TECHNOLOGIES OF THE SELF HEALING GRID

Cleber ANGELO
ABB Inc. – USA
cleber.angelo@us.abb.com

Peter SELEJAN
ABB Inc. - USA
peter.selejan@us.abb.com

ABSTRACT

A self-healing grid refers to automated ways of removing temporary faults from the distribution power network. This paper will present three available technologies to help utilities improve overall system reliability by restoring power to the healthy portions of the grid. Three technologies were selected to support utilities' achievement of service quality goals at different budgets and to start implementation of Smart Grid oriented FDIR – Fault Detection Isolation and Restoration- schemes. This will mitigate losses of revenues, penalties from regulators and cost of restoration while improving customer satisfaction.

INTRODUCTION

Seventy five to eighty percent (75-80%) of the outages in distribution overhead networks are temporary in their nature. A temporary fault is considered to be an event that triggers a protection element and consequently trips the apparatus protection device (circuit breaker or recloser), driving the circuit voltage to zero, resulting in the loss of power for 3 to 5 minutes. If power is not restored within 5 minutes, the outage or fault is considered to be permanent, requiring substantial efforts on behalf of the utilities to fix the source causing that event.
Traditionally, utilities have identified permanent faults on their networks from their own customers, who call to report a power outage after a permanent fault is isolated by a protection device. Armed with this information, the utility identifies the fault location, and implements restoration options/patch activities to mitigate the outage.
This traditional restoration methodology incurs high operational cost for the utilities since several resources such as operations staff, crew members and dispatchers are involved in the restoration activities. The methodology, besides being costly, does not restore the power quickly enough to the healthy portion of the circuitry, increasing the risk for the utilities of incurring penalties from the regulatory agencies and unnecessary revenues losses.
The following are the most common indices used by regulatory agencies and electric power utilities to measure reliability and performance:

SAIDI – System Average Interruption Duration Index is the average outage duration for each customer served, and it is calculated as:

$$SAIDI = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customers served}}$$

SAIDI is measured in units of time, often minutes or hours. The median value for North American utilities is approximately 1.50 hours.

SAIFI – System Average Interruption Frequency Index is the average number of interruptions that a customer would experience, and is calculated as:

$$SAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}}$$

SAIFI is measured in units of interruptions per customer. It is approximately 1.10 interruptions per customer for North American utilities.

CAIDI – Customer Average Interruption Duration Index is related to SAIDI and SAIFI, and is calculated as:

$$CAIDI = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customer interruptions}} = \frac{SAIDI}{SAIFI}$$

CAIDI gives the average outage duration that any given customer would experience. CAIDI can also be viewed as the average restoration time.
CAIDI is measured in units of time, often minutes or hours. The median value for the North American utilities is approximately 1.36 hours.

All indices above are usually measured over the course of a year, according to IEEE Standard 1366-2003.

The estimated financial impact of power outages is considered to be 79BUSD in the USA and is composed of the following segments:

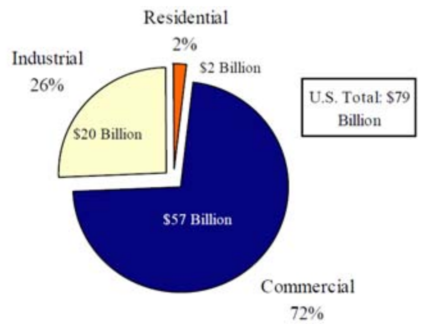

Figure 1: Financial Impact of Outages [4]

By implementing self-healing technologies on the grid, the utilities can:

- Improve CAIDI and SAIDI metrics by up to 33%
- Decrease restoration times from 45 min to less than 3 minutes – see Figure 2 and 3 comparison below
- Reduce the cost of restoration
- Drastically reduce lost revenues
- Boost the utility's reputation with customers,

stockholders and regulators.

