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Abstract

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The paper considers the challenges which the modern energy systems control faces - introduction of renewable energy sources, rapidly changing loads, and energy markets liberalization. Some possible approaches for overcoming these challenges are outlined like introduction of thousands of actuating, sensing and controlling devices, smart sensor networks development, decentralized control systems implementation, web-based SCADA organization, Internet of Things (IoT) networks building. A model of a smart metering transducer is described and an architecture of a transducer network using a PLC as a gateway is developed. The key to sustainable operation of complex systems, such as the power system, and all blocks of them from one side is the collection, processing and archiving of large amounts of data about the parameters of the system and on the other hand is the fast and accurate transmission of control information. The adoption of cloud technologies in the power grids control can contribute for a safe operation and energy efficiency increase. © 2016 IEEE.

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Approaches and Instruments for Overcoming the Challenges of the Smart Grids Control

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***Abstract* – The paper considers the challenges which the modern energy systems control faces - introduction of renewable energy sources, rapidly changing loads, and energy markets liberalization. Some possible approaches for overcoming these challenges are outlined like introduction of thousands of actuating, sensing and controlling devices, smart sensor networks development, decentralized control systems implementation, web-based SCADA organization, Internet of Things (IoT) networks building. A model of a smart metering transducer is described and an architecture of a transducer network using a PLC as a gateway is developed. The key to sustainable operation of complex systems, such as the power system, and all blocks of them from one side is the collection, processing and archiving of large amounts of data about the parameters of the system and on the other hand is the fast and accurate transmission of control information. The adoption of cloud technologies in the power grids control can contribute for a safe operation and energy efficiency increase.**

I. INTRODUCTION

Modern energy systems control faces many challenges due to the introduction of renewable energy sources and rapidly changing loads. This requires innovative approaches in automation systems aiming energy efficiency increase. The key to sustainable operation of complex systems such as the power system and all blocks of them from one side is the collection, processing and archiving of large amounts of data about the parameters of the system and on the other hand this is the fast and accurate transmission of control information.

In the recent years the development of the computer networks has made the global computer network – Internet accessible to more and more people and organizations. Meanwhile the development of the information technologies has allowed their incorporation in all areas of the social life like medicine, industry, agriculture, education. Modern concepts for e-learning, e-business, e-government, e-health and etc. have been formulated. Cloud computing provides convenient, on-demand network access to a shared pool of configurable computing resources including networks, servers, storage, applications, and services.

The integration of information and communications technologies in the electric power system (EPS) leads to creating intelligent power systems (smart grids). In such systems the energy and the communications flows are integrated as it is shown in Fig. 1. Generally, Smart Grid is a data communications network integrated with the electrical grid that collects and analyzes data captured in near-real-time about power transmission, distribution, and consumption [1].

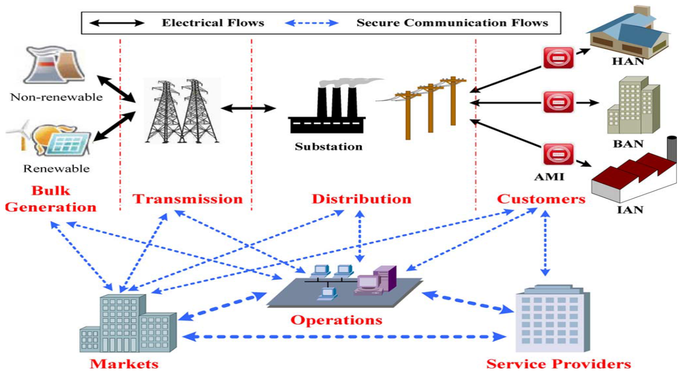

Fig. 1. Power and information flows in a smart grid [1]

European Working Group for smart grids defined as intelligent energy networks that can efficiently integrate the behavior and actions of all connected to them users - producers, consumers and those that do both - in order to ensure efficient and sustainable power system with low losses and high quality, security of supply and safety.

