LAN interconnections applied to transmit data between remote control devices in power industry installations

Robert Jędrychowski, Michał Wydra
Lublin University of Technology
20-618 Lublin, ul. Nadbystrzycka 38 A, e-mail: r.jedrychowski@pollub.pl, m.wydra@pollub.pl

The paper discusses technological solutions that are used to organize communication between technical devices within the electrical substation area. Design and operation of presently used supervision and control systems are based on various communication solutions. Ever growing standards concerning the required quantity of data and their transmission rate induce a search for new solutions. The paper presents new concepts of LAN-based data exchange and an equipment that can be applied to develop SCADA systems using that technology. An example physical model of communication has been used to present a configuration of devices that form a frame of the network and remote control elements that use it.

KEYWORDS: LAN, IEC 61850, remote control

1. Introduction

The development of power system protection and control systems as well as the supplementation of new tasks to be realized by the systems have made it necessary to elaborate new ways of data exchange. New standards of communication between component devices of the systems of power system protection, remote control and supervision & control (SCADA) induce the application of LAN-based communication. For a few recent years gradual implementation of Ethernet-based LANs to new power industry installations has been observed. It has been feasible owing to the ever increasing network operation rate and the application of new technological solutions that enhance operational safety and organize data exchange among component devices of the systems. Additionally, communication protocols, both the ones hitherto used in power engineering and the new ones, can apply such communication technology.

New technical requirements have been defined based on communication standards and then thoroughly described in the operation and service manuals for a transmission system operator and the distribution network operators to be applied 0. They make a basis for designing and realization of new power substations and the modernization of already operating ones. In order to fully assess the cooperation potential of the protection and control systems and LAN, a communication model that interconnects various cooperating devices of the systems has been elaborated in the Power System Department of the Lublin University of Technology 0.

The model is characterized by an open arrangement, which makes possible to add on new devices supplied by various manufacturers as well as to apply various communication circuits and protocols. It is a scalable model that can be continuously developed. It fully meets requirements of the IEC 61850 standard, which makes a reference point for the evaluation of the communication network operation. Assumptions concerning the LAN operation that are specified in the mentioned standard are discussed in the first part of the presented article. Further parts present communication technologies that have been applied to the model. Interconnections within the hardware and communication layers are described. An example configuration of the power system protection and remote control devices exchanging information that is adapted for the operation within the LAN framework.

The laboratory communication model presented in the article makes a background for the presentation of developments that are introduced to the organization of communication circuits within the area of power industry installations of various scale.

2. Technical requirements for new SCADAs

Management of a power grid with dispersed generation requires the development of a supervision and control system (SCADA) that enables acquisition of data that describe the grid condition and makes possible to control its operation as well as to monitor the operation of its generating units. Realization of that task can involve the application of various communication technologies 0. Individual power industry installations include elements that cooperate with one another by the exchange of data. Particular attention should be paid to SCADAs in substations, where considerable developments have took place for the recent few years. General structure of SCADAs can be described at three levels: of a field, a substation and a master center. Operation manuals specify elements that are indispensable at each of the levels 0, 0 and they are the following:

At the field level

- field controller to realize signal acquisition within the field area,
- control panel that is an interface that enables presentation of local data and realization of control tasks.

At the substation level:

- substation controller to realize acquisition and exchange of signals within the substation area with the application of adequate links; the controller can be additionally equipped with a control panel,
- substation computer that operates in a redundant arrangement and realizes almost all the tasks related to the central data processing and to the organization of applications that can be accessed by supervisors,

- Human Machine Interface (HMI), a control center, wherefrom a control over the whole installation can be performed,
- communication controller or hub for the protection equipment; those elements can be installed, when there is a need to connect devices of incompatible communication standards,.
- substation recorder,
- substation automatic control,
- WEB sever – realization of the WEB server function enables remote access to the diagrams and data,
- router to organize the access to WAN by determining the best paths for the data transfer using the IP protocol,
- communication modules to enable communication among the SCADA elements as well as with the master center.

