Chapter 143
Communications and Quality Aspects of Smart Grid Network Design

Vladimir Sobeslav and Josef Horalek

Abstract This chapter presents the global perspective of communication infrastructure and its specific use and the application approaches and specificities of Smart Grid network features. It presents a general view of Smart Grid domain qualities. It further specifies the distribution flows from the perspective of application and use of Smart Grid technologies and their adaptation to individual regions on the basis of their global analysis in respect to the dependency of electricity distribution, energy resources, and alternative and standard energy accessibility. This chapter shows the implementation analysis of the Smart Grid networks by the most prominent producer and distributor of electric power in the Czech Republic.

Keywords Energy management • Power distribution lines • Power grids • Smart Grids • Current supplies • Power system reliability substation automation

143.1 Introduction

The Smart Grid has become a popular and modern issue recently. Thanks to its dynamic development, Smart Grid offers various topical perspectives. At first, Smart Grid is subject to energy-communicational perspective considering the large variety of the communication norms used in energetics. They not only include the family of IEC 60870, IEC 61850, or IEC 61968/61970 standards [1, 2].

Principles and structure of the Smart Grid network communication offer another perspective of their use as the main component of the intelligent control and management of energy networks. Although this perspective may appear elemental and fully solved, the reality is different; due to frequent focus on local issues, such as the communication of alternative electrical energy sources with the SCADA systems, the possibility of Smart Grid implementation is significantly influenced by requirements of the network infrastructure and requirements of individual communication elements in Smart Grid networks. This point of view is accentuated [3, 4]

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where the authors are focusing on the analysis of quality and meaning of the information transferred, which is highly symptomatic of Smart Grid networks. More technical Smart Grid perspectives are provided [5], where the authors correlate the connection between the IEC 61850 protocol and the communication of ISO/OSI network model with the application of packet analyzer. The question yet to be resolved concerns the Smart Grid network particularities and their components and general architecture; according to the implementation of Smart Grid networks such as intelligent remote data collection from electrometers or remote optimization of electricity consumption units that use the Smart Grid metering, these issues are insightfully treated; however, it only focuses on the provision of electricity and its way from the source to the distributor. For example, this perspective is offered. It can be used generally for understanding the requirements of Smart Grid networks if we ignore the photovoltaic system specificities [6]. Similarly, the authors solely considered the use and optimization of Smart Grid networks in the field of wind power plants [7]. The authors provided a groundbreaking and comprehensive treatment of implementation and optimization of Smart Grid networks [8].

Furthermore, the project [9] cannot be omitted although it predominantly deals with the practical implementation of Smart Grid networks and their reliability. It introduces reliability and measurement calculations. This project is also connected [10], which deals with the error detection of Smart Grid network.

This chapter is a result of the analysis of the implementations and use of Smart Grid networks at a Czech location selected by the most prominent producers and distributors of electric power; therefore, this chapter constitutes a different perspective from other researches in the field. This analysis scrutinizes not only the horizontal perspective of Smart Grid implementation but also the vertical perspective, in other words, the perspective from distributor to individual customers of various types. The present local specification is influenced by the regional activity of the company; nevertheless, their generalization enables to realize similar solutions in the whole of Europe, where the citizen stratification differs from the case of the Czech Republic.

143.2 Smart Grid Concept of Power Distribution

This analysis presents similar understanding and approaches toward the Smart Grid issues as treated [11]. Similarly [12], this chapter specifies the approach to the migration of the IT technologies to the Smart Grids and further accentuates a classical perspective via the ISO/OSI model in the process of implementing the network elements into Smart Grid networks; however, the Smart Grid implementation and its possibilities, uses, and optimizations are influenced by its geographical locations and classical distribution network topology. The requirements of both the Smart Grid network implementation and its individual organizational networks, as involved in this analysis, are greatly influenced by the current situation in the

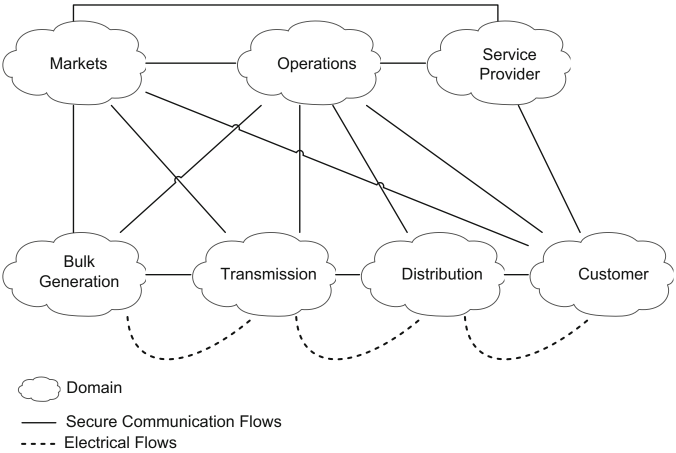

Fig. 143.1 Smart Grid domains

Czech Republic, where the conditions in similar geographical settings of distribution networks are similar to those in Western Europe.

