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"IGOR SYKORSKY KYIV POLYTECHNIC INSTITUTE"

COMPUTER CONTROL OF TECHNOLOGICAL PROCESSES, EXPERIMENTS, EQUIPMENT. GUIDE FOR CALCULATIONAL GRAPHIC WORK

Recommended by the Methodological Council of the Igor Sikorsky Kyiv Polytechnic Institute

as a study aid for master's degree applicants
on the educational program "Engineering of Intellectual Electrotechnical and Mechatronic Complexes"
of the specialty 141 Electric Power Engineering, Electrotechnics and Electromechanics

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Electronic network educational edition

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The presented guide outlines the main provisions for performing computational graphic work, the subject of which includes the sections of the course on studying the procedure of programming logic controllers, hardware configuration of distributed automation systems, development of automation and control systems. The educational edition for performing computational and graphic work contains basic theoretical information, the work program, instructions for its implementation, requirements for the content of computational and graphic work, and control questions.

The existing methods of the synthesis of the theory of digital automata, the features of the implementation of the visualization system, as well as the hardware configuration of the automation system are considered.

The educational edition is intended for master's degree holders in specialty 141 "Electric Power Engineering, Electrotechnics and Electromechanics", educational program "Engineering of intelligent electrotechnical and mechatronic complexes". Also it could be interest for masters degree holders in speciality 151 «Automation and computer-integrated technologies» and other educational programs of speciality 141.

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КОМП'ЮТЕРНЕ КЕРУВАННЯ ТЕХНОЛОГІЧНИМИ ПРОЦЕСАМИ, ЕКСПЕРИМЕНТАМИ, ОБЛАДНАННЯМ

РОЗРАХУНКОВО-ГРАФІЧНА РОБОТА

(Англійською мовою)

У представленому посібнику викладено основні положення щодо виконання розрахунково-графічної роботи, тематика якої охоплює розділи курсу з вивчення процедури програмування логічних контролерів, конфігурації апаратного забезпечення розподілених систем автоматизації, розробки систем автоматизації та керування. Навчальне видання для виконання розрахунково-графічної роботи містить основні теоретичні відомості, робочу програму, вказівки до її виконання, вимоги до змісту розрахунково-графічної роботи, контрольні запитання.

Розглянуто існуючі методи синтезу теорії цифрових автоматів, особливості реалізації системи візуалізації, а також апаратну конфігурацію системи автоматизації.

Навчальне видання призначене для магістрів спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» освітньої програми «Інжиніринг інтелектуальних електротехнічних і мехатронних комплексів». Також може бути цікавим для магістрів спеціальності 151 «Автоматизація та комп’ютерно-інтегровані технології» та інших освітніх програм спеціальності 141.

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Content

INTRODUCTION

The academic discipline "Computer control of technological processes, experiments, equipment" is one of the final ones in the professional training of engineers in the specialty "Electric power engineering, electrical engineering and electromechanics ". It is a logical continuation of such special disciplines as "Theory of automatic control", "Control systems of electric drives", "Theoretical foundations of electrical Engineering" and others.

The main goal of computational and graphic work is to give students thorough skills in the development, design, research and debugging of modern automation systems based on programmable logic controllers. As a result of the work, students should acquire solid knowledge about the general features of the construction of distributed automation systems, the development of industrial automation schemes on logical programmable controllers. In addition, students choose a rational engineering solution based on technical and economic analysis, find reserves for increasing the automation efficiency, carry out an objective analysis of the properties of electric drives and automation systems, and evaluate its advantages and disadvantages.

The educational quide for performing calculational graphic work contains basic theoretical information, the work program, instructions for its implementation, the content of the report and control questions. For independent preparation, students use the lecture notes and recommended literature.

Calculational graphic work on A4 format sheets, taking into account the requirements of the IEC standards, is submitted. In addition, it must contain a drawing with electric diagram at A3 format of paper for the selected automation system according to the variant, as well as a list of selected elements for this diagram. Calculational graphic work should be submitted to the head of practical classes and defended.

1. BASIC THEORETICAL KNOWLEDGE

1.1. General characteristics of industrial interfaces

The choice of automation elements, namely the programmable logic controller, the operator's panel in practice is carried out not only on the basis of the number of necessary inputs/outputs that enable system control, but also on the number and type of interfaces for data transmission.

