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Implementation of hardware and software solutions for remote monitoring in substations (Conference Paper)

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Implementation of Hardware and Software Solutions for Remote Monitoring in Substations

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Abstract—**The paper discusses the challenges in front of the smart grids control and the possibilities for migration the new information and communications technologies for their overcoming. A model of distributed system for remote monitoring and control in substations is proposed. The hardware and software design are considered. Attention is paid on the use of PLCs as servers and gateways. Their application expands the flexibility and the reliability of the system. Experimental results are presented.**

Keywords—Network-based control; Infrastructures for industrial informatics; Sensor Networks; PLC.

I. Introduction

Nowadays the power grid is one of the most complex existing systems. Variety of components is connected in the electricity supply chain, the main parts of which are generation, transmission, distribution and consumption. All these components must work reliably, to ensure uninterrupted power supply for the homes and businesses, despite the continually changing conditions in which the grid operates. The wide introduction of renewable energy sources, electric vehicles and energy market liberalization is giving a significant impact on the operation of the modern grid. The changes in electricity demand need an instantaneous response from electricity production. Consequently, the values of the grid parameters - voltage, current, active and reactive power are changing. The challenge in front of the grid management is to ensure that the grid will continue its safe operation by overcoming these conditions [1].

The integration of information and communications technologies in the electric power grid leads to creating intelligent power systems - Smart grids. The model of a smart grid that is proposed by NIST [2] and is shown in Fig. 1, contains three more participants of the system - markets, operations, and service providers which are added to the mentioned above traditional electricity supply chain.

The key features of smart grids are monitoring, protection, automation, optimization, integration and security of the power flow from utility generators to the end user appliances [3]. Generally there is a bi-directional or two way communication along with power flow between the two concerned entities i.e. consumer and grid. The role of the communications in the industry and particularly in the power grids becomes increasingly important. The application of modern technologies like computer networks and cloud computing is a perspective approach in the power grids management.

Substations are basic points in the power grid and their proper functioning is very important for the whole system because they are a bridge between the transmission and the distribution. The transmission system delivers the power to the substations and the transformers there decrease the voltage levels from high transmission values to lower distribution voltage values. In the distribution system the voltage is stepped down again to the appropriate values for the customers [4]. Additionally substations perform several other important functions, such as grid protection and power control. There are installed advanced metering, intelligence, and automation in order to monitor and manage more effectively the local system.

When faults are detected, local control is responsible to limit their propagation and impact on the rest of the grid by switching off the proper circuit breaker. Substation measuring infrastructure also provides real-time monitoring of dynamic line ratings, so operational limits on lines and transformers can

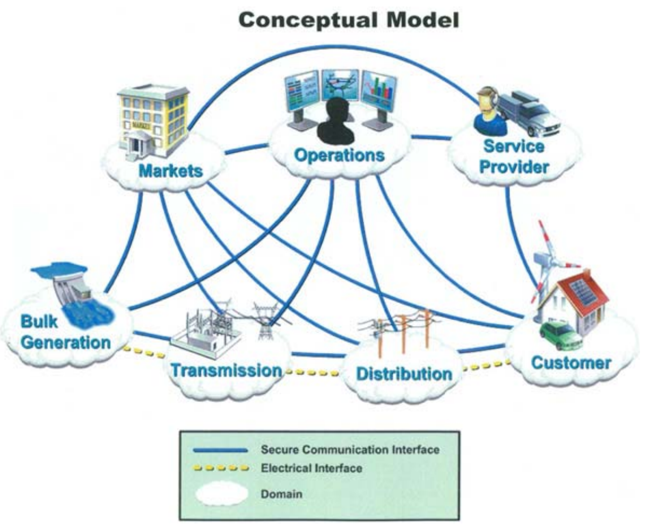

Fig. 1. Conceptual model of a smart grid, containing the basic sub-domains and the electric and information interfaces between them [3].

adapt in real time to safely ensure maximum utilization of existing grid assets.

Intelligent data filtering and validation occurs at the substation, which provides the control centers with more clean, coherent, correlated, and validated data [1]. The organization of the measuring and automation infrastructure requires the application of innovative approaches in order to be able to ensure reliable and effective operation of the entire power grid and of a particular substation.

This paper is organized as follows: section 2 provides some advantages of the cloud computing and its application in different areas in order to motivate the introduction of network-based control in the power system. The proposed infrastructure is considered in section 3. The hardware and software design are described in section 4. The conclusions and the future work are presented in the last section.

