A computer system for controlling temperature in a two-state mode and by means of a PI controller in an "intelligent building"

Tomasz Jarmuda
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3a, e-mail: Tomasz.Jarmuda@put.poznan.pl

The article presents the application capabilities of the LOGO! controller produced by the Siemens company with respect to heating control in an automated "intelligent building". The wide range of capabilities of the logic controller finds its reflection in practical implementation, as illustrated by means of a computer simulation example prepared in the LOGO! Soft Comfort v6.0 program. The work presents a comparative analysis of two programs serving two-stage heating control: with and without hysteresis, as well as a control program for an "intelligent" holiday cottage. The article also presents the results of parameter calculations for the B007 analog adapter, based on the examples of sample heating curve characteristics. The wide range of capabilities of the logic controller finds its practical implementation on the basis of examples of PI controller operation simulations in the LOGO! Soft Comfort v6.0 program.

1. Introduction

Electric energy consumption has increased within the last few years. Traditional electricity infrastructure solutions have been replaced with new power plants, new transmission lines, sub-stations, and new equipment that is connected with them. However, the process of localizing and constructing new transmission lines has become extremely difficult, expensive, and time-consuming. As a result, the recipients of electric energy from the power network are stressed with the compromised reliability and higher energy costs [1].

Despite the problems described above, the reliability of a power supply system is of key importance and cannot be compromised. The loss of a line causes overload, which, in turn, leads to ineffective operation of the power market [13].

Hence the justified need to implement modern, intelligent electrical installations should be based most of all on the security, energy efficiency, and reliability of power systems supplying automated complexes of intelligent buildings with electric energy obtained from renewable energy sources [5].

Transforming the current Electrical Power System (EPS) into a Smart Electrical Energy Network (SEEN) is of vital importance. The future of SEEN looks very promising thanks to the greater flexibility, reliability, self-control, and full automation of the system. SEEN will serve as a platform enabling co-existence of an intelligent network with a large number of recipients of the

Distributed Generation (DG), including centralized wind and solar power plants developed on a large scale [2, 3, 6].

The need for change requires removal of the obstacles connected with the use of distributed generations DG on a large scale. This will require research and development of a new, innovative technology of electric energy production, transmission, and distribution in relation to the communication tools with a much higher number of sensors compared to the number that is used now. That is why it is expected that elementary systems, such as the Flexible Alternating Current Transmission System (FACTS), the Custom Power Systems (CUPS), the Energy Storage Systems (ESS), the Distributed Generation Systems (DG), and intelligent devices owned by the end user including the communication among them will constitute the core of the future of SEEN [9, 10].

In the SEEN transmission system, the power of electronic devices of the CUPS, ESS, DG systems as well as the power of intelligent devices owned by the end user can be used in energy distribution systems in order to increase the reliability and the quality of the energy that is supplied to the clients [12, 14, 15]. Thanks to the use of modern technologies, it is possible to improve the reliability and the quality of the power supplied thanks to the reduction of the number of energy supply breaks. Proper usage of modern technologies will be beneficial to all the industry and commercial recipients as well as to household recipients [13].

All the available energy saving methods are used in "intelligent buildings". What is offered is the maximum level of environment microclimate comfort quality at minimum energy consumption devoted to that purpose. In the future, actions aiming at protecting the environment in building exploitation processes are also planned. This aspect leads to the creation of the next generation of an "intelligent building", the so-called „sustainable building", which is a balanced, environmentally friendly building. The buildings of the "green building" and "eco building" type that are currently constructed are signs of intelligent sustainable buildings [11].

The LOGO! controller produced by the Siemens company belongs to the micro controller group, sometimes also referred to as intelligent or programmable transmitters. They make it possible to provide control which means the operation of an object in such a way so that it would not require human intervention and which applies only to small objects. A small object is an object whose total number of inputs and outputs, also referred to as points, does not exceed 64. Our house can be classified as such an object [7].

2. Automation of an "intelligent building"

2.1. Controlling an "intelligent" holiday cottage

The control program for an "intelligent" holiday cottage is presented on Fig. 1, Fig. 2 presents a simulation of the program operation. The operation of the control system is initiated by means of a button attached to I1, which is manifested, for example, by the opening of the anti-burglary roller blinds. When the control system is switched off, the blinds are automatically closed. A temperature sensor attached to input AI1measures the temperature inside the house. If the temperature falls below 23,0°C, the heating controlled from output Q1 is switched on. The B008 clock controls the switching of the garden lights and of the front lights. The lights are switched on during the night from 7 pm to 5 am. When the front door is opened, the lights are switched on at the same time for 10 seconds in order to light the way from the house to the car. A sensor attached to input I5 (in the form of a cable placed under the fence) detects a potential burglar trying to break through the fence. An acoustic signal as well as emergency lighting is switched on (from output Q6) and the entrance gate is locked so that it cannot be opened. The system works independently of the status of the button attached to I1 that switches the control system on or off [7].