To compare the main interfaces used in industrial interface networks, the most important characteristics are summarized in Table 1.

Table 1

Comparative characteristics of serial interfaces

Standard name	RS-232C	RS-422A	RS-485	CAN
Signal type	voltage	Voltage, differential symmetrical	Voltage, differential symmetrical	Voltage, differential Unsymmetrical
Connection mode	duplex	duplex	Halfduplex, duplex	duplex
Quantity receiver/transmitter	1/1	1/10	32/32 (with resistance12kOhm)	63/63
Max. length	15m	1200m	1200m	Up to 5 km
Max rate	115200 bode	around 10 Mbit/s	around 10 Mbit/s	1 Mbit/s

As for the 32 receivers/transmitters in RS-485, this applies only to cases where the resistance of the receivers is equal to 12kΩ. With other resistances, for example 48kΩ, the maximum number of receivers will be 128, respectively.

For all interfaces (except RS-232C), the maximum bandwidth depends on many factors. First of all, it is the length of the communication line, as well as the type of cable, the level of interference, ways of matching lines, etc.

Which interface to choose for implementation depends on the situation. Sometimes the development Engineer has no choice because the device can only support one specific interface. For communication with other devices, the use of interface converter adapters or even special communication controllers is very likely. In addition to the compatibility of interfaces, an important aspect of the implementation of data transfer from a programmable logic controller to an operator panel or to a personal or industrial computer is the compatibility of data transfer protocols.

1.2. Methods of synthesis of logical control schemes

One of the most important stages in the development of a technological process automation system is the writing of a work program that must be "entered" into the memory of the programmable logic controller. This program should turn on and off the output elements of the controller and analog and discrete output modules in accordance with the logic of the circuit and the state of the inputs of the controller and expansion modules. At the same time, the logic of the circuit can be both single-stroke and multi-stroke.

Single-cycle scheme is logic control scheme, in which the output signals are determined only by the combination and level of the input signals. Multi-cycle scheme is a scheme in which the output signals are determined not only by the input signals, but also by the previous values of the intermediate and output signals.

In modern automation systems, in a much greater number of states, multi-cycle logical control schemes are used, while the procedure for synthesizing algorithms for such schemes is a rather complex procedure.

There are several basic methods of synthesizing multi-cycle schemes, some of the most famous of which are:

1. Synthesis by the method of Carnot maps. It is one of the most complex methods from the point of view of synthesis; it is used with a small number of input signals. This method allows convenient work with acyclic processes.

2. Synthesis by the clock divider method. Leads to quite large logical expressions but is quite simple from the point of view of working with processes that are executed sequentially and cyclically.

3. Synthesis by the method of RS-triggers. Leads to the largest expressions for logical control laws but is very convenient when working with cyclic and acyclic processes.

4. The method of graphs and conditional transitions. Suitable only for programming languages that have conditional transition functions, leads to rather cumbersome programs.

At the same time, the designer can choose the most convenient and familiar synthesis method for him, or a combination of several of them. At the same time, it is not known which of the synthesis methods will lead to the smallest logical expression and will occupy less memory in the programmable logic controller, so it will largely be determined by the experience of the designer. In addition, the work program could be significantly simplified when using ready-made functional blocks that can be used in combination with the above synthesis methods.

1.3. Synthesis of multi-cycle schemes by the method RS - triggers

Let's consider the method of synthesis using this example.

The condition of the task of automation. The output of the DO1 controller, which turns on the HL1 lamp (100W, 230V), must perform the function of a polarized relay, when the button is pressed without fixing DI1. At the same time, pressing the DI1 button (the button without locking) turns on the output relay DO1. When this button is released, the relay remains on. When the button is pressed again, the relay turns off and remains off after releasing it.

For the synthesis of a logical control scheme, a technique using a transition graph.

At the same time, RS-triggers are used as circuit elements. The number of circuit states determines the number of triggers. Thus, the system states can be summarized in Table 2.

