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Control and visualisation of illumination and irrigation processes

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The paper presents the design of the integrated illumination and irrigation system using a PLC and its visualisation. In the introduction, the history of PLCs and the SCADA software was briefly described. It was followed by the presentation of the design intent, the description of its operation and components. The control algorithm created especially for this design, the programme for the selected controller and visualisation prepared in VijeoCitect software were also described. The last part of the paper contains the summary of the design and the trends for its development.

KEYWORDS: control, visualisation, SCADA system, integrated control system

1. Introduction

Programmable Logic Controllers *(PLC)* were used for the first time in the American automotive industry in the sixties of the 20^{th} century, instead of contactor logic control systems. As time passed by and as the capabilities of controllers developed, they were applicable in the industrial automation systems. [2, 5, 7].

SCADA (*Supervisory Control and Data Acquisition*) is the name of the software which serves the purpose of master control, acquisition, real–time processing and archiving of data. Its operation is based on variables connected with graphic elements that represent a given technological process on synoptic screens [6].

2. Design of the garden lighting and irrigation system

2.1. Design assumptions

The designed system is supposed to allow the intelligent control of the lighting and irrigation system area near a house. The functioning of the system will depend on such factors as type of power supply, lighting intensity, temperature, presence of the user within a given zone, occurrence of atmospheric precipitation and soil humidity [9, 10].

The illumination was divided into the decorative part and the lighting of paths and the terrace, which guarantees safe movement around the garden – the lighting intensity amounting to at least 1 lx in each point of the path, and in the usable part of the terrace – minimum 50 lx. The process of switching on the lighting is controlled using photocells, motion sensors and door reed switches [10, 13, 14].

The features of the decorative lighting should include: high color rendering index ($R_a \geq 85$), and, because it is switched on all night long, energy efficiency. The used luminaires should be aesthetic and the sources of light should accentuate the illuminated structures without causing glares [10, 11].

The irrigation system was divided into four zones, with a soil humidity sensors placed in each one of them. In the first two zones (decorative bushes), the drip irrigation lines will be used, and in the two others (lawn) – sprinklers. The operation (standby/irrigation) of the system will be interrupted during the atmospheric precipitations and when motion is detected within the paths in zone III and IV. The system will also be capable of using rainwater [9].

Emergency power supply which maintains the operation of the systems for 12 hours will be provided by using the emergency power supply unit that uses an external battery [10].

2.2. Functionality of the system

Decorative lighting will be switched on depending on the occurrence of mains supply, the lighting intensity lower than or equal to the preset value and the temperature of air greater than or equal to the preset value. The decorative lighting will be switched off when the aforementioned conditions are not fulfilled except the temperature criterion – in order to avoid multiple switching related to temperature fluctuations. The temperature criterion per se is related to the vegetation cycle of plants [10].

The lighting of paths and the terrace is independent of the power supply source – a decrease in the lighting intensity value to a value lower than or equal to the preset value and the high state at the relevant controller input (sensors responsible for detection of motion) will cause the lighting to be switched on [10].

The irrigation process will be commenced at the moment of a decrease in the lighting intensity below the preset value and an increase in the air temperature above the set–point. The opening of the solenoid valves in the respective irrigation zones will depend on signals from the relevant soil humidity sensor. The irrigation will only be interrupted for the time of atmospheric precipitations, and in zone III and IV, additionally during motion detection [9].

The opening of any solenoid valve initializes the water source selection algorithm. The signal from the float reed switches installed in the rainwater reservoir, will allow the estimation of water level, i.e. the minimum level, the sufficient level and the maximum level. The sufficient level at simultaneous power supply from the mains will cause the operation of the water pump which will operate until the level falls below the minimum or the power supply failure.

The solenoid valve operation for the water flow from the gutter, that depends an atmospheric precipitation or water level below the maximum point, will be used in the system [9].

The emergency power supply system will consist of the emergency power supply unit that cooperates with an external battery selected on the basis of the requirements of the designed system. The power supply unit is to charge the battery or operate as the 12 or 24–240 V DC/AC converter. In order to detect the power supply failure, the current from the AC grid will be measured [10].

2.3. System components

The system components are responsible for the detection of external states in the form of analog signals (lighting intensity, temperature, soil humidity and current flow) and digital signals (motion, water flow in a given zone, occurrence of atmospheric precipitation and water level). On top of this, the subassemblies of the irrigation system, luminaires, solenoid valves as well as the water pump, the PLC and emergency power supply components were selected [9, 10].