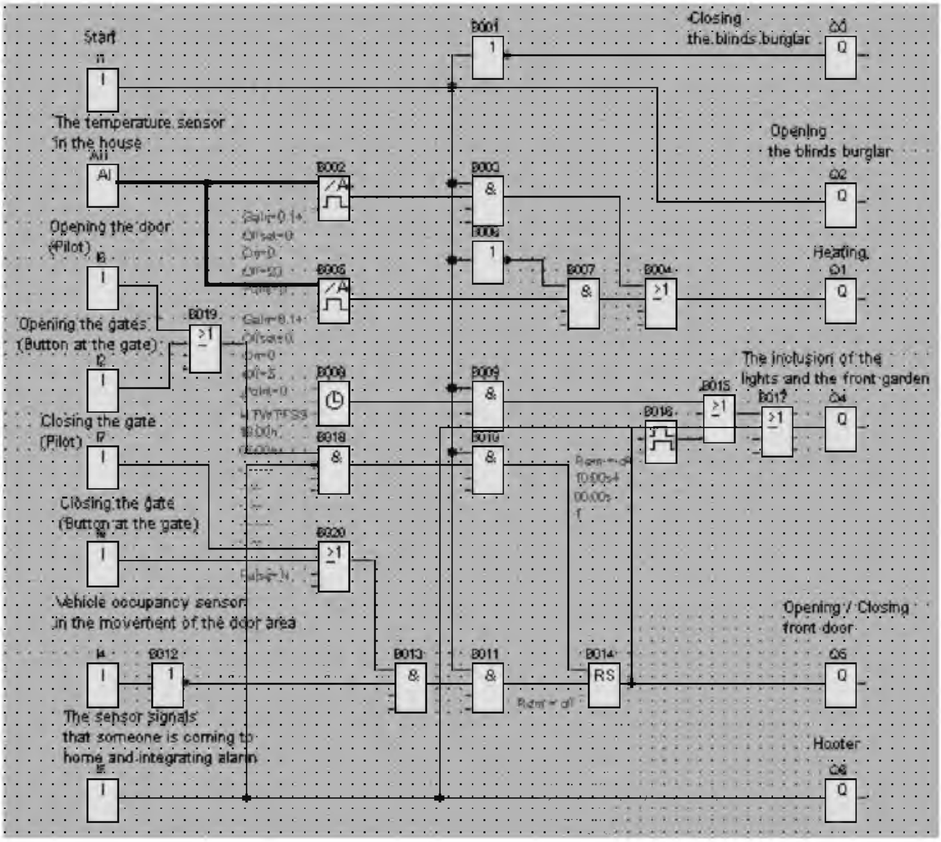

Fig. 1. A control program for an "intelligent" holiday cottage [8]

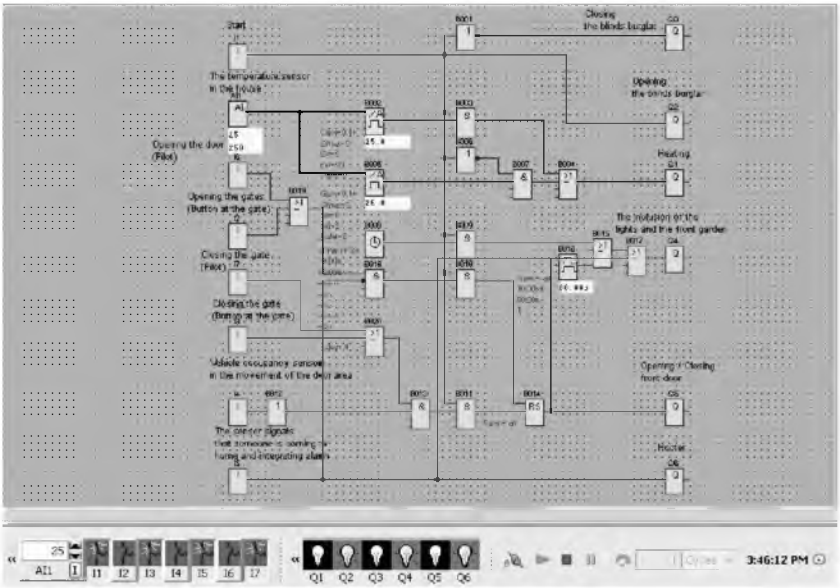

Fig. 2. A simulation of the operation of the control program for an "intelligent" holiday cottage [8]

3. Heating of an "intelligent building"

3.1. Two-state heating control (without hysteresis)

Temperature is a physical quantity which is a part of our everyday life. We usually expect it to be relatively stable. A popular method of temperature stabilization is two-state control. The characteristic feature of this method is that the outside temperature and the temperature of the heating medium are measured by two sensors (PT100) attached to inputs AI3 and AI4, which is presented on Fig. 4. The principle of operation of the LOGO! controller consists in that if the temperature outside falls, the temperature of the heating medium is increased and vice versa [7]. A simulation of the operation of a program fulfilling two-state heating control (without hysteresis) is presented on Fig. 5.

