EXPERIENCE WITH SELF-HEALING GRIDS

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ABSTRACT

This paper describes the experiences (including challenges) gained from two practical implementations of automated distribution feeder self-healing pilot projects.
The first project, located in the Isle of Wight in UK, was implemented for Scottish and Southern Energy plc (SSE) and comprises thirty two S&C IntelliRupter® PulseClosers installed at interim-feeder locations among the 11kV interconnected circuits. The IntelliRupters are controlled by S&C IntelliTeam® II Automatic Restauration System using peer-to-peer communication and real-time feeder loading data. The primary objectives of the SSE pilot program were to evaluate the benefits of PulseClosing technology and an automated feeder self-healing solution using distributed intelligence.
The second project was implemented for State Grid Corporation of China (SGCC) and is located in Ningxia, China. Seven S&C IntelliRupter® PulseClosers controlled by S&C IntelliTeam® SG Automatic Restoration System were installed on two 10kV feeders. The IntelliRupters communicate with each other and the utility's SCADA system. The primary objectives of the SGCC pilot program were to investigate the potential of an automated feeder self-healing solution to improve reliability.
The two projects successfully validated the technological benefits of IntelliRupter® PulseClosers features and economic benefits of reducing or eliminating the load-restoration responsibilities of SCADA operators by automatically restoring power to unfaulted feeder segments in less time than the restoration target set by the regulator.

INTRODUCTION

Significant reliability improvement is considered as the main reason behind implementation of distribution automation. Reduction of system average interruption duration index (SAIDI) is a key driver of this improvement. When a decision to improve reliability has been made, then the evaluation of relative costs to reduce SAIDI shows that feeder automation is the most efficient route to achieving that goal. Scottish and Southern Energy (SSE) and State Grid Corporation of China (SGCC) selected the 11kV Isle of Wight and 10kV Ningxia networks respectively to demonstrate the performance of an automated feeder self-healing solution featuring distributed intelligence. The network selections were based on the utility configuration and area severe weather conditions that would rigorously test the performance of the self-healing solution, as well as demonstrate the technological advantages of PulseClosing. The switching device locations selected for automation were chosen based on cost justified reliability improvement calculations. These calculations considered the impact on Customer Minutes Lost (CML), total load lost, and customer interruptions, and took into account the following factors:

- Fault rate
- Average time to switch
- Average time to complete a repair, and
- Underground / overhead splits.

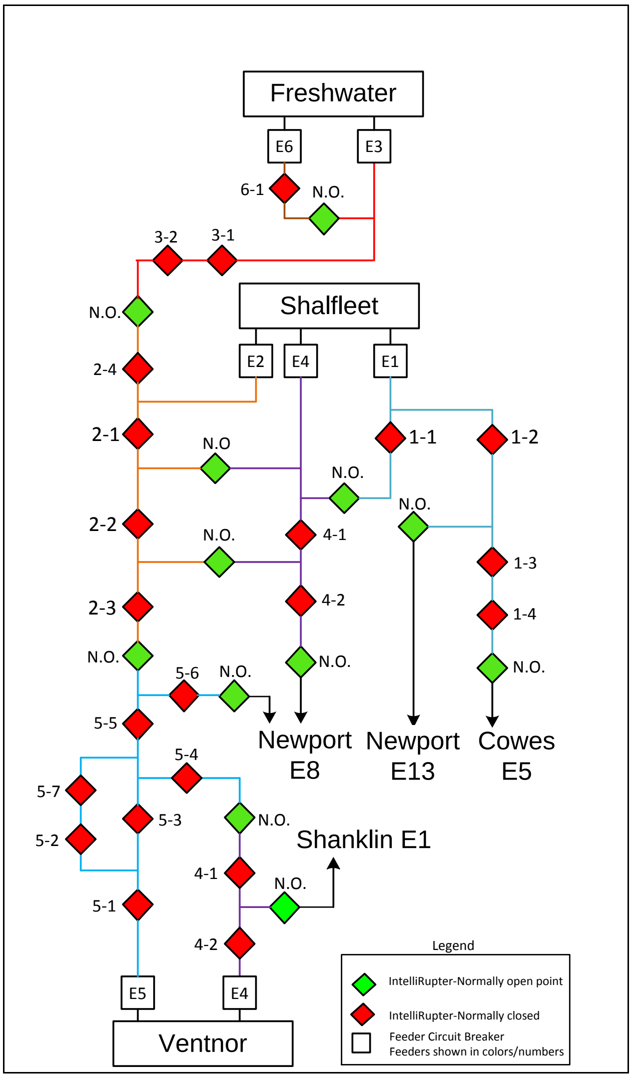

Figure 1: SSE Isle of Wight automated feeders self-healing

The SSE project shown in Figure 1 comprises 32 new S&C IntelliRupter® PulseClosers and a mix of underground and overhead feeders. The SGCC projects comprise seven S&C IntelliRupter® PulseClosers as illustrated in Figure 2.

