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The role of information and communication technologies in smart-grid development

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Abstract. The paper presents the smart-grid concepts and the role of information and communication technologies in their development. The idea of smart grids represents the evolution of the existing power grid. The today's power grid is faced with many challenges, like adoption of distributed generation (DG) and other elements in the grid, ageing infrastructure, etc. The basis of smart grids is the information and communication system (ICS). Its future goal is to actively connect as many users as possible (DG, loads, electric vehicles, etc.), with a particular emphasis laid on two-way communications between grid users. To manage and control such a big number of elements and data, new information solutions and new concepts of grid management are looked for. Solutions already used in telecommunications are now also being applied in the power system. Standardisation of ICT solutions is very important. Two of the most efficient standards in this area are IEC 61850 and CIM.

Keywords: smart grids, ICT, IEC 61850, CIM

1 INTRODUCTION

The classic power system is composed of large power plants, that are connected to the transmission network and users, which are connected to the distribution network. Electric energy is being carried towards the end users through the distribution network. As seen in Fig. 1, we have a one-way power transmission, from power plants towards users.

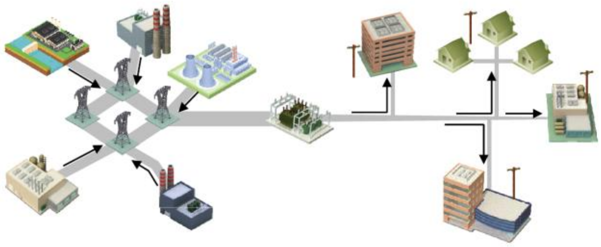

Figure 1: Classical power system [1]

The power system, which has been operating reliably for more than 100 years, is today facing numerous challenges, like the growing power consumption, ageing infrastructure and increasing number of distributed energy resources (DER) connected to the distribution network. An increasing number of other new elements (eletricity storage facilities, electric vehicles, etc.) is expected to be connected to the system in the near future. While a small number of new elements doesn't significantly threaten the system stability, a raising number can cause problems in the system operation for not having been designed for it. Another issue to be solved is unpredictable nature of the renewable energy sources constituting the major part of the distributed generation.

The above problems have given use to smart-grid development. The concept of smart grids doesn't only upgrade the existing power system from a passive to an active way of working, but also implies a completely new approach to the power system planning and operation [2]. The smart grid (Fig. 2) merges togheter all the power system elements, the old and new ones. Information and communication technologies (ICT) play a key role in this process.

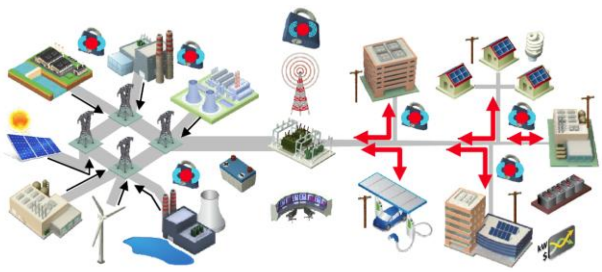

Figure 2: Smart grid [1]

By using ICT, all the system elements are connected. Today, informatisation of the power system has been done on the high (HV) and medium voltages levels (MV), while on the low voltage level (LV) it has not yet been adopted. In the near future, all the system elements will be informatically connected, including the end

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users. It is for this reason that the two-way communication, allowing both control and management of the network devices, is becoming even more important. The same applies to the question of which technology should be used to set up a communication infrastructure. Another issue still to be resolved is management of a large amount of data generated by the large number of inteligent electronic devices (IED). Standardisation of data transfer and integration of information systems are also a huge task. Smart grids also provide an opportunity for the development of new communication applications and services [3].

It is only by developing of smart grids that Slovenia, as a member of the European Union, will be able to fulfill its environmental commitments by 2020:

1) 20% reduction of greenhouse gas emissions,
2) achievement of a 20% share of renewable energy in the total power generation, and
3) 20% improvement of energy efficiency.

2 SMART-GRID CONCEPTS

The idea of smart grids entails a wide range of different concepts. In this chapter, the concepts where ICT plays the key role will be presented.

Today, the information and communication system of a power system extends to transformer stations. This means that for a part of MV and the entire LV system we practically have no information. The aim of the smart grids is to connect practically any user and device in the system. To control such a large number of elements, the new IT solutions and the power system management concepts need to be developed.

