On the intelligent smart grid network

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Abstract: - Smart Grid Networks present a modern solution for network automation and digital communication in order to improve the efficiency, sustainability and reliability of electricity distribution. The development of Smart Grid networks is not a simple matter. Electronic grids consist of a large number of systems, intelligent and regular electronic devices, substations, switching stations, dispatching centers and many other elements. This paper analyse the technological requirements of intelligent Smart Grid network with a focus on networking aspects, standards and protocols.

Key-Words: - Smart Grid, IEC, LAN SG, GOOSE, IED, SCADA

1 Introduction

During intensive cooperation between the Faculty of Informatics and Management (FIM UHK) and ČEZ, a leading Czech energy distribution company, a project aroused demanding specificities of intelligent networks of Smart Grid type, whose implementation in the Czech Republic is inevitable. The whole concept of Smart Grid networks implementation is conditioned by the application of IED (Intelligent Electronic Device) technologies, which support the IEC (International Electrotechnical Commission) communication standard family. These issues concerning the IEC standard connection with TCP/IP protocols are further treated in [1].

2 Standards

The absence of electric devices interoperability and unification a non-profit non-government organization International Electrotechnical Commission (IEC) was founded in 1926. Its task is to define international norms for electric and electronic devices. The IEC norms cover a large scale of technologies form production, transmission and distribution of electric energy, or home appliances and office facilities. New requirements for the management of electric energy production, distribution and consumption management have made IEC to expand the norms in order to implement Smart Grid projects. The relevant standards from the TC57 group - Power systems management and associated information exchange are mainly IEC 60870, IEC 61850 and industrial standards used for communication among devices within the substation or switching station [2].

2.1 IEC 60870

The IEC standard is international communication standard which specifies communication protocols designated for remote management and SCADA systems. They are used namely in geographically large systems predominantly in electric network. IEC 60870 part 5 of the mentioned standard defines transmission protocols for remote management of devices and systems. These are mainly protocols built on serial transmission of binary coded data predetermined for supervision and control of geographically large processes. IEC 60870-5 norms are built on master-slave model. From our perspective the most substantial is part 101m which defines mechanisms of data transmission, and, part 104, which recommends their use in common communication networks, such as Ethernet with TCP/IP. IEC 60870-6 also identifies protocols for remote control compatible with ISO standards and ITU-T recommendations from the client-server model perspective. It is used predominantly for transmission of information among individual dispatching units of electric systems or power plant dispatching units.

2.2 IEC 61850

The IEC 61850 norm is the standard for designing the automation of electric substations. This standard is a set of norms used for communication in energetics, setting rules for communication among substation devices, defining communication demands for substations and their facilities. Methodological support of the communication networks production and integration of individual devices is another part of IEC 61850. The primary goal of creating the standard was to enable the production of new systems where products from different manufacturers labelled as IED (Intelligent Electronic Devices). Such devices then provide not only the protection of the substation, but also supervise its operation and automation, as well as measurement and regulation in the substation. The task of the EC 61850 norm set is to ensure reciprocal cooperation of used devices and systems in switching stations. This set of norms standardizes mutual interface, protocols and data models. As a result, the costs for integration of switching station devices are lower. Another function is to define the communication between substations and other electric network elements (power plants, dispatching etc.). Another asset is that IEC 61850 protocols are developed from Ethernet. Thanks to that they enable the use of various tools and devices of communication infrastructure, which are frequent part of the systems of company management of energy enterprises. Each knot connected as client into the network according to IEC 61850 can control the network operation and communicate with all servers and both interior and superior devices, which are predominantly IED. These mechanisms control for example transformers or switches in substations. Thy enable listing of all operation data which individual IED provide. IEC 61850 protocols further allow to transmit data reports (including their current and archival activities) from IED to SCADA. These functions make this set of protocols substantially different from its competitors that do not allow such functionality. Another asset is the ability to create profiles of timelines of operation values including the offline mode, which enables sampling in milliseconds.