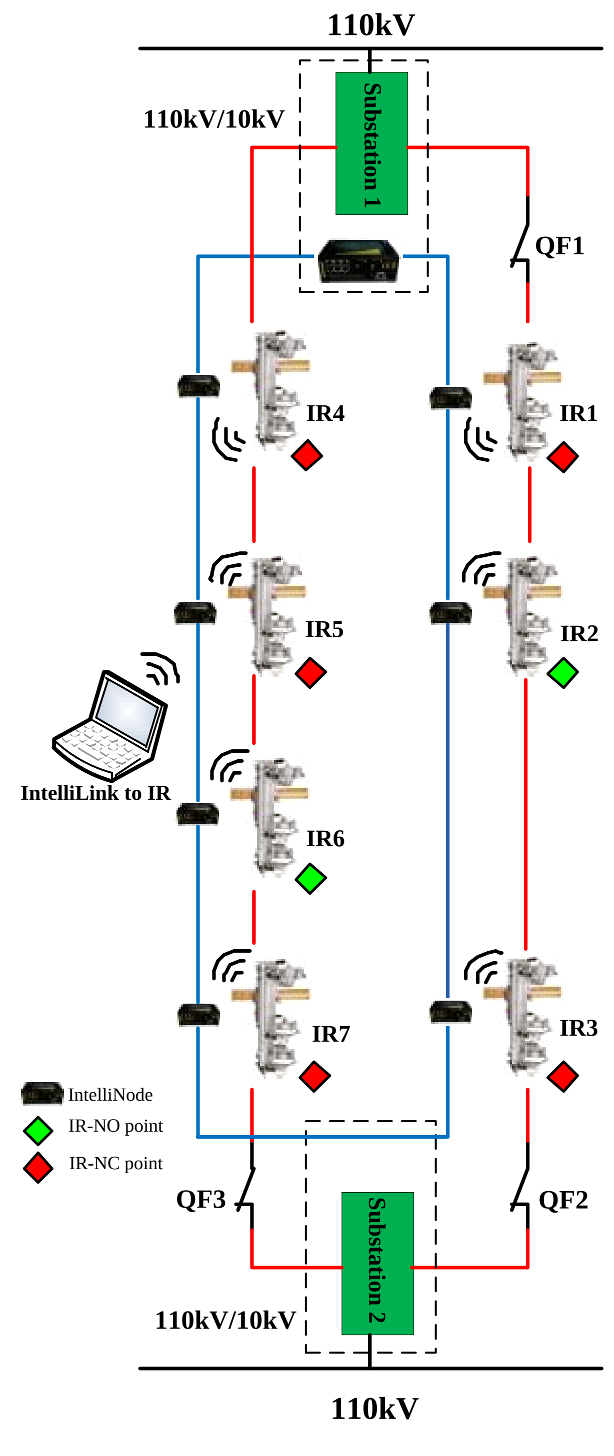

Figure 2: SGCC Ningxia automated feeders self-healing

The IntelliRupters are furnished with IntelliTeam® Automatic Restoration System software. The IntelliRupters communicate with each other and the utility's SCADA system. It should be noted that for the SSE project IntelliTeam® II were used while the upgraded version (IntelliTeam® SG) is used in the SGCC project. S&C IntelliTeam® Designer software is used to configure the teams and retrieve operational data.