Figure 143.1 depicts the domains affected by the changes related to the implementation of the 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 of the specification of individual requests for Smart Grid concept in the field of electric energy distribution and its control shall be highlighted in comparison with the state-of-the-art condition.

143.3 Secure Smart Grid Distribution Flows

The Smart Grid concept is primarily to optimize the operation of the distribution system and the consumption control at individual consumer level. The optimization of the local sources and their use during the control of self-contained regions of distribution network are also important. The Smart Grid distribution enables the island operation and its control, limits the number of blackouts, and minimizes the blackout impact by automated interference in network configuration (self-healing). Besides, efforts are made to increase the resistance of the energy system, increase the operation efficiency, provide detailed information to the customer concerning his consumption, balance the peak load of the network, and decrease the influence of unpredictable sources on the network stability. The electric energy distributors require a high level of automation of the controlling processes and systems, close cooperation with the central control systems (Dispatching Control System), temporary autonomous operation during blackouts between the 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 terms of the regional sizes, source possibilities, population density, consumption, and balance. On the basis of these main differences, it is necessary to define the type of regions, which can cover the whole distribution system with respect to regional distribution characteristics. The following section briefly outlines various types of regions in respect of Smart Grids: the region of high population density, which is a small-scale utilization with high population density; the region of scattered population density, which consists of a number of medium-sized large cities and smaller communities; the industrial region, which features a highly developed energy-intensive industry; and the region of low population density, which lacks regional resources and features problematic development for many reasons.

Communicative infrastructure is a crucial element of the whole network. Without the complex of corresponding communication, it means to create the required vertical and horizontal connections, and Smart Grid concept cannot be realized. It shall be established based on the existence of the communication connection with the backbone communication system of distribution at the abovementioned structure level. The distribution switching station of 110 kV/hV system should be designed with regard 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 the required vertical connections at a lower level (e.g., application of GSM/GPRS communication in controlling systems of switching points in the network). This kind of communication is solved centrally; there is a direct vertical connection between the given point and the central level. This solution rather complicates the potential use for local control of such constructed switching points. A typical division of communication infrastructure into individual network segments is depicted in Fig. 143.2. The backbone network also provides the connection to the SCADA system. The MAN SG (Metropolitan Area Network Smart Grid)

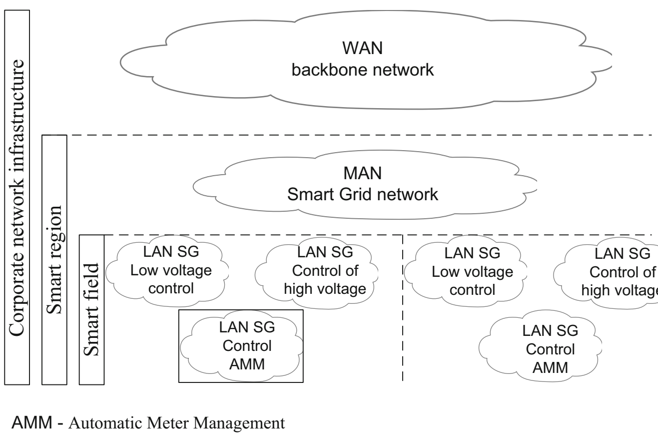

Fig. 143.2 Segments of the communications infrastructure

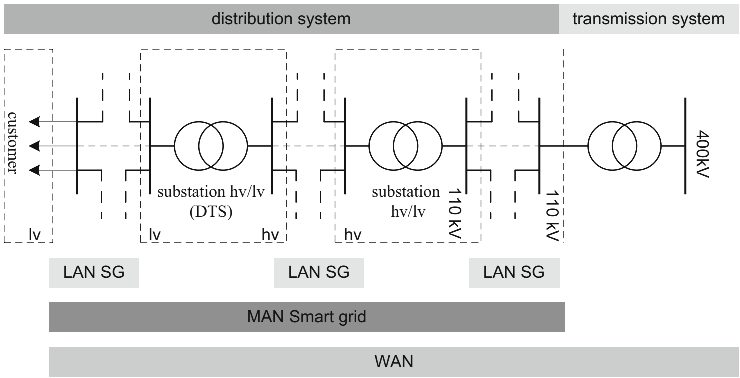

Fig. 143.3 Relationship between IT network and distribution system

network is also connected to the backbone network; MAN SG provides connection between individual LAN SGs (Local Area Network Smart Grid), which represents individual local networks of Smart Grid architecture. The MAN SG is typically spreading at the level of one smart region, which connects individual LAN SG local networks at the smart field level.

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.

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

In case of the horizontal connection for protection function adaptation (e.g., between neighboring hv substations), it is necessary to realize the data networks to enable fast and reliable communication, which can be achieved by using simple technology (without complicated processing of transmitted data) with minimum intermediate elements (Fig. 143.3).

