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Research and Development of IoT based Solutions for Introduction the Cloud-aided Control in the Energy Systems (Conference Paper)

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Abstract

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Research and Development of IoT based Solutions for Introduction the Cloud-aided Control in the Energy Systems

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Abstract – **The paper describes the development and implementation of Internet of Things oriented solutions which are expected to help the introduction of Cloud computing in the industrial and home energy management systems. The challenges in front of the control of energy systems are outlined in order to motivate the introduction of smart metering infrastructure and information technologies. Two models of IoT based solutions are explained which consider the Internet connectivity of modern and legacy measurement and control equipment. Experimental results are given.**

Keywords – **Cloud computing, Infrastructures for industrial informatics, IoT, Sensor networks, Smart grids**

I. Introduction

The modern trends in the energy systems development are a limitation of the usage of coal and oil derivatives as energy sources, and the expanding of the generation from renewable energy sources (RES) like water, wind and solar radiation. These trends aim at environment protection and decrease of air and water pollution. Another step in this direction is the increase of the electric vehicles. The liberalization of the energy market also significantly affects the power systems operation. To respond to these major challenges a new phase in the energy systems development emphasizing on the modernization of the grid has to be initiated. This modernization will spread over all parts of the energy chain - generation, transmission, distribution and consumption [1]. The key to overcome the challenges is in developing Smart grids which means the integration of information and communication technologies in the energy system. In general in Smart grids there is a bi-directional communication between the participants in the energy chain along with the power flow. The highlights of Smart grids are monitoring, protection, automation, optimization, integration and security of the power flow from utility generators to the end consumers. Smart grids implementation is expected to help reaching the goal – effective, reliable, safety and sustainable energy provision along with green environment and attractive living conditions. In this case the development of power systems follows that of the computer systems and from hierarchical and centralized they become distributed. Hence every part of such complex system is transformed which changes its character. Along with the traditional bulk generation there are the wind and solar power plants which production depends on the environmental conditions, so it is difficult to predict it. Also it is difficult to predict the demands requested by the electric vehicles charging stations and by the industrial and home consumers. Thus the substations bridging the transmission lines and the distribution domain need additional smartness in order to be able to connect consumers to the energy producers. In the consumption domain there are various smart devices - household appliances, home automation, electric vehicles, electricity meters and etc.

In Smart grids along with the traditional performers on the energy field – generation, transmission, distribution and users, the new ones – markets, operators and service providers are involved [2]. Weather forecasts and demands models profiling begin to play important roles in the power systems control. Thus there is a need of big data storage and processing.

A promising and realistic approach to deploy Smart grids is the development of smart sensors networks for gathering the information from the energy system and the introduction of Cloud computing for processing, storage and visualization of this information in order to ensure fast, reliable and adequate control.

The goal of the presented research is to develop smart measuring transducers based on the IoT concept and to deploy industrial networks for integration a legacy measurement and control equipment to Internet.

This paper is organized as follows: section 2 outlines some advantages of Internet of Things and the cloud computing in order to motivate their implementation in the network-based control in the power system. The proposed infrastructure models, the hardware and software design are described in section 3. The conclusions and the future work are presented in the last section.

II. IoT and Cloud Computing Essentials

In the Smart grids there are installed different types of monitoring, analyzing and controlling devices. They are deployed at all domains of the energy system - power plants, transmission lines, transmission substations, distribution centers and consumers places, and their numbers amount to the hundreds of millions or even billions [3]. One of the main activities in Smart grids is the connectivity, automation and tracking of such large number of devices. This requires distributed monitoring, analysis and control using high speed, ubiquitous and bi-directional digital communications.

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All these matters are the main features of the paradigm Internet of Things (IoT).

The term “thing” is used for people, machines, devices, sensors and data [4], or the essence of the IoT concept means their integration to Internet.

The main goal of IoT is to support the development of smart environments for application in different areas of the industry and social life like e-government, e-learning, e-health, e-business, smart homes, smart cities and etc. This technological jump has become possible as a result of the strong progress of electronics, computing and telecommunications.

The implementation of two important achievements - IPv6 and Cloud computing, has given a significant support to the Internet of Things. IPv6 allows the communicability, giving an address to multiplicity of devices, which number is expected to reach 24 billion by 2020 [5]. Additionally, it eases the management of the networks because of the capabilities for auto configuration and offers improved security features as well. Cloud computing is already a building block of the Internet and the Internet of Things is expected that will be the biggest user of Cloud. Cloud environment is also able to provide the services for analysis of the data streams in order to support ensuring the information to the end consumer in an optimal form.