SYSTEM COMPONENTS

These projects system configuration include the following components:

<u>IntelliRupters</u>

The IntelliRupter is a vacuum interrupter with unique features designed to accommodate advanced distribution automation functions, including S&C's self-healing. For both projects each installed IntelliRupter features the following:

- Unique PulseClosing Technology to confirm there's no fault on the line before initiating point-on-wave closing.
- Vacuum interrupters with unique actuating system that enables PulseClosing Technology™.
- An integral visible disconnect,
- Integrated three-phase voltage sensing on both sides of the interrupters
- Integrated three-phase current sensing, providing linear output over the range from load to fault current
- Integrated power module on both sides of the interrupters. The inclusion of a second integral power module enables powering of an open IntelliRupter when either side is energized
- Communication and control modules

The communication module of each IntelliRupter is equipped with a licensed-frequency VHF Radius PRD121 Radio. The communication module also contains the backup batteries, and along with control module, is contained within the unitized stainless-steel base of the IntelliRupter. Each self-contained IntelliRupter was quickly mounted on a wooden pole using its single-point lifting bracket. The only site wiring required was connection of the IntelliRupter terminal pads to the power lines.

The high sensor measurement accuracy and rapid response time of IntelliRupter permit more devices to be connected in series than is possible with conventional reclosers. IntelliRupter has multiple protection profiles to allow for quickly switching between applications and offers bidirectional load measurement and coordination. Its protection capabilities include simultaneous independent directional phase, ground, and negative sequence instantaneous and time overcurrent elements; simultaneous independent directional phase, ground, and negative-sequence definite-time elements; intelligent fuse-saving overcurrent elements; over and under voltage elements, over and under frequency elements, synch-check, and Sensitive Earth Fault (SEF) protection.

Conventional reclosers trip to clear a fault then reclose to determine if the fault has disappeared or if it still remains. Each reclose attempt applies the full magnitude fault current thus stressing the network equipment until a tripping and lock out condition is reached as configured for each operation (Figure 3). Additionally, voltage sags are experienced by all upstream loads, including adjacent healthy feeders fed from the same substation bus since the reclosing is random relative to the voltage point-on-wave.

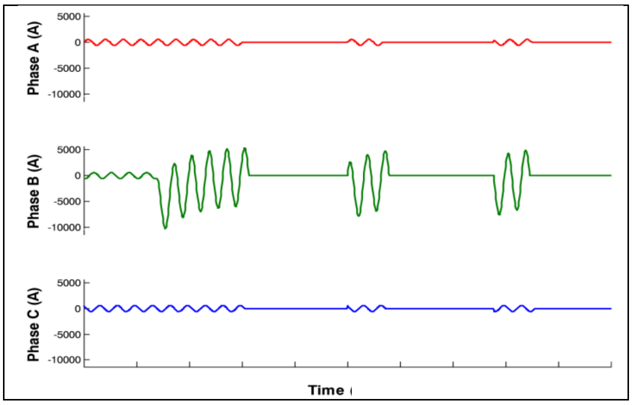

Figure 3: Typical recloser reclosing sequence for a permanent B- phase-to-neutral overhead fault, illustrating successive fault currents that result, and impact on unfaulted phases

Unlike the conventional reclosers, the IntelliRupter PulseClosing feature injects, after fault interruption, a low energy current pulse into the line to determine if the fault was cleared. The low energy current is immediately analysed and a load or fault condition is declared within few cycles. The technology has the ability to close the IntelliRupter contacts at a specified point on the voltage wave that generate enough current to measure and analyse while still keeping the let-through energy into the fault as low as possible.

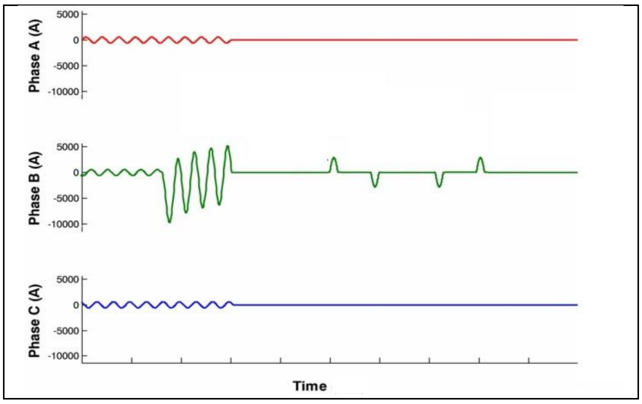

Figure 4: Benefits of using PulseClosing to test for a permanent B-phase-to-neutral fault. PulseClosing uses minor loop of current to test for fault persistence. A second minor loop of current results when the first pulse is declared a fault, to confirm magnetizing inrush is not a factor.

