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Measurement system with wireless communication for acquisition of current signals

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***Abstract*— This paper presents the implementation of a system for the acquisition of current signals and their wireless transmission using available hardware components. The basic idea of this project is to perform test measurements in inaccessible parts of the plant using a programmable logic controller and send them to a computer via a Wi-Fi connection using the MQTT protocol. The electrical scheme of the project was realized in the SEE Electrical program, while the PLC was programmed in the Velocio vBuilder program.**

***Keywords*— SEE Electrical, vBuilder, ACE Gateway, ACE PLC, system, measurement, current signal, 4 mA to 20 mA, MODBUS.**

I. Introduction

Measuring various physical quantities in industry is a daily occurrence. There is no branch of industry that does not require the measurement of some physical quantity in production. In order to measure some physical quantity such as temperature, level, pressure, flow, voltage or current with electronic instruments, it is usually converted and scaled into a standardized current or voltage signal. The most commonly used current signal is 4 mA to 20 mA. In addition to it, 0 mA to 20 mA, 0 V to 10 V, -10 V to 10 V signals are also used. The reason why the current signal 4 mA to 20 mA is most often used is that with 4 mA the minimum value of the measured physical quantity is detected, while anything below that is classified as wire damage.

This paper presents an example of a test system for the acquisition of 3 analog current signals. The goal of such a system is to perform a temporary measurement at a specific position in the production facility and to send the measurement results wirelessly to a computer. In this way, unnecessary installation of cables in the plant is avoided. Connecting measuring devices to the system is very simple and is done via a 3-pin connector. Hardware of this system has the ability to supply the current loop with 24 VDC on all three channels (loop power) or to connect only the current signal to one channel in case the transmitter is powered from another source.

Also, the paper will show test measurements of signals on all three channels. On one channel, the temperature measurement with a Pt100 probe is connected to the corresponding measuring transducer. The SIEMENS QFA3171 device is connected to the other two channels, which provides information on the ambient temperature and air humidity at its outputs.

In addition to the hardware part, a complete software part was also developed for this system. A simple control code for PLC was developed. Also, the MQTT gateway as well as the MQTT broker are set up.

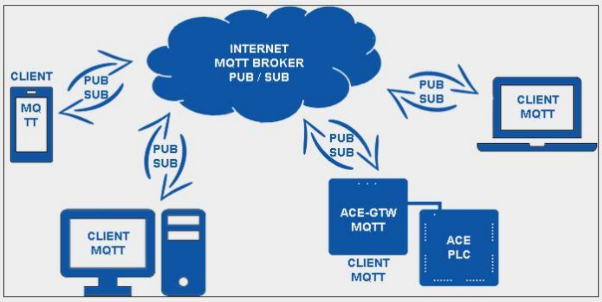

Figure 1. Illustration of the appearance of the system in reality [1]

II. Analysis of System Parts

A. *Electrical schematic of system*

The electrical scheme of the system for acquisition and wireless transmission of current signals was designed in the See Electrical programming environment. See Electrical is a program that is used to draw electrical diagrams for industrial devices, that is, for associated electrical cabinets.

The system is designed to be powered from a 230 VAC mains supply. The measuring system has a connector on it. A cable with a voltage of 230v is connected to it. By using this type of power supply, it is possible to use any outlet with mains voltage in the plant for the purpose of test measurement. By means of a switching power supply, the AC voltage is converted into a DC voltage of 24 V. The switching power supply can deliver a maximum of 1.1 A of current at its output, that is, about ~25 W of power. DC voltage 24 V is used in one part to power the sensor, while in the other part the same voltage is lowered again to 5 V using a step-down regulator. A voltage level of 5 V is used to power the PLC as well as the MQTT Gateway.

