COMMUNICATIONS FOR SUBSTATION AUTOMATION AND INTEGRATION

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Abstract

In the past decade, new communications schemes have been designed and retrofitted into the substations by the utilities to integrate data from relays and Intelligent Electronic Devices (IEDs) and capitalize on the protection, control, metering, fault recording, communication functions available in digital devices. A modern power system is one of the largest complexes constructed and operated both in terms of geographical distances as well as generated and transmitted power. Such a system needs precise and high quality control with protection functions as primary due to the top priority safety reasons. Traditionally protective relays have been electromechanical devices whose purpose was only to protect electrical power systems against system failures. Application of microprocessors to power system relaying has increased the functionality of protective relays and brought new concepts, which considers control, protection and monitoring functions integrated together. This paper describes substation communications and the ongoing communication standardization efforts discussing the IEC 61850 and the Utility Communications Architecture (UCA) standards.

1.0 INTRODUCTION

A protocol is basically a set of rules that must be obeyed for orderly communication between two or more communicating parties. Communication between data processing systems from different manufacturers has often been particularly difficult due to the fact that there has been separate development of data processing and data communications techniques, often resulting in complex and expensive interfaces. With the International Standards Organisation (ISO) model, which is commonly known as the Open Systems Interconnection (OSI), the communications process has been divided into seven basic layers as shown in Figure (1).

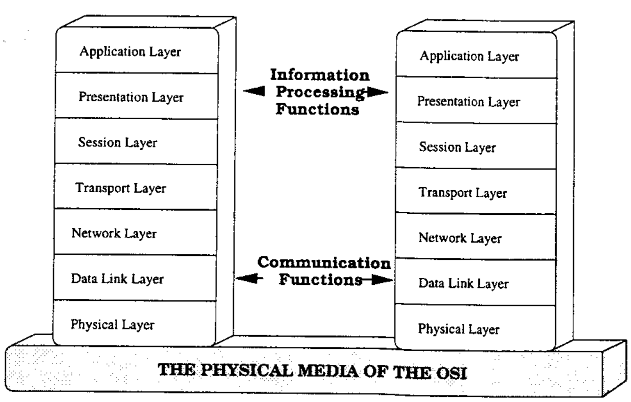

Fig.1 The OSI Reference Model

These layers define how data flows from one end of a communications network to another end and vice versa. Two devices can only communicate if each layer in the model at the sending device matches with each layer in the model at the receiving device [1,2]. The user can quite often make choices in any given layer. The ensemble of choices made to implement a protocol is termed a profile. The rules designed by a protocol profile are designed to organise operating issues in the following areas [2]:

- Framing
- Error control
- Sequence control
- Transparency
- Line control
- Time-out control
- Start-up control

There are literally thousands of combinations of protocol agreements that can be created with the large domain of existing pieces. The main protocol that have found widespread use in the substation environment are [2]:

- MODBUS: A popular master-slave protocol with industrial users, which has also become popular in substations. It issues simple READ/WRITE commands to addresses inside an IED.
- Distributed network protocol (DNP): An

increasingly popular master-slave protocol mainly in North America. DNP can run over multiple media, such as RS-232 and RS-485 and can issue multiple types of READ/WRITE messages to an IED.

- IEC-870-5-101: is considered as the European partner to DNP. It differentiates itself from DNP with its slightly different messaging structure and the ability to access object information from the IED.
- UCA: is the Utility Communications Architecture designed to satisfy every possible requirement in substation equipment.

Many of today's electric utility substations include digital relays and other intelligent electronic devices (IEDs) that record and store a variety of data about their control interface, internal operation and performance, and about the power system they monitor, control, and protect. Nowadays, digital relays are widely replacing the aging electromechanical and solid-state electronic component-type relays and relay systems. Figure (2) shows a digital relay with its target interfaces. Digital relay's popularity comes from their price, reliability, functionality, and flexibility. However, the most important feature that separates the digital relay from previous devices is its capability of collecting and reacting to data and then using this data to create information. Such information includes [3]:

- Fault location and fault type
- Prefault, fault, and post-fault currents and voltages
- Relay internal element status
- Relay control input and output status
- Instantaneous and demand metering
- Breaker operation data
- Relay operation data