The master center is equipped with a dispatcher stand that makes possible to remotely supervise selected objects, a central computer (*Supervision Center* – CS) that supplies detailed analyses and reports and communication modules that enable data transfer form the CS to slave objects.

It is indispensable that communication among devices at each of the levels as well as between the levels is ensured. In the case of new installations, connections based on fast versions of the Ethernet technology using fiber optic links are preferable within the substation area, while for the communication between substations as well as between a substation and its master center WAN optical links mostly based on the SHD technology can be applied.

3. The ethernet network technologies

The fundamental rule for the development of a communication structure in new power system substations is to meet requirements of the IEC 61850 standard. It provides for the possibility of data exchange between intelligent devices IED 0.

Main communication services defined in the standard are the following:

- writing and reading data from the IDE devices,
- transmission of reports,
- transmission of log (*logs*),
- transmission of events or critical statements GSE (*Generic Substation Event*)– using GOOSE statements (*Generic Object Oriented Station Event*) and GSSE (*Generic Station State Event*),
- transmission of control commands,
- transmission of measurements as a stream of signal probes.

The above mentioned services require an application of various communication mechanisms defined for LAN networks and TCP/IP protocols. The IEC 61850 standard imposes the application of at least the IEEE 802.3u (*Fast Ethernet*) standard and switches as a primary apparatus to form the network backbone structure. Owing to fast operational speed of the network (minimum 100 Mb/s), operating in the *Full Duplex* mode and the application of switches, collisions should be eliminated 0. It is particularly important at the GOOSE statement transmission between power protection devices when, the delay cannot exceed 0,4 milliseconds 0. In order to meet so restrictive requirements of the IEC 61850 standard it is necessary to apply many additional technologies defined for the Ethernet networks 0 as the below listed ones:

1. Autonegotiation mechanism. It has been elaborated following the need for operating links of various speed rates, signaling schemes and varied communication modes. Devices exchange the FLP statement and that way set the best communication way.
2. Flow Control – connection of networks operating at varied operation rates, which can result in transferring various amounts of data at the same time has ensued the need to solve a problem of controlling data transfer from a faster network to a slower one. The solution given in the IEEE 802.3x standard, makes possible to control the data flow at a point-to-point communication with the use of a special control frame called PAUSE.
3. Virtual Local Area Networks – the application of manageable switches has made it possible to develop and control virtual sub-networks. The core of the VLAN concept is to form a logical group of devices that physically operate in the same network. VLANs can be developed based on switch ports, physical addresses or IP sub-networks. In order to make the VLAN realization possible in networks, where the backbone consists of many switches, two additional standards should be used: the first one that is responsible for the transmission of information about actual VLANs between switches - IEEE 802.1Q (*VLAN Tagging*), the other one is the IEEE 802.1p (*Class of Service*) and it introduces packet or statement priorities. Application of the above mentioned standards results in the data frame modification. After the source address, a 32 bit field has been inserted with an information about an identifier (Tag), priority or a sub-network identifier.
4. *Spanning Tree Protocol* IEEE 802.1D together with its recent versions 802.1w (*Rapid STP*) and 802.1s (*Multiple STP*) –its function is to prevent so called broadcasting storms in a network. The phenomenon occurs in complex networks, where there are alternative links between switches. Recent solutions speed up the network reconfiguration process, with its division into VLANs considered.
5. Network Security Management (Authentication) – in order to enhance the network security, authentication mechanism has been introduced to be applied to data transferred among the system devices (IEEE 802.1X). It is meant to prevent an intrusion of unidentified senders (devices) into the network operation.
6. Link aggregation – according to the IEEE 802.3ad standard, the rate of data transfer between switches can be increased by using more than one port for the

transmission. That standard manages data transmission by balancing packet traffic at individual ports as well as by managing the reconfiguration in the case of connection failure.

7. Time synchronization – it is an element that is indispensable to realize the event identification with a time stamp. The task is performed with the use of the NTP protocol of the TCP/IP family as well as with some specialized protocols described by the IEC 1588 standard.