This dependency is executed by means of the B004 analog comparator block. If the threshold is reached, the heating is switched off. The pitch of the heating curve is determined by the parameters of the B007 analog adapter. In order to determine the parameters of the B007 analog adapter, that is – the gain and the offset, the heating curves must be prepared. We determine them on the basis of two set points based on Table 1 and Fig. 3, between which we extend a straight line. After the straight line is charted onto the curve on the basis of Fig. 3, we can determine the two parameters necessary for the B007 analog adapter [7].

The parameters of an analog controller, that is the gain and the offset, are determined by means of the following method. The gain is the ratio between the change of the heating medium temperature and the change of the outside temperature, and offset is determined for the temperature value of 0°C on the basis of the characteristics of sample heating curves.

Table 1. Calculation of the parameters for the B007 analog adapter [7]

No	Heating curve	Outside temperature	Heating medium temperature	Gain	Offset
		°C	°C	-	-
1.	1	20,0	30,0	-0,25	350
		-20,0	40,0		
2.	2	20,0	30,0	-0,50	400
		-20,0	50,0		
3.	3	20,0	30,0	-0,75	450
		-20,0	60,0		
4.	4	20,0	30,0	-1,00	500
		-20,0	70,0		

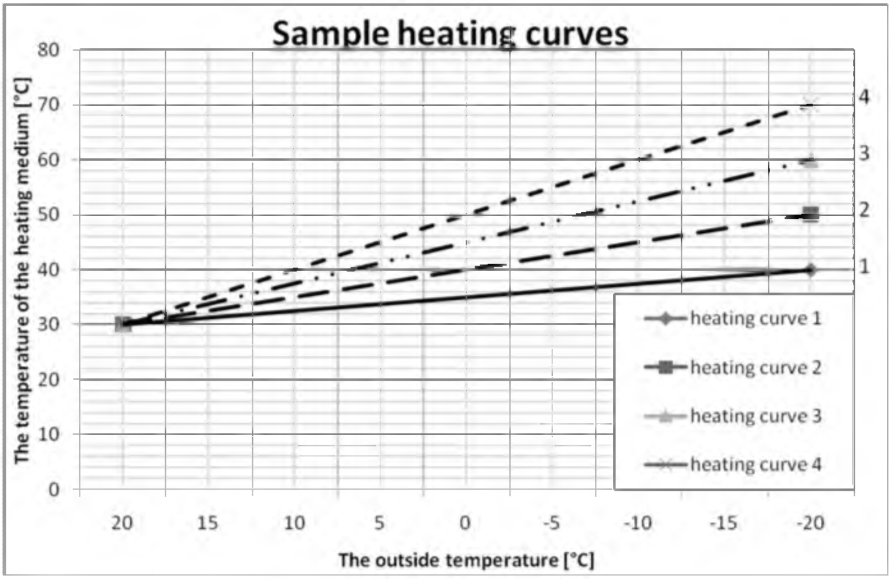

Fig. 3. Sample heating curves [7]

The conclusions resulting from the calculation of the parameters for the B007 analog controller are as follows:

– Heating curve 1

  For the outside temperature of 20,0°C, the temperature of the heating medium is 30,0°C, and for the outside temperature of -20,0°C, the temperature of the heating medium is 40,0°C.

- Heating curve 2
  For the outside temperature of 20,0°C, the temperature of the heating medium is 30,0°C, and for the outside temperature of -20,0°C, the temperature of the heating medium is 50,0°C.
- Heating curve 3
  For the outside temperature of 20,0°C, the temperature of the heating medium is 30,0°C, and for the outside temperature of -20,0°C, the temperature of the heating medium is 60,0°C.
- Heating curve 4
  For the outside temperature of 20,0°C, the temperature of the heating medium is 30,0°C, and for the outside temperature of -20,0°C, the temperature of the heating medium is 70,0°C.