The standard power system has not been designed to connect a high proportion of DG, which affects the power system operation in various ways:

1) The voltage profile – the voltage of transmission lines in the network decreases with the increasing distance from the transformer, and the amount of the power consumed at the user side. DER connected to the "users side" of the system increases the voltage value at their connection points and, in extreme cases, the voltage may exceed the set limits. This problem can be solved in several ways [4]. One of them is participation of the involved DGs in the voltage control.
2) Power quality – DGs can affect power quality both positively and negatively (system frequency, flicker, harmonic distortion) [4].
3) Balance between production and consumption – unpredictable production of a large number of DGs can cause operational problems [4].

2.1 Advanced metering infrastructure

Advance power-consumption measuring systems had been developed before the emergence of the smart grid concepts. Until now, power consumption on the customer side has been measured with conventional, manually-read electricity meters. Energy was charged with a flat sum dependable on past power consumption. One of the smart-grid objectives is to equip the end users with smart meters capable of reporting the power-consumption measurements to a meter measuremet center in real time through a communication infrastructure.

The advantage of the smart meters is their enabling the users to control their own power consumption and energy prices, thus making them aware of their own consumption habits. This option allows them to lower the cost on their electricity bills by economising their energy consumption.

ICT is the basis for advanced metering infrastructure.

2.2 Demand Side Management

Having the end-users connected allows realization of the Demand Side Management (DSM) concepts, by making the user to actively participate in the power-system management.

There are many classifications of the DSM programs. They can be divided into incentive-based programs that are based on financial incentives for clients willing to take part in power-consumption management (various modes of load management) and programs based on electricity-price variations.

2.3 Virtual power plant

The idea of the virtual power plant (VPP) concept is to connect a large amount of DER by ICT. DER can consequently participate n the electricity as well as in the ancillary-service market. In this way, the minor power plants, as part of a larger VPP, can be more competitive on the market. VPP can also include active customers which may, upon the operator request, adjust their consumption.

2.4 Electric vehicles

In future, a notable development in the field of electric vehicles (EV) and an increase in their widespread use can be expected. The increase in the number of vehicles will consequently increase also the number of electric filling stations, which will altogheter give rise to many changes in the power system. Charging electric vehicles will have to be well controled to avoid excessive simultaneous charging which could overload the power system. Electric vehicles will also be used as an electricity storage facility, used when the electric vehicle is connected to the network, with a corresponding battery.

3 SMART-GRID COMMUNICATION ARCHITECTURE

Communication network is a most vital smart-grid element. It connects each of the network elements: DGs, electric storage facilites, active users, etc. This connection allows automation, management and operation of the entire system. Therefore, to realize the smart grid, a sufficiently powerful, scalable, reliable and secure information and communication infrastructure is needed.

Fig. 3 shows the communication architecture of the smart grid. It is composed of several subsystems, which use different technologies. For each segment of the network there are many possible standardized, non-standardised and proprietary technological solutions available. The ultimate goal is to provide a two-way communication between the elements, regardless of the technology used in the lower layers of the OSI (Open Systems Interconnection) model.

At the end-user side there are different user networks: Home Area Network (HAN), Building/Business Area Network (BAN) and Industrial Area Network (IAN). In these networks, a large variety of possible wired and wireless technologies [5] can be implemented.

In the access network, the number of possible technological solutions is considerable. The choice of the most appropriate technology depends on many parameters, such as local data rate requirement, delay, level of security, price, etc. The access network aggregates the traffic from many different systems and applications such as advanced metering infrastructure, demand side management, management of distribution network and transformer substations. Several different technologies are expected to be used in this segment [5] in the near future.

The Wide Area Network (WAN) aggregates and carries the traffic of different applications and systems. WAN constitutes a bridge between the access network and the transformer substation networks on one side, and control centers, service providers and associated local area networks on the other side. WAN comprises the backbone networks and metropolitan/regional area networks. The backbone networks mostly use high-performance optical connections.

The transformer substation networks and the devices like advanced metering infrastructure data concentrators (also part of the distribution network) should be reliably connected to the backbone network. For the transmission and distribution system operators (TSO, DSO) there is a great number of technologies available: leased lines, private microwave links, virtual private networks (VPN), MPLS protocol, IPsec protocol, etc.