Table 2

System states

State number	State description	Output state
1	The DI1 button is unpressed. The output relay is off	F=0
2	The DI1 button is pressed. The output relay is on	F=1
3	The DI1 button is unpressed. The output relay is on	F=1
4	The DI1 button is pressed. The output relay is off	F=0

The number of triggers is determined from the expression:

$2^N \geq M,$

where M - the number of system states; N – needed quantity of RS-triggers.

In our case, the minimum number of triggers – 2.

Let us define for P1 second and third states, and for trigger P2 – third and fourth state:

The condition for turning on the first trigger:

$S_{P1} = a * \overline{P2}.$

The condition for turning off the first trigger:

$R_{P1} = a * P2.$

The condition for turning on the second trigger:

$S_{P2} = \overline{a} * P1.$

The condition for turning off the second trigger:

$R_{P2} = \overline{a} * \overline{P1}.$

Then the formulas describing the operation of the triggers will be recorded:

$P1 = \left(a * \overline{P2} + P1\right) * \overline{a * P2}.$

$$P2 = (\overline{a} * P1 + P2) * \overline{\overline{a} * P1}.$$

In the FBD programming language, we get a record in the form presented in Figure 1.1.

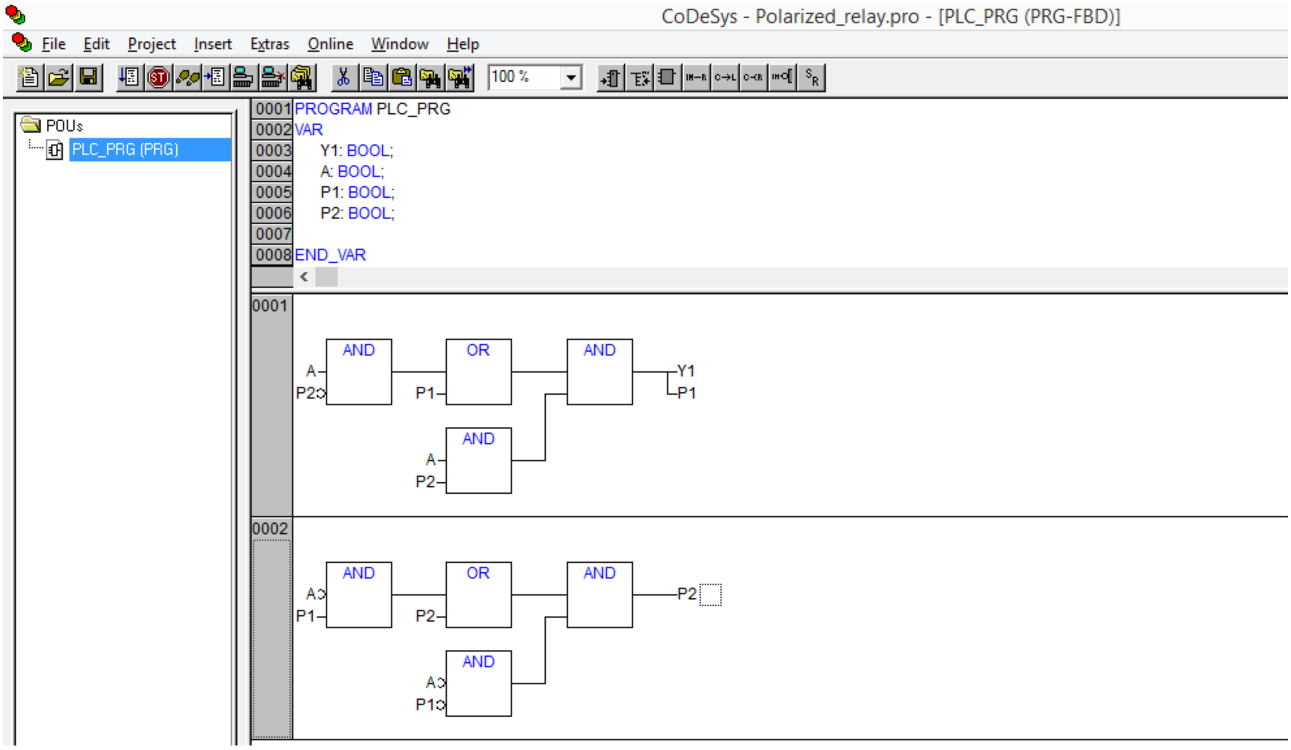


Fig. 1.1. Program for implementation of "polarized relay" in FBD language

As mentioned earlier, the method of RS-triggers does not always lead to the simplest and most compact solution. So, for example, a simpler implementation of such a control system using functional blocks is possible.