Based on all of the above discussed elements it is fully justified to consider Fast Ethernet and Gigabit Ethernet as predictable and controllable high-speed networks. Additionally, their switches and links are characterized by high operational reliability owing to technological solutions applied there. The additional requirements are listed below:

- possible use of various communication interfaces for fiber optic links,
- wide operating temperature range from -40 up to 80 °C,
- no spinning elements within the switch design,
- resistance to EMI,
- power supply options: 24/48 V DC and 110/230 V DC/AC.

Aside with the above mentioned technological solutions, manufacturers of switches offer their own brand solutions that enhance operational speed and reliability of the devices as well of the network that is based on them.
The latest technological solutions for switches offer their full integration with the remote control apparatus by providing the IEC 61850 Server functions and data exchange based on the MMS protocol described by that standard 0.

4. Physical model of communication

Ever growing significance of dispersed energy generation poses a number of challenging problems for the modern power engineering. A scientific project on „A System of Optimal Wind Farm Power Control in the Conditions of Limited Potential of Power Transmission Systems" realized by a team of the Power System Department of the Lublin University of Technology has been a response to the challenges..

The control system has been elaborated at the assumption that it will be used for a selected fragment of a real electric power system. Devices that are used for the remote control and power system protection purposes by the National Power Grid have been also applied by the project team to develop the SCADA. The SCADA is composed of the following three principal elements:

- communication network,
- communication hub,
- real time SCADA system.

The network that has been realized for the project purposes is characterized by a simple structure, which follows from the lack of restrictive timing imposed on the communication between individual elements of the model. The structure is presented in Fig. 2.

The communication network has been developed based on fiber optic links and MOXA switches of the PT 7710 series and PT 7728 series (Fig. 1) that meet strict requirements of the IEC 61850 standard as well as the electromagnetic compatibility condition set for the power substation apparatus 0. The network forms a communication backbone based on the technology of a fiber optic ring that interconnects all the control system elements and includes the option of the system expansion by the connection of new devices (Fig. 2).

Fig. 1. Front view of a Moxa PT7728 switch

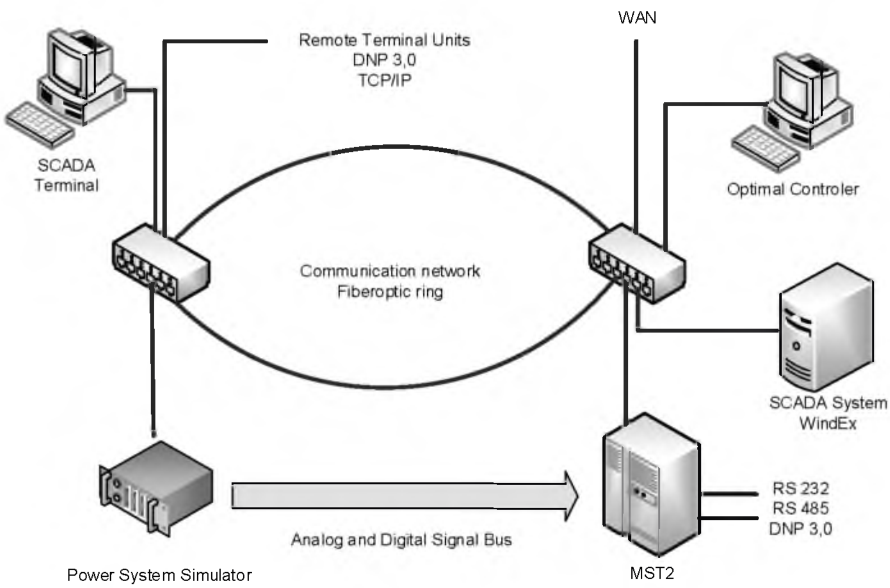

Fig. 2. Communication model for a dispersed generation simulator

MOXA switches are characterized by a modular design. It is the reason why they have been selected for operating multimode fiber optic and copper links. The application of those switches has made it possible to:

– connect devices of various Ethernet ports, which is of key importance considering the great variety of technological solutions applied by various manufacturers of the remote control and power system protection devices,
– form a fiber optic ring between the switches using the Turbo Ring technology, which ensures redundancy of connections to the backbone network, which is recommended by the IEC 61850-3,
– develop redundant fiber optic interconnections among the Ex-MST2 controller and two switches,
– monitor the network traffic on individual switch ports.