Various smart grid applications meet different quality of service (QoS) requirements. Even without a communication technology which would be most appropriate for any smart grid applications, the internet protocol (IP) is most important. TCP/IP is a robust technology with a large number of mature security and management applications.

4 STANDARDISATION

Smart grids comprise a large number of different participants, facilities, and hence many different systems. Therefore, standardisation and integration of different information systems are very important.

On the European level, the European Commission released a standardisation mandate [6] to the standardisation organisations CEN, CENELEC and ETSI. Its main guidelines will be given below.

It is very important to create a smart-grid conceptual model, that would define the main smart-grid participants and their mutual relations. The IEC Technical Report no.62357 [7] provides a reference integration infrastructure (Fig. 4) for integration of devices, systems and power system applications. In the lower horizontal there are end-user devices. Each of them is in some way connected with a certain information system, which includes:

- SCADA (Supervisory Control And Data Acquisition),
- Energy Management System - EMS,
- Distribution Management System - DMS,
- Market operation applications,
- Engineering and maintenance applications, and
- External applications.

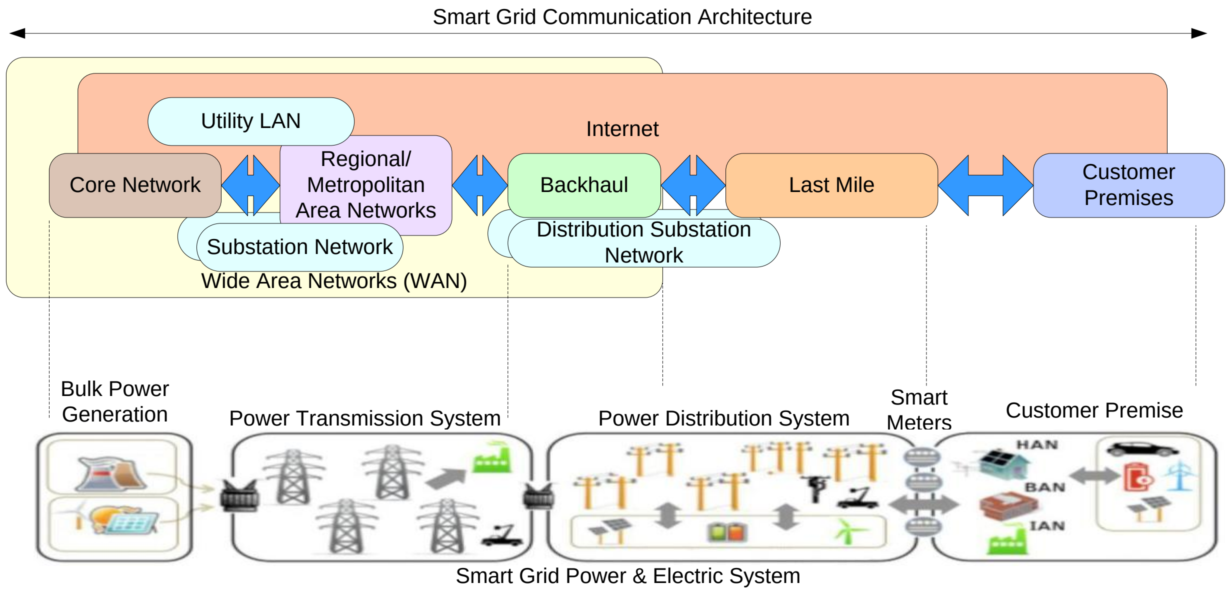

Figure 3: Smart grid communication architecture [4]

Communication methods for particular cases are shown in the architecture verticals. In advanced metering infrastructures, the relevant standards are the IEC 61334 and DLMS/COSEM. In the field of network automation, the IEC 60870-5-101 standard and its adaptation to the data packet communication IEC 60870-5-104 are prevalent in Europe. The most promising standard in this area is the IEC 61850 designed for transformer substation and power system automation. In contrast to the above standards, the IEC 61850 is not limited only to data transmission, but also provides a full data model. Between control centers, the IEC 60870-6 is used.