For the purpose of the correct selection of the water flow signaling devices and solenoid valves within the respective zones, a simplified water system based on the guide prepared by the Hunter company [16] was prepared because of the necessity to estimate the aggregate water flows [9].

Table 1. List of used subassemblies in the irrigation system, including the calculated water flow values [9]

Zone	**Used elements**	**Q [l/min]**
I	70 meters of the drip irrigation line	4.5
II	140 meters of the drip irrigation line	8.5
III	Sprinklers with a nozzle: – 10A – one with the sprinkling angle of 90°, two with the sprinkling angle of 180° and one with the sprinkling angle of 215°. – 12A – two with the sprinkling angle of 90°, one with the sprinkling angle of 180° and one with the sprinkling angle of 215°. – 15A – one with the sprinkling angle of 90° and two with the sprinkling angle of 120°	43
IV	Sprinklers with the nozzle: – 10A – two with the sprinkling angle of 180°. – 12A – one with the sprinkling angle of 90 one with the sprinkling angle of 255°.	17
	TOTAL:	73

By following the design assumptions and accepted rules for selection of the respective components (e.g. ingress protection IP [15]) the subassemblies of both systems were selected.

The system components (except lamps and water pumps) are supplied with 12 V DC or 24 V DC voltage, hence the necessity to select the power supply units to the system. Based on data from manufacturer's sheets [21], maximum power for respective components were calculated [1].

The power supply for components which required the 12 V DC voltage was resolved by using the converter that ensures a voltage reduction from 24 V to 12 V, which causes the necessity of adding the additional power consumption for the 24 V power supply unit according to the following formula [18]:

$$P_1 = \frac{P_2}{\eta}, \tag{1}$$

where: η – component efficiency, P_1 [W] – component input power, P_2 [W] – component output power.

Based on the calculations included in Table 2, K4/24/12–D1H has been selected as the 24/12V DC converter [21], and HLG–185H–24 with the active PFC (Power Factor Correction) system has been selected as module power supply unit that ensures the 24 VDC voltage [21, 9, 10].

Table 2. Parameters of elements with 12 VDC rated supply voltage [10]

No.	Component	Pcs.	I [mA]	U [V]	Operating time [h]	P [W]	ΣP [W]	W [Wh]
1	Bosch OD850 TriTech motion detector	2	62	12	12	1.488	1.488	17.86
						TOTAL	1.488	17.86

Tables 2–4 also include data that present the energy consumption for the 12–hour normal operating time because of the necessity to select the battery [10].

The commercial availability of a much bigger number of battery models with the voltage of 12 V determined the use of a pack of two serially connected batteries. The minimum battery electric charge was calculated according to the following formula [3, 4]:

$$Q = \frac{2W}{U}, \tag{2}$$

where: Q [Ah] – battery electric charge, W [Wh] – average energy demand of the system, which the battery must cover – it is doubled because of the fact that the battery should not be discharged below the 50%, U [V] – nominal voltage of the battery pack.

Table 3. Parameters of the components with the 24 VDC rated supply voltage [10]

No.	Name	Pieces	I [mA]	U [V]	Operating time [h]	P [W]	ΣP [W]	W [Wh]
1	Satel B4–L reed switch with a relay.	2	7	24	12	0.168	0.336	4.030
		2	11	24	12	0.264	0.528	6.336
2	Photocell (receiver)	1	7	24	12	0.168	0.168	2.016
		2	11	24	12	0.264	0.528	6.336
3	Photocell (transmitter)	3	10	24	12	0.240	0.720	8.640
4	Lighting intensity sensor	1	–	24	12	–	–	–
5	Temperature sensor	1	20	24	12	0.480	0.480	5.760
6	Humidity sensor	4	20	24	12	0.480	1.920	23.04
7	Rain sensor	1	230	24	12	5.520	5.520	66.24
8	Rain sensor circuit	1	7	24	12	0.168	0.168	2.020
9	Float reed switch	3	7	24	12	0.168	0.504	6.050
10	Water flow signalling device	4	7	24	12	0.168	0.672	8.064
11	Twido TWDLCDE40DRF controller	1	–	24	12	17.20	17.20	206.4
12	TWDAMI8HT analog input module	1	50	24	12	1.200	1.200	14.40
13	Zone valves	1	–	24	4	19.00	19.00	76.00
		4	–	24	1	19.00	76.00	76.00
14	DC/DC 24V/12V converter	1	–	24	12	0.907	1.815	21.78
15	Pump contactor	1	–	24	–	3.000	3.000	–
16	Water supply valve	1	–	24	–	21.00	21.00	–
						TOTAL	150.8	533.1

The minimum electric charge calculated on the basis of formula (2) amounts to 95.25 Ah – two AGM CB100–12 batteries [21] with the charge of 100 Ah each were selected [10].