A simplified relay implementation scheme is written in the ST language. In particular, for this task, the module for determining the presence of a growth front, the appearance of which is presented in Figure 1.2, is interesting.

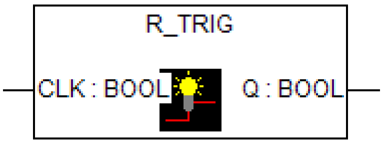


Fig. 1.2. Functional unit for determining the trigger edge

```
FUNCTION_BLOCK R_TRIG
(*      Rising Edge detection*)
VAR_INPUT
        CLK: BOOL;      (*Tracked signal*)
END_VAR
VAR_OUTPUT
        Q: BOOL;   (*Edge detection signal*)
```

```
END_VAR
VAR
	M: BOOL;
END_VAR
```

Using this functional block obtains:

```
Front(CLK:=knopka);
IF Front.Q AND NOT lampa THEN
lampa:=TRUE;
ELSIF Front.Q AND lampa THEN
lampa:=FALSE;
END_IF
```

There is simpliest realization of this function at ST language.

```
Front(CLK:=knopka);
IF Front.Q THEN
lampa := NOT lampa;
END_IF
```

1.4. Synthesis of multi-cycle schemes by the method of graphs and conditional transitions

The conditional transition operators include the following commands of the ST programming language:

- IF THEN;
- REPEAT UNTIL;
- WHILE DO;
- CASE OF.

In the case of using programmable logic controllers with a watchdog timer, it is advisable to use IF THEN statements, since other statements can lead to cyclic polling of the same function of uncontrolled duration. That is why, we will consider the synthesis procedure with this operator on the example of controlling a steam valve.

The condition of the task of automation. When the start command is given, pressing the DI1 button (button without locking) turns on the output relay DO1, which, in turn, turns on the steam valve. Upon reaching a certain value of humidity in the system, the humidity stabilization mode begins due to the operation of the relay regulator with hysteresis. At the same time, the timer that determines the duration of the stabilization mode is turned on. When the timer is triggered, the DO1 output signal is turned off and the process ends.

First, let's define all possible states of the system in which it can be:

1. The initial state in which the steam valve is turned off.

2. The process of setting the humidity to the set value, the steam valve is constantly turned on.

3. Stabilization of humidity, in which the steam valve is turned off, the countdown timer is turned on.

4. Stabilization of humidity, in which the steam valve is on, the countdown timer is on.

According to these transition states and conditions, we make a graph of transitions. In this graph of transitions, the states are defined by circles, and the transition conditions between them are defined by arrows. The transition condition itself is written above the arrow. The variables that are enabled in this state are recorded under the circles. At the same time, the graph of transitions has the form presented in Figure 1.3.

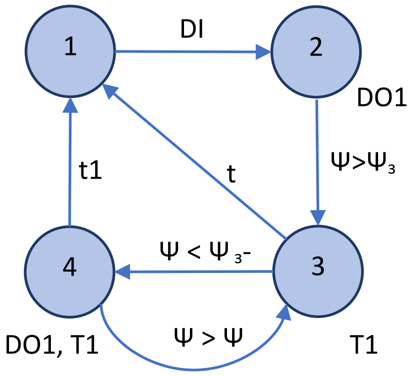


Fig. 1.3. Transition graph for the humidity control problem

The following symbols are used on the graph:

Ψ – actual humidity;

Ψ з- setpoint value of humidity;

DI1 – trigger signal of the "START" button;

DO1 – turning on the relay signal for starting the steam valve;

T1 – timer counting down the duration of the process;

t1 – a timer trigger signal with a switch-on delay;

Δ – switching hysteresis of the relay regulator.

The states of the system are also determined by their intermediate variables P1, P2, P3, P4.

It should be noted that the procedure for using synthesis by the trigger method for such a graph is much more complicated, since it contains diagonal lines. When using the trigger method, "contact competition" occurs in the system, which, in turn, leads to unstable system operation.

The program writing window in Codesys v.3.5 has the appearance presented in Figure 1.4.