II. Migration of New Technologies into Power Grids Control

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. Adaptation of these technologies and their application in the industry is expected to contribute new possibilities in the field of information and control of the enterprises. The need for new communication infrastructures in the industrial domain has led to the idea of technology transfer from business systems to distributed measurement systems. In both cases there is a need of data exchange organization, their processing and visualization, i.e. a Human-Machine Interface (HMI) [5]. TCP/IP protocols and Web technologies are proper software instruments for implementation in the remote monitoring systems. Industrial networks comprising smart measuring transducers, PLCs, gateways and servers are the hardware infrastructure for gathering and transfer the operating data from the industrial objects to the dispatching centers.

Typical examples of complex systems are power grids, water management systems, oil derivatives production and etc. Despite the strong hierarchical structure of the electric power system, the modern intelligent power grids are changing from centralized to distributed ones similarly as the computer networks. This is forced by the mentioned above factors which introduction have made an important impact on the power grid functioning. These processes turn the power system into a system of systems. In the same way the production control and monitoring systems have moved away from central operational structures and towards Decentralized Control Systems (DCS). In the same time the information from every point of the system, e.g. a substation must be available not only for the local control but on request for the central dispatching station too. The need of remote monitoring and control of substations is vast and many efforts are directed to ensure reliable, fast and secure hardware and software approaches and tools for collection, processing, storage and transfer the operating data from the power grid. Service Oriented Architecture (SOA) is considered as a perspective approach to develop cross-layer integration to make distributed systems more interoperable [6]. The huge scale of the system makes the design, deployment, management, and maintenance of a process monitoring and control subsystem significantly more difficult. SOA is a possible approach to overcome the key challenges in order to provide reliable and flexible process monitoring and control [7]. It allows the clients to have an access to the HMI from anywhere and any time via any device, including mobile ones, but not only from one static location.

III. Infrastructure Proposal

SCADA (Supervisory Control And Data Acquisition) systems are generally used in the power systems control in order to ensure reliable and sustainable operation. They are hierarchical systems and have a multi – layer organization. The lowest layer is intended for connection to the industrial environment and it contains sensors and actuators for collection process information and control of different devices. To integrate legacy systems in the new service oriented architecture providing web services, it is needed to have mediators between the field devices and the information network which the remote clients are connected to. The system for remote monitoring of a substation is organized as multi – layered and is shown in Fig. 2.

The lowest layer contains universal measuring transducers which measure the values of the parameters of the power grid.

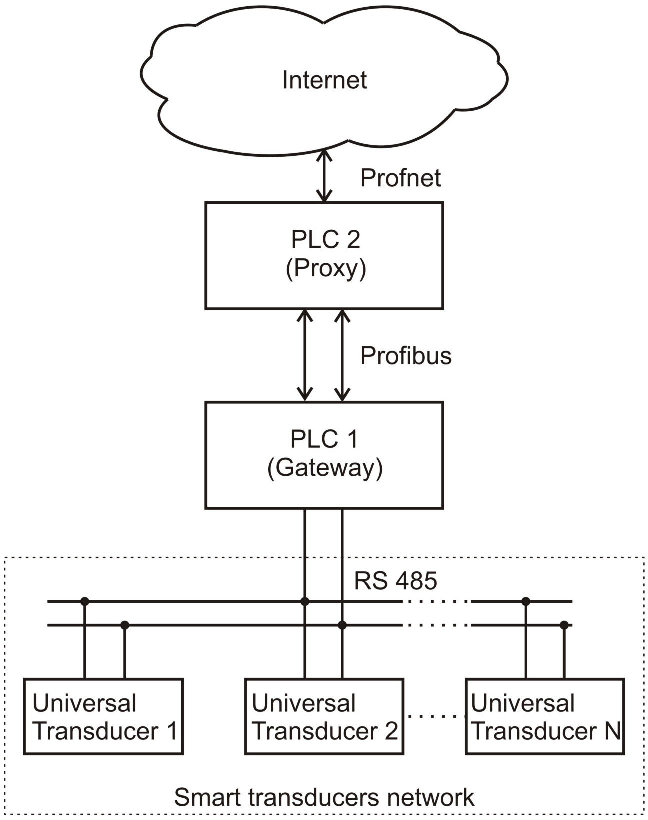

Fig. 2. Organization of a multi – layer system for remote monitoring of a substation.