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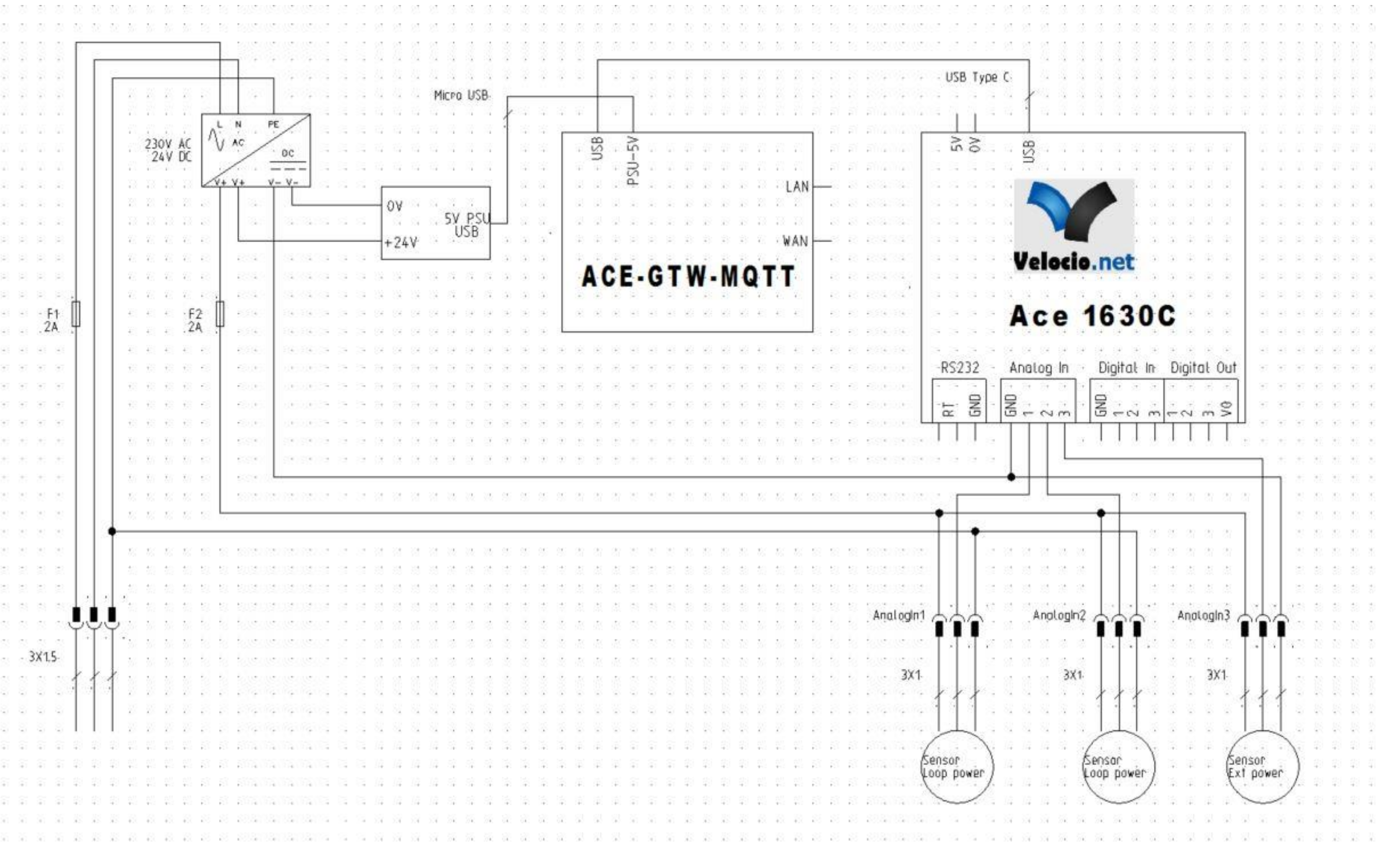

Figure 2. Electrical scheme of the hardware realized in the See Electrical program

B. PLC

The data acquisition component is the ACE 1630c PLC. PLC stands for Programmable Logic Controller. As its name suggests, this component can be programmed depending on the need or purpose of the machine or device. A particular PLC model has a scan cycle of 110 µS. This enables it to process analog data very quickly and acquire signals, which is what it is used for in this project. ACE 1630C consists of 3 digital inputs, 3 digital outputs, 3 analog inputs and an RS232 communication port.

Figure 3. ACE 1630c PLC [2]

C. MQTT Gateway

MQTT ("Message Queuing Telemetry Transport") is an open pub/sub protocol designed for constrained devices used in telemetry applications [5].

MQTT Gateway is a component that serves to establish communication between the PLC and the broker/computer. The role of the gateway is to read the signal values from the MODBUS registers and to place them in the appropriate MQTT topics, as well as to send the same topics via a Wi-Fi connection to the appropriate broker. The broker will process this data and send it via MODBUS TCP communication to the DCS server where the data will be stored and displayed.