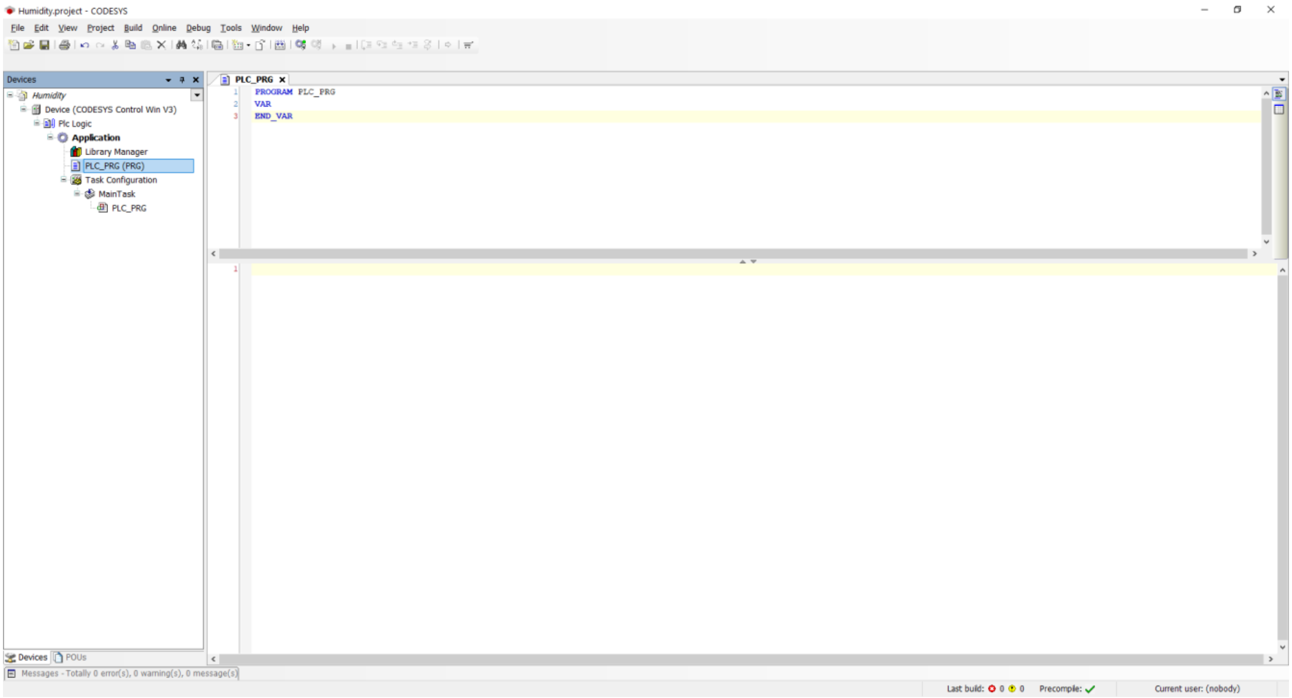


Fig. 1.4. A window for writing an application program in the Codesys 3.5

Since, when the controller is turned on, the system should already be in the initial state, when defining the variables, it is necessary to set P1=TRUE. In addition, it is necessary to immediately set a non-zero value of the specified humidity and the hysteresis value for the false operation of the valve.

```
VAR
    P1: BOOL := TRUE;
    HUMset: INT := 80;
    DeltaHUM: INT:=1;
END_VAR
```

We leave the other variables undefined, i.e. equal to zero at the beginning of the cycle.

The condition for transition from the first state to the second is determined by the conditional loop:

IF DI1=TRUE AND P1=TRUE THEN P2:=TRUE; P1:=FALSE;

END_IF

That is, when the system is in the initial state and the DI1 button is activated, the variable of the second state is turned on, and the first one is turned off.