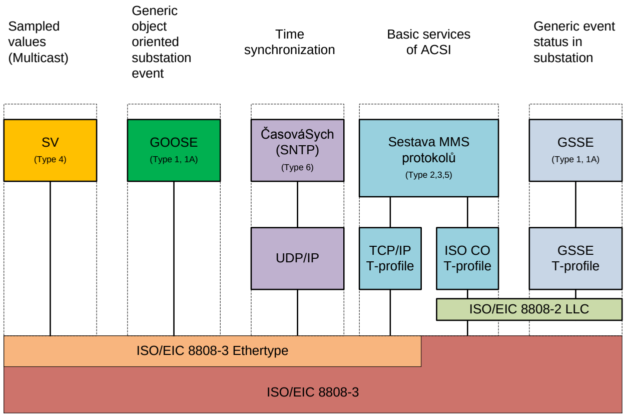

Fig. 1 Overview of IEC61850 functional parts and related communication standards

These issues are most importantly treated in IEC 61880-1 to IEC 61880-10, which are fully treated in [2], [3].

Distinguished elements in IEC 61850 are **GOOSE** and **GSSE** protocols. *GOOSE (Generic Object Oriented Substation Events)* is generic, object-oriented event of substation. Status data and values of variables are grouped here into one data object and transmitted in given time period. The aim is to substitute conventional devices for logical control, used for coordination of internal communication via substation bus. When an event is detected, IDE devices use the multicast transmission to inform the devices registered for its data collection.

2.3 IEC 61968/61970

The norms IEC618450 for DMS (Distribution Managemet System) systems and IEC61970 for EMS (Energy Management System) systems describe normatives for information exchange among control centres by using so called CIM (Common Information Model). These define interface and messaging model for sharing among controlling applications. CIM warrants application SW to exchange information about setting and status of electric network. The most important part of this standard is CIM data model, which is characterized in IEC 6170 part 3 and IEC 61968 part 11 via Unified Modelling Language (UML). CIM is thus mental model presenting a full list of objects of energetic company. This scheme contains public categories and attributes of these objects as well as their interrelationships. Parts 4 of IEC 61970 and 1 of IEC 61968 define components connected into the data exchange in the range of CIM model. Its use may consist of one or more components; its component is the means of its use containing inseparable unit of tasks and setting the interface for other components. The norm defining the interface of the displayed component is called CIS (Component Interface Specification).

2.4 Industrial communication standards

Industrial communication standards enable communication among the components which are part of the network and end in a superordinate unit. It is frequently a simple transmission sharing on the basis of serial link transmitting information from sensors to the computer. The computer is understood as for example an RTU unit responsible for the transmission of data from sensors to dispatching system (SCADA). This system analyses the data transmits signals to control the components in distribution network. The typical exponent is the MOBDUS norm, which is fully quoted in [4]. MODBUS communication protocol is predominantly used in the systems of industrial technologies. It is an open parallel protocol of the master/ slave type. This protocol is often used due to its simplicity, security and high reliability. It is often used with network elements in the nv level networks (controlling systems, components for monitoring, control and protection etc.). Record packets are determined exclusively for sending data; they do not support sending of parameters (names, resolution, units etc.). Nowadays various communication media are used – serial links RS -232, RS-422 and RS-485, optical and wireless networks, Ethernet with the use of TCP/IP protocol. Sharing of data is realized with the request – response technique. Mapping of MODBUS onto OSI model is depicted in the picture 2.

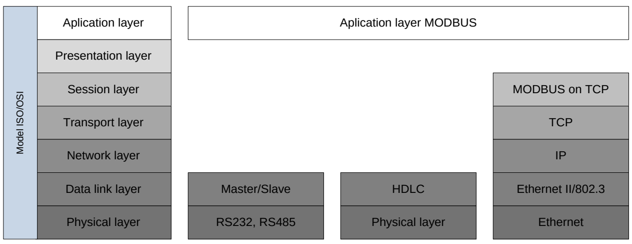

Fig. 2 MODBUS - examples of implementation

Another significant communication technology in the field is profibus also called industrial bus. This bus is used in automation of production lines and in controlling on the level of nn networks (controlling systems, the systems for monitoring, controlling, protection etc.). Among commonly used versions of communication profibus protocol belong PROFIBUS DP a PROFIBUS PA.

3 Control of Smart Grid Network

The term Smart Grids can be defined as intelligent automatically regulated electrical networks able to transmit produced energy from any source of centralised or decentralised energy power plant to its end customer. In January 2010 the National Institute of Standards and Technology (NIST) defined the first version of Smart Grid reference model [5]. It was divided into domains describing the electrical power production, its transmission, distribution, markets, control of distribution system, service provider, and customer.