IntelliNodes Interface Module

The IntelliNode is an Universal Interface Module (UIM) that enables a substation breaker and other electronics devices (not of S&C manufacture) to operate as part of an IntelliTeam® Automatic Restoration System, helping to further minimise the impact of an outage. It interfaces with the microprocessor relay of the substation breaker and provides full team-member logic and communication capabilities to the fault-interrupting decisions made by the relay. Upon loss of substation bus voltage, the module allows IntelliTeam® logic to restore power to the line segment between the substation breaker and the first switching/fault-interrupting device. The IntelliNode can allow an additional reclosing attempt, if desired, and still restore all unfaulted line sections.

The IntelliNode Interface Module exchanges information with other team members and polls the relay for status and analog data. Upon the occurrence of a fault or loss of source, the module provides an interface to/and operates the breaker to restore as many feeder segments as possible.

The IntelliNode connects to the protective relay or recloser control through a serial or Ethernet cable and supports DNP 3.0 protocol for communication with a SCADA master or substation RTU. All DNP points are configurable. They consist of all the DNP points normally scanned by the SCADA master plus all IntelliTeam DNP points.

IntelliTeam®

IntelliTeam® is a field-proven universal Smart Grid solution that automatically reconfigures the distribution system after a fault and quickly restores service to segments of the feeder which are not affected by the fault. Although fully compatible with SCADA, no SCADA control or central monitoring is required as decisions are made locally, based on real-time loading data. IntelliTeam® supports complex systems of virtually any size and accommodates tie points from multiple sources and can handle as many teams of switches (IntelliRupters) as line loading will allow.

IntelliTeam® monitors real-time voltages and currents throughout the system using sensors integrated into the IntelliRupters. Each IntelliRupter is configured to know its normal role in the system, its name (DNP address), and other key settings such as the maximum load capacity, allocated function within the team or power source priority.

Using the voltages and currents measured at the IntelliRupter, along with the configuration settings, IntelliTeam® will identify the location of a fault anywhere in the system. The fault will be automatically isolated to the one affected team by opening the IntelliRupter in conjunction with the source-side protective devices. Once the fault has been isolated, IntelliTeam® will seek out all possible power sources, to restore service to as many teams as possible, as quickly as possible.

IntelliTeam® can manage virtually any number of alternate sources and loads. Before closing a switching/fault-interrupting device to restore service, the system automatically verifies that the alternate source will not be overloaded, by adding the pre-fault load of the de-energised segment to the present real-time load of the alternate source. Restoration is typically completed in seconds.

After clearing the fault (and any damage repaired) and the SCADA dispatcher or field personnel has closed the open-source switching/fault-interrupting device of the faulted section, IntelliTeam® signals the teams to return the circuit to its normal configuration. Either open or closed transition return may be selected.

PulseFinding Technology

Where PulseClosing is employed standard time-current coordination practices between series-connected IntelliRupters can be ignored. The protection settings in any number of series IntelliRupters is implemented by keeping the same settings or marginally faster than their next upstream IntelliRupter. This technique is called PulseFinding and the way it works is illustrated by sequences in Figure 5 through Figure 9 where IntelliRupters IR-2, IR-3, IR-4, and IR-5 are sharing the same time-current characteristic T3.

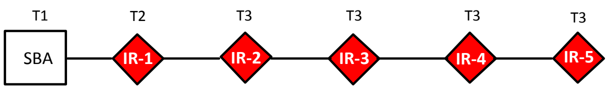

Figure 5: A circuit with five IntelliRupters in series

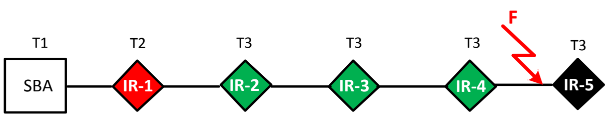

Figure 6: A permanent fault occurs between IntelliRupters IR-4 and IR-5. IntelliRupters IR-2, IR-3 and IR-4 trip

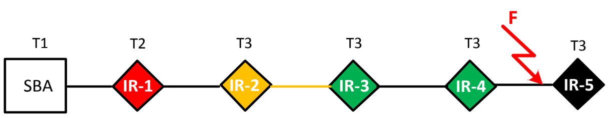

Figure 7: After 1 second (the delay can be adjusted), IntelliRupter IR-2 pulses to determine if a fault is present.

