DISTRIBUTED SYNCHRONOUS COORDINATION FIELD TESTING OF AN ACTUAL AUTOMATED DISTRIBUTION FEEDER SYSTEM

Stephan GEIGER	Andre SMIT	Don BOWMAN
OMICRON – Austria	SIEMENS – USA	Wake Electric - USA
stephan.geiger@omicron.at	andre.smit@siemens.com	don.bowman@wemc.com

ABSTRACT

A Distribution Feeder Automation system deployed at Wake Electric using IEC61850 "GOOSE" over a WiMAX wireless communication provided the real world test bed to prove a new testing method and procedure. The Wake system consists of 7 reclosers connected in a mesh network supplied from three different substations. The system typically performs automation sequences in less than 0.5 seconds.

This paper will discuss how this complex high-speed feeder automation and associated communication systems were tested to prove correct and predictable protection isolation and restoration sequences. The testing was first performed in a laboratory environment to verify test protocols, followed by the actual field test. For comprehensive testing, the test equipment was deployed at all 7 recloser locations, and simulated faults were applied on different line sections. The test equipment operated synchronously to simulate a real-life event at all locations as would be the case when real faults were to occur. All test sets used to perform the required transient current and voltage injections were GPS synchronized and controlled through the installed WiMAX system from a single PC located at one of the recloser locations. This paper will in addition provide a comparison of a test performed to a real event that occurred on the system.

INTRODUCTION

Testing a standalone protection device for its protection functions and operating times has become commonplace due to the availability of accurate test equipment. But testing wide area automation systems consisting of several devices is a very difficult task since many factors need to be tested including communication between the devices, dynamically changing power system parameters etc. One of the prominent wide area automation systems is the high speed feeder automation system, whose main goal is to locate the fault, isolate a faulted line section and restore power to the unaffected line sections as fast as possible. This system is often called on to perform in stormy, chaotic conditions where it is difficult to predict the behavior of a power system due to dynamic changes in power system parameters at different points on the feeder. In addition, healthy communication between the devices is very crucial at all times for correct operation. These communication networks have several limits in terms of bandwidth and latency which are affected by weather conditions and also real time changes in power system parameters. All of these factors must be taken into consideration when designing and testing a feeder automation system.

To achieve good performance, these systems must be thoroughly tested. Some of the challenges of testing include:

- Synchronous injection of all devices in the system
- Collection of data from all the test units in the system and analysis of system performance
- Simulation of adverse scenarios affecting the communication network

The latest testing tools have advanced simulation software which can be used to address the items listed above. The remainder of this paper will provide details of how these tools were utilized to test an actual in service feeder automation system.

WAKE ELECTRIC HIGH SPEED FEEDER AUTOMATION PROJECT

Wake Electric Cooperative, Youngsville, NC chose to automate a mesh connected system which includes three substation and four midline reclosers. The system was deployed using a WiMAX communication network. All WiMAX base stations were installed on a radio station tower (WCPE) at an appropriate height to allow good coverage of all required locations. The topology of the system is represented in the figure below.

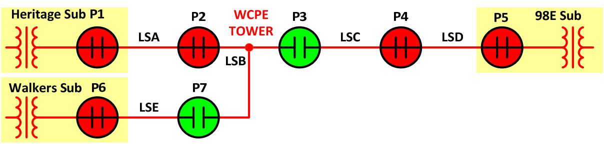

Figure 1: Wake Feeder Automation System Topology

In order to minimize the outage time on the feeder serving the WCPE radio tower as well as other customers, Wake EMC decided to implement the new protection philosophy utilizing a differential principal. In the event of a fault, differential protection should pinpoint the fault and isolate the faulted line section from both ends. Following this operation, the recloser at the normally open point should close to provide service to the unfaulted line section from another source. This approach helps to restore service on