The next level is integration between information systems within the same company as well as with external companies. With the increasing inflow of data from different sources, it is not only the way of transmission that is important, but also determination as to which data are relevant for transfer. With object modeling data become well separated from the data-transfer protocols. The concept of Model Driven Architecture (MDA) is quite well established. For modeling smart grids, it is the CIM standard that is the most suitable.

4.1 CIM

The Common Information Model (CIM) provides a standardised object description of the power system elements and information flows between the various processes. This enables the different kinds of software to exchange information about the configuration and status of the power system [8].

CIM is maintained as an information model in the Unified Modeling Language (UML). It provides a basic ontology for the electric power industry. It is defined in the IEC 61970 for the transmission network, whereas in the IEC 61968 standard its usage is extended to the distribution networks.

4.2 IEC 61850

The IEC 61850 standard defines the data models for elements and processes of the transformer substation equipment.

The IEC 61850 was originally intended for substations, but later its use was spread to connecting subsystems, integration of distributed resources and connecting the control centers.

The standard defines data models as well as communication profiles. It standardises various types of communication services, such as reading and setting up values, reporting, alerting, configuration, clock synchronisation, etc. [9] The standard services can be mapped to various protocols. The standard defines the following communication profiles (Fig. 5):

- ACSI core profile allows client-server connection. Mapping in the MMS protocol and transmission with the TCP/IP protocol stack is used.
- GOOSE profile is intended for time-critical data exchange. GOOSE applications are mapped directly into Ethernet frames, thus assuring short response times.

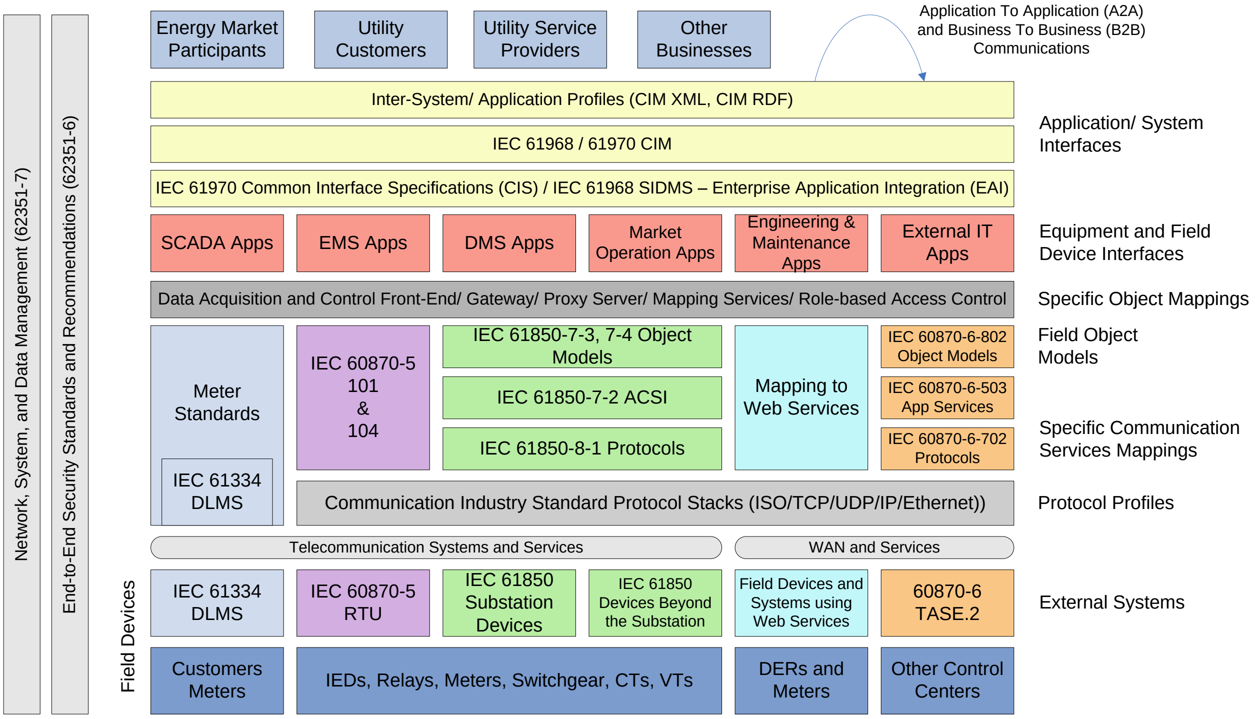

Figure 4: Reference integration infrastructure [1]

- GSSE profile is intended for time-critical exchange of statuses.
- SMV profile allows a multicast data transfer over a process bus. SMV applications are also mapped directly into the Ethernet protocol.
- Time synchronisation profile in which data is mapped in the UDP and IP protocols..

