REFURBISHMENT STRATEGIES FOR THE PROTECTION OF DISTRIBUTION SYSTEMS

Alexander APOSTOLOV
OMICRON electronics – USA
alex.apostolov@omicronusa.com

Damien THOLOMIER
AREVA T&D Automation - Canada
damien.tholomier@areva-td.com

ABSTRACT

The paper analyzes refurbishment strategies for the protection of distribution systems based on functional requirements, available devices, communication protocol selection and future technology trends. The impact of IEC 61850 and how legacy devices can be integrated in distribution protection systems based on the new standard are discussed.

INTRODUCTION

The changing industry requirements for improvements in the performance of distribution protection systems during short circuit faults or other abnormal system conditions, as well as for availability of measurements, monitoring and recording functions are some of the forces that drive the refurbishment of protection and control systems in distribution substations.

Refurbishment strategies for the protection of distribution systems are based on multiple factors such as the existing systems, short-term and long-term goals, available technology and future trends, reliability and power quality requirements,. They should meet the current requirements, but also allow flexibility and be future-proof in order to be able to adapt to changes in the technology or the needed functionality.

Since the integration of protection devices in substation automation systems is one of the key requirements for the development of refurbishment strategies, the selection of communication protocols, substation communications architectures and implementation of communications based distributed solutions need to be carefully analyzed.

Modern substation automation systems are based on the integration of multifunctional, usually protection IEDs from different manufacturers. Requirements that they support IEC 61850 – the new international standard for substation communications are seen more and more around the world. Such systems not only support features available in the communications protocols currently used in substations, but they allow different distributed applications, such as protection, monitoring or event and disturbance recording. This results in significant improvement in the efficiency of use of new technology in the substation.

The existence of numerous substations with an installed base of millions of electromechanical or solid-state relays that are still meeting the protection requirements of the user presents a challenge to the industry. On top of that, many of the substations have been upgraded in the last several years with microprocessor based relays that do not support IEC 61850. The replacement of all these legacy products will be very time consuming and costly. The upgrade process requires careful consideration of all available options and the development of a migration path that will allow smooth transition into the IEC 61850 based distribution protection and automation world.

A successful refurbishment strategy can be developed only based on a proper definition of functional and performance requirements, good understanding of the capabilities of existing and new devices, as well as the acceptable levels of application of communications based solutions. Knowledge of IEC 61850, adequate substation local area network architecture selection and decisions on which components of such solution should be implemented at different stages of the refurbishment process also play an important role.

DISTRIBUTION SUBSTATION FUNCTIONS

The first step in the development of a refurbishment strategy is the definition of the functional requirements for the upgraded substation. It is required in order to allow the optimal selection of the new protection and other IEDs that will support the requirements at minimal costs.

Some of the key functions implemented in distribution substations are as follows:

Protection: Multi-step phase, ground or sequence components based instantaneous and time-delayed overcurrent; thermal overload; circuit breaker failure protection; broken conductor detection, cold-load inrush and many other

Control: Three phase multi-shot autoreclosing, circuit breaker control, load-shedding and restoration, multiple settings groups control

Measurements: Comprehensive measurement values: RMS, instantaneous; integrated

Post Fault Analysis: Fault location; event and fault records; disturbance records

Condition Monitoring: Trip circuit supervision; breaker state monitoring; breaker condition monitoring; voltage transformer supervision; current transformer supervision

Power Quality Monitoring: Detection of voltage sags, voltage swells, power interruptions, frequency and power factor variations

Most of the listed above protection and non-protection functions are common to many different types of IEDs. All of them (or a subset) have to be made available to the IEC 61850 based distribution substation system regardless of the

level of compliance of the individual devices with the standard.
The main goal of IEC 61850 supporting the interoperability between multiple devices from different vendors applied at different levels of the distribution substation system. Considering the fact that protection and metering devices have very different requirements for accuracy of instrument transformer and the dynamic range of the measurements, as well as the difference in sampling rate requirements and recording capabilities between power quality monitoring devices and protection relays, it is clear that in a conventional substation there is a need for multiple devices in order to satisfy the different applications. Each of the above mentioned devices needs to be installed, wired to the substation equipment that it interfaces, tested and maintained. Adding the requirements for redundancy, many of these devices need a primary and backup, which doubles all of the above costs.
A significant improvement in the functionality and reduction of the cost of integrated distribution substation protection, control, monitoring and recording systems can be achieved in IEC 61850 based systems using state of the art devices and sensors (existing or under development) as described below.
Non-conventional instrument transformers with digital interface based on IEC 61850-9-2 [6] eliminate some of the issues related to the conflicting requirements of protection and metering IEDs. It is important to be able to interface with conventional and non-conventional sensors in order to allow the implementation of the system in different substation environments.
A simplified diagram with the communications architecture of an IEC 61850 Process Bus based substation automation system is shown in Fig. 1.