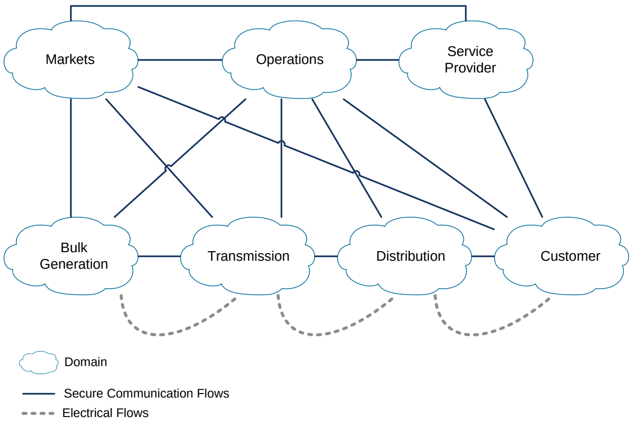

Fig. 3 Smart Grid Domains

Picture 3 depicts the domains which are affected by the changes connected to the implementation of Smart Grid concept. It is a large field (territory), but this work deals with the distribution of electric energy and its control. The significance and complexity regarding specification of individual requests for Smart Grid concept in the field of electric energy distribution and its control shall be highlighted in the comparison with the state-of-the-art condition.

3.1 Classical distribution flows

The major characteristics of the classical model is that the process begins at the power plant, continues via transmission system (in the Czech Republic 400, 220 and 110 kV) and distribution system (most frequently 35, 22, 10 and 0,4 kV) to the energy consumption site. The topology of place is designed to suit unidirectional flow of electric energy, since the source of energy are mainly large power plants connected into high voltage (hv) network and consequently transformed to lower voltage levels (nv, lv). The increasing number in small sources connected to hv and nv brings the following drawbacks:

- Decrease in quality of electric power delivery to its end-user, influence of higher harmonious (imperfect sinusoidal process) frequencies.
- Losses during transformation from nv level to hv level, or from hv level to vhv level (at the expense of distributor profit)
- Impossibility of the source to control effectively neither during normal connection nor in emergency.

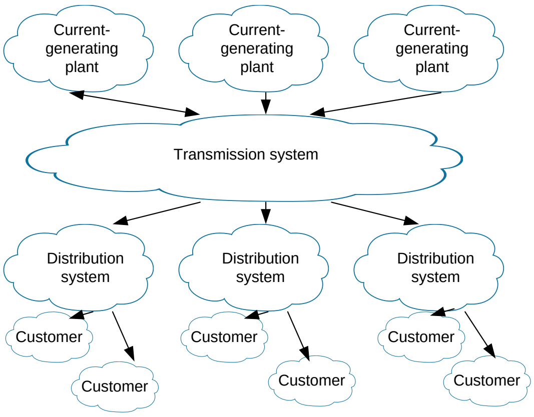

Fig. 4 Classical distribution flows

3.2 Smart Grid distribution flows

The elemental task of Smart Grid is implementation of intelligent elements for effective control of individual technological devices od distribution system, such as distribution switching stations, circuit breakers (switches), isolator switches, accumulation devices, intelligent electrometers etc. The implementation of these local systems of distribution system control will manage distribution system in order to optimize processes of local production, accumulation and consumption in the region. Local control systems will operate autonomously, including the function to control regions in island operation and black-start modes. Local control centres then must be integrated into central control system, which enables to control the region under its supervision. Detailed and aggregated data concerning consumption and other operation characteristics measured by intelligent electrometers, active elements and probes must be provided to central systems of energetic company to be processed. This enables advanced functions such as tariffication of subscribers, analysis and prediction of consumption of distribution system operation.

3.2.1 Requirements for the power distribution

The main goal of Smart Grid concept is the optimization of distribution system operation, optimization of consumption control as far as individual consumer level, optimization of the local sources and their use during the control of self-contained regions of distribution network, enabling island operation and its control, limiting the number of black-outs and minimization of the black-out impact by automated interference in network configuration (self-healing). Other goals are increasing the energy system resistance, increasing of operation efficiency, providing detailed information to the customer concerning his consumption, balance the peak load of the network, decreasing the influence of unpredictable sources on the network stability. Electric energy distributors require a high level of automation of controlling processes and systems; close cooperation with central control systems (Dispatching Control System), the function of temporary autonomous operation during black-outs between region and central systems (data island) and high security of solution. Because of their complexity and high-investment, Smart Grid regions evolve gradually with great differences in the regional sizes, source possibilities, population density, consumption and balance. On the basis of these main differences it was necessary to define type regions, which can cover with their model solution the whole distribution system.