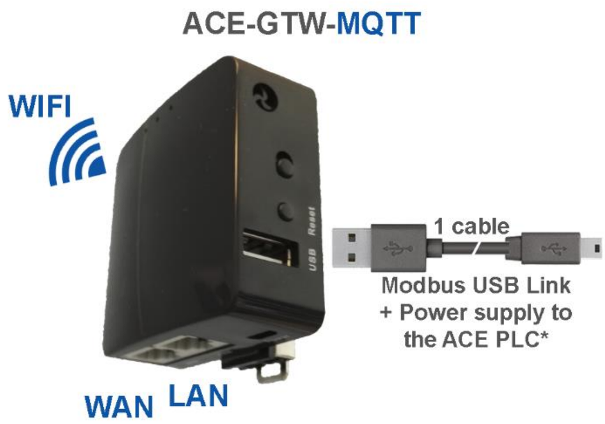

Figure 4. Mini Modbus MQTT Gateway
Ethernet/Wi-Fi MQTT Client to USB Modbus RTU Master Gateway [3]

By means of the Mini Modbus MQTT Gateway, all scaled data are sent from the ACE PLC to the MQTT broker, i.e. to the computer wirelessly. A USB connection is used to connect MQTT Gateway to the PLC. Via USB, the PLC is powered by a voltage of 5 V and also communicates with MQTT Gateway. Communication takes place via the MODBUS protocol. In order to set up the MQTT Gateway, it is necessary to set up MODBUS communication on the one hand, while on the other hand it is necessary to make network settings for communication via a Wi-Fi connection. The MQTT Gateway device can be accessed through the web interface in 2 ways. The first way is through a network cable through the LAN port and the second way is through a Wi-Fi connection. In both cases, it is accessed by entering the IP address in the web browser on the computer. In this case, the defined IP address for LAN connection is 192.168.8.1, while the Wi-Fi address is 192.168.1.5.
When it comes to MODBUS communication, the PLC has its own MODBUS registers to which the data to be sent is mapped. In this case it is 3 scaled analog inputs. MQTT Gateway accesses that data through the tag name in the PLC and through the corresponding register in the address field. Of course, the PUB option was selected for all three values because the data is sent (publish) from the PLC via the Gateway to the broker. If, for example, some digital output on the PLC were to be changed, the SUB (subscribe) option would be selected. In this case, the MQTT broker has the IP address 192.168.1.10, and the MQTT Gateway with the IP address 192.168.1.5 sends data to the broker.

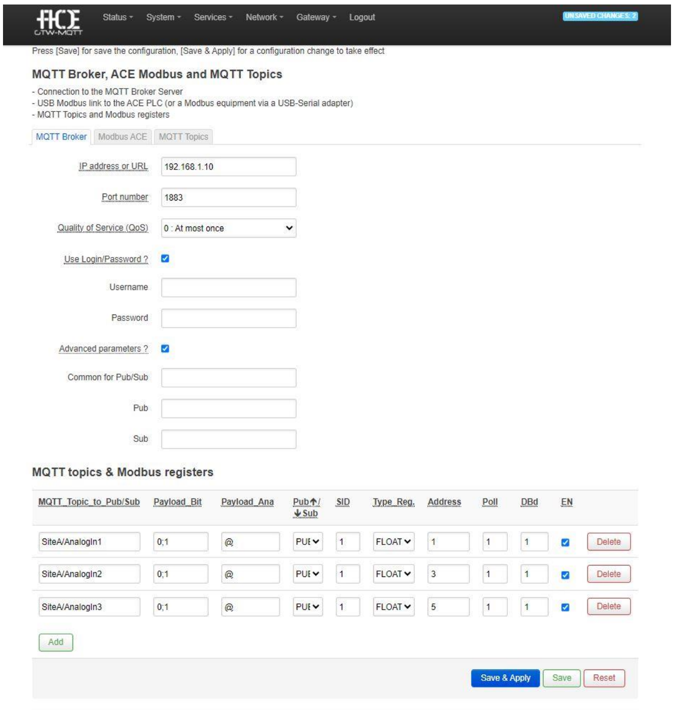

Figure 5. MQTT Gateway settings

D. Program code

The program for the PLC controller was written in the form of a Flowchart, i.e. flow diagram in the Velocio vBuilder programming environment. The program itself is very simple and consists of only 4 instructions. The START instruction is executed only once, when the PLC is turned on. This is where the working memory of the PLC is initialized so that new values can be entered into it. Then, from the START instruction, the program goes to the instruction for reading the first analog input. There, the analog input is read and mapped to a value between 0 and 4095 and scaled to a value between -2500 and 10000. This results in a signal value of 0 mA being mapped to -2500, 4 mA to a value of 0 while 20 mA is mapped to the value of 10000.
The values of the other two analog inputs are read and processed in the same way. After all the inputs are mapped, the cycle starts from the beginning. It is important to note that the scaled values are stored in the internal MODBUS register so that later on the MQTT gateway it can be set which values will be sent to the broker.

