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Temperature Control Solution With PLC

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***Abstract*— In this paper, different solutions for power supply of a resistance used for the liquid heating were analyzed. The authors propose the best solution in terms of reliability, harmonic pollution of power network and precision temperature control. For this were used: the XC-CPU101 PLC, the XV102 HMI (Human Machine Interface) from EATON. The temperature control used a PID controller based on PLC and it was observed by HMI. Desired temperature is set by the user using the HMI and the PID controller, within the PLC, will try to minimize the error value as the difference between desired temperature and measured temperature by adjustment of a control variable.**

Keywords—temperature control; PID control; AC-AC converters; harmonic distortion; PLC

I. INTRODUCTION

Temperature control has a very important role in industrial/home applications and is difficult to be implemented through ordinary control techniques. PID controllers are widely used in temperature control. The advantages are the reliability and the satisfactory control results of such algorithms [1].

PID measures the differences between the desired temperature value and the actual temperature value by using the error calculated. It attempts to minimize it by adjusting the control input in order to obtain the desire output value. By tuning the parameters (proportional value, integral value, derivative value) in PID, the controller can realize a specific control action designed for different requirements [2]. The most common used controllers are the P controller, PI controller and PID controller.

The PID controller design can be implemented using a programmable logic controller (PLC) in order to control the time to heat up a liquid to a desired temperature, efficiently.

PLC has been widely used in the industrial control and other fields for its advantages like: small size, reliability and configuration flexibility features [3].

PLC has special PID programming instructions; therefore this control is implemented directly in software [4]. Differences between the set and real temperature values through the proportional, integral, differential operator have become the output of the controller. PID parameters can be set in the PID controller module configuration process.

Different solutions for power supply of a resistance used for the liquid heating were analyzed by authors. The temperature control used a PID controller based on PLC and it was observed by HMI.

II. PROPOSED HARDWARE SOLUTION

In this chapter an analysis of various hardware solutions that can be used for automatic temperature control and motivation for the solution adopted, are presented. For this we used the experimental arrangements illustrated in Fig. 1. Water heating is done with a thermal resistance of 1 KW supplied from the alternating voltage of 230 V. For temperature measurement was used a temperature sensor LM35 mounted on the tank surface (with a constant of 10 mV/°C). To adjust the water temperature in the tank, a PI regulator was used. We choose the best solution in terms of reliability and harmonic pollution of the power network.

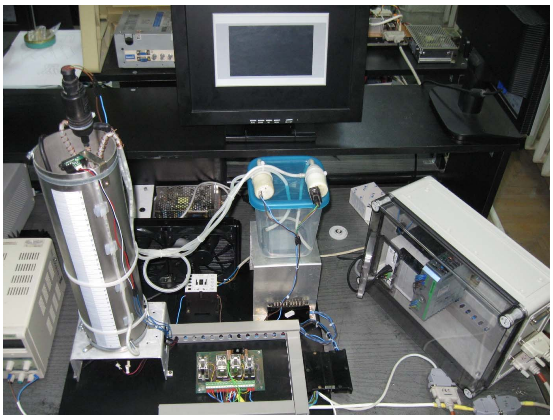

Fig. 1. Experimental arrangement

The system consists of the following components:

- an electrical resistor with which it heats water in the tank;
- a temperature sensor LM35, which measures the temperature of the water. The voltage from sensor, which is proportional to the water temperature, is read by the PLC through an analog input;
- a PLC XC-CPU-101 at which is connected an analog input/output module. Four of the PLC digital outputs are galvanically separated with four relays;
- HMI (Human Machine Interface) XV102, used for easy monitoring and control system. The communication

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between HMI and PLC is performed through CANopen protocol.

If the prescribed temperature exceeds the maximum permissible, the system allows water heating only up to the maximum allowed value. To prevent switching oscillations in this case this value was accompanied by a band of hysteresis.

For achieving a system that maintains constant water temperature in a tank, using a PLC, we can use the following solutions:

- The supplying of a resistor (which heats the water), through an AC/AC converter. This solution has the advantage that the RMS voltage is continuously adjusted according to the real and prescribed temperature, but it has the disadvantage of harmonic pollution in power network. The current and voltage harmonics spectrums of the AC/AC converter are determined by the load and the thyristors delay angle. For example Fig. 2 shows current and voltage waveforms/ harmonic spectrums for the AC/AC converter when the thyristors delay angle is 90° [5]. With increasing of thyristor delay angle, the RMS voltage decreases, but the current and voltage harmonics increase.