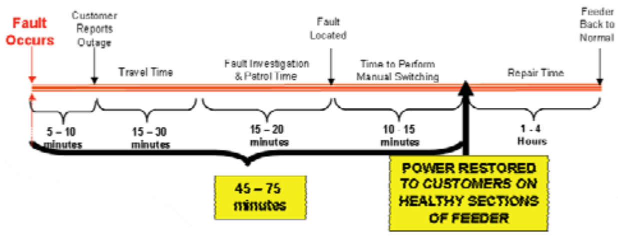

Figure 2: Typical utility response time without FDIR technologies [4]

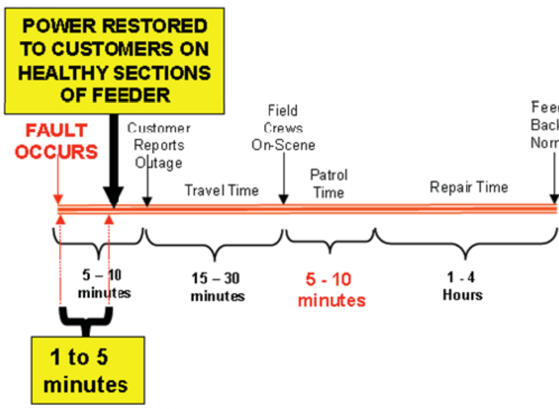

Figure 3: Typical utility response time using FDIR technologies [4]

The challenge facing utilities is how to optimize the power distribution system to deliver greater reliability while lowering the operation costs and building a modern grid.

SELF HEALING TECHNOLOGIES – VOLTAGE AND CURRENT BASED SOLUTION

Driven by the necessity to lower the SAIDI, SAIFI and CAIDI indices, utilities are investing in solutions that automatically switch and protect the network to reduce restoration time by eliminating temporary outages from the system.
The microprocessor controlled reclosers are instrumental devices for the utility in its fight to increase grid reliability. Reclosers with Loop Control Module (LCM) logic - built-in restoration logic, based on fault and voltage information combined with timers and alternate settings groups - are capable of performing simple and cost effective FDIR schemes without the need for communication technologies.
The distribution one-line diagram in Figure 4 represents a simple loop system that will be used for analysis of the voltage based FDIR scheme. This system consists of the following components:

- Source – Substation breakers 1 and 2
- Sectionalizing recloser
- Midpoint recloser
- Tie Point recloser

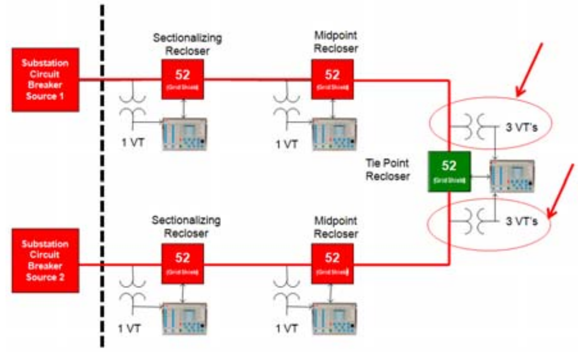

Figure 4: Example of single tie distribution circuit

A permanent fault out of the substation and before the sectionalizing reclosers would cause the Substation breaker 1 or 2 to operate (until lockout, granted those breakers have reclosing capabilities). This operation would cause loss of power for the entire feeder protected by the breaker, until repairs are completed and the fault is removed.
The Loop Control scheme is designed to automatically detect loss of voltage and switch to an alternative source.
Considering the example above of a fault just out of the fence of the substation, using the automatic transfer scheme the Substation breaker would lock out. During this brief outage the other normally closed reclosers on the line detect a loss of voltage and, after a time delay, switch to an alternate settings group. The alternate settings are designed to coordinate with the reclosers from the other side of the Tie Point recloser. The alternate setting includes a special feature that prevents reclosing for a short period after the line is re-energized from the alternate source. This is necessary as the fault still exists. Meanwhile, the normally open Tie recloser detects a loss of voltage on the faulted side. When the timer reaches its programmable setting, the Tie recloser closes, energizing the line from the alternate source. When the Tie point recloser closes, the faulted line will be energized. This will cause the closest recloser energized from the alternate source to trip and lock out. The fault has now been isolated between the substation breaker and the first Sectionalizing recloser. The customers between the faulted section of the line and tie recloser are restored and the crew can more easily determine the fault location.
In order to help the crews find the fault, each recloser controller can be programmed with the feeder data to the next downstream device, allowing the controller to estimate the distance to the fault. These estimations are based on the available data and may not be accurate for evolving faults such as a line to line fault that eventually involves ground.
The healthy portion of the circuitry is restored without any crew dispatch and the restoration time is reduced considerably.
The following is another FDIR example based on voltage-

current and loop control capabilities. Let's consider a permanent fault between the Sectionalizing and Midpoint reclosers.

