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Abstract

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Application of PLC as a Gateway in a Network of Smart Power Transducers

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Abstract: The modern control of the electrical power system faces various challenges caused by the introduction of renewable energy sources and rapidly changing loads. Key problem in reaching successful and sustainable control is the smart sensor networks development. The paper presents an approach for development of such network using the possibilities of the programmable logic controllers. The considerations in the organisation of the network and the choice of a PLC as a gateway are discussed. The main options of the proposed software solution are explained.

Keywords: PLC, smart power transducer, industrial network, electrical power system, control.

1. INTRODUCTION

The electrical power system (EPS) is very complex and consists of some major parts – manufacturing, distribution and consumption. The modern control of such systems faces various challenges caused by the introduction of renewable energy sources and rapidly changing loads. Although the topology and structure of processing plants are usually fixed, a challenge is still given by the large size of a typical plant, which may have thousands of actuating, sensing and controlling devices. This makes the design, deployment, management, and maintenance of a process monitoring and control system significantly more difficult as it is explained by Karnouskos et al. (2012). This requires the application of innovative approaches in the automation systems aiming energy efficiency increase. Key problem in reaching this goal is the smart sensor networks development. One device becomes smart through the integration of embedded processing and the next logical step is remote communication with the smart device as it is depicted by Freescale and ARM. In the electrical power system are in use transducers, which measure the values of the main quantities of the three phase electric power system – voltage, current, frequency and calculate the derivatives – active power, reactive power, power factor, active energy and reactive energy. The block diagram of such transducer is shown in Fig. 1.

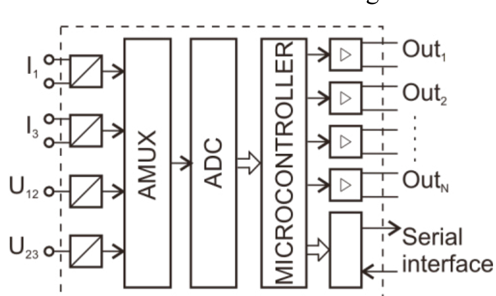

Fig. 1. Block diagram of a smart universal transducer.

Most of the transducers have two types of interface: analog and digital. The output quantities of the analog outputs can be load independent direct current or direct voltage signals. The range of the current outputs may be different - -5mA÷ +5mA, 0mA÷20mA or 4mA÷20mA. Usually the range of the voltage outputs is 0÷10V. The transducers may have several analog outputs. Their number limits the number of the quantities which values can be transmitted as it is mentioned by Yakimov et al. (2005).

The digital interface is usually serial in order to minimize the number of the wires. The standard is mainly RS-485 or RS-232. There are custom defined interfaces as well.

The digital interface uses only two or three wires but presents the possibility to transmit the values of all parameters of the electric power system. This transfer has higher noise immunity than the analog.

At a given point of the electric power system – power plant, sub-station, there are usually a big number of transducers. It is useful they to be included in an industrial network. The digital interface makes it possible.

The network can be developed using the well known configurations – star, ring, bus etc. In order to minimize the connections bus topology is suitable.

2. SMART UNIVERSAL MEASURING TRANSDUCER

In the Development Laboratory for Semiconductor Circuits Design at Technical University of Sofia have been designed smart universal transducers for use in the electric power system. The most common used transducers in the electric power system are connected to three phase grids with delta configuration and asynchronous load. This system has three wires. The input variables are the line voltages U12 and U23 and the phase currents I1 and I3. This is known as the method with two wattmeters. The voltage range is 130V and the current range is 6A.

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They have standard serial interface RS-485, electrically isolated, which allows development of industrial network using bus topology as it depicted in Fig. 2. The serial interface operates with 9600 bit/s baud.

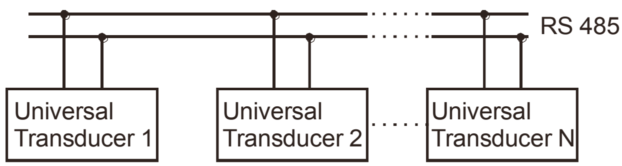

Fig. 2. Universal transducers in an industrial network.