- <u>The supplying of a resistor, through an electromagnetic contactor</u>. This solution is cheap, but has the disadvantage of low reliability because for an efficient temperature adjustment, a large number of commutations are used.

- <u>The supplying of a resistor, through a solid-state relay.</u> The solid-state relay (SSR) is an important power electronic device within automation power systems [6]. SSRs perform the same circuit function compare with electro-mechanical relays (EMRs) [7]. SSRs have a sensor which responds to a control signal, a solid state electronic switching device which switches power to the load circuits and a coupling mechanism to enable the control signal to activate this switch without mechanical parts [8].

This solution has the following advantages: high reliability because it has no mechanical parts in use, currents switching zero because the switching (turn ON / turn OFF) is made at the zero crossing of the voltage supply, do not pollutes with harmonics and its control is easy. The solution has the disadvantage of a relatively high cost price.

For the proposed solution, we choose the SSR because its benefits are superior to the other two versions.

III. THE SOFTWARE APPLICATION

The software application for PLC is made in XSoft-CoDeSys (an acronym for controller development system), a development environment, according to the IEC 1131-3 standard. The CoDeSys accepts six different programming languages as follow: *Instruction list* (IL), *Ladder diagram* (LD), *Function block diagram* (FBD), *Sequential function chart* (SFC), *Structured text* (ST), *Continuous function chart* (CFC). The program developed for PLC, was made of several subroutines programmed in different languages. The temperature control is based on a PID controller. Depending on the set temperature and the real temperature measured with a temperature sensor, the PID controller adjusts the output value (heating time) between 0 and 200ms.

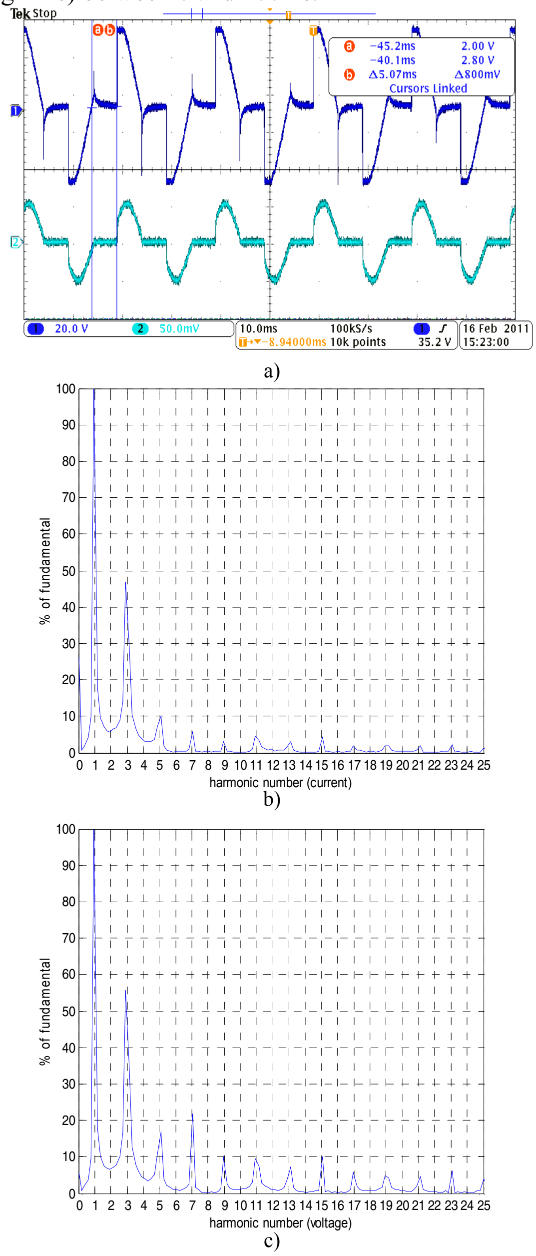


Fig. 2. Current and voltage waveforms/harmonic spectrums for AC/AC converter

The "Clock_Signal" subroutine is illustrated in Fig. 3 and it is programmed in Ladder Diagram language. This subroutine generates one pulse at every 200ms and the pulse width (generated by Timp_inc_time variable) is variable depending on the PID temperature controller output. The "Control" subroutine is shown in Fig. 4 and it is programed in CFC (continuous function chart language).