The Sectionalizing recloser will go to lockout. The Midpoint recloser recognizes a loss of voltage and after a time delay switches to its alternate settings. The normally open Tie recloser recognizes a loss of voltage and senses the voltage is still present from the other source side. The Tie recloser, after expiration of the dead bus timer, closes, re-energizing the line from the other source. The fault is still present and the midpoint recloser trips in one operation, since it has previously switched to its alternate settings. The alternate settings have a switch on the fault timer – SWOFT. This setting blocks reclosing after the recloser is energized for a brief period of time. The midpoint recloser is the closest to the fault and will trip directly to the lockout state when the fault is energized. The fault has now been isolated and the customers connected to the healthy portion of the system are restored by the alternate source. Other fault locations and restoration schemes are considered on this voltage and loop scheme based solution.

The FDIR technology described above is commonly available on microprocessor based reclosers and does not incur incremental communication infrastructure costs for the utilities to deploy such schemes.

SELF HEALING TECHNOLOGIES – PEER TO PEER GOOSE BASED COMMUNICATIONS

The distribution one-line diagram in Figure 5 represents a simple loop system that will be used for analysis of FDIR. This system consists of the following components:

- Source – Substation breakers 1 and 2
- Sectionalizing recloser
- Midpoint recloser
- Tie Point recloser

All recloser controllers in Figure 5 are IEC 61850 capable. One important benefit IEC 61850 provides is the use of interoperable Generic Object Oriented Substation Event – GOOSE messaging between recloser controls. GOOSE data is exchanged between recloser controls at deterministic time intervals and is based on a publisher/subscriber model. The publishing recloser control multicasts data over the local area network to different subscribing recloser controls. The content of the GOOSE message allows the receiving recloser controls to perform processing of the data in order to execute required actions.

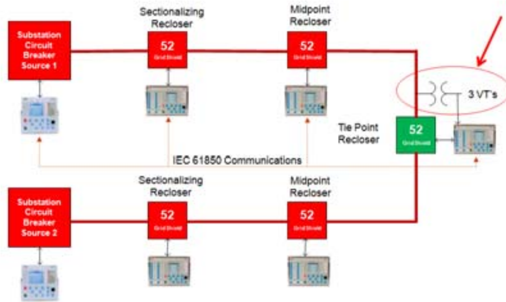

Figure 5: Example of single tie Distribution Circuit

Consider an example of a permanent fault between the Substation 1 breaker and the Sectionalizer recloser.

The Substation 1 circuit breaker recognizes the fault and goes through its reclosing shots to lockout (for illustration purposes we assume 3 operations to lockout for all devices). At the same time, the Substation feeder relay multicasts GOOSE messages that contain the Lockout information. The Sectionalizing recloser receives a Lockout message and automatically trips after t1 seconds, isolating the faulted zone on the source side of the Sectionalizing recloser.

Lockout GOOSE from the Substation 1 breaker and Open position GOOSE from the Sectionalizing recloser are used as inputs for the Midpoint recloser. Two GOOSE messages from Substation 1 breaker and Sectionalizing recloser request the Midpoint recloser control to start its Switch-on-to-fault (SWOTF) timer, and if programmed, to use setting group 2 after t2 seconds.

The Lockout GOOSE from the Substation 1 breaker and Open position GOOSE from the Sectionalizing recloser are used as an input for Tie Point recloser. Two GOOSE messages from the Substation 1 breaker and sectionalizing recloser request the Tie Point recloser control to use setting group 2 after t3 seconds.

The un-faulted portion of the distribution feeder circuit between the Sectionalizing recloser and Tie Point recloser is picked back up per sequence of events on Figure 6.