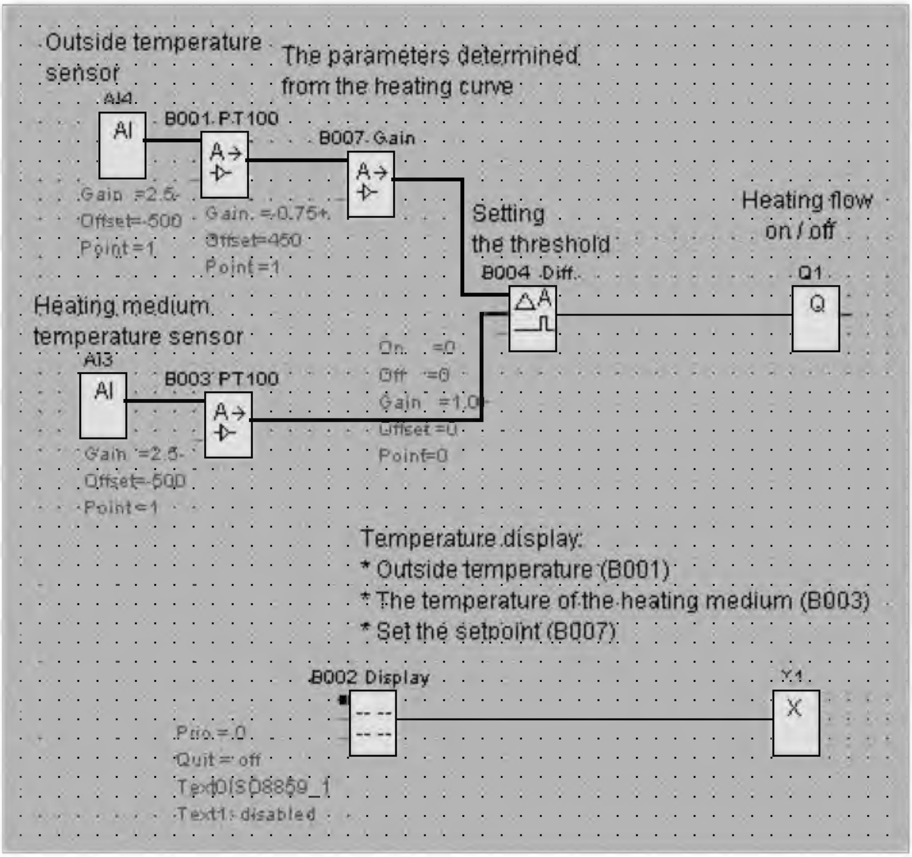

Fig. 4. A program executing two-state heating control (without hysteresis) [8]

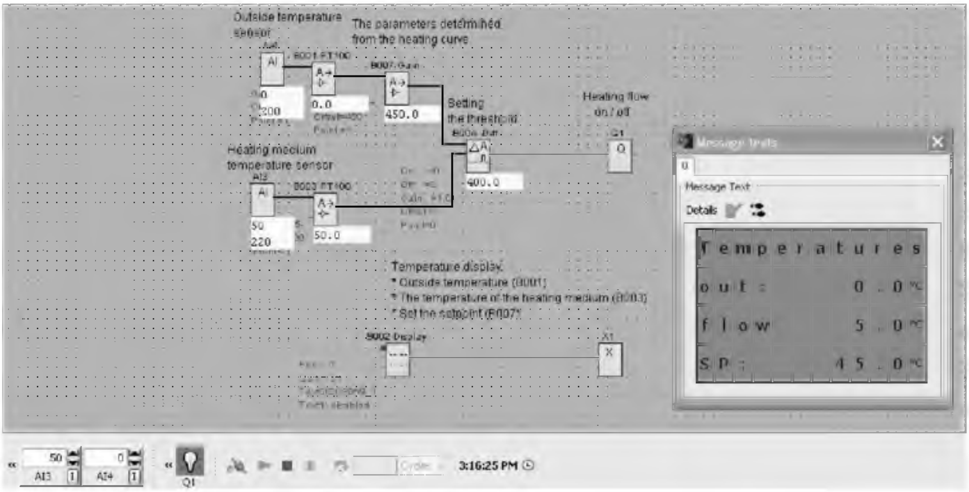

Fig. 5. Operation simulation for the program executing two-state heating control [8]

3.2. Two-state heating control (with hysteresis)

The program presented on Fig. 6 performs two-stage heating control with hysteresis, that is with certain delay in the reaction of the system in relation to the actual ambient temperature (within the range from 31,0°C to 33,0°C). During the heating process, the heater is switched on till it reaches the temperature of 33,0°C. When the temperature value is exceeded, the state of the analog threshold switch B002 changes to high and the transmitter B003 is set to zero. The temperature starts falling and when it falls below 31,0°C, the threshold switch B001 is switched on and the heater is activated again. In this way, the number of activations and deactivations of the transmitter is reduced if the actual temperature value falls within the hysteresis range of [7]. A simulation of the operation of a program fulfilling two-state heating control (with hysteresis) is presented on Fig. 7.