They are organized in an information network using the standard interface RS-485 and a custom protocol for data exchange. The function of the gateway or mediator is performed by a programmable logic controller (PLC 1). It is a rugged, reliable and flexible device which has a wide application in the process control, also in the power grid. Particularly in the substations the PLCs can read the states of relay inputs (contacts) and control relay outputs, e.g. circuit breakers.

Using their analog inputs the PLCs can monitor analog signals, proportional to different electrical and nonelectrical quantities which are important for the proper operation of the substation, e.g. the temperature of the transformers and etc. In the same time the communications possibilities of the PLC can be used to maintain the network of smart transducers. In this way it transforms the custom protocol of the transducers network to standard Profibus for communication with another control devices. Thus PLC 1 is connected to PLC 2 which handles the local control and monitoring and also it supports HTML document which is accessible by the remote clients. The growth of Ethernet-based industrial networks such as Profinet and Ethercat makes possible the remote monitoring and control of field devices directly from the network.

IV. DESCRIPTIO OF THE HARDWARE AND SOFTWARE DESIGN

A. Hardware

The block diagram of such system which achieves an automation of the process in the substation is shown in Fig. 3. The system is divided into two layers, namely Field devices network and Local control and visualization.

The smart transducers network is developed using universal power transducers with rated input values 57,7 V and 5 A, connected to the grid by measuring transformers with ratios k_V and k_I. They measure the main quantities of the three phase power grid – voltage, current, frequency and phase angles, and calculate the derivatives – active and reactive power, power factor, active and reactive energy, and etc. The data exchange is with fixed length messages. The request is two bytes long as follows:

Byte 0 - address	Byte 1 - command
HEX - 11xxxxxx	HEX - 10xxxxxx

The first byte contains the physical address of the transducer and the maximum is 50. The command is in the second byte. When its value is \$82, the chosen transducer transmits the whole buffer, which is described in Table 1.

The first two bytes of the response repeat the request and the third has a fixed value. The values of the quantities of the power grid are sent in three formats. In each of them the value of the bytes is limited to \$7F. So they are transmitted as ASCII string and can be recognized by standard processing programs. Using this format the values of the quantities are sent with the following accuracy: voltage – 0,1V, current – 0,001A, frequency – 0,01Hz, phase angle – 0,1°, active power – 0,1W and reactive power – 0,1VAr. The last two bytes contain the checksum (CS) and the value is equal to the sum of the all bytes of the buffer [8].

TABLE I. DATA BUFFER DESCRIPTION

Byte number	*Value*	*Format*
0	address	HEX - 11xxxxxx
1	command	HEX - 10xxxxxx
2	40 (\$28)	HEX - 00101000
3, 4	V_1	HEX - 0aaaaaaa, 0bbbbbbb
5, 6	V_2	HEX - 0aaaaaaa, 0bbbbbbb
7, 8	V_3	HEX - 0aaaaaaa, 0bbbbbbb
9, 10	I_1	HEX - 0aaaaaaa, 0bbbbbbb
11, 12	I_2	HEX - 0aaaaaaa, 0bbbbbbb
13, 14	I_3	HEX - 0aaaaaaa, 0bbbbbbb
15, 16	P	HEX - 0±aaaaaa, 0bbbbbbb
17, 18	Q	HEX - 0±aaaaaa, 0bbbbbbb
19, 20	f	HEX - 0aaaaaaa, 0bbbbbbb
21, 22, 23, 24	ENA+	BCD
25, 26, 27, 28	ENA-	BCD
29, 30, 31, 32	ENRL	BCD
33, 34, 35, 36	ENRC	BCD
37, 38	k_V	HEX - 0aaaaaaa, 0bbbbbbb
39, 40	k_I	HEX - 0aaaaaaa, 0bbbbbbb
41, 42	φV_1	HEX - 0aaaaaaa, 0bbbbbbb
43, 44	φV_2	HEX - 0aaaaaaa, 0bbbbbbb
45, 46	φV_3	HEX - 0aaaaaaa, 0bbbbbbb
47, 48	φI_1	HEX - 0aaaaaaa, 0bbbbbbb
49, 50	φI_2	HEX - 0aaaaaaa, 0bbbbbbb
51, 52	φI_3	HEX - 0aaaaaaa, 0bbbbbbb
53, 54	CS	HEX - 0aaaaaaa, 0bbbbbbb

Field devices network layer includes module Relay inputs, module Relay outputs, two transducers with analog output, and industrial network containing eight smart universal transducers, and PLC Simatic S7-200 CPU 226.

