

An Example of setting up a SCADA Controlled Distribution Automatic Restoration Systems' Tests

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Reclosers and sectionalizers are located along distribution lines to limit the effect of problems on the system thus reducing the geographic area and number of customers affected. Modern types of this equipment are now increasingly used as part of the "Smart Grid" automation systems. This means that reclosers and sectionalizers no longer only isolate the problem or fault but they can now be set to reconfigure the circuit(s) to automatically re-energize the system for those customers not directly connected to the problem area of the circuit. Compared to the former hydraulic and electro-mechanical types, the new generation of reclosers and sectionalizers with their new abilities and digital controllers put much higher demands on the test personnel and the test equipment used.

The new digital controllers of reclosers and sectionalizers can trip and/or close 1, 2 or 3 phase modes depending on the fault type and logic settings. This means that only the faulted phase may be set to trip. They can detect an evolving fault and change the operation when a fault evolves into a multi-phase fault. They can also detect a defective primary switch and activate the logic to block reclosing.

The latest applications include a variety of auto restoration systems used in looped and/or underground systems. With these distribution automatic restoration (DAR) systems comes the need for checking synchronization of each phase before the circuit is automatically closed. Checking the communications system is now a necessity, especially when large volumes of data are to be transferred.

Background on the system being evaluated

This Smart Grid system consists of multi-loop circuits with several Reclosers, Sectionalizers, and basic, remotely controlled, motor-operated switches. The protection system will initially isolate any system fault to the area which conventional coordination of reclosers and sectionalizers allows. The SCADA system will then further locate the problem to an area between any two remotely operated devices. Then the SCADA system will open the devices on each side of the problem area and restore the remainder of the system to pick up the maximum number of customers.

To enable the SCADA system to refine the problem, or fault location; the SCADA system will

collect all of the system data (Voltages, Currents, Phase Angles, etc.) from each intelligent device in impacted part of the system, such-as the reclosers, the sectionalizers, and substations. This data is then used to accurately calculate the actual fault location in the system. The SCADA system will use this fault location data to then open the two remotely operated devices closest to the fault. An example: Two motor operated switches even though these switches may not have fault sensing or data measurement may be controlled to isolate the faulted line segment before the system is restored around the faulted line segment. One of the major concerns is the radio communications band width and if it will allow the efficient and accurate transmission of all of the required data from each IED during the system disturbance caused by the fault(s). Another concern is how the SCADA system will handle a fault in 2 or more line segments.

We shall define a device as any remotely controlled Switch, Recloser, Sectionalizer, or Breaker. We shall define an IED as any Switch, Recloser, Sectionalizer, or Breaker that has both system data measurement ability; the ability to send that data to the SCADA system, plus being remotely controlled. Example: A remotely controlled switch that does not have the ability to measure the system voltages and current is considered a device but not an IED.

Conceptualizing the Project (What you expect to accomplish from this test)

Testing a Distribution Automatic Restoration System with a central point of control requires injecting simulated power system signals at many points in the field. The information needed to perform this test is:

- A visual representation of the circuits being tested
- The number of protection devices involved.
- Active (tripping) vs. Passive (non-tripping).
- The type of protective devices and how they should perform
- Understanding of how the DAR system will work on the system.
- A written description of how a given fault will react on the system.

- Test the effectiveness of the communications system.

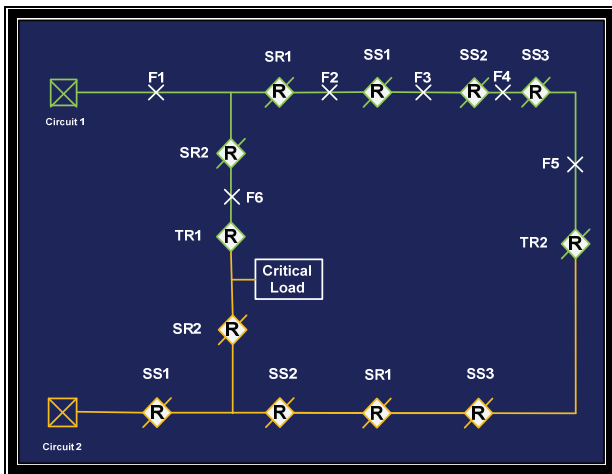


Fig. 1 A one line diagram circuits involved with the testing

What points to test and which to monitor on each device

Determine monitoring points; determine if the device is behaving according to event. The use of (Pass / Fail) qualifiers can also be used to troubleshoot while tests are being developed.