The most important parameters of LOGO! controllers [14] are:

- working temperature range: 0°C…+55°C,
- protection level: IP20,
- input voltage options: 12/24 VDC or 230 VAC,
- maximum number of two-state inputs: 24,
- maximum frequency of two-state inputs: 5kHz,
- maximum number of outputs: 16,
- maximum number of analog inputs: 8,
- maximum number of analog outputs: 2,
- built-in PI controller,
- virtual outputs: 16,
- built-in real time clock,

- display: LCD 12 signs x 4 rows,
- cursor keys: 4,
- maximum number of blocks in a program: 200, and 250 in REM,
- average execution time of a block function: less than 0,1ms.

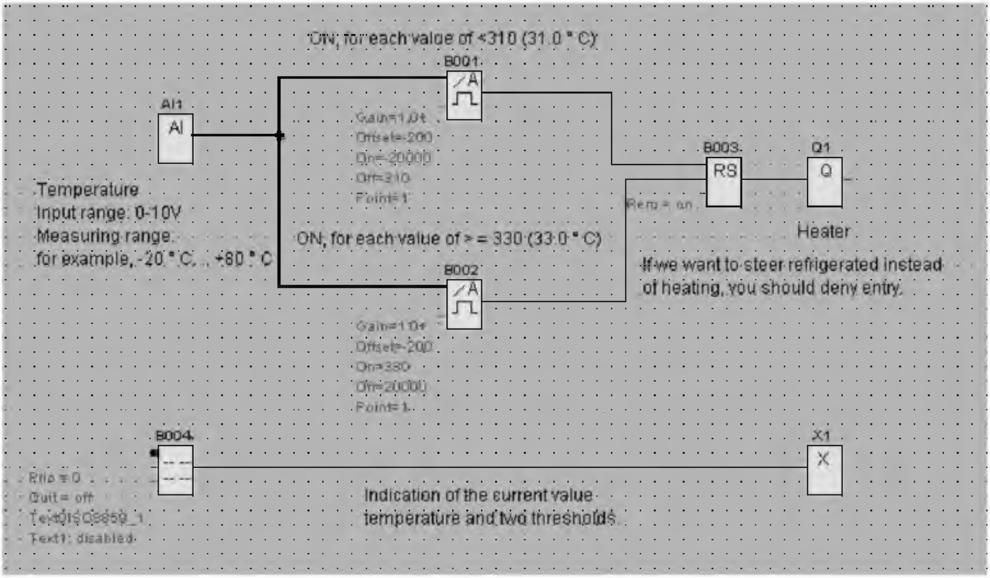

Fig. 6. A program executing two-state heating control (with hysteresis) [8]

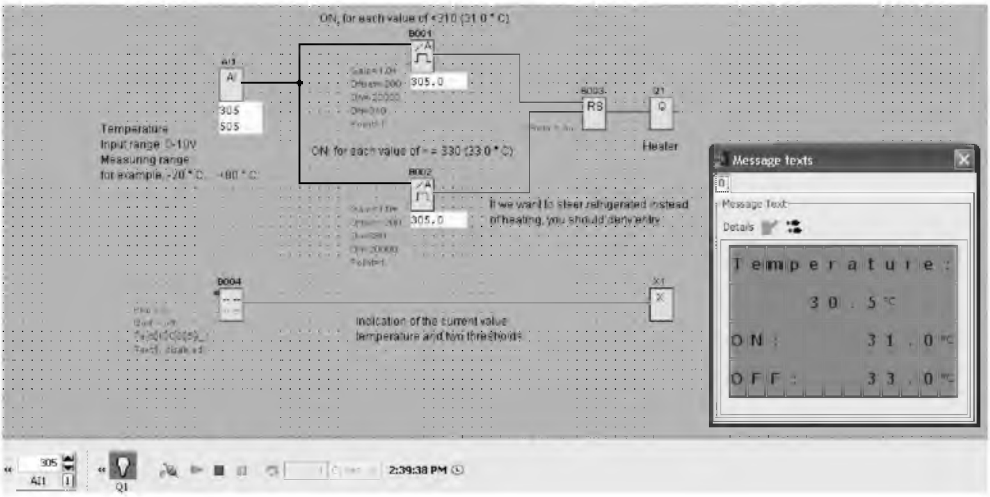

Fig. 7. Operation simulation for the program executing two-state heating control (with hysteresis) [8]

4. A simulation of PI controller operation in order to stabilize the temperature in an "intelligent building"

The chapter presents the application capabilities of the LOGO! logic controller produced by the Siemens company with respect to temperature control in an "intelligent building". The wide range of capabilities of the logic controller finds its practical execution on the basis of an example of PI controller operation simulation prepared in the LOGO! Soft Comfort v6.0 program.

The LOGO! controller produced by Siemens belongs to the group of micro controllers, sometimes also referred to as intelligent or programmable transmitters. They make it possible to provide control, which means the operation of an object in such a way so that it would not require human intervention and which applies only to small objects. A small object is an object whose total number of inputs and outputs, also referred to as points, does not exceed 64. Our house can be classified as such an object [7].