The data included in table 4 allowed for the selection of a line–interactive ORVALDI KC–1000L SINUS emergency power supply unit with the UPS function [21], also the power supply switching time was taken into account. The said time should be shorter than the power failure duration withstood by the controller [10].

The specific operation conditions of the wiring system in the garden lead to the necessity to design it in accordance with specific rules. Depending on the location and method (in the PVC tube sheathing or without it) of placement of the cable, a specific depth of laying the cable under the layer of ground is required. The cables are laid on a 10 cm layer of sand, and 25 cm over them, a warning tape made of blue film is placed. At intersections with the existing systems or pipelines, it is necessary to use a sheathing [19, 20].

Table 4. Parameters of the components with the 230 VAC rated supply voltage [10]

No.	Component	Pieces	I [mA]	U [V]	Operating time [h]	P [W]	ΣP [W]	W [Wh]
1	LUG Runa 1	8	–	230	2	3.000	24.00	48.00
2	Thorn Tea (bed)	4	–	230	2	19.00	76.00	152.0
3	Thorn Tea (arbour)	1		230	2	19.00	19.00	38.00
4	Thorn Tea (terrace)	1		230	6	19.00	19.00	114.0
5	Thorn Tea (path)	1	–	230	2	19.00	19.00	38.00
6	BGP490 1xLLM3200/840 DTS	1	–	230	6	30.00	30.00	180.0
7	Switched–mode power supply (calculated)	1	–	230	–	162.1	162.1	573.2
						Total	349.1	1143

While selecting cables for the garden system, attention must be paid to the permissible voltage drop – due to the length of the sections between the source and the receiver. It is necessary to ensure the adequately low resistance [10].

The arrangement of the luminaires and sensors detecting motion is presented in paper [10], while a simplified diagram of the irrigation system can be found in paper [9].

2.4. Controller algorithm and program

The process control algorithm (Fig. 1) is presented on the basis of the SFC graph, which is based – according to IEC 61131–3 – on the Grafcet method, by means of which, the controller is preprogrammed [2, 5]. Control is divided into synchronized processes in order to ensure the simplification of the program [9, 10].

In step 1 of the algorithm of the given process, the primary cancellation of an action in the block of actions takes place, T1 is the transition (condition for transition) to step 2, in which the primary setting of a given action takes place. Transition T2 is, on the other hand, a condition for moving back to step 1 [10].

Fig. 2 presents the irrigation process algorithm in zone I, whose running consists in the resetting of the output state in step 1, controlling the solenoid valve of zone I and values of meter No. 1. If the user forces irrigation using a push button, the program will switch to step 2, in which solenoid valve will be opened. After releasing the push button, the process will return to step 1. There is the second option of operation of the program – if conditions of switching to step 3 are fulfilled – the lighting intensity will be below or equal to the set–point value, the temperature will be higher than the set–point, the soil humidity in the given zone will be lower than the one that was preset and a failure will not be signaled – the process of irrigation will start and the operating time will be measured.

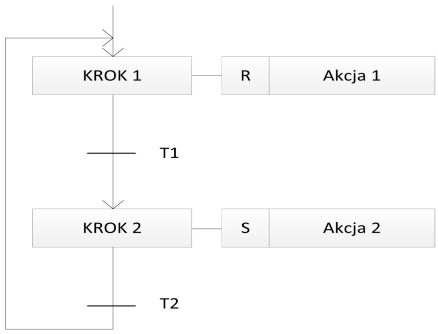

Fig. 1. Schematic diagram (in Polish) of the algorithm for control of a single process of the lighting system (the respective transitions and actions are included in Table 5) [10]