The PLC Simatic S7-200 CPU 226, extended with two modules (analog module type EM235 and Profibus-DP slave module EM277), is working as a gateway and provides the following functions [9]:

- reading the states of module Relay inputs and setting the Relay outputs;
- monitoring the analog signals of voltage and frequency measuring transducers;
- maintaining the communication with the smart transducers using a serial interface RS-485;
- realizing communication with the upper level of the automation system via Profibus-DP interface.

Local control and visualization layer includes PLC Simatic S7-1200 CPU 1214C extended with Profibus-DP master module CM1243-5 and HMI Siemens KTP600 basic color PN.

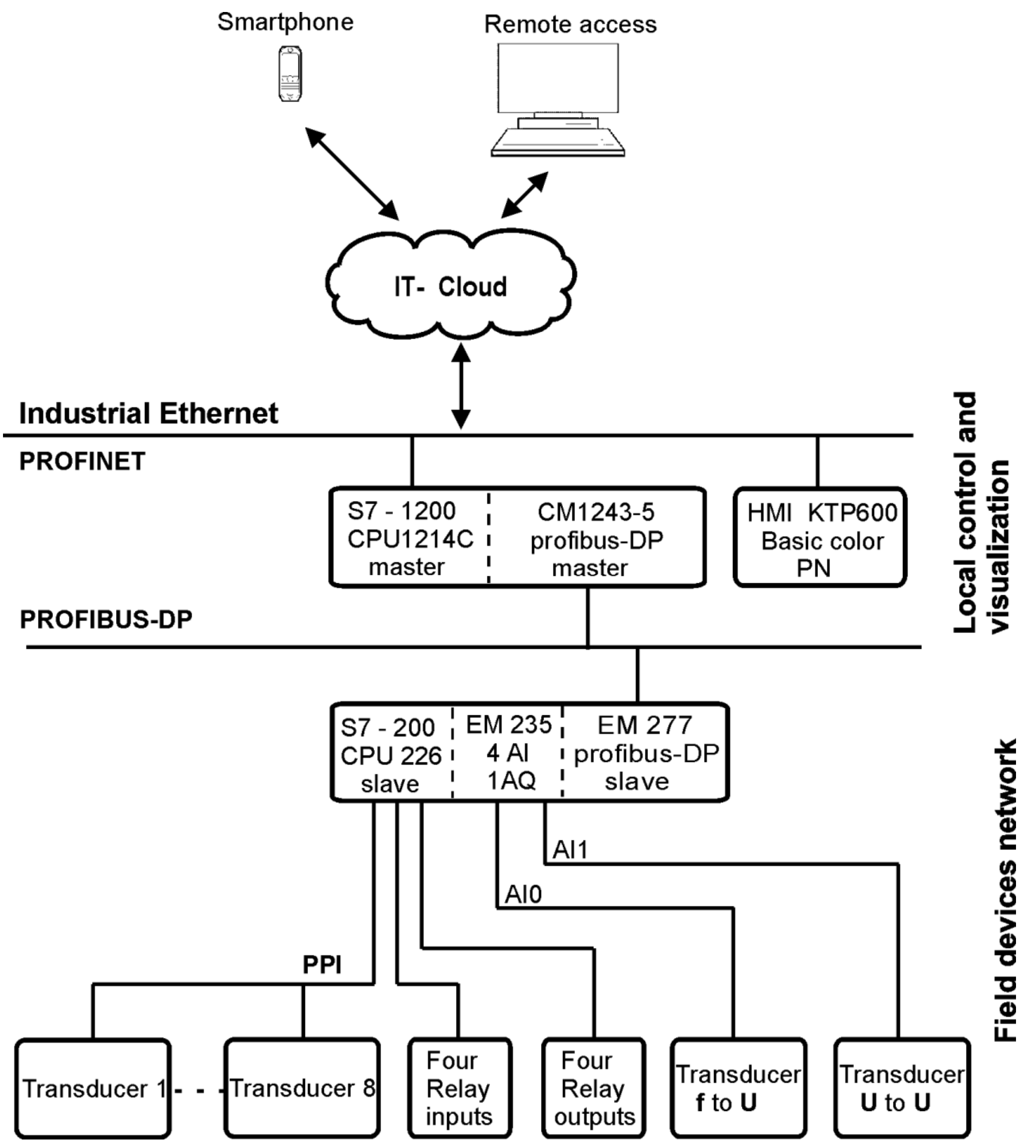

Fig. 3. Block diagram of a multi – layer system for remote monitoring of a substation.