The high rate of data transfer enables transmission of large amount of information. The data transmitted by the transducer includes the values of line voltages (U12, U23), phase currents (I1, I3), active power (P), reactive power (Q), frequency (f), active and reactive energy in four quadrants (ENA+, ENA-, ENRL, ENRC), ratios of the voltage and current measuring transformers (kU, kI), phase angles of the vectors in relation to U12 (φU23, φI1, φI3). The last two bytes contain the checksum (CS) and the value is the sum of the all bytes of the buffer. The communication data buffer is described in Table 1.

Table 1. Data buffer description

Byte number	Value	Format
0	address	HEX - 11xxxxxx
1	command	HEX - 10xxxxxx
2	40 ($28)	HEX - 00101000
3, 4	U_{12}	HEX - 0aaaaaaa, 0bbbbbbb
5, 6	U_{23}	HEX - 0aaaaaaa, 0bbbbbbb
7, 8	I_1	HEX - 0aaaaaaa, 0bbbbbbb
9, 10	I_3	HEX - 0aaaaaaa, 0bbbbbbb
11, 12	P	HEX - 0±aaaaaa, 0bbbbbbb
13, 14	Q	HEX - 0±aaaaaa, 0bbbbbbb
15, 16	f	HEX - 0aaaaaaa, 0bbbbbbb
17, 18, 19, 20	ENA+	BCD
21, 22, 23, 24	ENA-	BCD
25, 26, 27, 28	ENRL	BCD
29, 30, 31, 32	ENRC	BCD
33, 34	k_U	HEX - 0aaaaaaa, 0bbbbbbb
35, 36	k_I	HEX - 0aaaaaaa, 0bbbbbbb
37, 38	φU_{23}	HEX - 0aaaaaaa, 0bbbbbbb
39, 40	φI_1	HEX - 0aaaaaaa, 0bbbbbbb
41, 42	φI_3	HEX - 0aaaaaaa, 0bbbbbbb
43, 44	CS	HEX - 0aaaaaaa, 0bbbbbbb

The value of the first byte is the physical address of the transducer in the network. It is limited to 50.

The next byte contains the value of the command. When it is $82, the transducer transmits the whole buffer.

The third byte always has the value $28.

After that starts the information part of the buffer consisting of the values of the quantities of the electric power system. They are in three formats. In each of them the value of the bytes is limited to $7F. So they are transmitted as ASCII string and could be recognized by standard processing programmes.

The first format is unsigned hexadecimal integer. It has length of two bytes and the mode 0aaaaaaa, 0bbbbbbb. Using this format the values of the quantities have the following accuracy: voltage – 0,1V, current – 0,001A, frequency – 0,01Hz, phase angle – 0,1°.

The second format is signed hexadecimal integer. It has length of two bytes and the mode 0±aaaaaa, 0bbbbbbb. This format is used for the values of the active and reactive power which have different signs in the four quadrants of the complex plane. The accuracy is 0,1W or 0,1VAr.

The third format is BCD. It is used for the values of the active and reactive energy. It has length of four bytes. The weight coefficients of the bytes are as follows: 100000Wh for the first byte, 1000Wh for the second, 10Wh for the third and 0,1Wh for the fourth byte.

3. CONSIDERATIONS IN CHOOSING PLC AS A GATEWAY

The gateway is a circuitry used to interconnect networks by converting the protocols of each network to that used by the other. 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. The goal of this research is to investigate the abilities of standard devices like PLC for application as a gateway in networks of smart power transducers. The successful application could lead to additional advantages. Besides using the PLC for mastering the communications and to connect the transducer network to SCADA systems its possibilities to handle analog and digital signals can be used to control another devices from the electrical power system. The digital inputs can be used to capture the states of contacts. The digital outputs can control under a programme relays and switches. The analog inputs can be connected to analog sensors of different quantities from EPS, for example to the analog outputs of power transducers. Also they can monitor some important parameters like temperature of the transformers and etc. Thus the flexibility and the universality of PLC make them suitable and useful tools for application in control systems including SCADA in the electrical power system.