The modern intelligent power networks are changing from centralized to distributed ones similarly as the computer networks. It will lead to distributed measurement and information systems too. The distributed measurements will be performed by intelligent sensors which will be able to measure and process the data primarily and to transfer them to different places for storage, analysis, accounting and etc. Despite the distributed character of this measurement system, in big parts of it a centralized control and information collection will be needed.

II. CHALLENGES OF THE SMART GRIDS CONTROL

The rapid transformation of existing electric grids is driven not only by technological innovations but also by economical, regulatory and societal factors. Those changes impose new operational scenarios and technical challenges to power systems [2].

The main challenges that the modern energy systems control faces can be considered as follows:

- Introduction of renewable energy sources;
- Rapidly changing loads;
- Energy markets liberalization.

A. Introduction of Renewable Energy Sources

First of all, the soaring demand for new power supplies, and the increasing public awareness of the need of more sustainable sources of energy, are promoting the use of renewable energy resources (e.g., wind and solar technologies) for power generation. According to various reports, half of the estimated 194 gigawatts (GW) of new electric capacity added globally during 2010 was derived by renewable resources [3]. Most importantly, renewable energy resources are intermittent and highly variable, and the uncertainty in energy supply can cause reliability problems or power quality degradations (e.g., undesired voltage fluctuations) [4, 5]. This necessarily requires more sophisticated coordination and control techniques than those supported in current electric grids [6]. This is forced by the unpredictable character of the renewable sources which strongly depends on the parameters of the environment. The traditional generation has to be switched off and on in relation with the presence or lack of renewable energy in order to use it effectively. So, the weather forecast becomes an important factor for the electric power system control.

B. *Rapidly Changing Loads*

Another challenge for electric grids is the mass adoption of electric vehicles. Their market penetration is forced in order to reduce the impact of the human's lifestyle to the environment. So, the charge stations for electric vehicles are a typical example of rapidly changing loads which can cause a dramatic soaring of electricity demands. For instance, the simultaneous charging of several electric vehicles located in the same area can easily determine unexpected peak loads and rapid fluctuations of power demands in different parts of the electric grid [7]. Therefore, new control capabilities are needed to regulate the recharging process of electric vehicles with the objective of flattening aggregated power demands and mitigating load imbalances in power systems [8, 9]. A possible approach to support taking dispatch decisions is the use of statistical processing of the information collected about the renewable energy sources generation and the consumption of the recharge stations for electric vehicles. Thus, a considerable body of work is concentrating on defining control strategies to distribute the charging spatially and temporally in order to avoid peak loads and to optimally utilize grid capacity.

C. *Energy Markets Liberalization*

The third factor that is contributing to the need of introduction intelligent technologies in the power networks control is the deregulation of energy markets. More specifically, power systems are no longer national monopolies, but there are independent power producers selling electricity to utility companies, and independent operators maintaining and controlling regional transmission and distribution networks. Then, electricity prices are determined in an electronic auction market according to demand and supply principles [10]. There is a need of commutations in the power grid which can cause uncertainties in energy delivery that current electric grids are not well suited to handle. However, this requires improved system flexibility to preserve the reliability and stability of the power system [4].

III. Approaches for Modern Control

The electric power system is a complex which consists of the following subsystems – generation, transmission, distribution and consumption. To apply an efficient control of all parts of the system new innovative approaches in the automation systems are needed. The main strategic goals of the control could be highlighted as:

- Reliability and sustainability;
- Permanent energy efficiency increase;
- Safe operation.

The innovative approaches for the control which will lead to achievement of the goals can be determined as:

- Introduction of thousands of actuating, sensing and controlling devices;
- Smart sensor networks development;
- Decentralized Control Systems implementation;
- Web-based SCADA organization;
- Internet of Things (IoT) networks building.