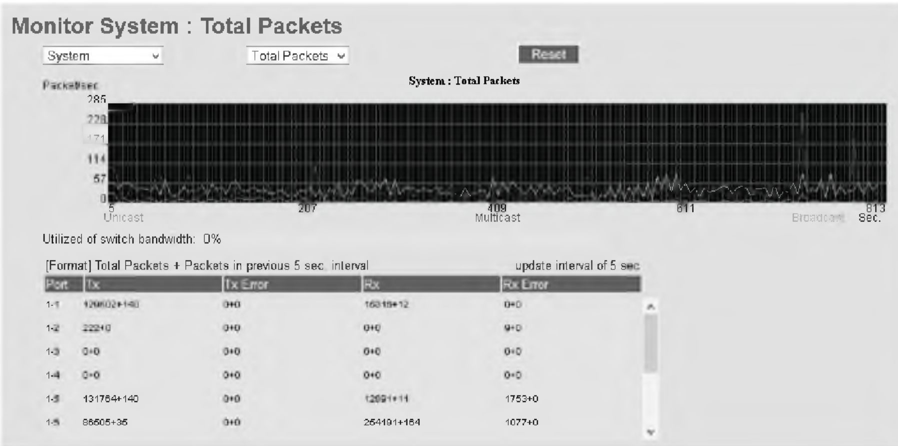

Fig. 3. Network traffic monitoring process realized by a MOXA PT7710 switch

Network backbone development technology deserves particular attention. The applied switches make possible to develop a network with redundant connections in a few ways, with the use of such technologies as: *Rapid Spanning Tree Protocol* (IEEE-802.1w), *Turbo Ring, Turbo Ring V2, Turbo Chain* and *Trunking* (IEEE 802.3ad) 0. In the discussed project, the MOXA brand solution, referred to as the Turbo Ring V2 has been used. Its configuration is shown in Fig. 4. It is a fiber optic ring structure managed by the switches and characterized by a very short network reconfiguration time (less than 20 ms)

Owing to the realization of many functions required by the IEC 61850 standard, the network is characterized by high reliability, security and efficiency and its operation is fully manageable 0. It is also highly scalable offering the option of further development of the system by connecting new devices that meet the Ethernet 100 Mb/s standard requirements and higher and communicate with the application of TCP/IP protocols.

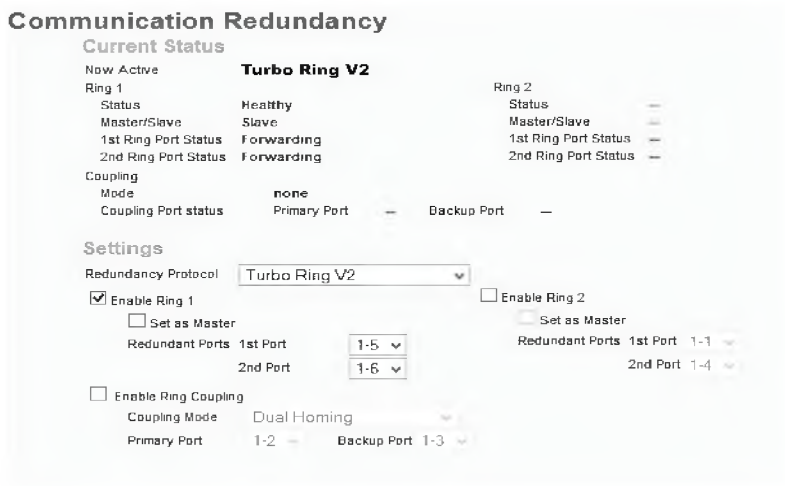

Fig. 4. Ring configuration in a MOXA PT7710 switch

5. Functional model of communication

At the first stage of the model development, packet transmission between the elements is based on the IP protocol, except for the communication between the WindEx system and Ex-MST2 controller, where the DNP 3,0 protocol is additionally used.