- Fault current in each section
- Typical load current prior to fault
- Time current curves to be measured
- Voltages in each section
- Trip for faults or witness a fault and do nothing
- What type of fault do you want to test (single phase fault)
- Supervise SUPV trip and close from the DAR and watch when the DAR will intervene.
- Time of event vs. time of receipt from SCADA to put events in order.
- Close and reclose times
- Special trips functions (O&R has a special counter function that is used)
- Loss of voltage timers
- Tests not measurable from test equipment like targets, alarms, SOE oscillography, etc.

Thorough functional test of each device

Each IED must be tested as thoroughly as possible by itself. This is the only efficient approach to ensure that when a number of crews are

assembled to do synchronized testing, that time is not wasted by several crews while one device is adjusted.

Some of these tests include:

- Critical points for coordination for both the upstream & downstream devices.
- Sequence logic for all of the various operating schemes for each IED.
- Proper operation of the status inputs & outputs of each IED.
- Accurate measurement of all of the voltages, currents, and phase angles at each IED during steady state operation during transient fault conditions.
- Different timing tests for Fast & Slow trips.
- The recloser has fast & timed overcurrent timed tests for both single phase and multi-phase faults.
- The recloser may be set for different numbers of reclosers that it will use to try to allow the fault to clear before it locks open.
- Evolving faults; A recloser may be set for faults starting as a single phase fault but evolves into a 2 or 3 phase fault, causes the recloser to Lock-Out or maybe just starting 3 pole tripping.
- A defective primary switch is detected by monitoring a delayed fault clearing, the controller then opens and blocks further reclosing.

Thorough SCADA test of each device

Again each device must be tested as thoroughly as possible by itself. This includes many of the SCADA related tests. Some of the field tests between the devices and SCADA include:

- Operation and timing of all remotely controlled devices via the SCADA system.
- Remote logic controls and timing of all remotely controlled IEDs via the SCADA system.
- Transmission of the all status data from the IED's to the SCADA system during both the steady state and the transient operations.
- Transmission of the all system voltages, currents and phase angles data to the SCADA system during both the steady state and the transient operations.