The PLC Simatic S7-1200 [10] is working as a proxy for the transducers network and provides the following functions:

- analyzing and processing data, received from the PLC Simatic S7-200;
- control of the Relay outputs module;
- control of he HMI Siemens KTP600 basic color PN;
- migration of the information from the substation to the cloud.

HMI Siemens KTP600 is used for visualization of relevant information from the substation.

B. Software

Modern automation technology including a built-in Ethernet-based communication increasingly integrates Internet technologies which enable direct access to a particular system via the Internet or Intranet. For access mechanisms via the Internet or Intranet it is reasonable to use already existing standards such as the HTTP technology, standard Web browsers and common "languages" such as HTML or JavaScript.

By having access options through various web browsers, control data can be displayed and to a limited degree controlled, by any computer or mobile communication devices such as tablet PC and smartphone without additional software installation as it is depicted in Fig. 4.

To realize an access to a CPU via standard Web procedures, the following requirements are to be met:

- access the CPU with standard hardware and standard procedures via Industrial Ethernet - it is not required any additional hardware and software;

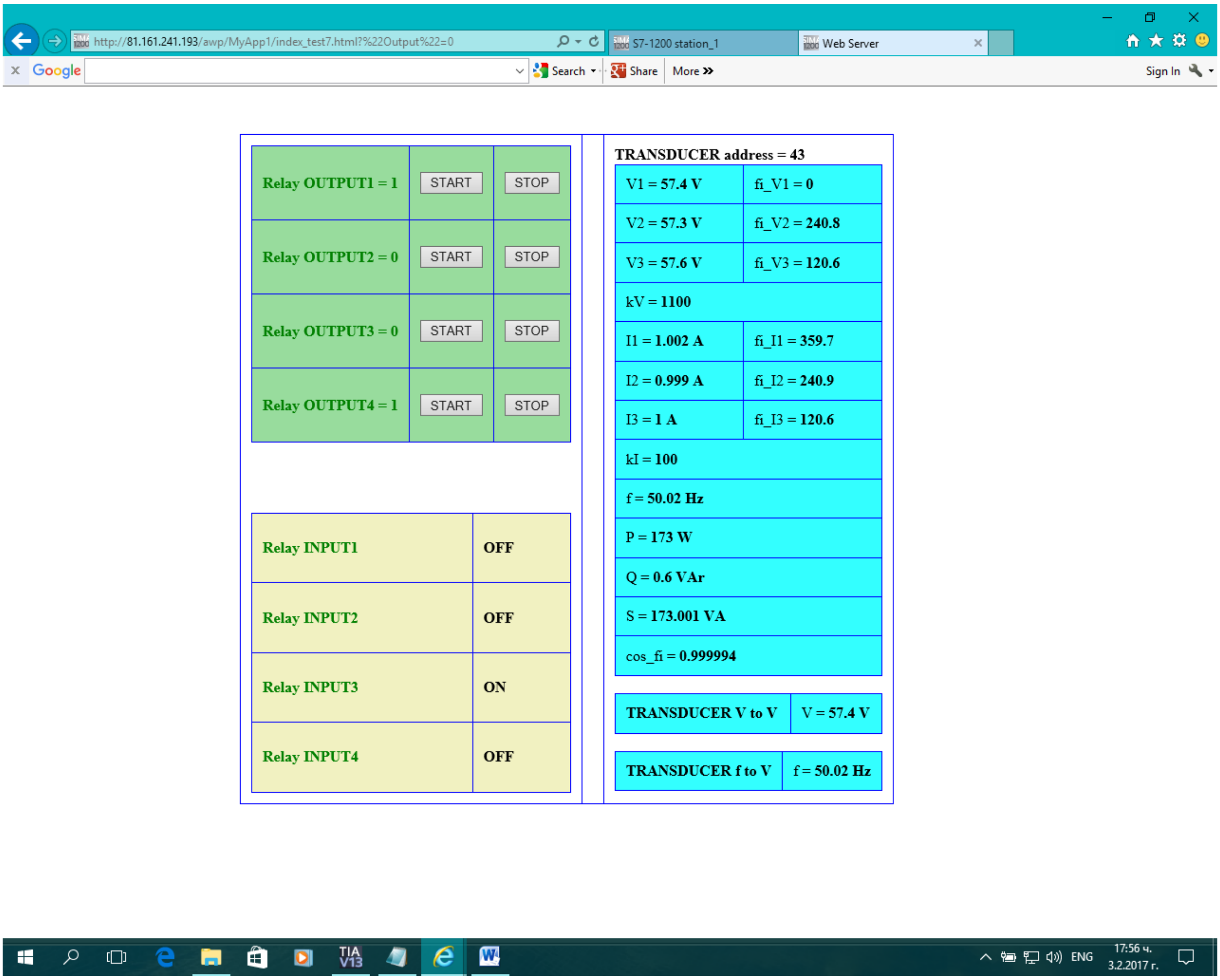

Fig. 4. View of the HMI for remote monitoring of a substation.