The elaborated communication system has made the starting point for its further development. To that end, the remote control and power protection system devices have been organized into groups according to the kind of information that is exchanged between them (Fig. 5). Communication protocols used by them have made one of the grouping criteria. In order to distinguish groups of devices using different protocols commonly applied to realize communication within power systems, VLANs have been developed.

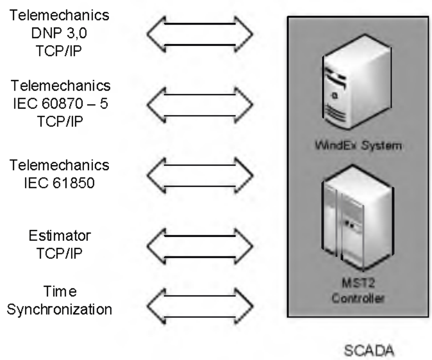

Fig. 5. Information exchanged between the devices, the Ex-EST2 controller and the WindEx system

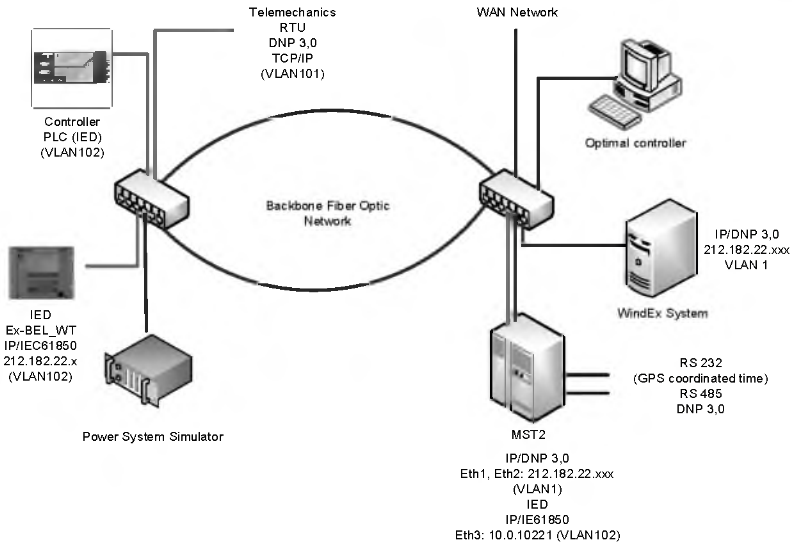

Fig. 6. Communication network with distinguished VLANs for different groups of the remote control devices

The main element of the system is the Ex-MST2 controller/data hub 0. Two independent Ethernet interfaces installed in it enable its communication with independent groups of power system devices and additional ones. Each of the interfaces is assigned to different VLANs. It is possible to assign an interface to more than one VLAN.

The device groups set according to the data exchange protocols used by them are the following:

- devices that use only the TCP/IP,
- IEC 61850,
- IEC 60870 – 5 and DNP 3,0.

All the above protocols are managed and operated by the Ex-MST2 controller, and that is why it can function as a protocol translator that enables data exchange between individual groups of the devices.

In order to enable the communication of the Ex-MST2 controller and other power system devices within an IP network it should be adequately configured (Fig. 7). For that purpose, an Excfged editor manufactured by the Elkomtech company has been applied. Its window is presented in Fig. 7. In order to enable the cooperation of individual communication interfaces with the IP network it is necessary to configure them following the below given steps:

- to assign addresses to individual interfaces, as for standard network cards, and set proper communication attributes,
- to define a list of the operated TCP/IP protocols and their attributes,

- to assign interfaces to protocols used for power systems (DNP 3,0, IEC 61850, IEC 60870 – 5 or other),
- to assign additional services such as telnet or SNTP.