Recently cloud computing is being more widely used in the government, education, business, healthcare, and etc., but it is relatively new as application in SCADA systems. The main components of these systems are Remote telemetry units (RTUs), Programmable logic controllers (PLCs), a supervisory computer-based system, databases, Human–Machine Interfaces (HMIs) and etc. The cloud computing allows the virtualization of some of the components of the SCADA systems except the RTUs, which are physical devices and are connected to the objects. The functions of the others can be distributed between various machines where heavy software algorithms can be run using the enormous computing resources of the cloud. This is especially valid for the supervisory computer-based systems, databases and HMIs. The cloud computing will enable the processing of big data which is needed in weather forecasts analysis and consumers’ demands profiling. Also it will support the control functions using virtualized PLCs. The inputs and the outputs of the controller are connected to the physical object but the control software is running on a virtual machine in the cloud using a big computing capability and heavy software packets like MATLAB and etc., which is impossible in the traditional practice.

The Internet of Things architecture is layered as it is shown in Fig. 1. It is intended to abstract and automate the integration of objects, and to provide smart services. The model can be divided into three layers [6], respectively perception, network, and application.

The perception layer is responsible for the front-end in order to identify and control the field devices, and also to collect the data provided by them. There are two recognizable sub-layers – a perception control sub-layer and a communication extension sub-layer. The first contains transducers (sensors and actuators), signal conditioning and data conversion blocks, and an application processor. The second one has a communication processor which connects IoT devices with the network layer.

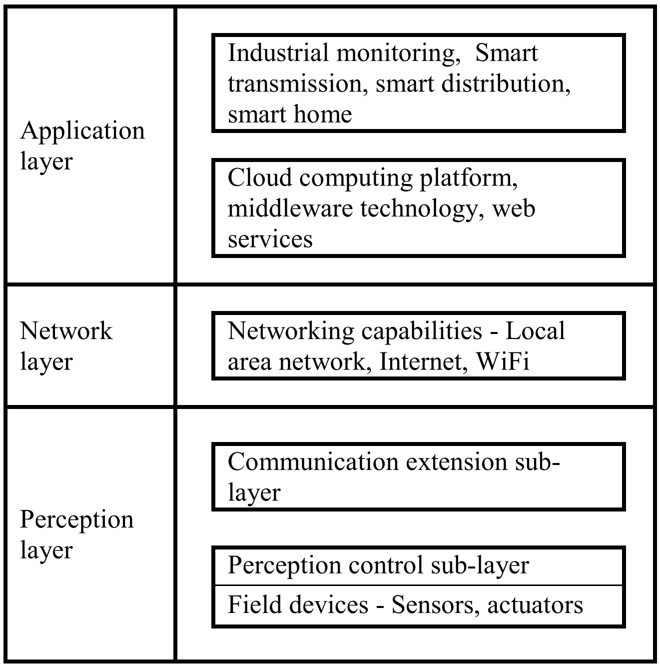


Fig. 1. IoT systems architecture model.

The function of the network layer is to conform the information collected by the IoT devices in the perception layer to the standard telecommunication protocols. Afterwards, it transmits the re-formatted data to the application layer through the corresponding telecommunication network. The main network - Internet performs the routing, information transmission, and control. The network layer contains also the IoT management and information centers. It uses public and industry-specific communication networks as well.

The application layer is responsible to process the information received from the network layer, and based on this information, to monitor and troubleshoot the IoT devices in real-time. It includes application infrastructure /middleware and various types of servers related to content, web services and directory services. This Infrastructure/ middleware provides computing, processing and resources for IoT technology. The key feature of the application layer is to ensure information sharing and security. The application layer is supposed to develop, in order to provide much richer data sets. From their point of view, these applications determine what data from the sensors and at what time intervals are required.

III. Implementation of IoT based Solutions for Power System Measurement and Control

IoT based devices can be fixed or mobile. The fixed ones (being in fixed locations) might use cable or wireless Internet connection. The mobile devices can be wirelessly connected to the Internet (e.g., by mobile phone). According to the networking capabilities the IoT based devices can be considered as ones working in active mode and others which operate in passive mode. When the thing itself is connected to the Internet, it is in active mode and is able to communicate in real-time. By now, there are many devices and sensors which are used in the power system monitoring and control, but they are not connected directly to the Internet. These devices could be connected as things to the Internet in a passive mode through the concentrated devices (gateways or mediators) which support sub-networks and are connected to the Internet. In the passive mode, a thing is not connected to the Internet, but can be uniquely identified through the gateway which maintains the network of smart units.

A. IoT based power measurement transducer working in active mode

The smart power measurement transducer is developed following the architecture model depicted in Fig. 1. The block diagram is shown in Fig. 2.