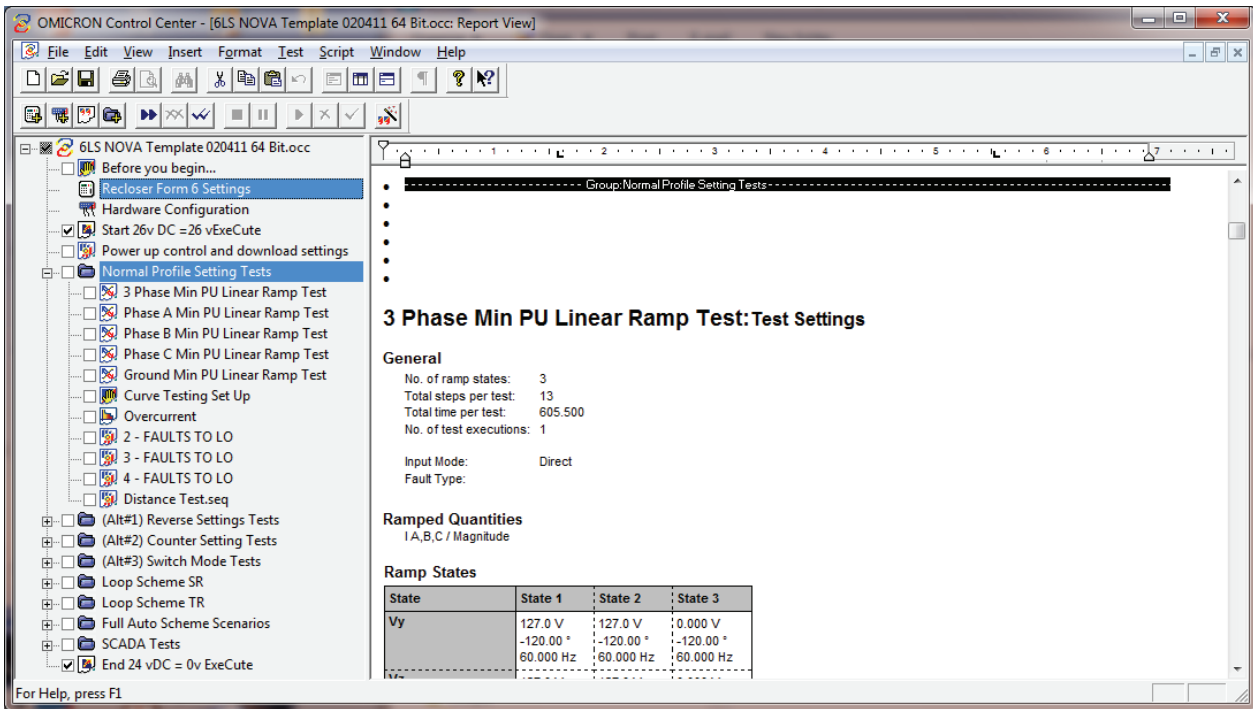


Fig. 2 Example of Test Modules Needed for Thorough Testing

Above is an example of a two shot reclosing test sequence. Each profile (or functional group) can have many tests and there could be dozens of tests to do a comprehensive test.

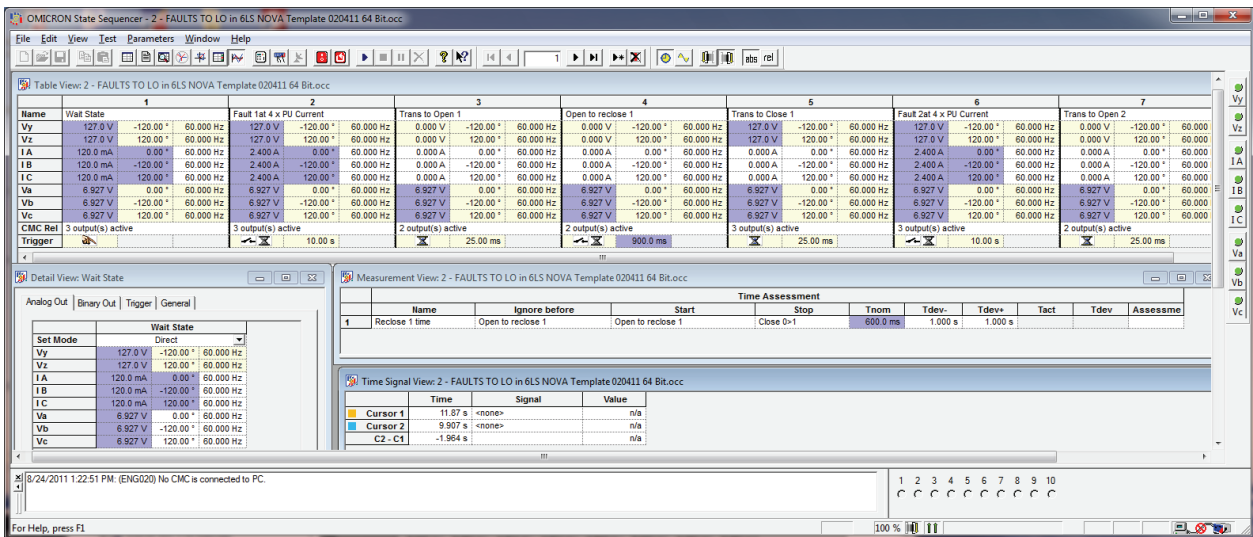


Fig.3 OMICRON Test States to Stage a Fault Scenario

Each state in the sequence will;

- Provide all required analog signals required by the recloser controller or IED under test.
- Provide links for any analog values to be automatically updated when the IED settings file is changed.
- Provide all required contact / status signals required by the recloser controller under test.