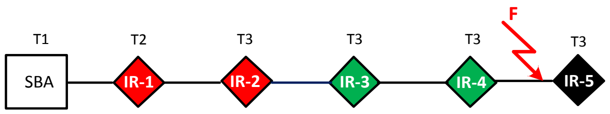

Figure 8: IntelliRupter IR-2 closes because it has confirmed no fault exists between it and IntelliRupter IR-3.

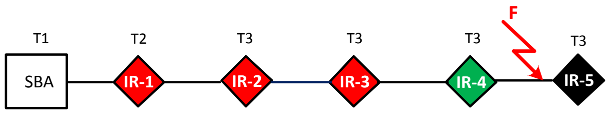

Figure 9: PulseClosing is repeated every 0.5 second by the next downstream IntelliRupter, to determine if a fault exists between it and its next downstream neighbour. The final status of the feeder is shown, achieved after 2 seconds. There is no reliance on communication between IntelliRupters.

VALUED OUTCOME

Location of Equipment

Access restriction to equipment deployed on private properties led to delays in simultaneously activating all system components. With part of system components (accessible) configured, the system "ready" status were achieved by eventually configuring components settings to reflect the inaccessible system devices. To circumvent this issue it is recommended to plan and organise commissioning per segment of the system in coordination with the SCADA operator.

Communication Devices

For better communication performance site surveys were carried out to identify optimal radio locations for both repeaters and IntelliRupters. However some selected radio locations (SSE project) were not optimal and created WiFi access issues to the IntelliRupters during start-up (devices configuring and testing). SSE concluded that those issues would have been greatly simplified had some of the IntelliRupters been located closer to public roads.

SCADA Interface Signals List

A SCADA connection is not required because IntelliTeam® utilises distributed intelligence. But a SCADA connection is nevertheless useful for obtaining system status as well as enabling remote command operation of the system. A wide range of device and automation system status parameters were initially mapped to SCADA that resulted in data overload thus leading to operators ignoring some important alarms. Therefore it was concluded to send to SCADA only signals defined in the SCADA Interface Signal List.

Increase segmentation

SSE and SGCC learned that increased feeder segmentation can be achieved with IntelliRupters if alternate coordination strategies and practices are embraced. By employing the PulseFinding feature of IntelliRupter, and abandoning traditional time coordinated overcurrent protection practices, a greater number of series-connected IntelliRupters can be installed than possible with conventional reclosers.

Data collection

During site SGCC automation testing the transmission power was lost at Substation 2 (Figure 2). The IntelliRupter teams on both feeders immediately responded to the event and restored service to the loads normally served by Substation 2. In fact IntelliRupters IR-3 and IR-7 experienced a loss of voltage and tripped open. Then IntelliRupters IR-2 and IR-6 closed thus restoring service to their associated line sections. State Grid engineers were anxious to retrieve data associated with the event since the SCADA connection to the IntelliRupters was not functional. A computer was used to access the network and run the IntelliTeam® Designer, to poll the affected devices and compile the event summary. The engineers were impressed that it took only minutes to gather data from the IntelliRupters and demonstrate the event.

Sensitive earth fault protection

Field personnel initially doubted the validity of SEF protection provided by the IntelliRupter, as one or two devices periodically tripped on SEF shortly after implementation on Isle of Wight. As conventional reclosers hadn't exhibited this behaviour and no obvious cause could be found initially the SEF trips were initially considered a nuisance. But when the SEF operations continued and field crews were encouraged to investigate the events further, the causes of the SEF operations were eventually found.

Training

SCADA operator training were planned to be done after the IntelliTeam® were fully commissioned. However the IntelliRupters were visible to the SCADA control after installation thus causing confusion to the SCADA operators as they were not familiar with the PulseClosing features of IntelliRupters. Therefore SSE concluded that SCADA operator training should have been conducted in instalments, with the initial training focused on the operating differences between IntelliRupter and conventional reclosers.

CONCLUSION

In this paper the principle and implementation of a self-healing grid is discussed using two pilot schemes. The pilot schemes have been deemed a success as the technological benefits of PulseClosing and economic benefits of reducing CML were repeatedly demonstrated. Lessons were learned about the need of establishing the project interface signals list and the importance of automatic load restoration in allowing SCADA operators to focus upon wide-area system events and post-restoration results. The importance of adequate site survey in deployment of communication based equipment was recognised for communication reliability. It is important that each utility learn their own lessons in a way that is consistent with their standards and recommendations, customer base and environmental challenges in order to achieve the level where investment in large deployment of self-healing devices can be justified.

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