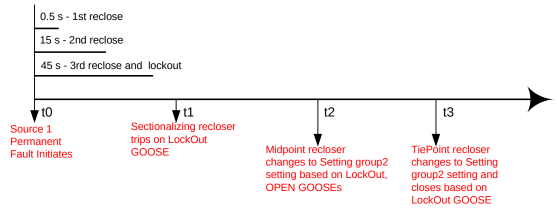

Figure 6: Sequence of Events for GOOSE FDIR

The restoration is completed expeditiously and without causing unnecessary fault stress on the grid by closing onto a permanent fault. The FDIR technology performance described above relies on the selected communications media and bandwidth available to transfer the GOOSE messages within a deterministic period of time. The decision is made locally by the devices without any latency from SCADA/DMS system, restoring power to unaffected areas quickly. Some recloser controls with IEC 61850 capabilities have both technologies available – Voltage based loop schemes and GOOSE messaging for implementation of the FDIR scheme. Another advantage of using GOOSE message technology is the interoperability of different IEC 61850/GOOSE capable devices, without locking the utilities in a limited number of devices (reclosers, switches, breakers) employing proprietary solutions.

SELF HEALING TECHNOLOGIES – SUBSTATION COMPUTER AND DMS/SCADA

A SCADA and substation computer solution is a more comprehensive way to implement a mashed or complex network FDIR scheme. Substation computers can be programmed to make decisions based on information from feeder devices. They further report status and metrics back to the SCADA/DMS system which has a more comprehensive view of the network.. The SCADA/DMS is capable of making decisions based on additional factors involved such as feeder loads, overload conditions and demand response. Combined with the restoration implemented from the local substation computer, a meshed SCADA and substation computer application can decide what devices to switch to improve the power quality of the overall system - Volt Var control schemes. The benefits of the combined SCADA/DMS and local substation computer offer are faster feeder level response to an event and scalability to implement future distributed generation into the grid such as energy storage units, electrical vehicles, solar panels and Volt Var control already mentioned. The substation computer combined with SCADA/DMS application also reduces the engineering hours to set each feeder device to perform FDIR schemes. The SCADA and substation computer solution does not require the recloser controls to use interoperable communication protocols, as long as the substation computer can interface to each recloser control. This is often the case for utilities that are in the process of modernizing their grid. In terms of operating speed, the GOOSE based FDIR may be faster, however, the additional information available to the SCADA/DMS and substation computer application allows FDIR to be based on the larger picture, using the factors mentioned earlier.

The complexity, budgets, and operational philosophy of the utility system will dictate the best solution in order to achieve the SAIDI, SAIFI and CAIDI goals. The three presented solutions offer tools for the utilities to address the different service areas' needs and diversify the solutions implemented. The technology chosen and feeder device selection play a key role for the future full deployment of the utility roadmap for attaining a Smart Grid.

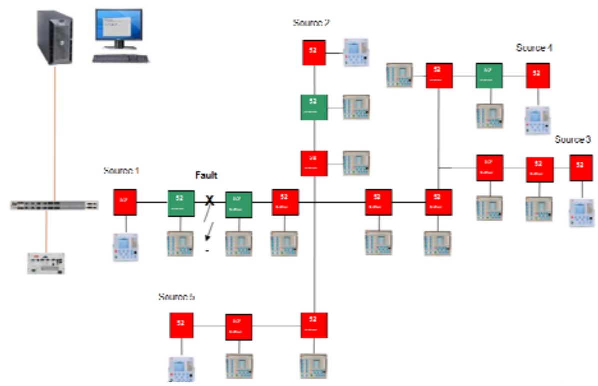

Figure 7: Sample of Substation Computer and SCADA/DMS system

SUMMARY

There are benefits to be gained at the presented levels of FDIR integration. In its simplest form, FDIR can be achieved without relying on communication technologies, however, it is possible to close onto a fault. Restoration time is based on the dead bus system timers.

GOOSE based FDIR solves the problem of speed and closing onto a permanent fault, however, it requires that all recloser controllers be GOOSE capable and interoperable and the additional expense of a reliable communication network.

The meshed SCADA and substation computer application allows integration of different generation of IEDs, and it is able to make better decisions based on power generation, demand, and real time power flow. Assuming that the infrastructure already exists, the cost and challenge will be in developing an application that will perform reliably under all possible system conditions.

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