection devices.

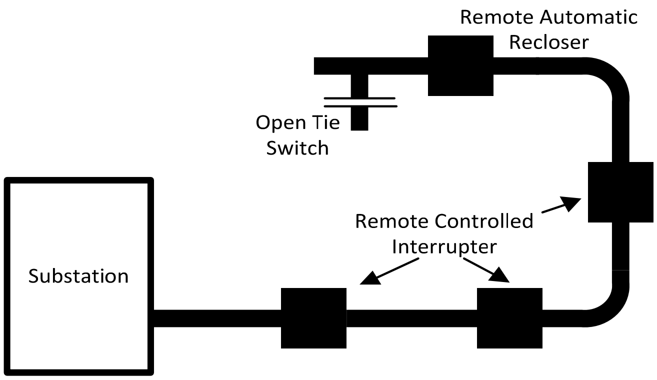

Fig. 2. Circuit of the Future self-healing circuit configuration

In order to minimize the number of customers affected by a circuit fault, three underground Remote Controlled Interrupters (RCIs) and an overhead Remote Automatic Recloser (RAR) are used to isolate the faulted section of the circuit. After a fault, control logic automatically opens the next downstream protective device to facilitate restoration of service to the unfaulted portions of the circuit. This automation function is referred to as an "Iso-Open." A five second delay is incorporated in the automatic opening logic to make it clear that the opening is an automated control operation and not the result of a second fault. For example, a fault between the first and second RCIs out of the substation will trip the first RCI. Five seconds later, control logic opens the second RCI automatically. Then a remotely controlled tie switch can be closed by the operator to restore service via a neighboring 12-kV circuit to all loads beyond the faulted circuit section.

Automation and coordination of the protection is provided by a Schweitzer SEL-2100 Logic Processor located in the control cabinet for two of the RCIs. Fiber optic cables connect the SEL-2100 to each RAR and RCI as well as to Shandin substation, as shown in Fig. 3. The RAR is programmed for one automatic reclose after a fault. The RCIs do not automatically reclose.

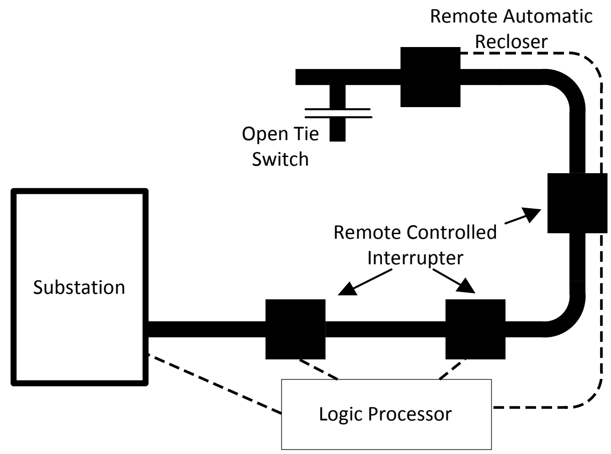

Fig. 3. Logic processor and fiber optic communication diagram

IV. Self-healing circuits on SCE's Irvine Smart Grid Demonstration Project

In the Circuit of the Future, fault interrupting switches were connected by fiber optic communications cables so the location of the fault could be identified by the Logic Processor and the proper switches opened. Since this circuit was a radial design, all customers beyond the opened fault switch would lose power until the tie switch to an adjacent circuit could be closed by the system operator. While this system was able to reduce the number of customers interrupted when a fault occurred, fiber optic cable installation was costly and still required actions by a system operator to restore customers located past the faulted section of the circuit.

To address these issues, the design of the advanced protection system to be used on the SCE Irvine Smart Grid Demonstration project made some changes to the one used on the Circuit of the Future. To address the cost issue, the fiber optic communication portion of the system will be replaced with a wireless radio system. This radio system needs low latency (~100 ms), but will not necessarily require high bandwidth. This is because the messages communicated between switches are short. In a move towards standards, the messages sent over the wireless radio system will use IP and conform to IEC61850 GOOSE standards. To fix the issue with operator intervention to restore customers past the fault, two distribution circuits will be looped together as shown in Fig. 4. With the circuits looped, the faulted section of the loop can be isolated while all other customers would not experience an outage. This protection method can also more easily integrate distributed generation since it can account for bi-directional current flow. Based on radio latency and coverage studies, protection logic simulations, and field circuit constraints, the final circuit protection system is being designed. This protection system is planned to go into operation in 2013.

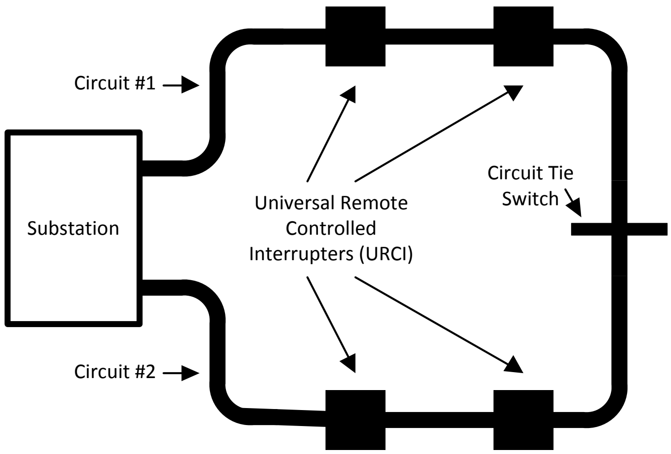

Fig. 4. ISGD Self-Healing Circuit Configuration

V. Conclusions

This paper describes the development of self-healing distribution protection systems at SCE. These protection systems will increasingly need to deal with the proliferation of distributed generation devices (e.g. rooftop photovoltaics, battery storage), the introduction of electric vehicles and their chargers, and the increased potential of demand response (e.g. smart appliances, air conditioner controls). These self-healing protection systems show promise in helping ensure reduced outage times and less momentary interruptions. The system that will be demonstrated on the Irvine Smart Grid Demonstration project shows promise to become the next generation of distribution protection for SCE.

VI. References

Papers Presented at Conferences (Unpublished):

[1] R. J. Yinger, "Southern California Edison’s Distribution Circuit of the Future," presented at the IEEE Power Engineering Society Transmission and Distribution Conference, Dallas, TX, 2006.

VII. Biographies

Robert J. Yinger (M’76) graduated from California State University, Long Beach with a degree in Electrical Engineering. He holds a Professional Engineer license in electrical engineering from the state of California and is a member of the IEEE. He is employed in the Advanced Technology Group of the Transmission and Distribution Business Unit at Southern California Edison. The group is responsible for researching and bringing into use new technologies for SCE. In his 35 years with SCE, he has been involved in a wide range of research and development activities including system planning, solar and wind energy development, power quality, communications technology development, electronic metering systems, and substation/ distribution automation. His present work is focused on planning the scope and implementation for the Smart Grid at SCE.