IEC 61850 GOOSE OVER WIMAX FOR FAST ISOLATION AND RESTORATION OF FAULTS IN DISTRIBUTION NETWORKS

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ABSTRACT

This paper will discuss how to achieve high speed detection, isolation and restoration of faults on distribution networks with WiMAX communications. All switching sequences use specially developed logic that will be discussed in this paper. With smart IED's at key switching points along the distribution feeder the faulted segment is quickly determined through the special use of IEC 61850 generic object-oriented substation event (GOOSE) "peer-to-peer" messages over the WiMAX wireless network. The faulted segment is quickly isolated by the IED's and where possible, segments at the end of a feeder have service restored through the tie-point switch. The IED's are "self-aware" and operate based on real-time information they have about the network, so no master is required reducing the latency to make logic switching decision. Once a fault has been repaired, the system can return to a normal state through a single command from the system operator or by the field crew.

FAULT ISOLATION AND SERVICE RESTORATION

Background

The Isolation and Restoration of faults on a distribution have made several advancements over the years. Prior to the digital age the breaker in the substation would be tripped when a fault occurred on the distribution feeder. A repair crew would be dispatch. The crew would drive and inspect the line to determine where the fault occurred; if there were manually operated switch along the feeder the crew would manually isolate the fault. Service could be manually restored to unaffected customers while the repair was being made. Once the repair was completed the feeder configuration was returned to normal by manually operating the feeder switches.

In the early 1990s systems were developed where smart IEDs were installed with automatic operated switches. These IED, during faults, would determine the direction of the fault and report this back to a central location. The breaker in the substation would still operate to clear the fault. The fault location identification would either be done by an operator using an HMI, or by logic at the enterprise or within the substation. Once the faulted segment was identified, switching commands would be sent to the IEDs on either side of the fault for isolation and the breaker would be closed to return service to the unaffected customers. Depending on the location of the fault and if the feeder configuration had a tie-switch, customers at the end of the feeder could have service restored by closing the tie-switch.

This advancement with smart IEDs on the distribution feeder drastically improved the system reliability and reduced costs. Faults could be repair faster by knowing the segment where the fault was allowed repair crews could find the fault faster. The restoring of service to customer not on the faulted segment was seen to happen in less than one minute. This would have a big impact on indices like SAIDI.

Impact of "Smart Grid"

What is the impact of "Smart Grid"? The distribution feeder is seeing the addition of distributed generation (wind, and solar), expected wide spread deployment of plug in electric vehicles, demand response, distributed storage, all the while improving or at least maintaining system reliability.

The goal of the system is to be able to Isolate a fault within 100 milliseconds and to Restore service to unaffected segments within that same 100 milliseconds. It was clear that a centralized system would not be able to achieve this level of performance. The system must, also, take into account the changing characteristics of the distribution network.

The Solution

We have discussed that a centralized solution would not meet the 100 millisecond performance requirement. That means that a distributed intelligence system is required, the intelligence has to be located throughout the system in each of the IEDs. A communication system and protocol was required to support communications between the distributed IEDs.

Depending on the switches along the feeder, fault interrupting capable or not, the system shall be able to operate under either configuration. When the feeder switches can interrupt fault currents the IEDs on either side of the fault with trip the switch. When the fault interrupting switches are not used, coordination with the substation breaker is required; opening of the feeder switch must be done during a reclosure operation.

One of the key requirements of the solutions was to support changes in the distribution network like the addition of distributed generation.

From the outset it was decided to use a differential method to detect faulty line sections. The advantage of using differential equations is that they are absolutely selective, typically very fast, and have only a few simple settings. Smart Grid requirements to develop adaptive protection systems for the introduction of distributed generation also influenced the decision to use a differential approach. By doing so, the need to adapt today's overcurrent settings is largely eliminated should a generator or similar device be switched into a feeder line section.

When selection the communication system a key consideration was to support multiple and future applications, an Internet Protocol (IP) based network was chosen as the technology is proven and supported all of the requirements of the system. The protocol must support high speed peer-to-peer communications that is fit for purpose in the power utility market, the IEC 61850 protocol and GOOSE messaging was selected.

IEC 61850 STANDARD

The IEC 61850 is the latest standard of Communication Networks and Systems for Utility Automation. During the last 5 years there has been spectacular growth of the number of substation installations worldwide where this standard has been deployed. It is worth noting that in the beginning IEC 61850 was mainly used in substation automation at high voltage level. While the standard is gaining maturity it is now implemented in protection and control devices from most of the vendors. There are more than 200 different models of IEDs manufactured in countries from all continents that have successfully passed protocol conformance testing and achieved KEMA certificates for IEC 61850. This helps in great manner to obtain the major goal of IEC 61850 which is interoperability of protection and control devices from multiple vendors.