3.2.2 Requirements for the communications infrastructure

Communicative infrastructure is a crucial element of the whole network. Without the complex of corresponding communication means creating required vertical and horizontal connections, Smart Grid concept cannot be realized. Its elemental precondition is the existence of communication connection with backbone communication system of distribution on the abovementioned structure level. This place is distribution switching station 110kV/hv with regards to its sufficient flexibility and usual solutions used within its distribution system. This point is the place which ensures the connections of all partial subsystems of individual layers according to their requirements. Inconsistent development requires integration or coexistence of other kinds of solutions different from required vertical connections on lower level (e.g. application of GSM/GPRS communication in controlling systems of switching points in the network). This communication is solved centrally; there exists a direct vertical connection between the given point and the central level. This solution rather complicates its potential use for local control of such constructed switching points. Typical division of communication infrastructure into individual network segments is depicted in the picture 5. The backbone network provides also the connection to SCADA system. MAN SG (Metropolitan Area Network Smart Grid) network is also connected to the backbone network; MAN SG provides connection between individual LAN SGs (Local Area Network Smart Grid), which represent individual local networks of Smart Grid architecture. MAN SG is typically spread on the level of one smart region, which connects individual LAN SG local networks which on the smart field level. There can be several smart fields within a smart region. Such designed hierarchical structure is highly flexible and allows easy implementation of new technologies and services.

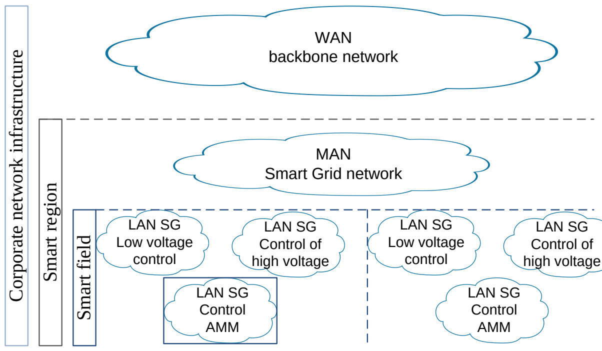

Fig. 5 Segments of the communications infrastructure

Regarding the requirements for communication infrastructure we may define the following levels and fields that are or can be components of communication infrastructure within Smart Grid concept:

Vertical connection between technology controlling systems and central level is applied both on the MAN SG level and LAN SG level. These connections are mostly realised in case of 110kV or hv objects; their fundamental application is essential in regions which will be controlled (DTS), but are mostly not yet controlled nowadays. If lv objects are controlled, lv increase in each given hv field.

Horizontal connection for adaptation protection function (for example between neighbouring hv substations). In this case it is necessary to realise data networks enabling fast and reliable communication, which is achieved by using simple technology (without complicated processing of transmitted data) with minimum of intermediate elements. These requirements may be met on the LAN SG level. Similarly to the previous example (most notably in hv and lv networks) during the implementation of Smart Grid there appear cascades of protection (loops of hv or lv networks).

Vertical connection between technology controlling systems and field networks controlling system may be defined on the LAN SG level. Parallel solution of vertical connection practically exists between the technology controlling system and central level. Each technology controlling system controlling an object, which is a part of network controlling, must have realised communication with given network controlling system.. It generally concerns all levels (110kV, hv i lv). Practically it will most frequently deal with selected hv objects and their affiliated lv objects.

3.3 Requirements for the Smart Grid network elements

On the basis of executed analysis generally valid requirements on this type of networks may be specified. Smart Grid in the Czech environment is influenced by the way of construction, operation and control of distribution network. The task of SG is to ensure the function and distribution of electric energy in the hv network part and adjacent lv network in the following extent:

Automation of hv network including hv objects part of transformation of hv/lv (DTS) – substation HV DTS. *Automation of lv network in hv/lv objects of transformation* (DTS) – substations lv DTS and isolating and secure boxes, possibly in bifurcation boxes of the lv network.

Connection and operation of local sources, both to lv network and hv network – cogeneration units, photovoltaic power plants, small water sources.