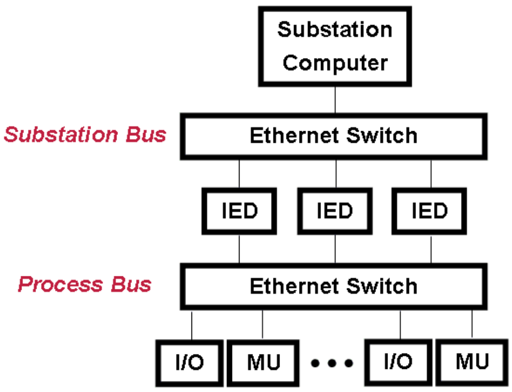

Fig. 1 Simplified IEC 61850 substation communications architecture

The Merging Units (MU) multicast sets of measured sampled values to multiple IEDs in the substation over the substation local area network. If a network segment is used exclusively for this purpose, it is called the “process bus”. Status information for breakers and switches is available through an input/output unit (IOU). In some cases the merging unit and the input/output unit can be combined in a single device.
The Process Bus offers significant advantages and can be successfully used especially in the refurbishment of old distribution substations that require replacement of copper cables with failing insulation.
The Station Bus is used for IED to IED communications in a peer-to-peer mode, as well as for interface between the IEDs and the substation level HMI and other applications in a Client – Server mode.
The Station Bus also allows the replacement of copper control cables with fiber. It leads to improvements in the functionality and reduction of the engineering, commissioning and maintenance costs.
The standard is developed in a way that supports the complete replacement of legacy devices, while at the same time it also allows their integration into in an IEC 61850 substation.

INTEGRATION OF LEGACY IEDS

The last 15 – 20 years have seen the gradual replacement of electromechanical and solid state relays with simple or more complex IEDs. The integration of IEDs is based on proprietary, semi-standard and standard communication protocols. The definition of hierarchical object models in IEC 61850 is one of the key benefits of IEC 61850 that allows seamless integration and interoperability. Legacy IEDs need to be modeled as well in order to be integrated into an IEC 61850 based distribution substation.
The highest level of complexity of modeling is in the case of integration of advanced legacy protection IEDs. This also changes the communications architecture in the substation, compared to the purely IEC 61850 communications architecture shown in Figure 1.

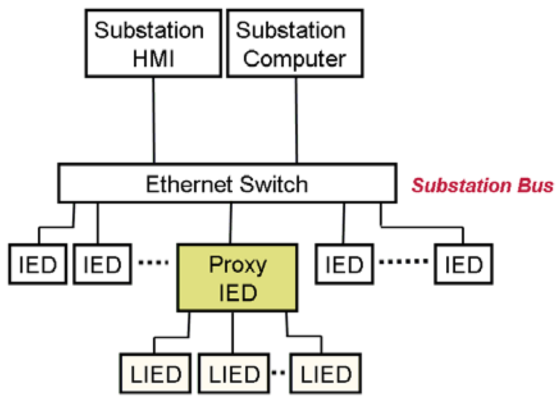

Fig. 2 Communications architecture with legacy devices

The legacy IEDs (LIED) in Figure 2 are connected to a Proxy IED usually through serial communications over RS 232 or RS 485 using Modbus, DNP3, IEC 870-5-103 or other common protocol.
Since legacy devices are modeled as logical devices in an

IEC 61850 based device, it is clear that this will add another layer in the model. Once all the individual legacy devices object models have been developed, the gateway object model can be completed. It will contain N+1 logical devices, where logical device LD0 should be reserved for the modeling of the gateway itself.