A. *Introduction of Sensing and Controlling Devices*

The information system in the generation process is intended to record key performance and quality of service issues such as scarcity (especially for wind and solar) and generator failures, to utilize the data provided by the market sub-domain in order to schedule the generation and to simultaneously provide availability data to the markets and to record the history of device operations and maintenance, and to analyze the performance and the life expectancy of devices. The information management part in the transmission subsystem should provide information exchange for monitoring and control of transmission substations and field devices. This information is generated from widely-deployed measurement and monitoring devices, such as sensors and phasor measurement units [11]. Furthermore, this information should be properly used to manage the operations in the transmission system, including optimizing power flows, improving reliability, and optimizing asset utilization. In the distribution subsystem there are performed communications in real time in order to manage the power flows associated with a more dynamic market sub-domain, and hence to promptly adjust localized consumption and generation [12]. A large amount of monitoring and control information, concerning load management and distribution system reliability, should be managed in this subsystem. The consumption is the activity that represents the customers' participation. This is the most important purpose of the system. Customers need accurate information to manage their energy usage, generation, and storage. It will support the realization of many advanced features, like remote control, monitoring and control of distributed generation, inhome display of customer usage, automatic reading of meters, and control of new electric devices (e.g. electric vehicles).

B. *Smart Sensor Networks Development*

To develop an information or industrial network of devices, they must have communication capabilities. In the case of the power system, the metering systems and devices must maintain definite communications protocols in addition to their basic characteristics. According to Article 2, paragraph 28 of the Energy Efficiency Directive (2012/27/ES), OJ L 315, 14.11.2012, p1 „smart metering system” or „intelligent metering system” means an electronic system that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication”. Third Energy Package requires states - member of EU to ensure the implementation of intelligent metering systems for the long-term benefits for consumers. Furthermore, in accordance with the spirit and in addition to the provisions of the Third Energy Package, the Energy Efficiency Directive supports the development of energy services based on data from smart meters, optimization of consumption (demand response) and the application of dynamic pricing. “Optimization of consumption” should be understood as voluntary changes by the end users of their usual electricity consumption patterns in response to market signals (such as time-varying electricity prices or preferential payments).

In [13] are explained models of smart power transducers with capabilities for inclusion in industrial networks and in Fig. 2 is shown the block diagram of one possible solution. The smart transducer integrates an analog or digital sensor or actuator element, a processing unit, and a communication interface. The transducer is based on a powerful microcontroller, for example ARM based like LPC1768 of NXP or similar, which executes the functions of the application processor and the network communication. They have enough resources to measure the parameters of the power grid – analog-to-digital converters, timer modules, digital inputs and outputs. Also they are supplied with different digital interfaces to maintain the network communications – serial like SPI, I2C, SCI and etc., and Ethernet because of the embedded medium access controller (MAC) and physical transceiver (PHY).

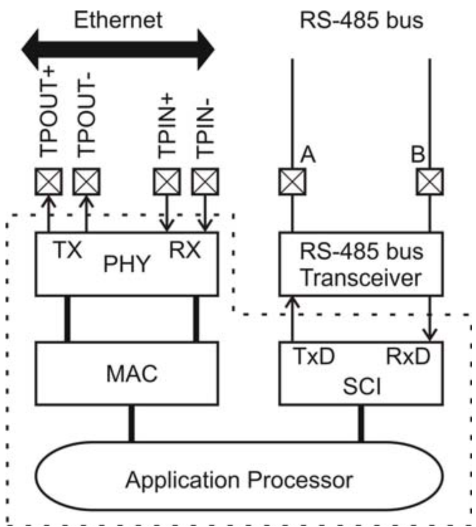

Fig. 2. Smart transducer based on a powerful microcontroller [13]

A very important part of the network development is to choose the gateway. It enables the connection of different network types within the architecture, or provides a means of transportation of data to different network areas for distribution. For application in EPS it has to be small, rugged, reliable device. In [16, 17] it is investigated the use of a standard device like PLC as a gateway and the block diagram of such network is depicted in Fig. 3. The PLC is a reliable device which has a wide application in automation in the industry and in EPS as well. The successful application could lead to additional advantages. Besides using the PLC to connect the transducers network to SCADA systems its possibilities can be used to control another devices from the electric power system.