Modern industrial automation and informatics integrate Internet based communication technology which allows direct access to a particular device via the Internet or Intranet. For these purposes it is reasonable to use already existing standards like IP-based communications, standard Web browsers and generally used program languages such as HTML or JavaScript. This allows access by any fixed or wearable device without additional software installation.

The structure of the transducer is divided into two parts, namely Application processor and Communication processor. Every part covers one sub-layer of the perception layer from the IoT architecture model. The parts are based on standard microcontrollers and the data transfer between them is serial using UART. This is a further development of a universal power transducer [7]. The Application processor deals with the input signals and it is connected to the power system by measuring transformers with ratios kV and kI. The transducer measures the main quantities of the three phase power grid – voltage, current, frequency and phase angles, and calculates the derivatives – apparent, active and reactive power, and power factor. The input signals have rated values respectively 57,7 V and 5 A which are standard for the measurement and control systems in the objects of the power grid – power plants, substations and etc. The transducer has the flexibility that after slight adjustments its rated input values can be changed. Thus the voltage dividers can be set for 230V and the transducer will be able for direct connection in industrial and home automated systems for energy consumption monitoring. The communication processor is intended to extend the networking capabilities and it supports the remote client interface using IP communications.

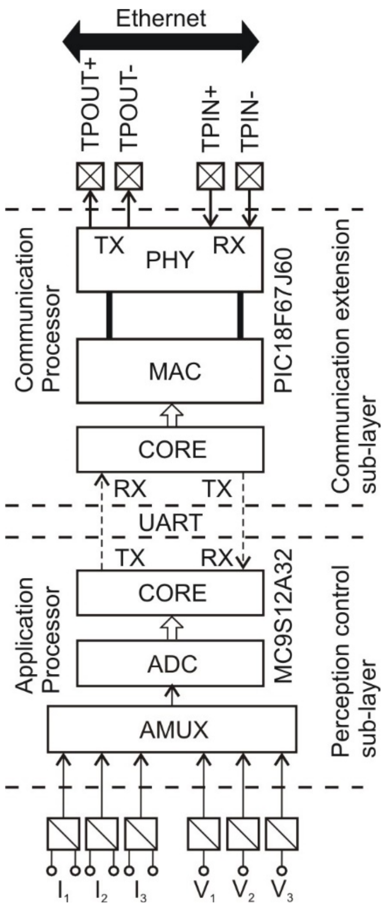


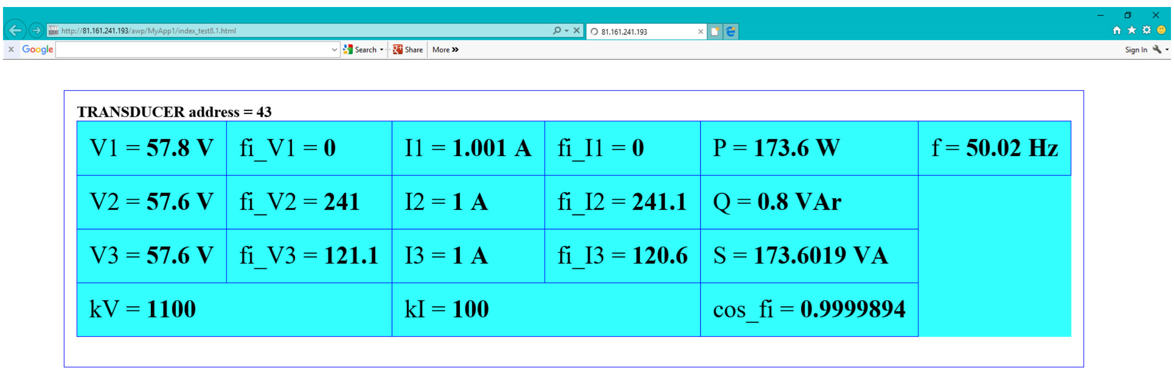
Fig. 2. Smart transducer block diagram

The processor is fully compatible with 10/100/1000Base-T Networks. Also it supports the HTML page containing the user interface (HMI). The implementation of IP-based communications capabilities gives the transducer possibilities for inclusion in Internet of Things networks. In Fig. 3 is presented the view of the remote interface.

B. Sensor networks development as IoT based solutions working in passive mode

Currently there are a lot of devices and sensors which are used for monitoring and control in the power system, but they are not able to be connected to the Internet.