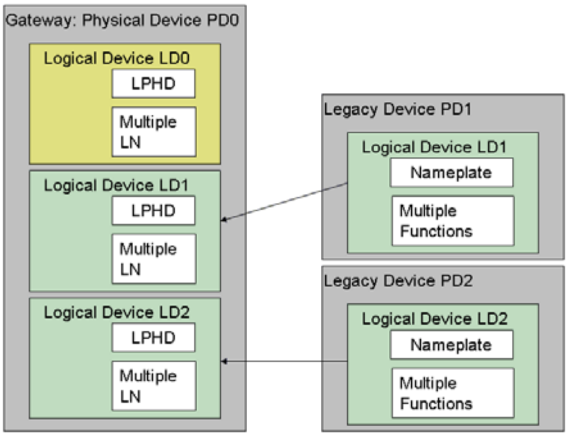

Fig. 3 Modeling of legacy devices in gateway

The legacy physical devices 1 through N are represented in the gateway by logical devices LD1 through LDN, where N is the number of legacy devices interfacing to the substation LAN through the IEC 61850 proxy server (gateway). Figure 5 shows a simplified block diagram of the gateway model, where the functions are represented by multiple instances of logical nodes.

It is clear from the above that the logical devices are the IEC 61850 component that enables the building of gateways (proxies) in such a way that logical devices are – from a functional point of view – transparent. Each logical device can be identified independently of its location (in a separate device connected to the network or in a proxy device). By definition a Proxy Server is a server that sits between a client application and a real server.

A gateway is a network interconnection device that supports the full stack of the relevant protocol which it can convert to a non 7 layer protocol for asynchronous transmission over wide area networks

Logical devices provide information about the physical devices they use as host (nameplate and health). They also provide information about external devices that are controlled by the logical device (external equipment nameplate and health). Only those aspects of physical devices that are defined as visible to the network are of interest in IEC 61850.

The logical node zero (LLN0) represents common data of the logical device, while the logical node physical device (LPHD) represents common data of the physical device hosting the logical device. LLN0 and LPHD are defined in any logical device. Due to the fact that LLNO and LPHD are required in each logical device, plus at least one logical node representing a functional element, the multiplicity definition for logical nodes in a logical device is 3 … *.

To represent the information about the proxy/gateway itself, the logical device LD0 shall be implemented in each device that acts as a proxy or gateway. The logical nodes LLN0 and LPHD of LD0 shall represent information about the proxy or gateway device itself.

If a physical device does not provide logical devices that mirror logical devices of other physical devices, then this physical device does not need to provide a LD0. To represent the information about the proxy/gateway itself, the logical device LD0 shall be implemented in each device that acts as a proxy or gateway.

INTEGRATION OF ELECTROMECHANICAL OR SOLID STATE RELAYS

The object modeling of the functions in electromechanical or solid state relays is actually very simple, since they were used to develop the object models of multifunctional protection devices. The same way a distribution protection scheme is built from multiple electromechanical or solid-state relays on a panel, it is built from different function elements in a multifunctional microprocessor relay. Since the model of any device in IEC 61850 based systems represents communications visible attributes only, electromechanical and solid-state relays are modeled within physical devices with communication capabilities.

As can be seen from Fig. 4 several electromechanical distribution feeder relays can be built in a single physical devices – a multifunctional power quality monitoring and recording IED or a bay controller IED.

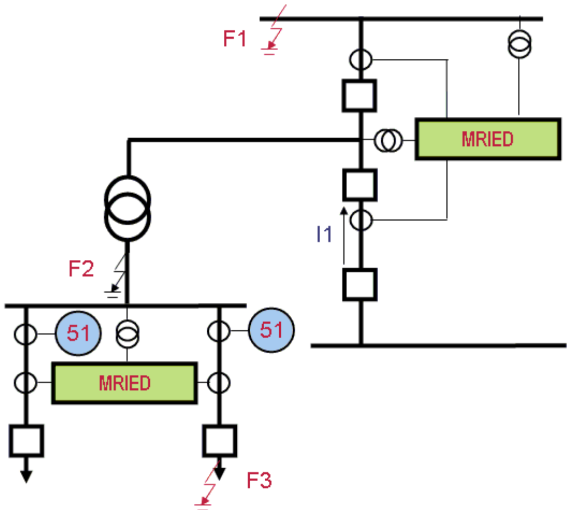

Fig. 4 Integration of electromechanical relays

Each of the electromechanical relays has some of its output contacts wired to the opto inputs of the IED that performs the proxy server function in a manner similar to Fig. 3. Each electromechanical relay in this case is also represented by a separate logical device.