unaffected line segments even before the first autoreclose operation is performed on the faulted feeder section. This fault isolation and reconfiguration sequence takes 350 - 450 ms, where conventional protection system with time coordinated curves might take seconds or even minutes performing a number of autoreclose operations and further steps to reestablish the service on the rest of the feeder.
Along with fast operating speed, the differential scheme is known for its selectivity. The differential zone can be applied on each feeder section individually without a need for time coordination between individual reclosers. To isolate a fault inside a zone, each recloser evaluates the information from upstream and downstream reclosers.
A true differential scheme typically requires the comparison of real time currents. In order to minimize the amount of data, reclosers convert magnitude changes in the phase currents to logical signals called “Positive jump” and “Negative jump”. (hence the name of the algorithm “Jump Differential Protection” or jDiff^{TM}). These signals can be transmitted through the network to the reclosers at the opposite side of the protected zone with less bandwidth requirements.

SYNCHRONOUS LAB TESTING

As noted previously, the test units were setup in a lab environment to verify test protocols and performance prior to field testing. The Wake Electric Feeder Automation system is replicated in the lab over a WiMAX communication network. Each protection point is injected by a test unit which injects currents and voltages into the Feeder Automation Controllers. The primary contact operations are also simulated by the test units. All test units communicate with each other over the existing WiMAX network in the lab to simulate field operation. A PC running the RelaySimTest software is also given access to this network to be able to communicate to all test units. Individual GPS antennas are used with all the test units to synchronize them.
To test the correct sequence of events for an automated distribution feeder e.g. from trip to reconfigure, it is important to have a realistic and consistent simulation of currents and voltages according to the breaker states. To achieve this, power system data provided by Wake EMC was entered into the test set software to provide simulation of different fault scenarios.
In case of a short circuit incident the controller will issue a trip. If the fault current does not extinguish after the circuit breaker trip time, the controller will assess it as a circuit breaker failure and will run a different sequence. Historically, to achieve a simulation in which the current is extinguished would require state sequences to be predefined, which was complex and error prone. Alternatively, a real time simulation system had to be used, which is costly, inappropriate for field tests and won’t work for a distributed system. To provide a system which could overcome the short comings of a real time system while including its strengths, the simulation software used an iterative closed loop approach.
Figure 2 shows the first two iterations of testing a permanent fault on line section A between devices P1 and P2. The test case is already defined by only placing a fault on line segment A. The first iteration simulates a permanent fault. As the software detected a trip of P1 it issued a second iteration. Assuming that the P1 controller trips consistently when simulating the same fault quantities, the software creates a circuit breaker event at the time of the last trip and includes additional time for circuit breaker operation. Following the previous iteration, the software would record a trip from the P2 controller triggering the next iteration and so forth until the last iteration does not record any further events of the automated feeder system. In other words it is a step wise approximation of a real-time simulation.

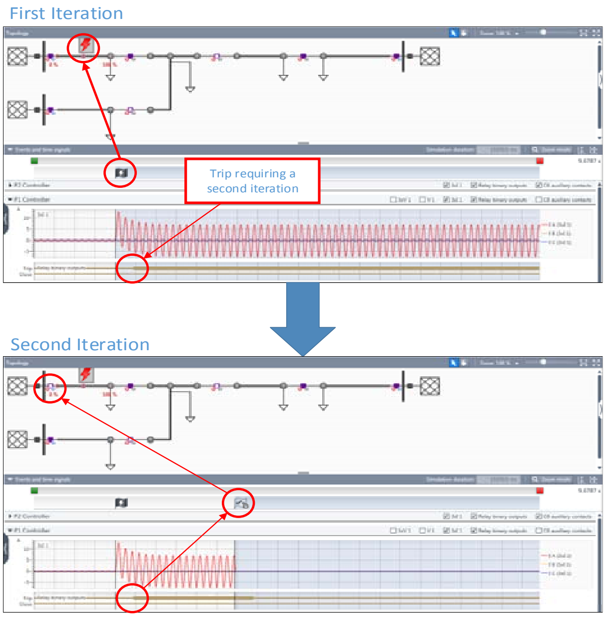

Figure 2: First two software iterations for a fault on line section A

After the test, all results are available in the software for analysis, which proved to be as desired:

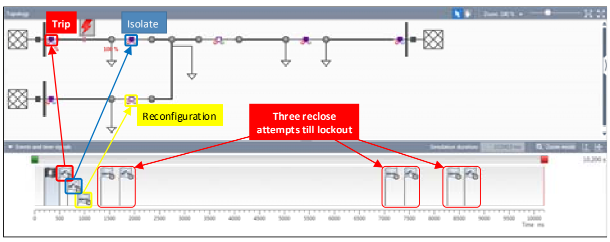

Figure 3: Software iterations showing automatic sequence for a permanent fault on line section A

SYNCHRONOUS FIELD TESTING

In the field, the protection points are located a few miles away from each other. The field test setup for synchronous testing is shown on figure 4.

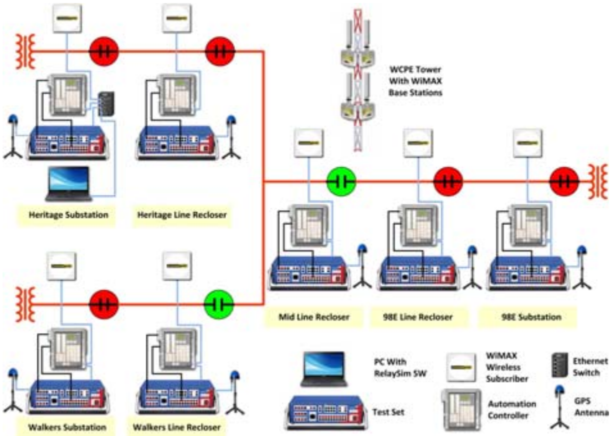

Figure 4: Field Test Setup

Prior to the test the following field actions were performed:

- The testing team assembled field test kits for all locations with additional hardware to streamline installation. Each kit included:
  - Two sets of wired connectors between the automation controller and the test unit to simulate primary contact operation and provide feedback
  - Pre-wired current and voltage plugs for local injection from the test set
  - An unmanaged switch at each location to connect into the existing WiMAX network
- By passing all primary switchgear at the 7 protection points
- Connecting each test unit to a GPS antenna
- The PC running the RelaySimTest software was connected to the WiMAX network at the Heritage substation. The test software accessed all GPS synchronized test units at each location using WiMAX communications.
- The same two sequences previously completed in the lab are tested in the field. Several iterations are performed and recorded by the software to analyze the system performance.
- Simultaneously, fault records and event data were downloaded from the devices that were exercised in each test sequence.

Field Test Results recorded by the Test Software

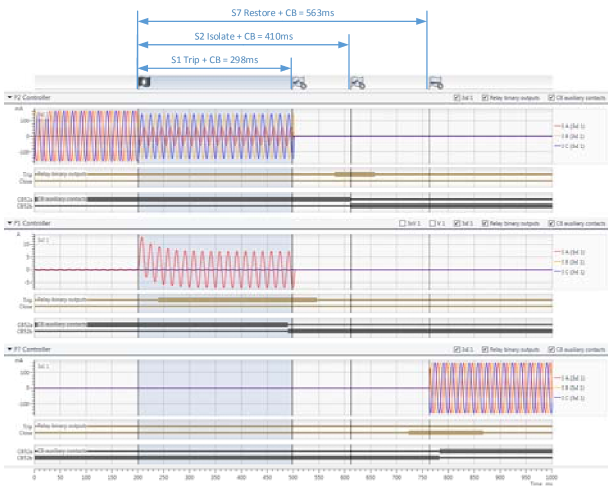

Figure 5: Software Iterations showing field results of automatic sequence for fault on line section A

From the above figure, the breakdown in times for each step with reference to the fault inception is as follows:

- Device P1 took 298 ms to trip
- Device P2 opened after 410 ms to isolate the faulted line section A
- Device P7 closed after 563 ms to reconfigure the system feeding line section B from Walkers Substation