The standard also defines the configuration description language SCL (Substation Configuration Language), which is based on XML (eXtensible Markup Language). SCL is designed to individually describe devices and their configurations.

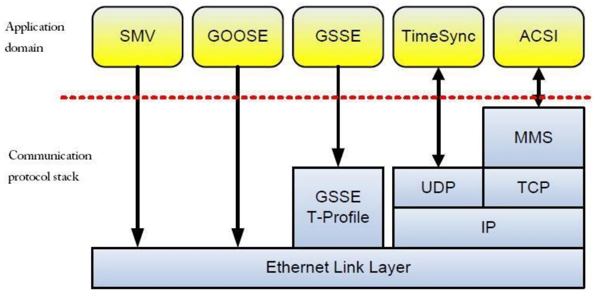

Figure 5.: IEC 61850 communication profiles [10]

5 CURRENT STATE OF SMART-GRID DEVELOPMENT IN SLOVENIA AND EUROPE

Smart-grid development brings with it some significant changes and adjustments in the current power system. Among the steps having already been taken in the smart-grid development in Slovenia are accelerated installation of remotely controlled automated switching devices and adoption of smart meters and new concepts of system management [11]. At the HV and MV substation level, the Slovenian distribution network uses a well automated management system. Most of the substations are connected with control centers over a proprietary fiber network. The MV equipment such as protective relays, circuit breakers and transformers are remotely controlled. To have the substations locally controlled, each substation is equipped with a computer system with SCADA.

In Slovenia there is a large number of smart-grid projects in progress [11]. Most of them are in the field of advanced metering infrastructure and several are with DSM, VPP and EV subjects.

Two major projects accomplished in Slovenia, financed by TIA, are the SUPERMEN and KIBERnet projects.

The aim of the SUPERMEN project [12] ("Intelligent Platform for electricity monitoring and control of distributed resources and users") was to develop solutions for managing DER and electricity consumption. It developed the Point of Common Coupling Interface (PCCI) controlable from the control center and representing smart users, distributed energy resources or some electric device.

The KIBERnet project [13] developed an active load and DER controller for industrial consumers.

In 2012 Slovenia adopted a program of smart-grids development. It defined tasks, research and implementation activities enabling smart-grid development and a financing method to have smart-grid concepts implemented by 2020. In 2011, the program "Advanced Systems of Efficient Use of Electrical Energy" (SURE) was laid down in which many Slovenian companies, research institutions and distribution network operators are involved. The program "Open Communication Platform for Integrated Service" (Opcomm) also participates [14] with developing smart-grid services and applications on the Internet of Things (IoT) open-communication platform.

There have been many smart-grid projects completed worldwide. FP7 (Framework Programmes for Research and Technological Development) is the main source of financing the EU projects in the period 2007-2013. A large percentage of them are related to smart grids. The focus of several of them is on the role of ICT and its development in smart grids [15]: ADDRESS, FENIX, MICROGRIDS, FINSENY ...

There are also many examples of real smart-grid deployments. One of them is the Italian Telegestore project [16] which has equipped over 27 million users with smart meters. The other is T-City [17]. It was implemented in Friedrichshafen, Germany. With its sub-projects and by using ICT it improves the quality of life in the city.

6 Conclusion

ICT provides the basis on which the future smart grids, allowing for two-way connections, will be able to control and manage the entire power system. The smart-grid communication infrastructure will be using many different advanced technologies. Their choice will depend on several parameters, like application importance, required quality of service, the existing infrastructure, etc.

With the increasing number of smart devices connected in the system, a large amount of data will be exchanged. Their managing and integration in the information systems will be one of the major future challenges. Two of the most important standards are IEC 61850 and CIM. The former standardises communications and data models for substations and the latter standardises object-oriented power-system elements and information flows between various processes.

There have already been several efficient smart-grid projects implemented in Slovenia. The space for their improvement is still considerable. Smart grids are also an opportunity for the Slovenian industry which is capable of developing and implementing new power system concepts.

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