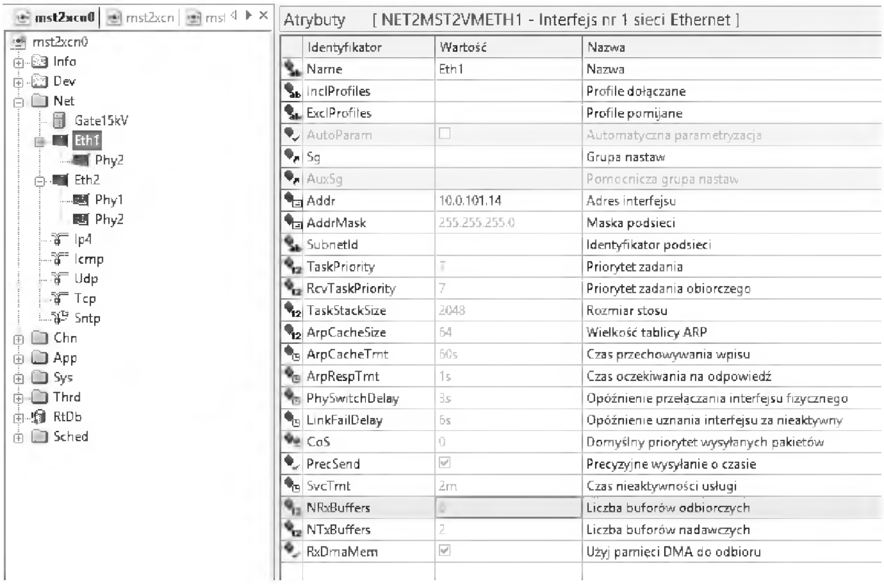

Fig. 7. Communication network with distinguished VLANs for various groups of the remote control devices

In the case of remote control devices of other brands, the configuration can be performed using the tool software supplied by the manufacturers

The Ex-MST2 controller system time can be synchronized by a GPS signal and owing to that it makes a time pattern for the remaining devices that synchronize clocks with it via the NTP. It is very important when the operation of the power system protection devices is evaluated. Then, the operating time is one of the criteria to decide whether the operation is correct. .

In order limit the data packet competition to get on a link, priorities for the data traffic have been set in individual VLANs. Owing to that solution, devices that communicate in the IEC 61850 standard get the highest priority and thereby the shortest packet delivery time, which is particularly important for the GOOSE statements that are defined in this standard.

The developed network (Fig. 6) offers the add-on option for new remote control devices via the LAN fiber optic links and thereby makes possible to analyze their cooperation with SCADA. It also offers shared use of the backbone at simultaneous data traffic separation of individual groups of devices. By meeting strict requirements of the IEC 61850 standard, the presented model solution reflects a communication system for the most modern electric power substations.

6. Conclusions

The implementation of LAN to exchange data between devices installed within the power industry installation area has principally altered the way of modeling the organization of communication between the devices. With the application of well known technologies such as Ethernet and the TCP/IP communication it gets possible to take advantage of technologies and skills hitherto used in information systems. However, there are precisely defined and restrictive requirements for the power industry devices and meeting them can give rise to a number of new problems.

In order to define and solve the problems as well as to assess their effect on the process of data exchange among the SCADA component devices it is necessary to develop a real communication model that is scalable.

The presented model that has been developed in the Power System Department of the Lublin University of Technology makes possible to render an operation representation of modern control systems for power industry installations. Owing to its flexibility and scalability it makes also possible to test new devices to be connected to the system. The model can be upgraded by altering the network backbone to be realized by the connection of new switches, adding on new devices of remote control and system protection, supplementing new communication protocols and introducing changes to the logic structure by defining new VLANs.

The presented SCADA model fully conforms to the requirements that are defined for systems to supervise operation of intelligent networks.

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