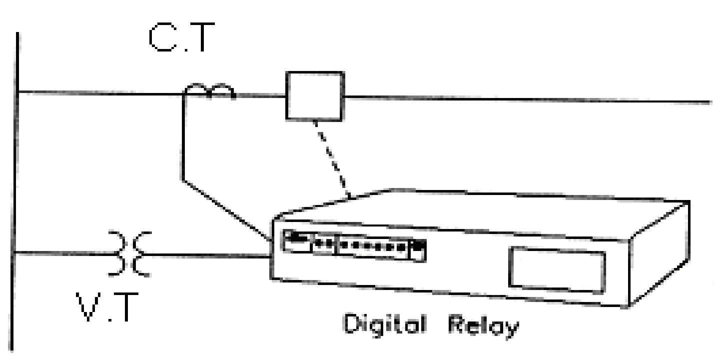

Fig.2 Digital Relay with Target Interface

Instrumentation & Control devices, which are built using microprocessors, are commonly referred to as intelligent electronic devices (IEDs). Microprocessors are single chip computers that can process data, accept commands, and communicate information like a computer. IEDs can also run automatic processes, and communications are handled through a serial port like the communications ports on a computer. Some examples of IEDs used in a power system are [4]:

- Instrument transformers
- Transducers
- Remote terminal unit, RTU
- Communications port switch
- Meter
- Digital fault recorder
- Protocol gateway

2.0 POWER SYSTEM COMMUNICATIONS

Communication systems have been used for decades to enhance the performance of power systems. Without the use of a proper communication channel, power system protection suffers from a major disadvantage of not being able to accurately discriminate faults. When voltages and currents are analysed only from one terminal, it cannot be concluded whether a fault near the far end terminal is internal or external to the protected line segment. This requires delayed tripping for such faults, which can endanger system stability or increase damage. At the far end terminal, the decision whether the fault is internal or external is obvious, not from a distance measurement but from knowledge of the direction of the fault. This information can be transmitted to the other terminal with the use of a proper

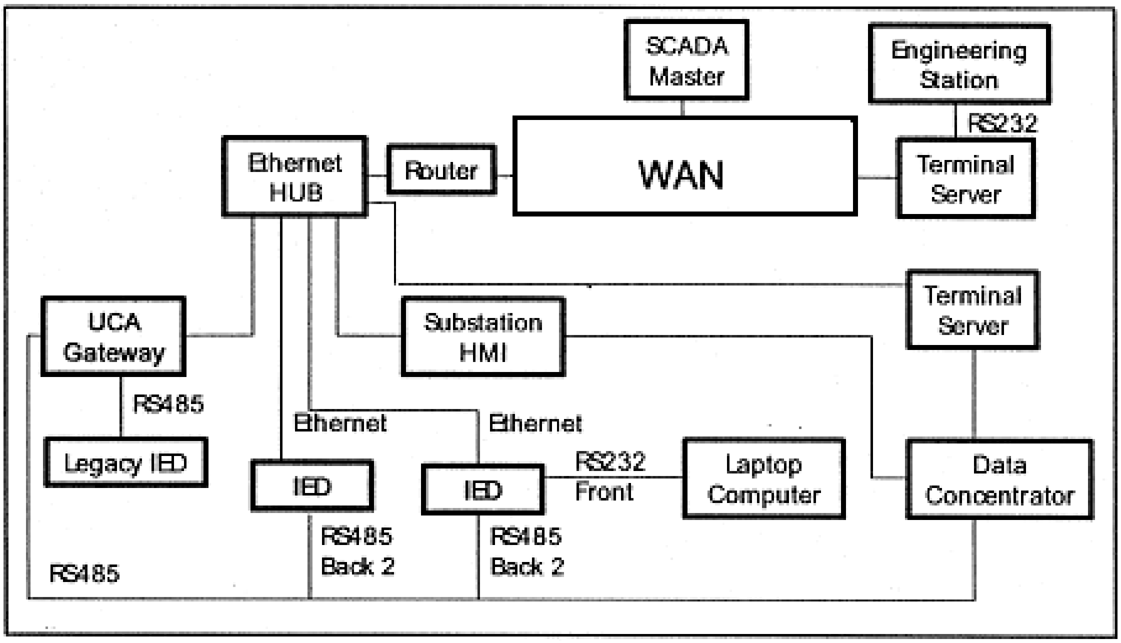

Fig.3 Typical Integrated Substation protection and Control System (from Ref. [9])

communication channel enabling it to decide whether to trip or not to trip [2].