- access the CPU individually related to the system and also visualized, if required;
- each CPU to have its individual Web server and Web pages.

The creation of user-defined pages for the CPU provides the following functions:

- displaying CPU variables;
- graphic display of CPU variables;
- setting CPU variables;
- checking the input values with Java script;
- displaying texts which are linked with CPU variables;
- displaying pictures which are linked with CPU variables;
- going to Web pages with links in the navigation bar;
- cyclic refreshing of the Web page;
- automatic refreshing of the variable with Java Script.

Siemens SIMATIC CPUs with PROFINET interface provide the opportunity to access tags of the CPU with the help of Web pages provided by the system. PROFINET facilitates rapid and safe data exchange on all levels and thus supports the realization of innovative machine and plant concepts. With PROFINET Siemens uses the Ethernet standard for automation. PROFINET offers maximum flexibility to the user when it comes to designing the machine and plant architecture because of its inherent flexibility and openness. The efficiency of PROFINET ensures the optimum utilization of available resources as well as a considerably increased plant availability. Innovative Siemens products coupled with the performance of PROFINET result in a sustainable increase in corporate productivity. As a part of IEC 61158, PROFINET is based on the international Ethernet standard (IEEE 802.3) as well as Fast Ethernet (100 Mbit/s) and switching technology. Two special PROFINET features, the integrated use of real-time and TCP-based communication on one line as well as scalable real-time communication for controllers, distributed IO and Motion Control facilitate short response times and continuity from the field level all the way up to the corporate management level –

even wirelessly with Industrial WLAN. The integrated Web server of the Siemens S7-CPU is accessed via a standard Web browser. In addition to the standard mechanisms of the Web page such as identification, diagnostic buffer, module status, communication, variable status and data log, individual Web pages can be designed and called for a particular application.

The communications resources of Simatic S7-200 CPU 226 include two ports realizing RS-485 serial interface. Port 0 operates with the transducers network using Freeport (custom) protocol and 9.6 kbaud rate is chosen to correspond to the same value that is used by the transducers. The maximum number in the transducers network is defined as 32. The software is developed for eight transducers. Port 1 is used for programming the controller. Two 12-bit analog inputs of the module EM235 are provided to measure output signals of one voltage and one frequency transducers. The realtime data from transducers and Relay inputs/outputs without processing are stored into a buffer which is transferred to the upper level of the system via Profibus-DP interface, in this case PLC of Siemens Simatic S7-1200 CPU 1214C extended with Profibus DP master module CM1243-5. MicroWIN programming package V4.0 STEP 7 is used for the realization of software for PLC Simatic S7-200.

The TIA Portal V13 programming package of Siemens is used to realize the necessary software for the PLC Simatic S7-1200 and the HMI Siemens KTP600. The realtime data received from the PLC Simatic S7-200 are processing and the main quantities of the three phase electric power system – voltage, current, frequency active power, reactive power, power factor, active energy and reactive energy – are stored into a buffer. The appropriate tags are developed that give the relationship between the realtime data from the buffer and the displayed values on HMI. The "Webdata block" is created in order to integrate realtime data buffer with built-in web server. The HTML software is developed to provide the appropriate user-defined Web pages. Thus the information from the substation is easily accessible in the IT – cloud. After passing the client authentication, the Web clients can read and control the data of the substation.

V. CONCLUSIONS

The proposed model for organization of remote monitoring has passed laboratory tests using power system simulator, universal power transducers and PLCs. The system is flexible and reliable which is due to the application of rugged industrial devices like PLCs. Their usage is a common approach in the industry automation. In addition to the general application of PLCs, using their communications abilities contributes new possibilities for industrial networks development allowing measurement, data transfer, processing and storage. Standard Web browsers allow access to the developed remote HMI from anywhere in anytime. The presented results will be used in further investigation of more complex systems for electric power management.

ACKNOWLEDGMENT

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