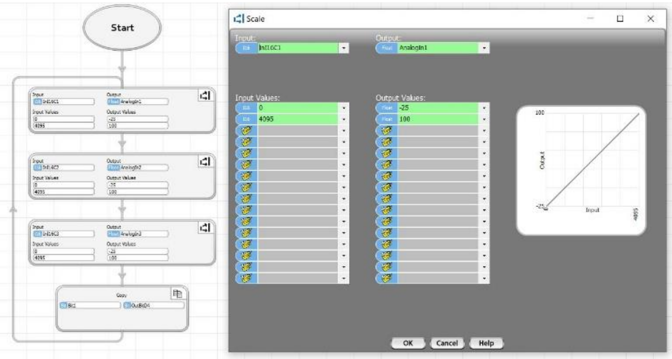

Figure 6. PLC code written as chart and scaling window

E. The principle of operation

The principle of operation of the system is based on the fact that the PLC collects a 0-20 mA current signal on its analog inputs. The PLC processes these signals and forwards them to the MQTT Gateway. Since the PLC has a 12-bit A/D converter, the same signal is converted in the range from 0 to 4095. In order to easily calculate any value of the physical quantity being measured, the signal scaling block is set so that for a current signal value of 0 mA the value at the output of the block is -2500, 4 mA is mapped to the value 0, while 20 mA gets the value 10000. The measured values are placed in the MODBUS register. The PLC is connected with a USB cable to a device that serves as an MQTT Gateway. MQTT Gateway reads data from the MODBUS register and assigns them to predefined topics. For example, the converted value of the signal from the first analog input of the PLC will be assigned to the MQTT topic "SiteA/AnalogIn1". In the same way, values will be assigned to the other two topics "SiteA/AnalogIn2" and "SiteA/AnalogIn3". Through a predefined Wi-Fi network that the user is required to set up, the system will send this data to the computer on which the server is installed, i.e. broker. There is also a client application on the computer that is responsible for reading MQTT topics. The same application processes the received data and forwards it to the distributed control system - DCS via MODBUS communication.

The system is connected to the mains voltage 230 VAC. It has a built-in switching power supply that outputs 24 VDC with a power of 25 W. A step-down power supply is used to power the PLC and MQTT Gateway, which lowers the 24 VDC voltage to 5 VDC. Knowing that most industrial measuring devices are powered by a voltage of 24 VDC, it is necessary to provide the mentioned power supply.

III. Data acquisition

In order to acquire data from the measurement system for wireless measurement of the system, it was necessary to install the MQTT broker on the computer. The role of that broker is to buy data from all clients who are subscribed to it and to forward the same data to the target device where further conversion of that data will be carried out and where the data obtained from the clients will be used for the purpose of measurement, analysis, control processes and the like. In the specific case, the data from this measurement system is sent to DCS where it is stored in the database and where it is possible to use it for the purpose of test measurements in order to obtain a clear picture of the behavior of certain measurements or sensors in operation. For the test measurement, 3 sensors were connected, of which two measurements were temperature measurements, while the third measurement measured air humidity.

The graphic shows the results of measurements with a test duration of 20 hours. The measurement resolution is 1 s, i.e. every 1 s the data received from the device was stored in the database. The measurement was carried out in the period from

16.11.2023. until 17.11.2023. The purple line on the graphic represents the temperature measurement from the Pt100 probe, i.e. the measuring transducer for Pt100. This measuring transducer converts the resistance of the Pt100 probe into a current signal of 4 mA to 20 mA in the range from -40 °C to +70 °C. This probe was resting on the insulation of the steam pipe, and a slightly elevated temperature can be seen. The blue line on the graphic represents the measurement of air humidity, and it can be concluded that the humidity during the measurement process was constant, i.e. it was around 30%. The orange line represents the ambient temperature measurement. The ambient temperature varied from 15 °C to 22 °C. For the purposes of these measurements, a SIEMENS QFA3171 temperature and air humidity probe was used. The humidity measurement is scaled from 0% to 100% while the temperature measurement is scaled from -40 °C to +70 °C, but the range from 0 °C to 100 °C is visible on the graph for better readability.