Power providers are focused on increasing productivity and making electric power safer, more reliable and more economical by providing innovative, simple to use, robust technologies for power system protection, automation, control, monitoring. Development of appropriate communications technologies and protocols is at the heart of this strategy. When relays and IEDs are integrated together, they form a powerful, economical Instrumentation and Control (I&C) system to support all aspects of electric power protection, automation, control, monitoring, and analysis [5]. Figure (3) shows how IEDs and relays can be interconnected together to form a protection of power system. Such a system also supports the substation in terms of the monitoring, analysis, and automation aspects.

The relaying and measurement tasks have been well understood and standardised. On the other hand, the technical methods and operating impact of data communications continue to evolve dramatically. There is a wide variety of incompatible communications approaches and systems in the marketplace. Competing manufacturers have been following unique approaches when designing the communications interface circuits. Other IED makers designed networks, which make it possible to connect a number of devices in one substation to a single local host that could dynamically address requests for data to any unit. However, the user could not directly interconnect competing products since the protocol remained unique for each system. Using competing products from competing vendors offers a variety of protection and monitoring capabilities for users, who are often frustrated by the communications variations. They could not interconnect the devices; they had to provide a different communications system for each vendor [6].

Nowadays, the desire and the need to merge the communications capabilities of all the relays and IEDs in a substation is clearly recognised, which is capable of providing not only data gathering and setting capability, but also remote control. Furthermore, multiple IEDs can share data or control commands at high speed to perform new distributed protection and control functions [6].

3.0 STANDARDIZATION DEVELOPMENTS

The introduction of higher-level protocols in IEDs has only enabled communications between like devices or in other words communications between devices from the same manufacturer. In order to communicate a variety of devices from different vendors, which enables the utilities with a variety of protection, monitoring and automation capabilities, there is a need to use protocol converters or gateways. Furthermore the IED protocols are also limited in capability including speed, functionality and services making engineering harder, and increasing operation and maintenance costs. Worldwide, electric utility deregulation is expanding and creating demands to integrate, consolidate and disseminate real-time information quickly and accurately within and with substations [7].

A non-proprietary, standard, high-speed protocol offering sufficient services is required to enable a robust, integrated substation communications network without protocol converters. The introduction of IEC 61850 and the Utility Communications Architecture has made it possible and justifiable to integrate station IEDs through standardization. Using the standardized high-speed communications between IEDs, the utility engineers can eliminate, many expensive stand-alone devices and use the sophisticated functionality and the available data to their full extend [7].

3.1 The UCA Substation Communications Project

The Electric Power Research Institute (EPRI) has existed since the 1970s to develop technologies for the benefit of electric utilities. It manages research and development projects with funds supplied by those utilities as a group and other sources. The Utility Communications Architecture (UCA) was commissioned by the EPRI, which identified the requirements, the overall structure, and the specific communications technologies and layers to implement the standardization scheme. UCA aims to dramatically improve device data integration into the information and automation technology in order to reduce the engineering, monitoring, operation and maintenance costs increasing the agility of the whole life cycle of a substation [6].

Many relay and IED manufacturing companies and progressive utilities showed their interest in UCA work and joined in the effort to define and demonstrate a communications network stack. The approach adopted defined the technical requirements for a system to control and monitor substations of any size. With the use of the substation local area network (LAN), the mass of the dedicated wiring among the IEDs and power apparatus is ultimately reduced or replaced [6].

With continued EPRI support, a long list of relay, meter, and IED vendors have built UCA-compliant versions of products. The elaborate specification for a communications protocol, which handles all the data collection and high-speed control functions, has been evolving quite rapidly. The equipment makers continue to modify and update the implementations in each of the products. Many US and overseas utilities have signed up to demonstrate UCA substation systems. The users can see an impressive and elaborate demonstration of interoperability among a broad variety of equipment from competing manufacturers in meetings held several times a year by the UCA Substation Initiative Project. The importance of achieving interoperable communications has forced collegial cooperation among competitors, who see the individual-product features and performance as the proper ground for competition [6].