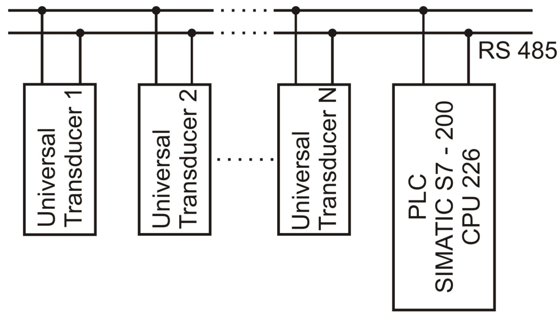

Fig. 3. Smart universal transducers network development

The PLC of Siemens Simatic S7-200 CPU 226 and three phase – two elements transducers are implemented in the developed network. The rated input values of the transducers are $V_{ph-ph} = 100V$ and $I_{ph} = 5A$. The possibilities of the PLC are enough to maintain the smart transducers network and to control digital inputs and outputs. Its communications resources include two ports realizing RS-485 serial interface. Port 0 of Simatic S7-200 CPU 226 is chosen to operate with the transducers network. The Freeport protocol is used and the available values of the baud rate are 0.3, 0.6, 1.2, 2.4, 4.8, 9.6, 19.2 and 38.4 kbaud. 9.6 kbaud rate is chosen to correspond to the same value that is used by the transducers. Port 1 of Simatic S7-200 CPU 226 using MPI protocol realizes the connection to the upper level of the SCADA, in this case to a personal computer. A communication processor module CP 5611 is added to the personal computer which enables it to communicate using MPI protocol. The SIMATIC WinCC flexible 2008 programming package is used for visualization of power transducers data. The communication parameters are defined as follows: interface MPI/DP, baud rate 19200, address 1, network profile MPI and communication driver SIMATIC S7 200, address 2. The appropriate tags are developed that give the relationship between the displayed value and the data from the buffer for visualization in the PLC memory. Two screens are provided for visualization. In Fig.4 is shown “Start screen” where are displayed the address and basic parameters of the power transducer. The other parameters of the transducer are displayed on screen “Secondary”. The project is starting in runtime mode. The information is updated every second.

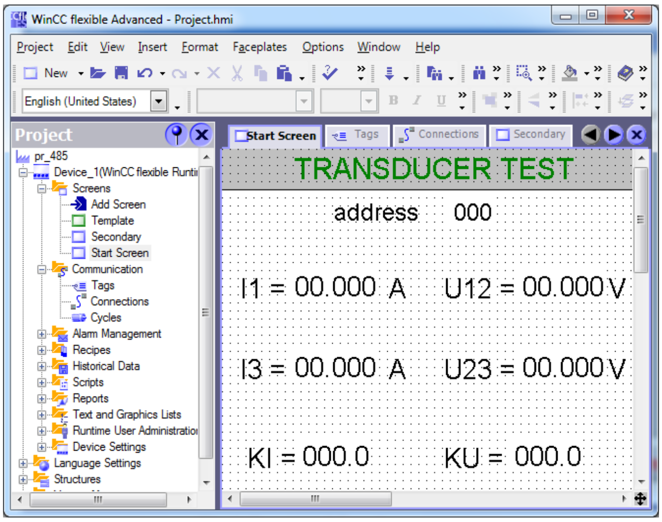

Fig. 4. Front panel for “Start Screen”

Thus in addition to the main functions of the PLCs to handle analog and digital inputs and outputs, their communications capabilities make them suitable and useful tools for industrial networks development.

C. Decentralized Control Systems Implementation

Similar to the production technology, production control and monitoring systems have moved away from central operational structures and towards Decentralized Control Systems (DCS) [14]. Industrial processes in many modern systems depend on SCADA and DCS systems in order to perform their complex functionality. Typical examples are power grids, water management systems and etc. An advanced trend in the distributed automation systems development for working with great number of sensors and large data arrays is the use of networks and Internet technologies based on Web services (Service Oriented Architectures - SOA) and cloud technology. The adoption of cloud technologies in the power grids control can contribute for a safe operation and energy efficiency increase.