Transition conditions for different states can be described in a similar way. The TON block from the Standard library is used as a timer function block with an on-delay. At the same time, the program looks like this:

(*Definition of variables*)

```
PROGRAM PLC_PRG
VAR
	P1: BOOL := TRUE; P2: BOOL; P3: BOOL; P4: BOOL;
	HUMset: INT := 80;HUM: INT;DeltaHUM: INT;
	T1: TON;
	DI1: BOOL;DO1: BOOL;
END_VAR
(*Main part program*)
IF DI1=TRUE AND P1=TRUE THEN P2:=TRUE; P1:=FALSE;
	END_IF
	IF HUM>HUMset AND P2=TRUE THEN P3:=TRUE; P2:=FALSE; (*HUM – actual humidity; HUMset – setpoint value of humidity*)
	END_IF
IF HUM<HUMset-DeltaHUM AND P3=TRUE THEN P4:=TRUE; P3:=FALSE; (*DeltaHUM – hysteresis value for humidity*)
	END_IF
	IF HUM>HUMset AND P4=TRUE THEN P3:=TRUE; P4:=FALSE;
	END_IF
IF T1.Q=TRUE AND (P3=TRUE OR P4=TRUE) THEN P1:=TRUE; P3:=FALSE; P4:=FALSE;
	END_IF
	T1(IN:=P3 OR P4, PT:=T#100S , Q=>, ET=> );
	DO1:=P2 OR P4;
```

The program settings window in the Codesys v.3.5 environment has the form presented in Figure 1.5.

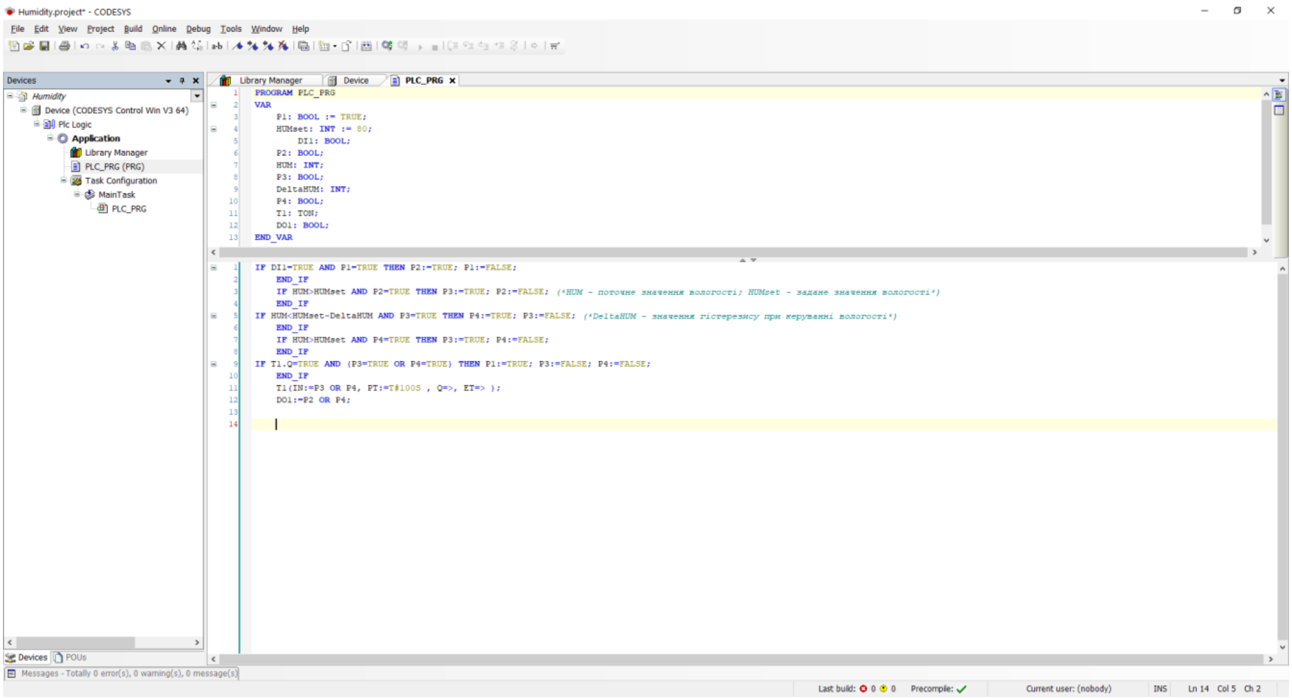


Fig. 1.5. Implementation of the moisture management program

To test the operation of the program, it is advisable to use the visualization settings presented in Figure 1.6.