3.2 IEC 61850 Project

IEC 61850 is based on the need and the opportunity for developing standard communication protocols to permit interoperability of IEDs from different manufacturers. Utilities also require IED interchangeability, which is the ability to replace a device supplied by one manufacturer with a device supplied by another manufacturer, without making changes to other elements in the system.

IEC 61850 makes use of existing standards and commonly accepted communication principles, which allows for the free exchange of information between IEDs. It considers the operational requirements since any communication standard must consider the substation operations functions. However the communication protocol standard IEC 61850 focuses on neither standardising the functions involved in substation operation nor their allocation within the substation automation systems. Identifying and describing the operational functions used define the impact of the operational functions on the communication protocol requirements.

IEC 61850 identifies all the known functions in a substation automation system and splits them into sub-functions or so called logical nodes. A logical node is a sub-function located in a physical node, which exchanges data with other separate logical entities. In IEC 61850, all logical nodes have been grouped according to their most common application area, a short textual description of the functionality, a device function number if applicable and the relationship between logical nodes and functions [7]. IEC 61850 decouples applications to design them independent from communication so they are able to communicate by use of different communication protocols. This is due to the fact that the vendors and utilities have maintained application functions that are optimised to meet specific requirements and that have reached a high degree of maturity and quality. Therefore IEC 61850 provides a neutral interface between application objects and the related application services allowing a compatible exchange of data among components of a substation automation system. Figure 4 shows the basic reference model [7].

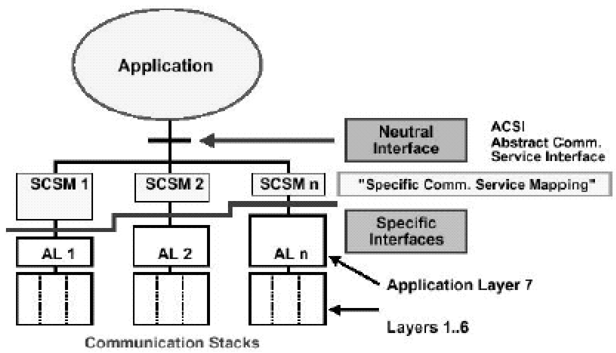

Fig.4 The Basic Reference Model (from Ref. [7])

One of the most important features of IEC 61850 is that it covers not only communication, but also qualitative properties of engineering tools, measures for quality management, and configuration management. This is necessary since when the utilities are planning to build a substation automation system with the intention of combining IEDs from different vendors, they expect not only interoperability of functions and devices, but also a homogenous system handling.

Quality assurance for system life cycles is one of the important aspects covered by the IEC 61850, which defines the responsibilities of utilities and vendors. Guidelines for environmental conditions and auxiliary services with recommendations of the relevance of specific requirements from other standards and specifications are also defined [7]. With the plug and play capabilities embedded in the standard and the immediate prove of concept in pilot projects, IEC 61850 promises to be a great step forward in the development and acceptance of substation automation systems world-wide. This will finally bring the real benefits of automation and integration to utilities that were originally promised years ago [7]

4.0 POWER SYSTEM AUTOMATION

Substation Automation is the use of the IED data within the substation and control commands from remote users to control the power system devices within the substation. Power system automation automatically controls the power system via I&C devices. Power system integration refers to communicating data to, from, or among IEDs in the I&C system and remote users. Substation integration is the act of combining IED's local data to a substation so that there is a single point of contact in the substation for all of the I&C data [4]

4.1 Single Master and Multiple Master Networks

In a multi-drop network, several devices can be physically connected in a bus or ring network. Figure (5) illustrates relays connected in a bus topology. In a multi-drop connection, only one device can communicate at a time. Each device requires a permission to transmit before transmitting any data, which is determined by various hardware and software in the system, so that data does not collide on the conductor. An addressing scheme is required to identify the source and destination of the data being communicated, which reduces the amount of data that can be transferred at a given speed by adding overhead in the form of processing time and amount of information that needs to be transmitted. Furthermore since relays from different manufacturers have varying protocol support capabilities, interactions must be carried out at the lowest common denominator and all devices must support the same baud rate and physical network connections [8]