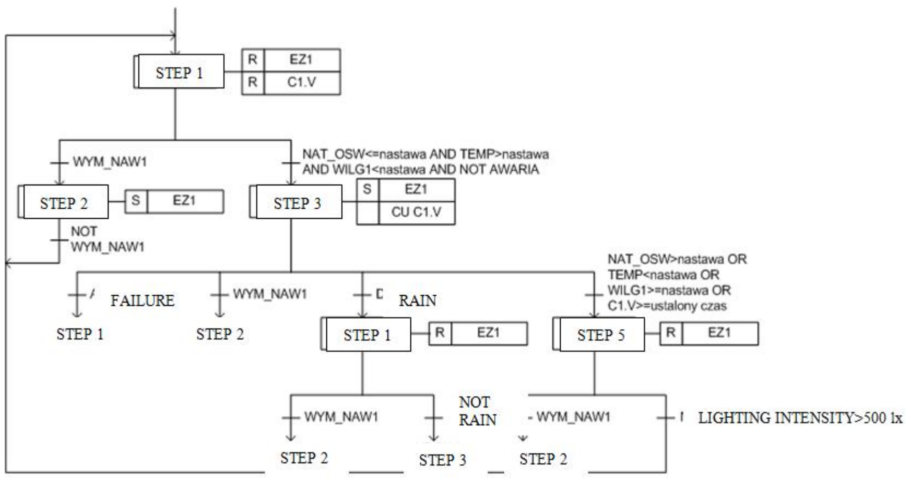

Fig. 2. Diagram of the algorithm of irrigation process control in zone I [9]

Switching from a given step will take place when a failure is signaled – switching to step 1, irrigation will be forced – switching to step 2, the atmospheric precipitation will occur – switching to step 4, the program will be active until the precipitation is forced or stopped. An increase in the lighting intensity, a decrease in temperature, the achievement of the preset soil humidity, or the achievement of the operating time limit will cause switching to step 5, in which the process will remain until the irrigation is forced or until a new day comes [9]. The algorithm for the irrigation process control for zone II, in comparison with the one from zone I, differs in terms of the variables on which it operates [9].

Table 5. Actions and transitions used in the control algorithm from Fig. 1 [10]

	T1	**T2**	**Action 1/2**
Decorative lighting	(NAT_OSW<=NASTAWA AND PRAD_SIEC>0 AND TEMP>=NASTAWA) OR WYM_OSW_DEKO	(PRAD_SIEC=0 OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_DEKO	OSW_DEKO
Terrace lighting	((FOTO_RABATA OR RUCH_TARAS OR FOTO_ALTANA) AND NAT_OSW<=NASTAWA) OR WYM_OSW_SC	((NOT FOTO_RABATA AND NOT RUCH TARAS AND NOT FOTO_ALTANA AND T>NASTAWA) OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_SC	OSW_TARAS
Lighting of the path to the arbour	((FOTO_ALTANA OR FOTO_ALTANA2) AND NAT_OSW<=NASTAWA) OR WYM_OSW_SC	((NOT FOTO_ALTANA AND NOT FOTO_ALTANA2 AND T>NASTAWA) OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_SC	OSW_ALTANA
Lighting of the path around the bed	((FOTO_RABATA OR RUCH_RABATA) AND NAT_OSW<=NASTAWA) OR WYM_OSW_SC	((NOT FOTO_RABATA AND NOT RUCH RABATA AND T>NASTAWA) OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_SC	OSW_RABATA
Lighting of the path leading to the house	((KONTAKTRON_DRZWI OR KONTAKTRON_FURTKA) AND NAT_OSW<=NASTAWA) OR WYM_OSW_SC	((NOT KONTAKTRON_DRZWI AND NOT KONTAKTRON_FURTKA AND T>NASTAWA) OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_SC	OSW_FD
Lighting of the driveway	((KONTAKTRON_BRAMA OR KONTAKTRON_GARAZ) AND NAT_OSW<=NASTAWA) OR WYM_OSW_SC	((NOT KONTAKTRON_BRAMA AND NOT KONTAKTRON_GARAZ AND T>NASTAWA) OR NAT_OSW>NASTAWA) AND NOT WYM_OSW_SC	OSW_BG

The process runs in zone III and IV, which are presented in work [9], approximate those presented so far, and additionally include the step in which the irrigation is interrupted temporarily after detecting any motion on the paths.

The algorithm shown in Fig. 3 presents the process of the water source selection. In step 1, all outputs that control the solenoid valve and from the water pump, the pump contactor and failure signaling contactor are cleared. While opening the zone valves, when the water level is sufficient and when there is mains power supply, the algorithm moves to step 3, in which the solenoid valve is opened and the pump contactor is switched on. In the event of occurrence of a situation in which the solenoid valve is open and the relevant flow signaling device does not transmit the high signal to the controller input after a specific period of time, the water level will fall below the minimum or the mains power supply will fail, the algorithm will move to step 2, in which it will reset the previously set outputs and open the mains solenoid valve. The further lack of flow, after a time delay, will cause switching to step 4 and signaling of a failure – the process will remain in a given step until failure is cleared with a push button. When the algorithm is in step 2 or 3, and when all zone solenoid valves are closed, the switching to step I will be achieved [9].