143.4 Requirements for the Smart Grid Network Elements

On the basis of executed analysis, the generally valid requirements on this type of networks may be specified. The Smart Grid implementation 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, and automation of lv network in hv/lv objects of transformation (DTS), substation lv DTS and isolation and secure boxes, possibly in bifurcation boxes of the lv network. This basic set of distribution network requires a corresponding communication technology type. Each unit of the energy system will be remotely controlled and monitored and define a basic set of requirements on permeability, latency, and reliability.

The permeability describes the speed of transmitted data from the source device to the target device. It takes a message sent from the source device to the target device. Reliability is affected by electronic or magnetic interferences or meteorological conditions. The goal of efficient Smart Grid network element architecture is to have maximum permeability, low latency, and high reliability. Figure 143.4 shows basic organization of physical communication infrastructure in Smart Grid region.

Protection network and command network are organized into a circuit for communication redundancy in case of switch blackouts. This network transmits commands and GOOSE communications. Access network for Smart Grid region connection to backbone is MAN and WAN network, through which it is connected to the central systems. Rather than physical communication infrastructure, we

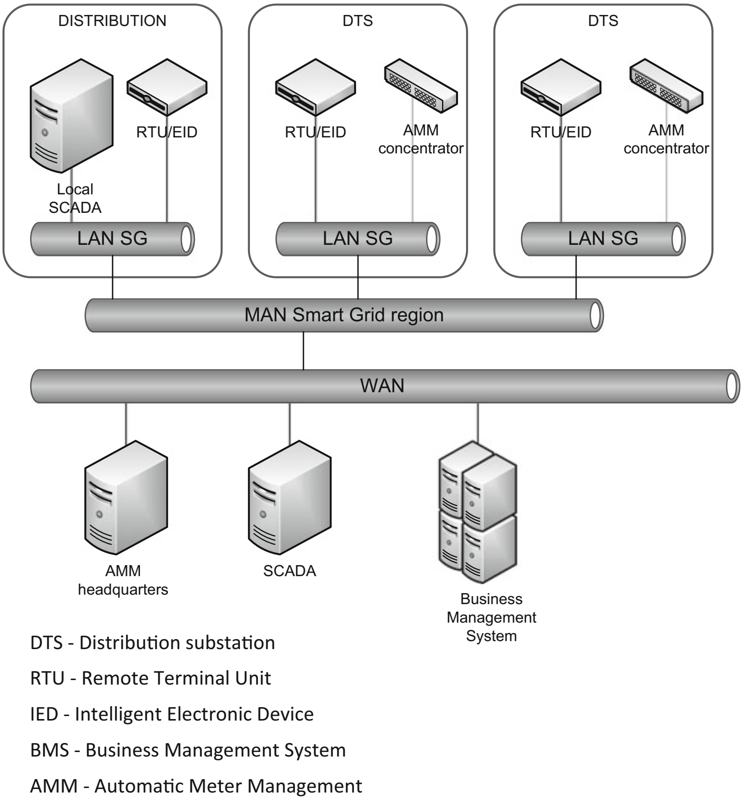

Fig. 143.4 Basic scheme of the communication infrastructure

recommend the implementation of virtual LAN networks according to IEEE 802.1Q standard. Individual networks will be used for separating individual communication types. The separation of individual communication types is substantial to ensure qualitative parameters of service (QoS) for individual communication types and 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. Considering the fact that the network is also used for control commands and GOOSE communication, high reliability and low latency technologies such as optical lines, BPL, and WiMAX are recommended. The design of the Smart Grid network should also contain primary and backup communication lines by preferably using different technologies. The optical fibers fulfill the challenging demands of network safety, throughput, and other qualities of services criteria. The utilization of BPL and WiMAX technologies is rather inappropriate because of their security and transmission stability mechanism. The Ethernet and its industry sub-versions is the fundamental protocol, which is implemented at higher network communication layers. The access network to the Smart Grid central system and the backbone of the region are MAN and WAN networks. This kind of network technology efficiently transfers a large amount of data over long distances including the control commands and priority settings (higher latency tolerance). The communication parameters and the Quality of Service (QoS) mechanisms are very important to the design of Smart Grid networks.

Conclusion

In order to meet the 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 the desired outcome, i.e., management of appliances via smart electrometers; therefore, the chapter provides a different perspective. Unlike similar analyses, it accentuates not only the horizontal perspective of Smart Grid implementation but predominantly the vertical perspective, i.e., from the distributor to various individual customers. The present regional specification is influenced by the local operation of producers, although the generalized results can be realized all over Europe, where the citizen distribution is the same as that in the Czech Republic. This work and the contribution has been supported by project “SP/2014/05—Smart Solutions for Ubiquitous Computing Environments” from the University of Hradec Kralove.

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