IEC 61850 is not just another communication protocol. It is instead a complete communication architecture for automation system. It defines an abstract model for common functions, devices and algorithms in protection and control systems. This model permits to describe every IED in a standardized way. The key components of IEC 61850 data structure are so called Logical Nodes which are abstract models to describe real devices, functions or algorithms. IEC 61850 defines an extensive list of standard Logical Nodes grouped into different categories based on their functionality in the automation system. For example there are Logical Nodes for protection, control, measurement, disturbance recording and other functions. Each logical node contains standardized data objects and attributes. The manufactures of equipment that is compliant to IEC 61850 will implement their devices according to a common model. For example a feeder relay that has three elements of time overcurrent protection will have three instances of a Logical Node *PTOC*, no matter which company manufactured this device. The syntax and semantics will be exactly the same in all devices.

Key features of IEC 61850

The following list summarizes the most important features of the IEC 61850 standard:

- Uses OSI 7 layer communication model
- Standardized data models for electrical applications
- Defines data types and communication services
- Models devices, functions, processes and architectures
- The data is organized in devices in a standardized way
- It introduces meaningful syntax at the protocol level
- The devices are ***"self-descriptive"*** via online MMS messaging of via electronic file format based on SCL language
- It describes the engineering and configuration process using the SCL language

IEC 61850 GOOSE

There are multiple models of communications in IEC 61850 that implement abstract communication services defined in part 7-2 of the standard. The most important communication models are:

- Client-server MMS communications
- GOOSE
- Sampled Measured Values
- Time Synchronization

In substation automation systems MMS client-server services are used to communicate IEDs with client systems such as substation SCADA, HMIs or gateways.

GOOSE is the "horizontal" communication used for very fast transmission of critical information between devices which in high voltage substation typically is tripping or blocking signals, interlocking, breaker failure initiation, oscillography triggers, etc.

Sampled Measured Values are streams of multiple digitized values from analog CT/VT signals from primary equipment. Sampled Measured Values are sent from intelligent sensors (Merging Units) located at the process level to the IEDs in the bay level.

Time synchronization is the service used in the communication network to distribute precise clock signal, typicall in IEC 61850 systems it is implemented with SNTP or IEEE 1588 protocol.

GOOSE (Generic Object Oriented Substation Event provides a very powerful IED to IED messaging mechanism that allows efficient real time exchange of any state or analog parameter. GOOSE is an incredibly powerful feature of 61850 and gives flexibility to the designer of the automation system. GOOSE messages are encapsulated directly in Ethernet layer. The lack of IP header was decided on purpose when these protocol had been designed in order to permit extremely efficient encoding and decoding of frames in protocol stacks of embedded devices such as protection and control relays. The elimination of IP and UDP or TCP layer can save priceless milliseconds of processing time in resource limited embedded devices. GOOSE uses layer 2 MAC multicast for ensuring one-to-many data transmission. GOOSE messages are priority tagged so that they have the highest Class of Service (CoS – IEEE 802.1P) in the network which minimizes network delay. To do this, GOOSE frames are placed in the front of the store and forward queue but frames already being sent are not interrupted.

The key features of GOOSE are listed below:
• Standard, interoperable and Ethernet based peer-to-peer communication between protection & control devices
• Very fast connectionless oriented device to multi-device communication
• Significantly reduces conventional copper wiring between IEDs in substation automation systems

WIMAX COMMUNICATIONS

The application drivers

Governments and people around the world pushing electric power companies to modernize the grid infrastructure to accommodate new applications including: electric vehicles, green energy through distributed generation, automated meter infrastructure and demand response. In order to accommodate these new applications, utilities need to extend automation and communication capabilities outside of the substation fence to literally thousands if not millions of devices in the distribution network. With such a wide area to cover and so many discrete end points, most utilities are turning to wireless alternatives for connectivity.

The application requirements

When examining wireless options, it is important to look closely at the requirements of the electric power applications since they differ from service provider or even large enterprise use.

Range/Scale: Electric Power companies often have territories that stretch for hundreds of kilometres. Scaling a wireless network over an area of that size limits the number of technologies that can be used. One of the key requirements of the chosen smart grid wireless technology is that it is able to simultaneously pick up AMI concentrators, distribution automation points and connect them back in to substation sites or back to the corporate network. This implies a technology that can extend point to multipoint connectivity over tens of kilometres. In addition, the technology should be capable of being deployed at every substation across an area, scaling to a regional area network.

Multiservice Capabilities: There are a number of different applications that need to be served by the wireless network, each with its own requirement for throughput, latency and reliability. The wireless technology should be able to handle multiple different traffic types and treat them differently should contention for resources be an issue.

Reliability: The wireless system should maintain a very high availability since the much of the traffic is reporting the status of mission critical devices.

Technology lifecycle: The lifecycle expectation of communications equipment in an electric power company is more than ten years. The chosen wireless technology should have some enough market traction to ensure that the power companies can continue to source parts for at least that length of time.

Suitability for Substation use: Most telecommunications equipment is designed either for "enterprise" use with IT grade features for private network use or "telco grade" designed for use in a telecommunications hut (like a cellular site). The electric substation has its own challenges with high levels EMI/C and wide temperature variations. Whatever technology is chosen, it should be delivered in a form factor that is designed to meet substation standards like IEEE 1613 or IEC 61850-3.