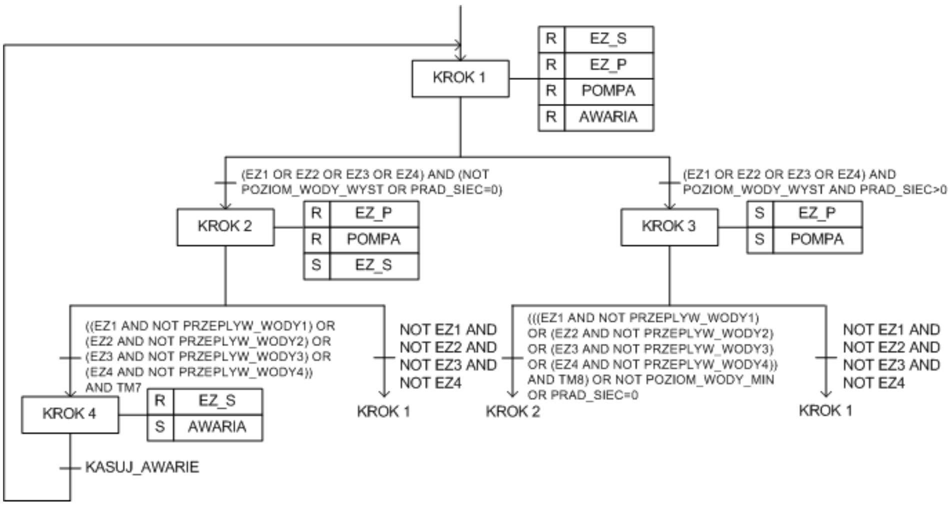

Fig. 3. Diagram (in Polish) for the water source selection control algorithm [9]

Fig. 4 presents the solenoid valve control algorithm for water supplied from the gutter to the rainwater reservoir. With the lack of the maximum level, the occurrence of precipitation and the mains power supply, the process will move on to step 2 and the supply solenoid valve will be opened. In the situation in which the maximum level is achieved or the atmospheric precipitation will cease, or the mains power supply will fail – the process will return to step 1 and the solenoid valve will be closed [9].

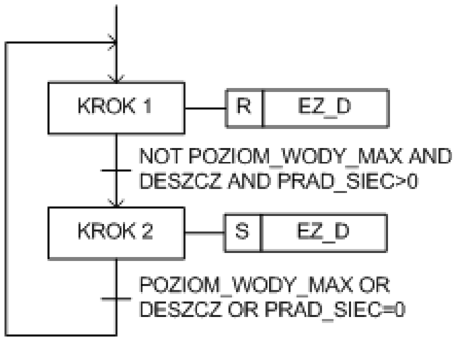

Fig. 4. Diagram (in Polish) of the supply solenoid valve control algorithm [9]

Based on algorithms for control of the respective processes, the software in the form of the list of Grafcet instructions written in the Ladder language was created. In the first section (Fig. 5), there are instructions responsible for the assignment of system set–point value memories to words [9, 10].

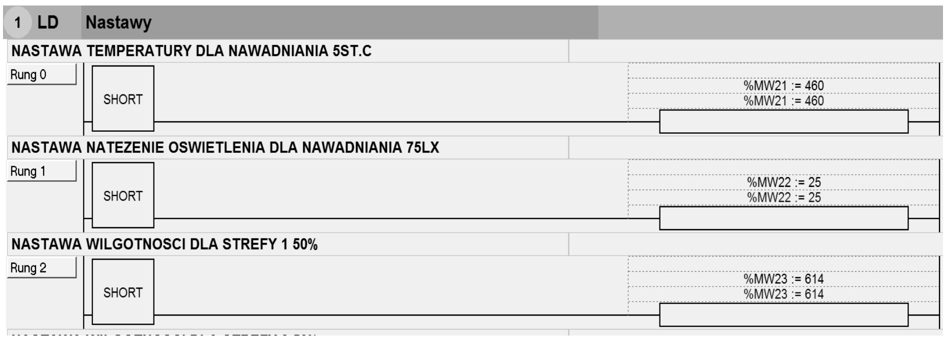

Fig. 5. Screenshot (in Polish) which presents a fragment of the first section of the software [9, 10]

In the next section of the software (Fig. 6), there are instructions that initiate the performance of the Grafcet instructions – provision of logic value 1 for system bit %S21, by assigning system bits %S0 (cold restart) or %S1 (hot restart) to it and unconditional switching to initial steps of each process [9, 10, 12].