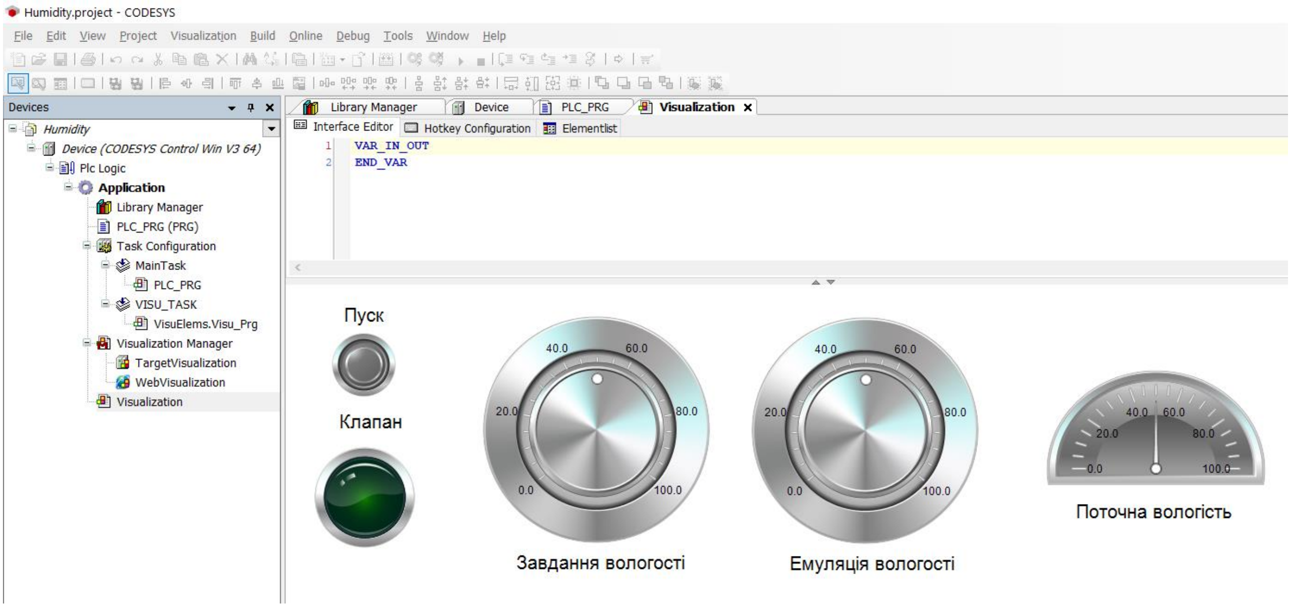


Fig. 1.6. Visualization of the operation of the automation system

All graphics components are selected as Toolbox tab items in the Measurement Controls and Indicators, Switches, Images folders.

It should be remembered that in addition to the synthesis of the software part of the project, it is necessary to develop the hardware part, namely the selection of appropriate switching devices, the formation of the necessary values of the power supply voltage, as well as the development of a workable control scheme.

2. HARDWARE CONFIGURATION DESIGN FOR AUTOMATION SYSTEM

2.1. Selection of a controller for application in automation task

In the Lenze range there are controllers both without a built-in display and with a built-in display, the appearance of which is presented in Figure 2.1.

Fig. 2.1. Variety of Lenze controllers

All of them have a built-in CAN interface and support the CANopen protocol. The difference between controllers without a display is the presence internal data transmittion bus, that is, direct communication with expansion modules is possible. The power supply of the controllers is 24V DC, and it is needed to use a stabilized power source of relevant power.

It should be noted that the full marking of the controller should be used in the list of elements, and not just Lenze C300. So, for example, the controller without any additional options has the name PC C30GAC00000F3G0XXX-02S3C300.

The controller connection diagram is shown in Figure 2.2.