D. Web-based SCADA Organization

Nowadays the development of the power grids as intelligent grids stimulates the integration of all subsystems (generation, transmission, distribution, consumption), operators, service providers and associated with them SCADA systems in a common distributed system for control aiming energy efficiency, usage optimization (demand response) and application of dynamic costs on the market [11]. This is one of the basic conditions for creation of a flexible system for energy measurement AMI (Advanced metering infrastructure) not only in the domains of generation and transmission but in the domain of consumption too. Essential part of the AMI development is the implementation of smart metering systems allowing the inclusion of the end users in Home automation networks (HAN) and Building automation networks (BAN), and the industrial users in Industrial automation networks (IAN). The web-based SCADA systems will provide services not only to the end users but also to the operators for control in all domains of the power grid.

E. Internet of Things (IoT) Networks Building

The foundation of Internet of Things (IoT) is the intelligence that embedded processing provides. The IoT is comprised of smart machines interacting and communicating with other machines, objects, environments and infrastructures. As a result, huge volumes of data are being generated, and that data is being processed into useful actions that can “command and control” things to make human lives much easier and safer - and to reduce the human’s impact on the environment [14]. Building networks of the type IoT (Internet of Things) and WoT (Web of Things) will contribute new possibilities to the control systems. By using the large quantities of information which are delivered by AMI can be monitored big parts of the EPS. The collected data and the processed information can be transmitted via the modern networks to different locations for storage, analysis, accounting and etc.

F. Distributed Network Example

A possible example of a distributed power network is shown in Fig. 5. The grid consists of all basic domains of the power system – generation, transmission, distribution and consumption. There are included renewable energy sources and electric vehicles recharging station. Also there are control centers connected to the system by information networks which redirect the energy flows using the data from the markets and the forecast.

The example completely represents the distributed character of the smart grids. There are distributed generation, transmission and consumption as well as distributed information and control infrastructure. The shown grid can operate not only as a part of the centralized system but as an autonomous power network too.

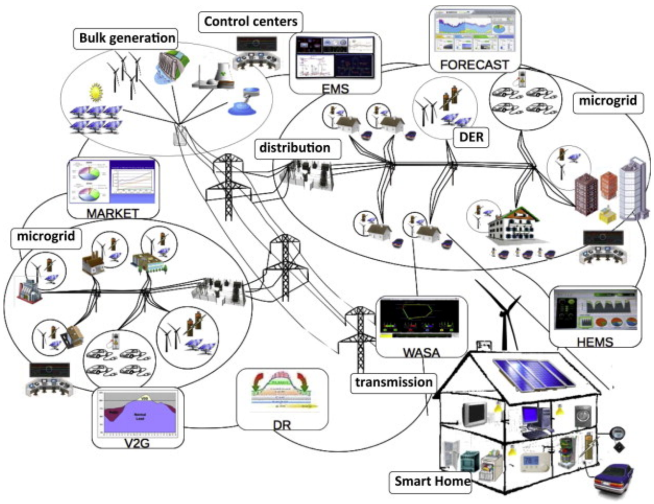

Fig. 5. Smart grid example [2]

There is presented the application of approaches for reliable and sustainable control of an intelligent power network aiming to achieve safe operation of the grid with energy efficiency increase.

IV. CONCLUSION

The paper presents a research on the challenges which the smart grids implementation puts in front of the control of the power network. Some approaches for overcoming these challenges are outlined. The metering and the information and communication infrastructures are analyzed. Some instruments which can be included in these infrastructures are proposed. Despite the distributed character of the future energy and measuring systems, in some big parts of them will be necessary centralized control and data acquisition. Especially in these parts of the systems can be applied the cloud technologies (Cloud services).

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