4.1. A proportional-integral controller (PI)

A proportional- integral controller (PI) of constant characteristics emits the control signal u(t) which is proportional to the sum of values e(t) and to the integral of error e(τ), which is presented in equation (1).

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int_{-\infty}^{t} e(\tau)d\tau\right) \tag{1}$$

where: u(t) – control signal, K_p – constant of proportionality, e(t) – error value, e(τ) – integral of error, d(τ) – change of the integral of error, T_i – integral time, t – sample moment, τ – sample period.

In the case of PI controllers, the integral time T_i is sometimes referred to as the double time as after the time has elapsed, the control signal increases two times from the moment when a step change in the error value occurs, that is – the portion of the signal originating from the integration operation becomes equal to the portion whose origin is proportional to the error value [4].

The transfer function G(s) of the PI controller is as follows, as presented in equation (2).

$$G(s) = \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i}\frac{1}{s}\right) \tag{2}$$

where: G(s) – transfer function, U(s) – Laplace transform of the control signal u(t), E(s) – Laplace transform of the error signal e(t), K_p – constant of proportionality, T_i – integral time, s – parameter.

4.2. A simulation of PI controller operation

A block PI controller (proportional-integral) stabilizes the object output signal. The signal is measured and transmitted to the PV input (feedback signal) and then it is compared in the controller block with the given SP value which is either set or provided by means the Reference value in the block properties. The block can act as the proportional term (then the value of the integral time parameter TI is 99:59) or as the integral term (the controller amplification parameter KC = 0) [7].

A simple simulation presenting the operation of a PI controller block can be developed with the use of the Arithmetic block (Fig. 8). The Arithmetic block becomes the proportional control term, and a high state is fed to the En input so as to activate it. In practice, the block serves as an accumulation node where the error set in AI2 is fed but it must be transmitted through the B004 analog adapter in order to be part of the Arithmetic block through the reference.

The parameters of the B001 PI controller block are presented on Fig. 9. It is also to the block that the given SP value from AI1 is fed through the B003 analog adapter. Finally, we can select the parameters for the B001 PI controller. The control system developed in this way maintains a constant PV output value, set to the given SP value for the AQ input value, which is visible on the trend diagrams (Fig. 10-13) for the controller that switches on automatically during the simulation [7].

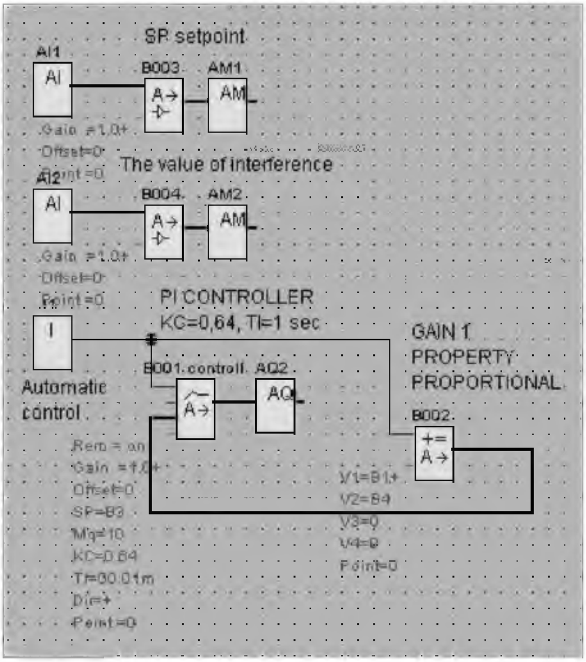

Fig. 8. A test program developed in the FBD language [8]

Fig. 9. The window used for editing the parameters of a PI controller block [8]

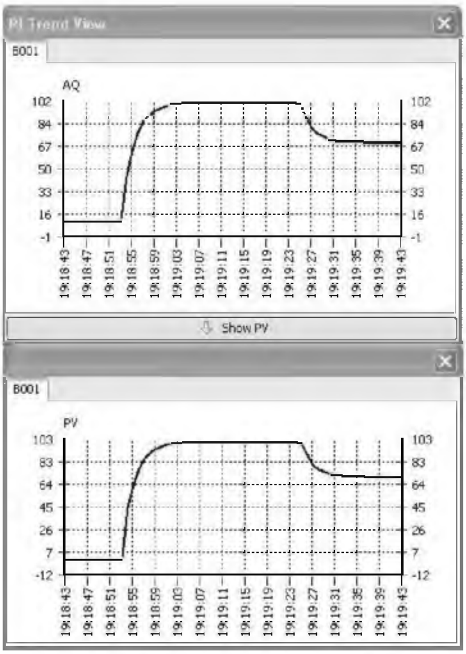

Fig. 10. Controller timing diagrams for the AQ and PV signal [8]