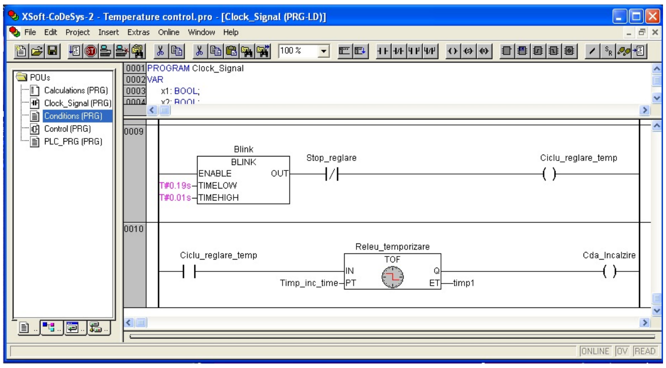


Fig. 3. *Clock_Signal* subroutine, programmed in LD language

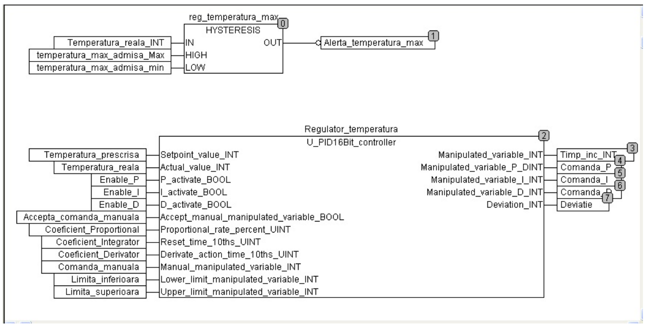


Fig. 4. *Control* soubrutine, programmed in CFC language

Depending on the set temperature and the real temperature measured with a temperature sensor, the PID controller adjusts the output value (heating time) between 0 and 200ms. At this controller we can set: the PID parameters (proportional coefficient Kp, integral coefficient Ki and differential coefficient Kd), the limits for the output value, cancellation of tuning function and activation of the manual command.

Fig. 5 shows a screenshot of the HMI window achieved. Through HMI, the system can be configured as follows:

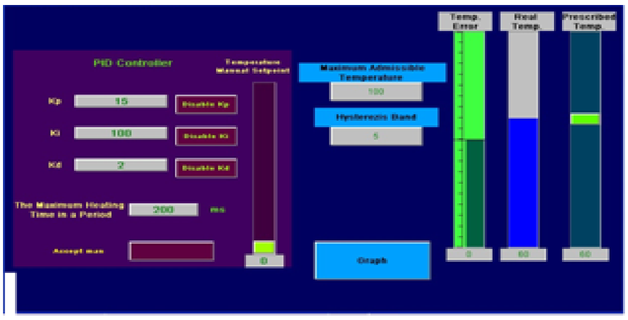


Fig. 5. The main mask in HMI

- enabling/disabling of PI controller functions
- setting the proportionality and integration constants for controller
- manual control of the system
- the prescription of the temperature value through a virtual cursor
- the reading of the real temperature of water in system
- the setting of the maximum temperature and the hysteresis band
- graphic display for variation in time of real temperature and prescribed temperature.

IV. The Experimental Results

The Fig. 6 and Fig. 7 show the results that were taken using Sampling Trace feature, available in CoDeSys. In these figures, with the green color was represented the prescribed temperature, with red the temperature measured by the temperature sensor through an analog input of PLC and with blue it is illustrated the digital signal which control SSR.