WiMAX as a solution candidate

WiMAX or the Worldwide Interoperability of Microwave Access is an industry group that is dedicated to drive interoperability around a subset or profile of the IEEE 802.16e standard. The technology is used to deliver wide scale broadband wireless coverage to fixed and mobile users. WiMAX is reaching critical mass of adoption, driven mostly by the emerging markets, with leading chip vendors now shipping over 1 million devices every three months. There are hundreds of member companies of the WiMAX Forum and many different end user devices from standalone modems, to vehicular CPEs, to USB dongles and even embedded chipsets in laptop computers.

WiMAX brings a number of key advantages for electric power usage:

1) Standards based private network: WiMAX is the only technology available on the market to deliver a wide scale private wireless network based on a widely adopted standard. This brings the advantages of a private network in terms of control and reliability, along with the interoperability and lifecycle of standards based equipment.

2) Quality of Service: WiMAX was built from the ground up to deliver to multiple service types that get treated differently over the wireless media. WiMAX employs a centralized scheduling mechanism where the base station decides based on traffic type, how much bandwidth to reserve, latency tolerance and other critical parameters.

3) Scale: WiMAX has many built in mechanisms to be able to deliver a wide scale network in a frequency constrained environment. It is possible for example to deploy an entire WiMAX network in a single frequency channel.

Necessary additions to WiMAX

Though promising as a technology, “off-the shelf” WiMAX has some shortcomings which make its deployment in electric power environments questionable.

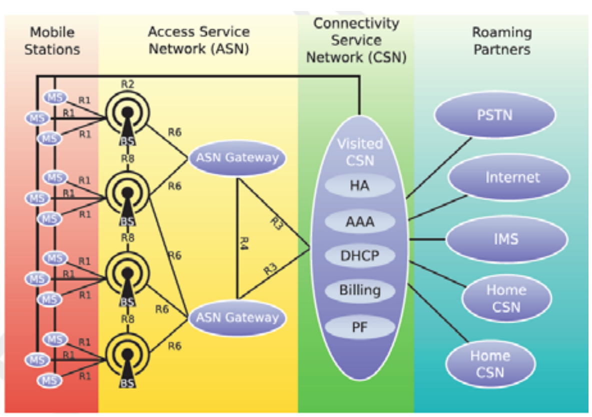

Figure 1. Architecture of WiMAX system

1) ASN Gateway – In commercial WiMAX networks, all traffic gets mapped in to a GRE tunnel which terminates at the ASN gateway. This implies that all traffic, even between neighbouring subscriber stations, must flow potentially hundreds of kilometres over disparate backhaul networks to a central point in the network. This extra distance makes the reliability and latency not suitable for utility applications.

2) IP vs. Ethernet Convergence Sublayer – In service provider applications, it is highly desirable to assume that each neighbouring subscriber is in a different network and wants to be isolated from each other. Thus the WiMAX equipment implements something called IP convergence sublayer.

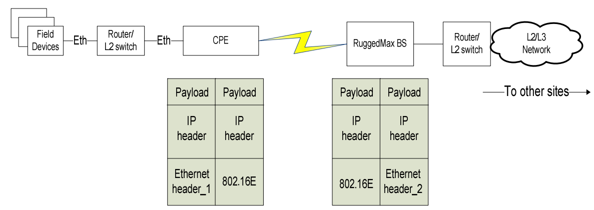

Figure 2. IP Convergence Sublayer Stack

In this mode, the Ethernet header is not carried over the air by the system. As applied by the name, non-IP traffic in this mode is not supported.
In a private network, this type of isolation is not required and in many cases can be a hindrance, for example in the case where Ethernet services are required.

In Ethernet CS mode, the IP packet is sent by the device over Ethernet. The CPE encapsulates the whole Ethernet frame and sends it using the 802.16e interface. The Base Station strips off the 802.16E header and forwards the frame to the network or to another CPE according to the destination MAC address.

CONCLUSIONS

The current paper is a result of a real project where one of the major protection & control vendors integrated their IEC 61850 based relays with hardended wireless communications devices. The obtained results consisted on total transmission latency of GOOSE messages on wireless WiMAX link in the range of 30-50 milliseconds. This is a substantial improvement when compared to latency times of several hundreds of milliseconds that today’s solutions based on cellular GPRS networks can achieve. The presented solution in this paper is characterized by a unique “standalone mode” in which a WiMAX equipment has a native support for layer 2 multicast traffic and GOOSE messages are only forwarded inside the same cell without the need of using centralized application gateway (ASN Gateway). This work is the world first practical application of IEC 61850 GOOSE over wireless WiMAX in medium voltage distribution network.

REFERENCES

[1] Andre Smit, 2011, " Distribution Feeder Automation using IEC61850 GOOSE Messaging over WiMAX Wireless Communications ", Siemens white paper