Transitions for the respective steps were defined in section 3 (Fig. 7), and in section 4, the STEP POST instructions, the actions in the respective steps were defined by reference to the %Xi bits and the step number. Fig. 8 presents the instructions for opening of the solenoid valve of zone I in steps 15 and 16 (steps 2 and 3 in Fig. 2) and measuring of the operating time using the system bit %S6 – the bit which amounts to zero for 0.5 s and one for 0.5 s [9, 10].

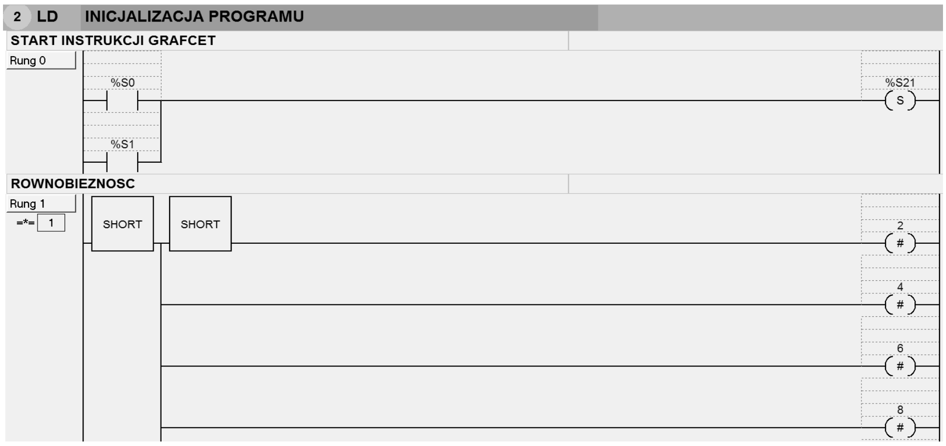

Fig. 6. Screenshot (in Polish) which presents a fragment of the second section of the software [9, 10]

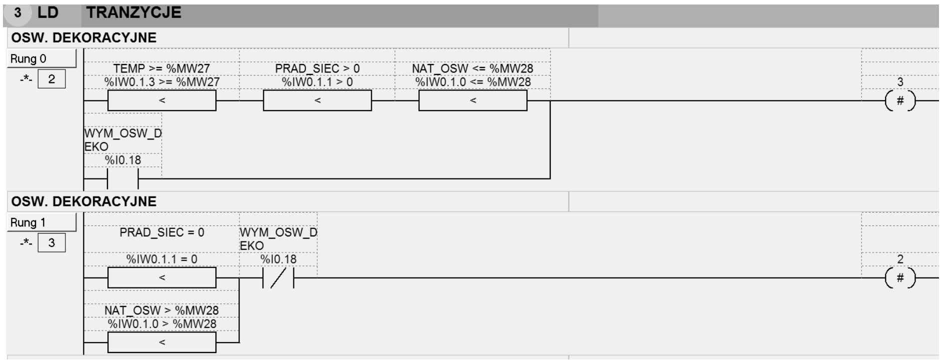

Fig. 7. Screenshot which presents a fragment of the third section of the software [10]

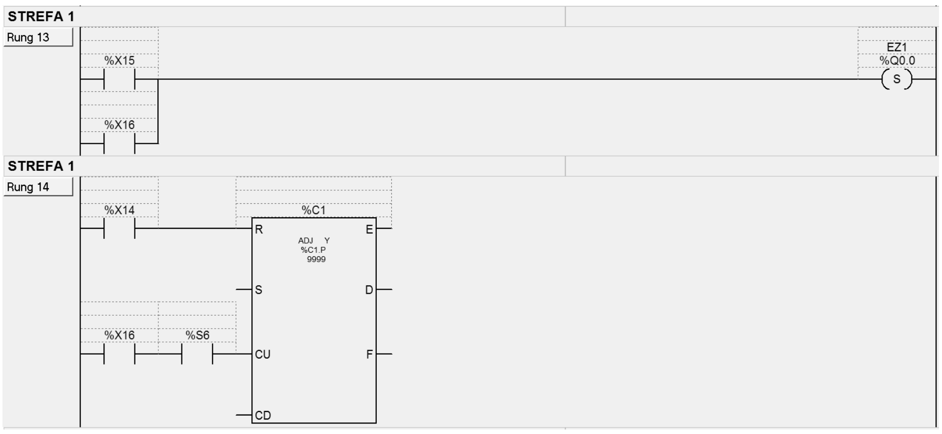

Fig. 8. Screenshot which presents a fragment of the fourth section of the software [9]