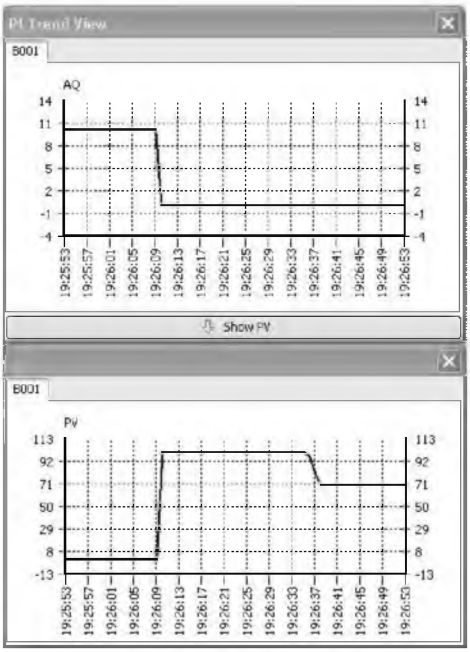

Fig. 11. Controller timing diagrams for the AQ and PV signal [8]

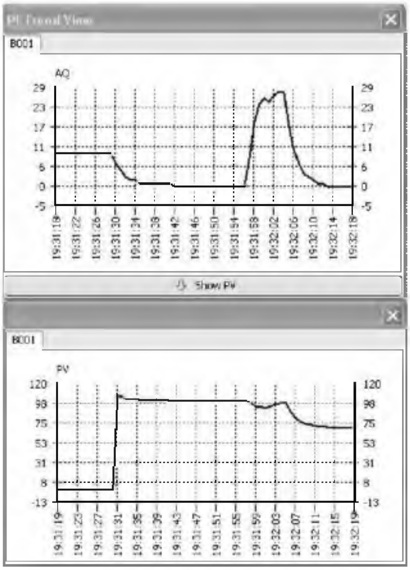

Fig. 12. Controller timing diagrams for the AQ and PV signal [8]

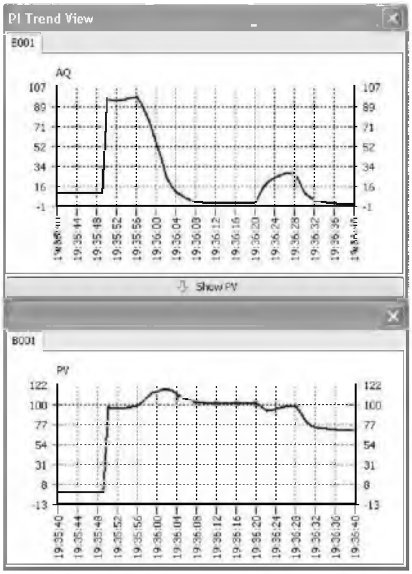

Fig. 13. Controller timing diagrams for the AQ and PV signal [8]

The simulations of PI controller operation conducted lead to the conclusion that the proportional-integral controller stabilizes the output signal from the object which can, for example, have the form of temperature. Temperature is a physical quantity which is a part of our everyday life. We usually expect it to be relatively stable. A popular method of temperature stabilization is two-state control. The characteristic feature of this method is that the outside temperature and the temperature of the heating medium are measured by two sensors (PT100) attached to inputs AI3 and AI4. The principle of operation of the LOGO! controller consists in that if the temperature outside falls, the temperature of the heating medium is increased and vice versa [7]. Two temperature stabilization methods can be distinguished: two-state heating control with hysteresis, that is – with certain time delay, and two-state heating control without hysteresis, that is – without any time delay.

Two-state control is the simplest and cheapest way to control heating. Temperature control consists of opening and closing a solenoid valve located at the inlet to the heating circuit, for example, of a given heater. A drawback of this type of control is the relatively high inertia of temperature control. Thus, it cannot be used for high inertia systems, such as floor heating which is becoming more and more popular [17].

Continuous control (PI) is the most advanced type of control. It is used everywhere where it is important to set the temperature quickly and precisely. Special valve drives that make it possible to precisely set the desired value are used in this control system. It is used in the most popular floor heating systems [17].

5. Conclusion

Two-state heating control in an "intelligent building" with the use of the LOGO! logic controller can have a considerable influence on the optimization of electric and thermal energy consumption from the energy efficiency perspective. Heating constitutes the greatest portion of energy consumption in residential buildings – 41,5%; hence the justifiable need to considerably reduce the amount of electric and thermal energy consumed for this purpose. In relation to that fact, the work presents a comparative analysis of two programs providing two-stage heating control: with and without hysteresis. On the basis of the analysis conducted, we can conclude that both programs are characterized with high operational functionality and flexibility. The program with time delay considerably reduces the number of transmitter switches if the actual temperature value falls within the hysteresis range. On the other hand, the program without time delay instantly reacts to any change of the actual ambient temperature on the basis of the parameters of the analog adapter. What is important, is the fact that both programs prove useful in real-life implementations involving heating control in an "intelligent building" with the use of the LOGO! logic controller. Thus, they can be successfully used for programming a system that will reduce or completely switch off the heating when the residents are away. The system can switch off the heating, the lighting, and any electrical equipment working in the house, creating electric and thermal energy savings.