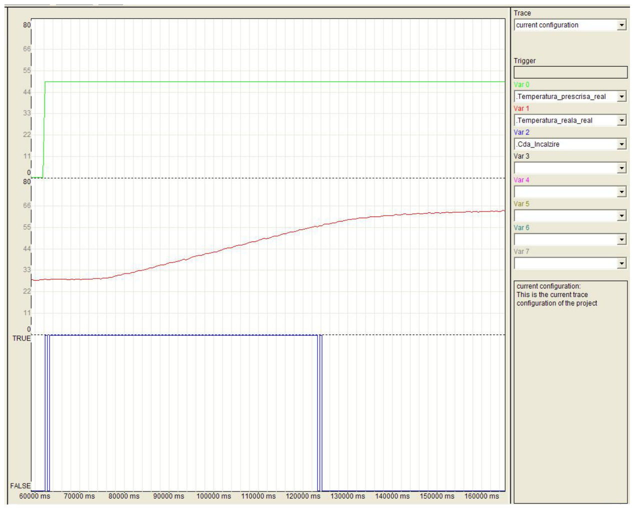


Fig. 6. Experimental results of heating regime in *Sampling Trace*

It can be seen in Fig. 6 that both at the beginning of the heating process and at its ending, the controller adjusts the voltage applied to the heating resistor by adjusting the duty cycle time, in a period of 200ms. Because the temperature measurement is not made by placing a temperature sensor directly into the liquid, but by its placing to the outer wall of the tank, it can be seen that from the moment when the regulator commands stop the heating process, the measured temperature continues to grow up. This is due to the time constant of heat transfer from the tank to the tank wall. To eliminate this shortcoming we should use a temperature sensor, immersed in liquid. Fig. 7 shows results during an operating cycle of regulator, when the temperature it's constantly maintained. When the actual temperature is lower than the desired temperature, it can be observed that the controller commands with PWM signals the SSR for maintaining the temperature at the set point.

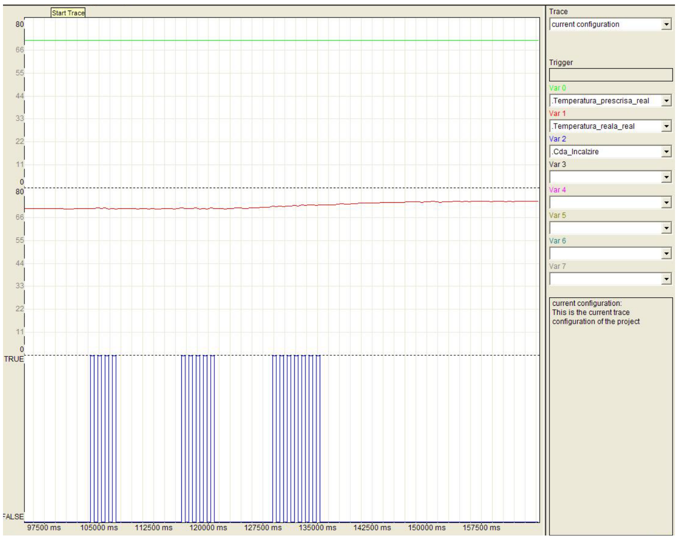


Fig. 7. Results, in *Sampling Trace*, during an operation cycle, in order to maintain the temperature constantly by the PID controller

The authors made a graph application in HMI, which can record both the prescribed temperature (with red color) and the real temperature (with green color). Fig. 8 illustrates the experimental results obtained from this graph in HMI.

Fig. 9 shows the SSR experimental results take with a scope. The signals illustrate have the following significations:

- Ch 1 – the SSR control signal from PLC (with blue color);
- Ch 2 – the SSR input voltage from power network (with green color);
- Ch 3 – the SSR output voltage used for supplying the heat resistor (with red color).

In Fig.9.a, the SSR signals at final time period of a heating process, is illustrated. It can be observed how the PWM control signal from PLC of SSR adjusting in time (the duty cycle of SSR control signal is reduced as the real temperature approaches to the prescribed temperature). The zero-crossover switching operating principle of SSR is detailed in Fig.9.b.