- Provide all required input control for the CMC to respond to recloser controller commands, i.e. Trip / close.
- The Measurement View will capture any defined event times that are monitored, i.e. Fault clearing times & reclosing times.
- The Time Signal View automatically captures any changes into or out of the CMC and displays the information in a Virtual Strip Chart recording. This help with troubleshooting timing & logic issues.

Synchronized Testing

After each IED is tested by itself then it is time to consider testing those functions that cannot be truly tested and measured as a single device such as communications dependent functions. These may be done by setting a synchronized test. In the transmission world, this is called End-to-End testing. However, the term End-to-End testing is deceptively simple when we talk of Synchronized testing in the Distribution world, as we now can be talking of 4 to 8 or more synchronized injection points. The testing done for the individual devices can be easily built upon to create the synchronized tests.

Some of the synchronization issues to be understood are as follows:

- How the system of devices will be tested in a coordinated fashion.
- How to get all the devices to start testing at the same time (GPS time synchronization).
- In case there are slight differences in performance, how do devices catch up and resynchronize at intervals, so stages are in synch.

Some of the functional and communication issues to be understood are as follows:

- Delays on the communication method (log jams in communication).
- Interference from communications system (other devices, unknown RF, weak signal).
- Process time delays or system times needed to determine what system operations will be initiated.

- How long a device needs to determine whether to sit and wait for external assistance or to work autonomously?
- Unreliability of the communication system (unsuccessful polling on the device).
- Devices not in their proper configuration for this test (HLT On, LS not Reset, Reclosing off etc.)
- Improper set up of settings on the device or OMICRON test or a lack of understanding of the devices or system being tested. Must be a subject matter expert (SME) on all aspects of the system being tested to know what to expect.

We should take a moment to determine where the test points should be located referring to figure 1.

- Set a goal(s) for the synchronized test(s)
- Check if the communications system's bandwidth is sufficient to transfer the required data.
- Select a fault location.
- Build a matrix table to see which devices will be required to transmit data.
- Each device that has event data to transmit will need to be an injection test point.

Fault 3 Scenario				
	State 1	State 2	State 3	State 4
	Wait State	First Fault	Transition to Open	Open to reclose
Circuit 1 Breaker	Load Current	Inst Trip for Fault	Open	Time Delay to close
Circuit 1 SR1	Load Current	See the fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 SR2	Load Current	No fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 SS1	Load Current	See the fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 SS2	Load Current	No fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 SS3	Load Current	No fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 TR1	Load Current	No fault	Stay closed Loss of voltage	Time Delay to see source return
Circuit 1 TR2	Load Current	No fault	Stay closed Loss of voltage	Time Delay to see source return

Fig. 4 Example of Staging the Logic in a Matrix

Is the communications system's bandwidth adequate to transfer all the data necessary?

The testing goal is to confirm that the communications system has sufficient bandwidth to handle all of the data being transmitted during an event. We can look at State 3 in the above Matrix for the sights that will have data to transmit to determine where the synchronized injection test point should be. This review shows us that all eight IED's require data to be transmitted. Therefore, we need eight injection test points.

Figure 5 shows the locations of the required synchronized injection test points.