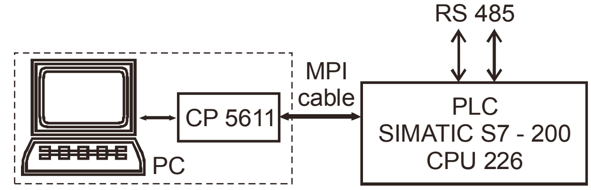

Fig. 3. PLC Simatic S7-200 CPU 226 as a gateway to an industrial network.

For the purposes of this project the PLC of Siemens Simatic S7-200 CPU 226 is chosen. Its possibilities are enough to maintain the smart transducers network and to control digital inputs and outputs. As it is depicted by Siemens (2009) the 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.

The set-up is shown in Fig. 3. A communication processor module CP 5611 is added to the personal computer which enables it to communicate using MPI protocol.

4. SOFTWARE DESIGN

The STEP 7 MicroWIN V4.0 programming package is used for realization of the program. During the startup initialization the communication parameters for the Port 1 are set: Micro/WIN → CP5611(MPI) interface and 19200 baud rate. This port is provided for programming the controller and receiving the manipulated data from the transducers, which will be displayed on a PC monitor.

The flow chart of the main PLC program is shown in Fig.4. Port 0 is initialized as described above. Interrupt event 8 is attached to interrupt routine INT1 to enable INT1 as the receive interrupt routine. Interrupt event 8 is triggered when a byte is received at port 0. Interrupt events are enabled.

In the main program is provided a programming timer (On-Delay Timer) representing 300 ms. The timer is starting when the address of the transducer and command are transmitted.

If during the time interval from 300 ms the transducer's data are received without "receive error" and "data error", the data are valid and must be manipulate.

Similarly the measured data are received in ASCII code and must be consecutively converted to HEX string and to array of digits in order to be manipulated. According data buffer submitted in Table 1 there are three data formats, so three types of manipulation are needed. The first one is manipulation of unsigned integer represented with two bytes (voltages, currents, frequency, phase angles and ratio of transformers from Table 1). In order to eliminate unused zeros high byte is multiplied by 256 and low byte is multiplied by 2. Two results is summed and divided by 2.

The equation is:

unsigned integer represented with **two bytes** = ((**high byte**)*256 + (**low byte**)*2) / 2.

Similar programming code is developed for second and third type of manipulation for signed two byte integer and for four bytes in binary decimal code.

Ready data for visualization are stored into a buffer and are intended for the program WinCC flexible.