Energy efficiency constitutes the greatest challenge of the contemporary civilization. This means that research on energy efficiency in passive buildings, connected with the design, positioning, and tightening of such "intelligent buildings, will play an important role in the future. Those aspects will have a positive influence on proper insolation of the building, in the rooms where it is especially important, at the same time providing the possibility to keep the heat in the building for a longer period of time. In the case of passive buildings, the heat generated by room lighting or by working electrical equipment should also be included, apart from the heat generated by sunlight and people. Energy efficiency can, then, be obtained in a passive way through the appropriate building design, as well as through active systems using new building technologies, such as solar collectors, photovoltaic panels, wind generators, biomass-powered processing systems [5].

The global demand for electric energy increases rapidly all over the world. It is assumed that the increase ratio is about 2,2% per year, which means that the current global consumption of electric energy of 20300 TWh will increase to 33000TWh in 2030. An intelligent system which will direct the energy exactly where it is needed will soon become a necessity. An Intelligent Power Network – the Smart Grid [16] constitutes such a solution. The idea behind the Smart Grid is communication among all the users of the power market. The network integrates small and large power plants as well as power recipients into one unified structure.

The Smart Grid can exist and function thanks to two elements: the automation build on the basis of advanced sensors and the teleinformation system. Additionally, it makes it possible for the end users to actively participate in the power market and, thus, to consciously contribute to environmental protection. The Smart Grid is currently an idea and a matter of the future but the future is not very distant. The technologies needed to construct such an intelligent network are already available [16].

References

[1] Benysek G., Improvement in the quality of delivery of electrical energy using power electronics systems, Springer-Verlag, London, 2007.
[2] Gellings C., Smart power delivery: a vision for the future, EPRI Journal, June, 2003.
[3] GridWise Alliance, Rethinking energy from generation to consumption, Brochure, 2003.
[4] Grochowski M., Komputerowe systemy sterowania. Sterowanie dwustanowe oraz przy pomocy regulatorów PID, Lecture materials, Gdańsk University of Technology, 2012, p. 11.
[5] Jarmuda T., Zdecentralizowane systemy automatyzacji w energooszczędnym „budynku inteligentnym", science and technology journal „Napędy i Sterowanie", No 12 (152), ISSN 1507-7764, Wydawnictwo „Druk-Art" SC, Sosnowiec, December 2011, pp. 87-89.
[6] Kannberg L. GridWise - transforming the energy system, Pacific Northwest National Laboratory, Conference Presentation, 2003.
[7] Kwaśniewski J., Inteligentny dom i inne systemy sterowania w 100 przykładach, Wydawnictwo BTC, Legionowo, 2011, pp. 101-103, 144-147.
[8] LOGO! Soft Comfort 6.1 software help (Polish language version).
[9] Massoud S., Wollenberg B., Toward a smart grid – power delivery for the 21st century, IEEE Power and Energy Magazine, vol.3, 2005, pp. 34-41.
[10] Mazza P. The smart energy network – electricity's third great revolution, http://www.climatesolutions.org, 19.11.2011, 22:00, 2003.
[11] Niezabitowska E., Sowa J., Staniszewski Z., Winnicka – Jasłowska D., Boroń W., Niezabitowski A., Budynek Inteligentny, [in] Niezabitowska E. (ed.) Potrzeby użytkownika a standard budynku inteligentnego, Vol. I, Wydawnictwo Politechniki Śląskiej, Gliwice, 2010, pp. 319-324.
[12] Strzelecki R., Benysek G., Conceptions and properties of the arrangements in distributed electrical power systems, MITEL Conference, 2004, pp. 241-248.
[13] Strzelecki R., Benysek G., Power Electronics In Smart Electrical Energy Networks, Springer, London, 2008, p.8.
[14] Strzelecki R., Jarnut M., Benysek G., Active electrical energy conditioners for individual customers, PES Conference, Warsaw University of Technology Press, vol.1, 2003, pp. 27-34.
[15] Thomsen P., Application and control of CUPS in the distribution grid, Institute of Energy Technology, Aalborg University, vol.3, 1999, pp. 2-11.
[16] http://elektroinzynieria.pl/newsItem, on 09.01.2012 at 14:00.
[17] http://www.intelidom.pl , on 21.08.2012 at 20:00.