The proxy server performs several additional functions that satisfy the requirements for the integration of the electromechanical relay:

- Time-stamps the operation of the relay, thus making it available to the distributed event reporting system.
- Calculates the location of the fault.
- Records waveforms and disturbances for the analysis of the relay performance under different abnormal conditions.

PEER-TO-PEER COMMUNICATIONS

One of the important differences between IEC 61850 and other communication protocols is the introduction of high-speed peer-to-peer communications defined as IEC GOOSE (Generic Object Oriented Station Event). These messages are used for the exchange of a wide range of possible common data organized by a DATA-SET. The most common applications at this stage are for replacement of the hard wired exchange of binary signals – from relay output to opto input.

Considering the importance of the functions performed using GOOSE messages, IEC 61850 defines very strict performance requirements to ensure that the operating times are equal to or better than what is achievable by existing technology. Thus the total peer-to-peer time should not exceed 4 ms.

Since the legacy devices do not support GOOSE messages, this function is performed by the proxy servers, that will continuously poll the legacy devices for status changes, and will form and send the appropriate GOOSE messages to the network. One GOOSE message is sent for each individual logical device in the gateway, i.e. there will be one GOOSE message for each legacy IED.

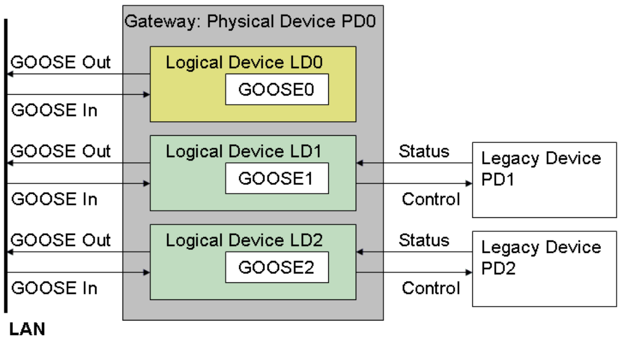

Fig. 5 Legacy IED GOOSE interface

If a GOOSE message has to be processed by a legacy device, the gateway will subscribe to this message, and after processing it, will send a control signal to the appropriate legacy IED for further action. This approach allows the interface of legacy devices with IEC 61850compliant devices on the substation LAN. However, since the messages between the legacy and the IEC 61850 IED will always go through the gateway, it will be affected by its characteristics and will always be slower than the pure peer-to-peer communications between IEC 61850 IEDs. The protection system designer has to evaluate the degradation in performance and determine if it is acceptable. If not, the legacy IEDs have to be replaced by IEC 61850 compliant IEDs.

TEST SYSTEM REFURBISHMENT

The refurbishment of a conventional distribution protection system requires appropriate changes in the test equipment in order to ensure that the legacy or IEC 61850 devices will operate as expected in real life conditions. In case of systems with station bus only, the test device should be able to simulate analog and binary signals, detect operation of the test object relay outputs, publish and subscribe to GOOSE messages.

Simulation of Sampled Measured Values (SMV) should be supported by the test device if Process Bus is used in the distribution protection system.

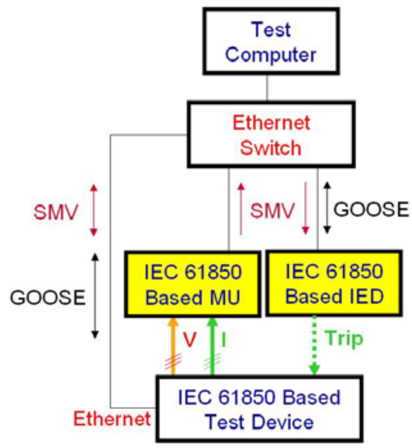

Fig. 6 IEC 61850 test device

CONCLUSIONS

The existence of thousands of substations with an installed base of electromechanical or solid-state relays and legacy IEDs that still meet the protection requirements of the user require the development of refurbishment strategies.

The paper describes the key IEC 61850 differentiators compared to conventional distribution substation system. The concept of the "proxy server" and the role of logical devices in the integration of legacy IEDs or even electromechanical and solid state relays are described.

High-speed peer-to-peer communications and how they can be used in substations with legacy IEDs are later discussed. Different levels of refurbishment of the test devices are also necessary to ensure proper testing of all used IEDs.