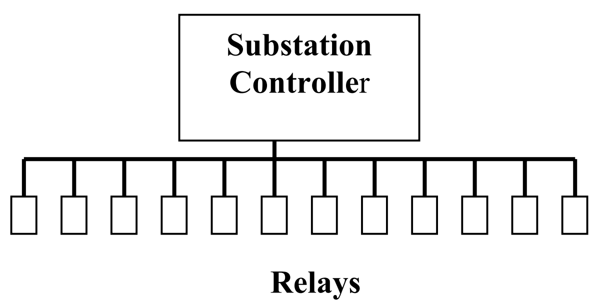

Fig.5 Relays connected in the bus topology

Until late 1990s the typical communication networks were only capable of being configured as a single master device communicating to slave devices. The application of high-speed communication networks in IED communications has made it possible to use multiple masters and peer-to-peer networking schemes. Peer-to-Peer refers to the direct transfer of data between devices functioning in a similar capacity. Unlike the EIA-RS485 multi-drop network, multiple masters can issue commands to several slaves and their responses could occur simultaneously. A major advantage of the multiple master environment is the distribution of the communication tasks to the various masters. During the critical periods of operation, when faults occur on the substation, multiple masters allow for the segregation of tasks. An application of the multiple master is when precise control logic requires the timely supervision of networked IEDs while at the same time system operators need information on the events. In a single master environment, it is possible that the less important data collection can cause congestion on the network preventing the time critical information exchange between the master and slave devices [11]

4.2 Implementation of the IED Network Interface

As mentioned in the previous section, there are numerous advantages of high-speed networks such as the possibility of multiple masters and peer-to-peer networking schemes. However several considerations are required for the successful implementation of the IED's network interface to be able to benefit from these advantages. The high data transfer rate is only as good as the weakest link in the entire system. Flexibility of the IED and the ability to provide a means of user customisation also allows for the ease of integration [8].

First of all the peer device needs to be able to process more than one command sequence concurrently. Otherwise a lower priority device may prevent a time critical command from being processed. This is quite important in a substation automation application where two masters request data to a common peer device. If the IED's network interface only allowed single command processing and the peer was busy processing a lower priority command from one of the masters then a higher priority command such as a Programmable Logic Circuit's (PLC's) request to trip a breaker would be blocked until the command path cleared. Whereas the ability to concurrently process commands allows the PLC trip command to be executed and not blocked.

IED's performance and its ability to execute requests efficiently is also another important consideration since certain requests, such as the metering requests, issued to the IED may not require immediate processing and can be deferred to a lower priority processing task. In contrast, the time critical control logic of the PLC has to be processed in the IED's high priority processing task since any delays could cause equipment damage in the power system [8].

5.0 CONCLUSION

Substation relay data has many uses and offers considerable value to utility operating, maintenance, planning, engineering, and customer services personnel. New technology offers several alternatives to collect, store, and distribute this information in an efficient and economical manner. The power system protection engineers have had the ability to communicate and extract information from the microprocessor type devices, commonly known as the IEDs, for the last decade. These IEDs perform instrumentation and analysis of power system equipment based on specific vendor algorithms. Substation Integration and Automation are the most important tools protection engineers use nowadays for integrating various relays and IEDs in the substation environment forming an economical I&C system, which supports the substation in terms of monitoring, analysis, and automation aspects. Design and development of appropriate communications schemes and protocols forms the basis of this strategy.

For many years, protection engineers suffered from a serious disadvantage due to the fact that different products (IEDs and relays) from competing manufacturers had different communication interfaces. In general, the protocol, or sequence and structure of messages, was unique for each system. However, the need and the desire to integrate relays and IEDs throughout the substation merging their communications capabilities has encouraged many engineers and organizations all over the world to work together in the definition of the next generation's communications infrastructure for substation monitoring and control. The generation of this standard would avoid the extremely complex incompatible systems assuring interoperability of the various vendor's IED's.

The introduction of IEC 61850 and the Utility Communications Architecture has made it possible and justifiable to integrate station IEDs through standardization. The use of existing standards and commonly accepted communication principles together with the new standards like the IEC 61850 and UCA provides a solid base for interoperability between IEDs in the substation leading to more flexible and powerful protection and control systems.

ACKNOWLEDGMENT

Cagil Ozansoy would like to thank School of Communications and Informatics for granting him

scholarship to carry out his Ph.D. studies at Victoria University of Technology, Melbourne, Australia.

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