Network control (functions of monitoring, control, protection and automation) of field via thy system or subystems of network control functions – field balance control, automation of island operation, sequence manipulation, regulation, voltage regulation in island operation mode.

Consumption monitoring and control of the filed in via cooperation of control system with AMM system (Smart Metering).

This basic set of distribution network requires a corresponding communication technology type. Each unit of energy system, which will be remotely controlled and monitored, will define a basic set of

requirements on *permeability*, *latency* and *reliability*.
Permeability describes the speed of transmitted data from the source device to the target device. By latency we mean time which it takes for a message sent from the source device to the target device. Reliability is affected by electronic or magnetic interferences, or meteorological conditions. The aim is to have maximum permeability, low latency and high reliability. Taking into consideration investment possibilities, technical requirements and operation costs in the given locality, corresponding technology will be suggested. Picture 6 shows basic organization of physical communication infrastructure in Smart Grid region and its connection to central systems and backbone network.

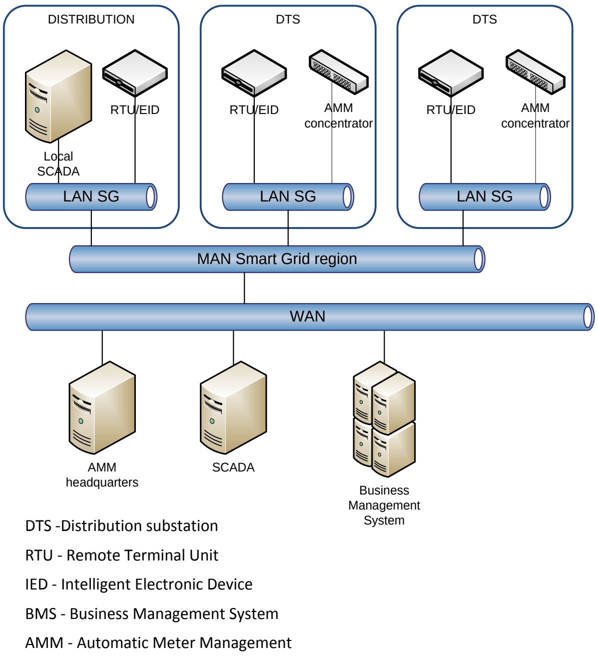

Fig. 6 The basic scheme of the communication infrastructure

Communication link among objects may be realised both on direct or wireless lines. To support switching and routing of network frameworks and packets in each locality, switch and router might be integrated into an individual physical device. Switch will then ensure local communication within the locality (DTS) and physical communication within regional communication network between localities. Router controls communication to MAN network. Furthermore, the communication is protected by coding and filtering. Among the network types within Smart Grid region belong **LAN SG, protection and command network,** and **access network**. *LAN SG* is a network connecting devices within an object (building). Communication is managed by a central switch. In critical localities central switches can be implemented as redundant for higher accessibility. From technological perspective metallic or fiber lines are used. Communication and application protocol of higher levels are realised above Ethernet, which is the Basic protocol.
Protection network and command network are organized into circuit for communication redundancy in case of switch blackouts. This network transmits commands and GOOSE communications.
Access network for Smart Grid regions connection to backbone MAN and WAN network, through which it is connected to central systems.
Rather than physical communication infrastructure we recommend the implementation of virtual LAN networks according to IEEE 802.1Q standard. Individual networks will be used for separation of individual communication types. The separation of individual communication types is substantial to ensure qualitative parameters of service (QoS) for individual communication types and for logical separation of individual operation types for security reasons. Basic VLAN networks are used for security, respectively GOOSE communication on horizontal level between IED and various DTS devices. They are also used for management; which is a network transmitting commands to distribution system elements, and collection of status and events in the distribution system. Data networks operates to collect measurement and reading from electrometers and other active elements such as probes and sensors. ICT supervision networks for configuration and monitoring of individual ICT devices.

4 Conclusion

To meet elemental aims of Smart Grid, effective communication with network elements on the consuming side must be ensured. The absence of standards for interoperability between data concentrator AMM and RTU units cannot provide desired outcome, i.e. management of appliances via smart electrometers. It is also caused by the fact that corresponding communication infrastructure meeting requirements of quick isolating and switching would be extremely expensive. Including the communication with smart electrometer during a blackout, when no controlling signals (to eliminate negative starting impulse) exists.

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