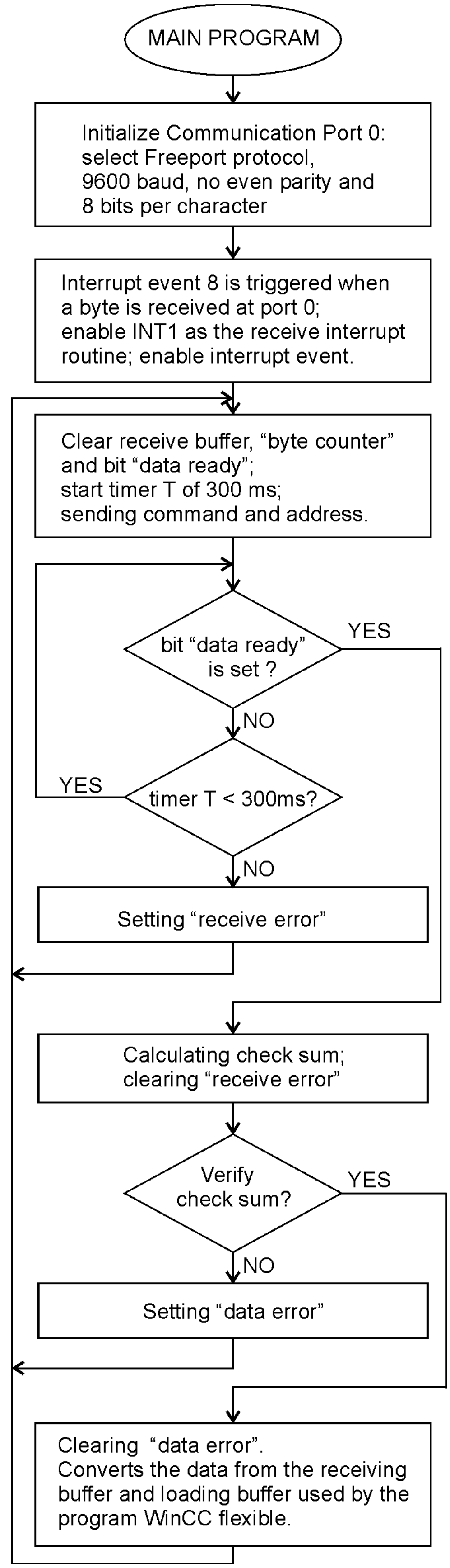

Fig. 4. Flow chart of the main PLC program.

The flow chart of the interrupt INT1 routine is depicted in Fig. 5.

When a byte is received at port 0, the interrupt routine is executed. The received byte is stored in receive buffer and “byte counter” is incremented by 1. If all of the bytes have been received, the bit “data ready” is set to 1.

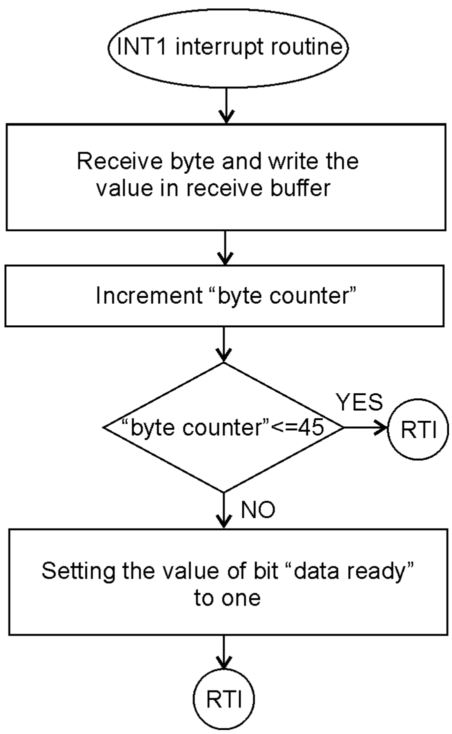

Fig. 5. Flow chart of the interrupt routine.

The SIMATIC WinCC flexible 2008 programming package is used for visualization of power transducers data.

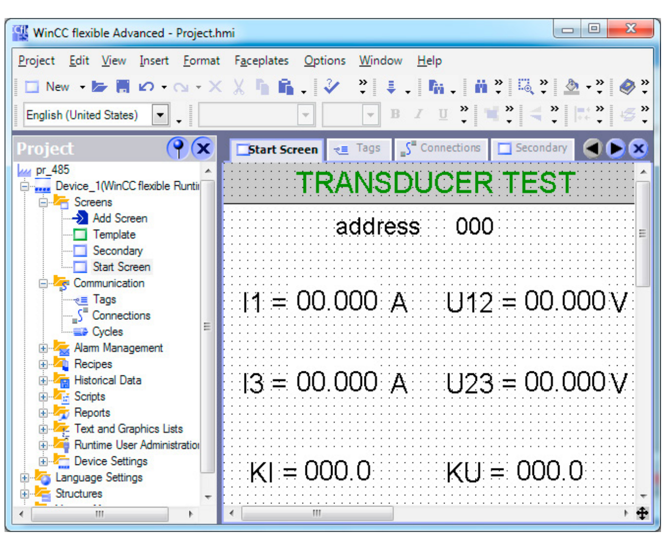

Fig. 6. Front panel for “Start Screen”.

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.6 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.

4. CONCLUSIONS

A system based on PLC as a gateway in a network of smart power transducers for parameters calculation and monitoring of three-phase power line is developed and considered in the present paper. The system can capture the signals from the power line and display the values of active power, reactive power, frequency, voltages and currents, active and reactive energy in four quadrants, phase angles, ratio of transformers and etc. The system can process data of up to 32 power ttransducers connected via industrial network using standard serial interface RS-485. The system can be easy adapted for data collection where the user can set the frequency of data collection and it can be restored. The presented results will be used in further investigation of more complex systems for electric power management.