2.5. System visualisation in the SCADA system

Visualisation was created in the VijeoCitect 7.30 software manufactured by Schneider Electric. Pages which enable logging, lighting system control and irrigation system control (separately), reading of reports on the system and controller operation, which depicts the state of inputs and outputs, were prepared [9, 10].

For the needs of system, four groups of users with different authorisations were separated:

– administrators – all functionalities,
– household members – only the view of the system statuses,
– electricians – lighting system functionalities,
– gardeners – irrigation system functionalities.

Fig. 9 presents the main screen in which it is possible to log on and move to the respective screens. The blocking of the majority of options is visible as a result of absence of the logged user [9, 10].

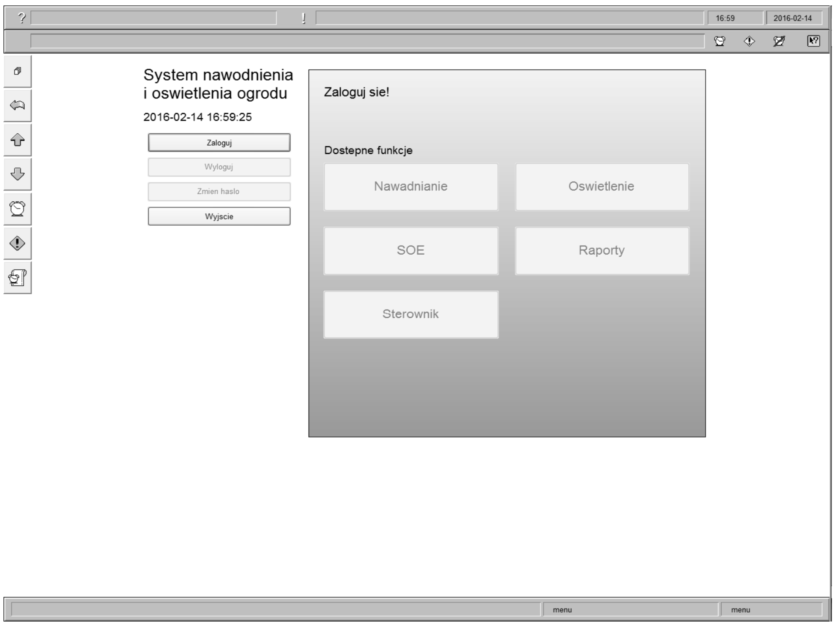

Fig. 9. Screenshot (in Polish) which presents the main menu (logging screen) [9, 10]

In Fig. 10, there is a screenshot of the synoptic screen of the lighting subsystem, which presents the top view of the garden area with controls that symbolize the luminaires. On top of this, the change in colors represents the power supply source – at a given moment, this is the mains power supply as the line which runs from the battery is grey, while the line running from the electric pole is green [10].

Fig. 11 presents the synoptic screen of the irrigation subsystem – just as is the case with the lighting subsystem, the top view of the garden area represents the components that symbolize the sprinklers, solenoid valves, the fragment of the irrigation system, the water reservoirs and the pump. The user can view the status of the system on a current basis, and the changing colors of pipes and other components provide the possibility of the system monitoring [9].

In both synoptic screens, there are also controls which serve the purpose of presenting the measured lighting intensity and air temperature values (upper right corner of the screen). Just below, there are push buttons intended for displaying the PopUp windows with set–points of the system and statistics of the system operation [9, 10].