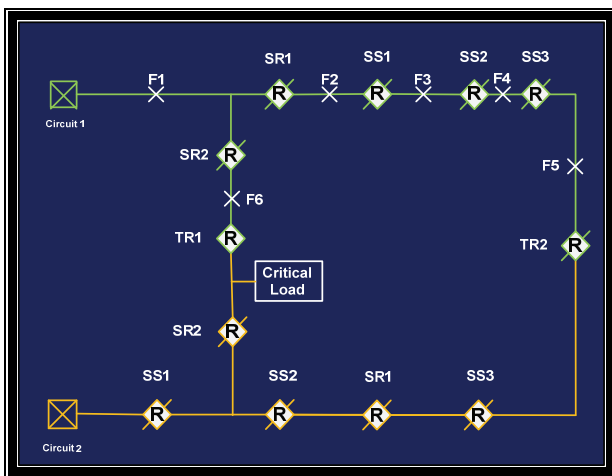


Fig. 5 CMC's at the required test points

The Field Test Day

Animals behave differently in captivity than they do in the wild. So do Smart Grid devices. The field test will require coordination of multiple personnel in different locations. To get to this point, all the devices will have been thoroughly tested. The SCADA, communications and DAR logic will have been tested in a controlled environment. The field test is still required to evaluate the local dynamics of the system.

Some of the issues testing in the real world will be as follows:

- In the real world test, there are other devices in service using the communications system while the test is going on. This will contribute to more data load on the system.
- GPS issues with testing under the tree line. Have GPS extension cord, so the antenna can see the sky. The test will not work properly if the test equipment does not synchronize with the rest of the equipment.
- One person must be the lead for the tests in the field. He/she must communicate to

the group via broadcast walkie-talkie to start test sequences. The GPS should keep the test states in sequence once the test starts.

- Have a plan for what to do if a test does not work properly. Two choices would be move on to the next test or to rerun the test again.
- Make sure all logging programs are running such as recloser sequence of events, SCADA data and alarming logs DAR control logic logs and communication logs. All these functions may be used in forensics later to see what worked and didn't work.
- If all the planning was done properly, this final test should prove out whether the other pieces of the overall system are working properly.

Here are two test sequence guidelines

- When setting up synchronized test sequences, each device related to a given fault must have the same number of states or at least the same active time between GPS start pulses to avoid timing confusion.
- Having most fault cases in a sequence initiated by a timing pulse (GPS Pulse), will allow the test sequence to adjust for minor deviations by individual devices while keeping all injection points synchronized.

Guidelines when considering other fault cases

The loop system or DAR system to be evaluated will determine the types, locations and number of test cases that should be performed during the synchronized testing. The following are some basic guidelines or typical practices that may be used with the testing goals that each will address. These guidelines are:

- Selecting a fault test case for the midpoint between each pair of devices to be remotely operated. These tests should prove that the SCADA control logic and timing is properly functioning when determining the reduced area to be isolated by refining the restoration. The selection of the line segment mid-point avoids minor distance calculation errors from unduly influencing the test results.
- To determine the sensitivity or accuracy of the SCADA fault distance calculations. Typically, fault cases will be placed at each remotely operated device. Two additional cases for each remotely operated device should be selected with a fault located 5 to

10% of the line segment on the source side and another located 5 to 10% of the line segment on the load side of each device. These test cases will help determine when a single line segment can be isolated and when two Line adjacent segments must be isolated because a device may be involved.

About the Authors

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Attended Vermont Technical College and the University of Vermont. Earned his Professional Engineering License in 1978. Worked for 27 years in numerous utility engineering & management positions. Had developed specialized testing interfaces at the utilities and has designed numerous Specialized Testing Interfaces for Reclosers & Sectionalizers at OMICRON. Has done synchronized testing of SMART Grid systems and multiple terminal lines. Written papers and seminars on SMART Grid testing and installation and testing Micro-processor based Protection Systems and testing of and multiple terminal lines.

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Associate and Bachelor degree in Electrical Engineering Technology Master of Science in Computer Science Information Systems. 13 years working as a system protection and control technician at New York State Electric and Gas. Work on relay protection and testing, RTU installations, all substation equipment testing and commissioning. 7 years working for Orange and Rockland. Initially a project engineer for all distribution automation projects. Now, I've picked up all Smart Grid equipment (reclosers, cap banks, regulators) development and testing, cyber security, communications, and SCADA development and equipment testing required to make this all tie together.

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