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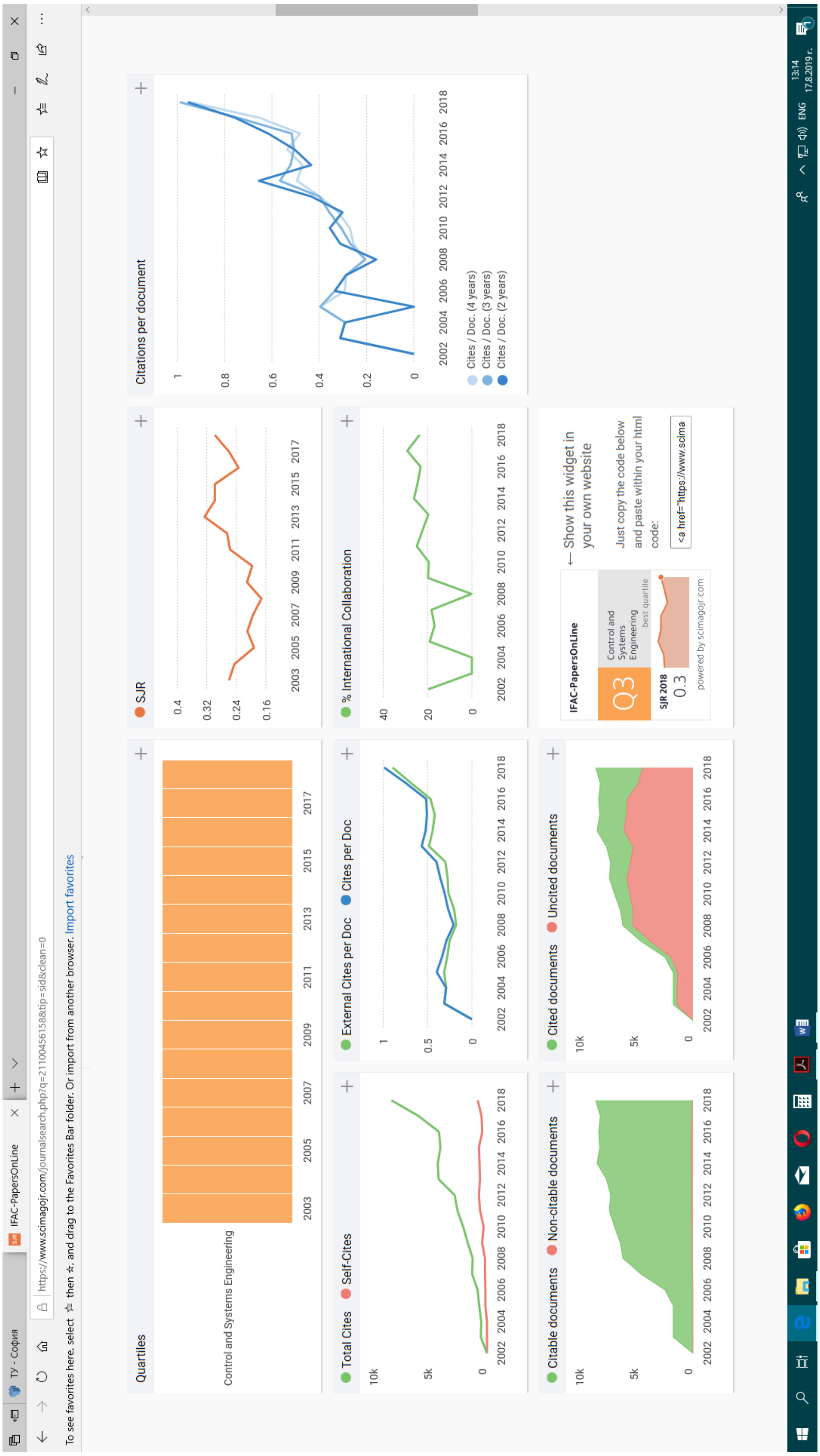

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