Figure 7. SIEMENS QFA3171 [4]

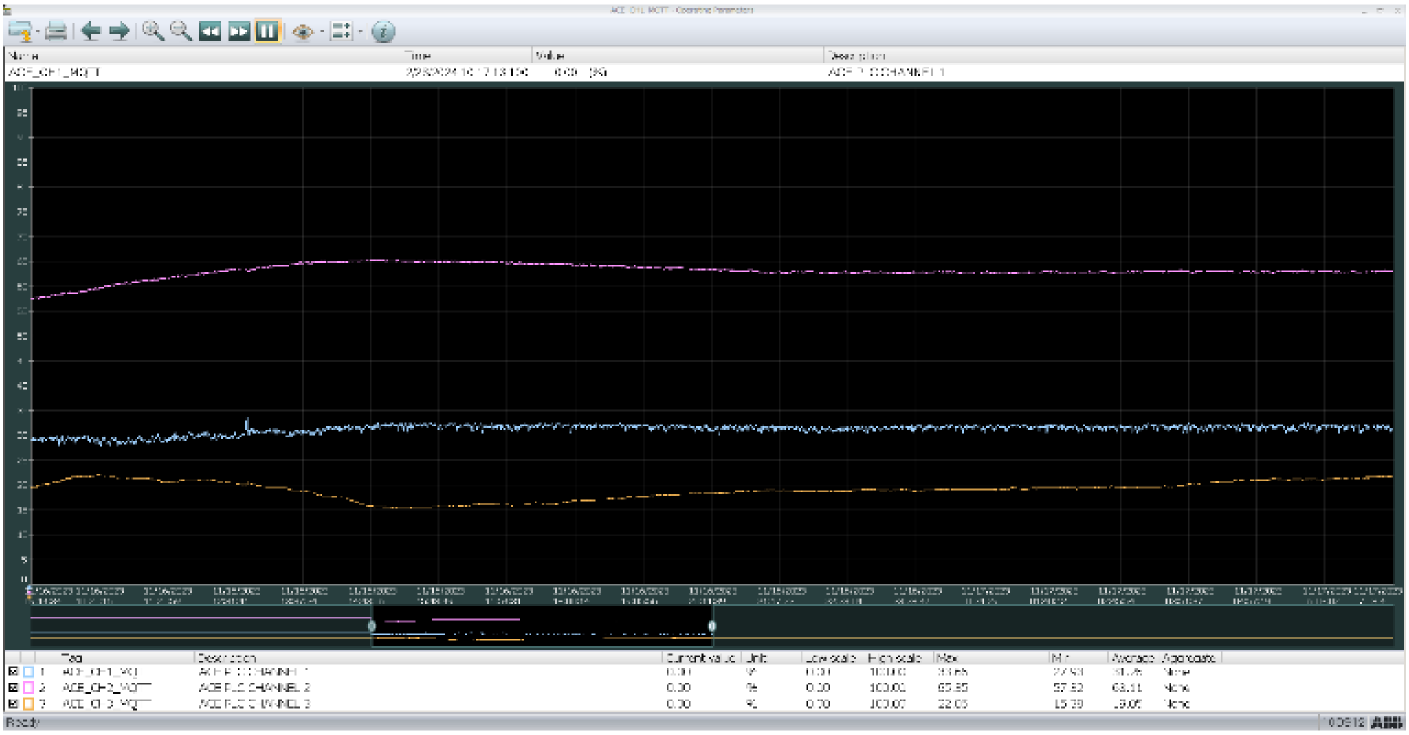

Figure 8. The measurement results

IV. Conclusion

Such a software and hardware solution can greatly facilitate individual test measurements in the industry and reduce the time required to implement the measuring equipment. Also, with this type of measurement system, it is easily possible to examine the justification of the investment in the measuring equipment. It is possible to perform a test measurement before the cable installation is placed to the measuring point. In addition, you can try several types of measuring devices and only then proceed with the installation when you reach a conclusion which is the most efficient measuring device.

Since the communication of this system with a computer or a complete system is based on the MQTT protocol, which provides a lot of possibilities. One of those possibilities is sending the measurement results to a cloud that can store the data and manipulate it in an appropriate way. In this way, we reach the sphere of industry 4.0, which means that a system for wireless measurement of current signals 4 mA to 20 mA would be of great help to advanced systems that collect, process and manipulate data and then manage systems without human presence and influence. In a word, the measurement system would also have applications in Industry 4.0 as a means of collecting information and sending it wirelessly.

The next step would be to definitely switch to battery power, because with the current implementation it is possible to perform test measurements, but only where there is a mains voltage of 230 V. Also, the system could be improved by adding more analog inputs or by having the possibility selection of several signal types and not only from 0 to 20 mA as is the case now. Of course, such modifications would require changing the current PLC because the currently installed PLC has only three current analog inputs. What is possible on the current system is to collect digital i.e. of binary signals with the addition of connectors because the PLC has 3 digital inputs and 3 digital outputs.

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