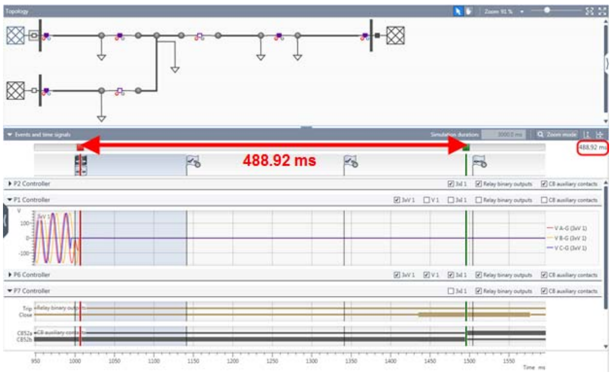

Figure 6: Software Iterations showing field results of automatic source transfer sequence

From the above figure, the total transfer time from the source loss to the close of normally open points P3 and P7. The total transfer time is 488.92 ms.

Comparison of the system performance during the Field Test with a Real time event

Several months after the installation a severe storm caused outage on the transmission line interrupting the service to Heritage and Walkers substations. The system detected loss of both substations and transferred the load over to the available substation 98E. The fault record from this transfer event is shown in figure 7, where:

1. Voltage at Heritage Substation dropped below the threshold
2. Voltage at Walkers Substation dropped below the threshold
3. Undervoltage element picked up at Heritage Substation
4. Undervoltage element picked up at Walkers Substation
5. Heritage Recloser (P1) is opened;
6. Walkers Recloser (P6) is opened;
7. Midline Recloser (P3) is closed, service to the major part of the system is restored (495 ms from source loss);
8. Walkers Line Recloser (P7) is closed, service to the line section E is restored (663 ms from source loss);

Analyzing the real transfer event and comparing it with the software field test results from figure 6, it was concluded that:

1. The system executed source transfer sequences correctly
2. The operation was as fast as the primary gear allowed
3. 234 ms delay and status contact chatter was caused by old VWE reclosers at Walkers 3. Software test result from figure 6 doesn't include this delay because the primary contacts were simulated by the test unit.
4. Operational sequence execution is fast enough to eliminate cold load scenario at 98 East Substation.
5. Sequential operation time per switching step is 158 ms. This includes additional WiMAX communication delays during the storm which is not the case when the synchronous field testing was performed.

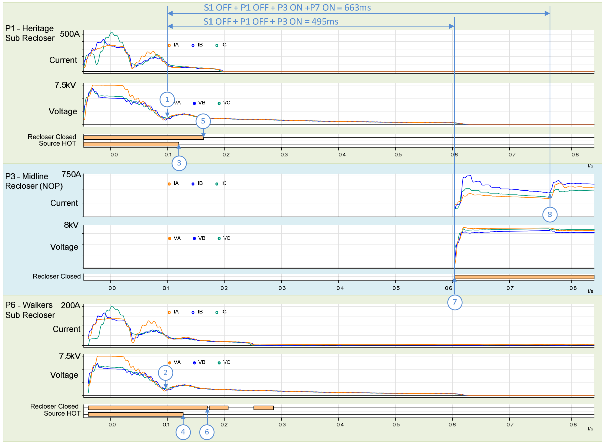

Figure 7: Fault Record from real source transfer event

CONCLUSION

Advantages

- It was possible to perform a distributed synchronous field test on an automated feeder system by injecting all the system devices simultaneously.
- This approach will provide the ability to test a wide area system using various scenarios.
- These tests will help identify the problems or concerns for a high speed automation system during adverse weather conditions where the power system parameters, including currents and voltages, change rapidly.
- By injecting all the devices in the field simultaneously, all controllers generate a significant amount of GOOSE messages which provides a good test for the communication network.
- The test units, being GPS synchronized help analyze the system performance accurately.
- The real time event sequence and speed of operation correlates with the test results

Shortcomings

- Primary switchgear operating time was simulated instead of expressly monitored.
- Any network issues which cause loss of connection to any test unit during the test resulted in the test software aborting the iteration with a warning.