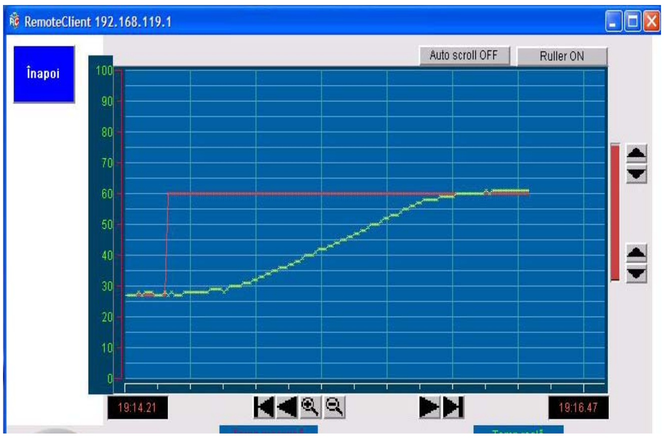
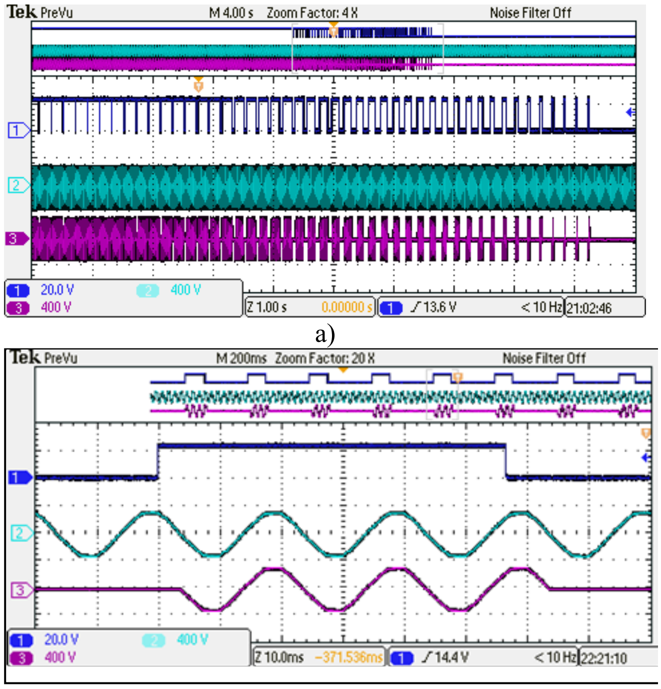


Fig. 8. Results recorded with the graph designed in HMI



a)

b)

Fig. 9. SSR experimental results

V. Conclusions

With the PLC, we have achieved the simplification of automation scheme. The Programming is simple because for the same program we can use subroutines in different languages (Instruction List, Structured Text and Ladder Diagram). The software can be customized for various practical cases. The solution for the temperature control was adopted after the analysis of three constructive variants about the supplying of the heating resistor through:

- an AC/AC converter;
- an electromagnetic contactor;
- a solid-state relay.

The authors choose the variant with SSR because it is more reliable than the version with electromagnetic contactor and does not pollute the power network with harmonics as AC/AC converter.

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REFERENCES

[1] J. Velagic, N. Osmic, K. Lutvica and N. Kadic, "Incubator system identification and temperature control with PLC & HMI," ELMAR, 2010 PROCEEDINGS, Zadar, 2010, pp. 309-312.

[2] R. E. Samin, L. M. Jie and M. A. Zawawi, "PID implementation of heating tank in mini automation plant using Programmable Logic Controller (PLC)," Electrical, Control and Computer Engineering (INECCE), 2011 International Conference on, Pahang, 2011, pp. 515-519, doi: 10.1109/INECCE.2011.5953937.

[3] R. Li, X. Du and P. Li, "Design of low-cost acquisition system for multi-channel analog signal for PLC and its application in temperature control system," Intelligent Control and Automation (WCICA), 2012 10th World Congress on, Beijing, 2012, pp. 93-98, doi: 10.1109/WCICA.2012.6357846.

[4] C. Weibin and M. Qingjian, "Based on PLC temperature PID - fuzzy control system design and simulation," 2010 International Conference on Information, Networking and Automation (ICINA), Kunming, 2010, pp. V2-417-V2-421, doi: 10.1109/ICINA.2010.5636480.

[5] G. Rata, V. Popa and M. Rata, "The Study of the Deforming Regime of AC/AC Converter using Fourier and Multiresolution Analysis," Elektronika ir Elektrotechnika, ISSN: 1392-1215, nr: No. 5(121), T 190, pp.7-12.

[6] A. Plesca, "Optimal Heatsink Design for a Solid-State Relay Using a 3D Modeling and Simulation Software," 2006 International Conference on Power System Technology, Chongqing, 2006, pp. 1-6, doi: 10.1109/ICPST.2006.321957.

[7] X. Zhang and H. Zhang, "The accelerated life experiment study of Solid State Relay," Quality, Reliability, Risk, Maintenance, and Safety Engineering (ICQR2MSE), 2011 International Conference on, Xi'an, 2011, pp. 349-351, doi: 10.1109/ICQR2MSE.2011.5976628.

[8] T. K. Smitha, B. A. Ravikiran, P. Karthik and T. K. Mondal, "Design and implementation of control of solid state relay switches using MSP 430 for instantaneous high current supply," Green Computing and Internet of Things (ICGCIoT), 2015 International Conference on, Noida, 2015, pp. 474-479, doi: 10.1109/ICGCIoT.2015.7380511.