Such devices could be connected as things to the Internet of Things in a passive mode through gateways. Gateways interconnect networks by converting the protocols of each



TRANSDUCER address = 43

V1 = **57.8 V**	fi_V1 = **0**	I1 = **1.001 A**	fi_I1 = **0**	P = **173.6 W**	f = **50.02 Hz**
V2 = **57.6 V**	fi_V2 = **241**	I2 = **1 A**	fi_I2 = **241.1**	Q = **0.8 VAr**	
V3 = **57.6 V**	fi_V3 = **121.1**	I3 = **1 A**	fi_I3 = **120.6**	S = **173.6019 VA**	
kV = **1100**		kI = **100**		cos_fi = **0.9999894**	

Fig. 3. Remote HMI for data access from the IoT based measurement transducer

network to that used by the other. Thus they make possible the inclusion of legacy equipment which has its original interface protocol to a modern infrastructure. In such cases the gateway bridges the custom developed protocol and a standard one. To integrate/connect and migrate devices, attached to different networks by the use of gateways is a well proven concept, which is applied to transform protocols as well as syntax of data [8]. For the development of sensor networks with extended capabilities for Internet communications it is required to choose the proper gateway. A possible solution is to use a programmable logic controller (PLC) as it is shown in Fig. 4. PLCs are widely used in the industrial automation and in the process control because they are rugged, reliable and flexible. In the substations of the power grid the PLCs can read the states of relay inputs (contacts) and control relay outputs, e.g. circuit breakers. Along with the control functions the PLCs have enough communications capabilities to operate as a gateway which can be used to maintain the smart transducers network.

The universal transducers in the sensors network are similar to the described above one. Their communication interface is RS-485 and a custom protocol is used. PLC 1 performs the function of the gateway and it transforms the custom protocol to standard Profibus. For this purpose is used the PLC of Siemens Simatic S7-200 CPU 226, extended with analog module type EM235 and Profibus-DP slave module EM277. Along with the sensors network maintaining the PLC reads four relay inputs and controls four relay outputs, accepts two analog signals from voltage and frequency transducers with analog outputs, and communicates with the upper level. The networking functions are performed by the PLC 2 which works as a proxy for the transducers network. It supports the HTML document which is accessible by the remote clients.

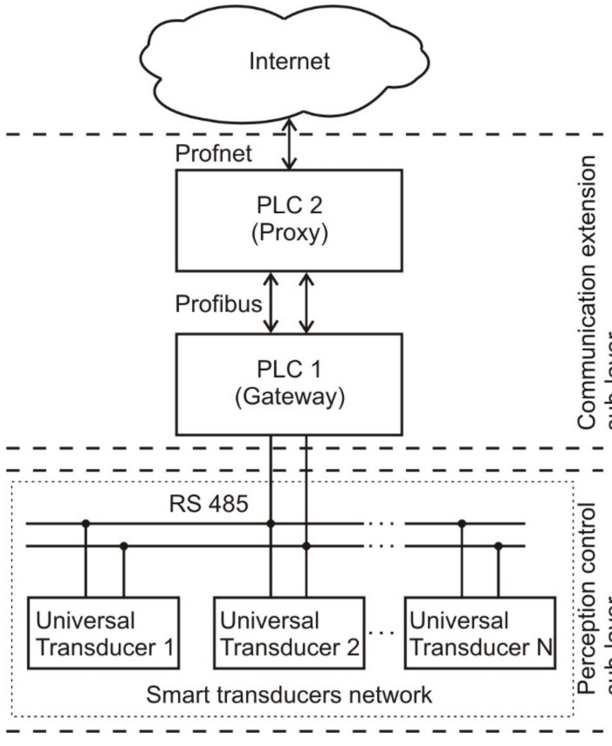


Fig. 4. Smart transducers network as IoT solution working in passive mode

The PLC of Siemens Simatic S7-1200 CPU 1214C extended with Profibus-DP master module CM1243-5 is chosen for this application. The proposed infrastructure is suitable for distant monitoring and automation of a substation or another particular object of the power system. The remote monitoring and control of field devices directly from the network has been significantly positively impacted by the growth of Ethernet-based industrial networks such as Profinet and Ethercat. The HMI has a similar view like the one shown in Fig. 3. In addition there are possibilities for relay inputs and outputs control.

IV. CONCLUSION

In this paper the main features of the IoT concept and Cloud computing are considered. The expected benefits from their implementation in the power grids measurement and control are explained. Two models of IoT based solutions working respectively in active and in passive mode are described. The developed remote HMI is accessible by the clients from anywhere in anytime using Standard Web browsers. Laboratory tests using power system simulator, PLCs and measuring transducers have been conducted. The developed experiments give reliable results for the application of the presented solutions in further investigation of more complex systems for electric power management.

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