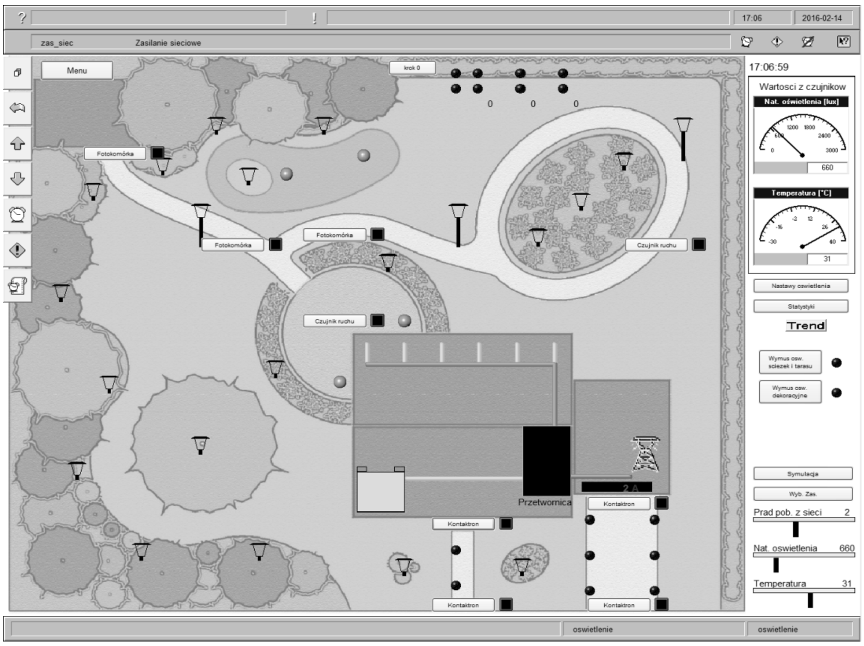

Fig. 10. Screenshot which presents the synoptic screen of the lighting subsystem [10]

The alarms, whose content is saved each time in .txt output files and which are set off when the status of the respective outputs is changed, were defined. Furthermore, the database file is run, whereby it is created using the Cicode function and allows for the tracking of the user operations [9, 10].

Based on the Accumulators components, the statistics of activation of the respective executive subassemblies are kept and their aggregate operating time is measured [9, 10].

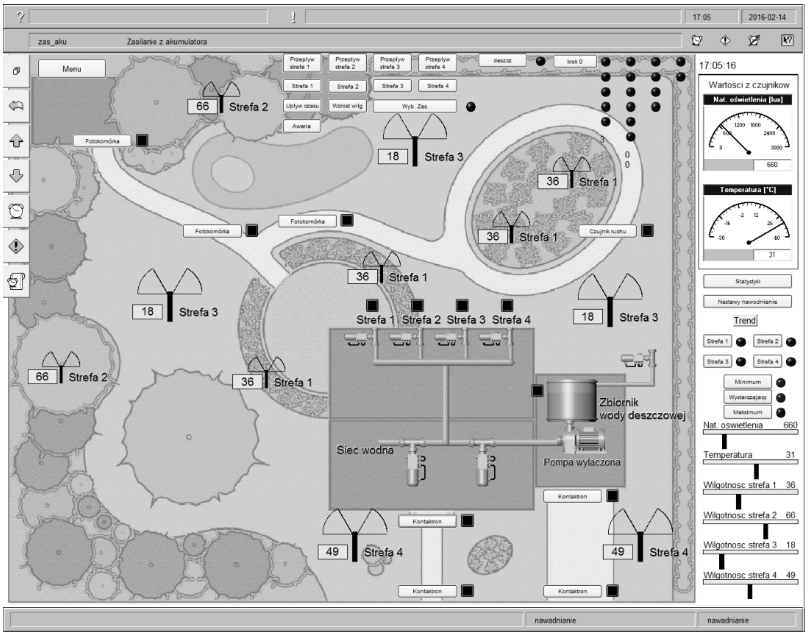

Fig. 11.Screenshot which presents the synoptic screen of the irrigation subsystem [9]

Communication with the physical controller takes place via Modbus and the OPC OFS controller – according to the manufacturer, the direct access to the status of inputs and outputs of the controller is impossible – it is necessary to assign these values to words and memory bits using the SHORT and OPERATION BLOCK components in the controller's program [9, 10, 17].

3. Summary

The presented design of the automatic irrigation and lighting system implemented by using the PLC and the SCADA software creates many possibilities in terms of its extension – it is an open system which may include components of various manufacturers, making only sure that the input elements should correspond to the characteristics of the controller inputs. Additionally, owing to the available modules and the possibility of connecting the controllers to form a network, such a system may be extended by additional functionalities such as door automation, security systems or automation system inside the building, without replacing the controller.

With regards to operation, the designed system is similar to open intelligent building systems – owing to the use of the PLC, it can be adapted to individual requirements, while the SCADA software and the HMI interfaces enable the friendly and universal visualization of the operation of such a system, depending on the expectations and requirements of the users. The solution presented in this paper may constitute one of the components of a larger management system for intelligent building systems and their environment.

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