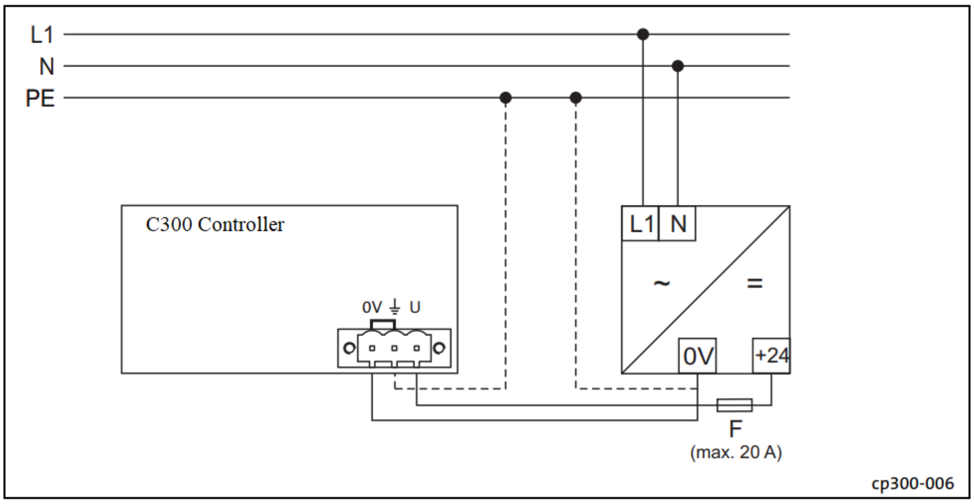


Fig. 2.2. Connection diagram of the C300 controller

2.2. Selection of input/output modules to expand the functionality of the controller

The instructions for the input/output module can be found on the lenze.com website at the link: https://download.lenze.com/TD/EPM-Sxxx__I-O%20system%201000%20System%20Manual__v8-0__EN.pdf

Modules are selected according to the required number of inputs/outputs used in the project, their functional purpose, and the types of sensors to be connected.

So, it is needed to select the necessary modules for a project that uses the following sensors:

- 1 Pt100 type temperature sensor (connection with a three-wire circuit);
- 1 pressure sensor with 4-20mA output;
- 2 buttons;
- 1 inductive NPN-type sensor.

At the same time, it is necessary to control two 230V valves and a latch with control input of 0..10V DC. Since the Lenze controllers do not contain built-in inputs/outputs onboard, expansion modules should provide the entire functionality of the system. Consider the list of modules available from Lenze, presented in Table 3.

Table 3

List of extension modules from Lenze

Modules communication	EPM-S110 – CANopen communication module EPM-S120 - PROFIBUS communication module EPM-S130 - EtherCAT communication module EPM-S140 - PROFINET communication module
Modules connection	EPM-S200 - 2 discrete inputs, PNP logic EPM-S201 - 4 discrete inputs, PNP logic EPM-S202 - 8 discrete inputs, PNP logic EPM-S203 - 4 discrete inputs, three-wire connection EPM-S204 - 2 discrete inputs, NPN logic EPM-S205 - 4 discrete inputs, NPN logic EPM-S206 - 8 discrete inputs, NPN logic

	EPM-S207 - 2 discrete inputs, speed 2μs EPM-S300 - 2 discrete outputs EPM-S301 - 2 discrete outputs EPM-S302 - 2 discrete outputs EPM-S303 - 2 discrete outputs, NPN logic EPM-S304 - 4 discrete inputs, NPN logic EPM-S305 - 8 discrete inputs, NPN logic EPM-S306 - 2 discrete outputs, load up to 2 A EPM-S308 - 2 discrete outputs, relay for voltage 230V EPM-S309 – 4 discrete outputs, load up to 2 A EPM-S310 - 2 discrete outputs, speed 2μs EPM-S400 - 2 analog inputs, 0 ... 10V DC EPM-S401 - 4 analog inputs, 0 ... 10V DC EPM-S402 - 2 analog inputs, 0/4 ... 20 mA EPM-S403 - 4 analog inputs, 0/4 ... 20 mA EPM-S404 - 4 analog inputs for thermistors EPM-S405 - 2 analog inputs for thermocouples EPM-S406 - 2 analog inputs, -10 ... 10V DC EPM-S408 - 2 analog inputs, 0/4 ... 20 mA EPM-S500 - 2 analog outputs, 0...10V DC EPM-S501 - 4 analog outputs, 0...10V DC EPM-S502 - 2 analog outputs, 0/4 ... 20 mA EPM-S503 - 4 analog inputs, 0/4 ... 20 mA EPM-S600 – Connection of 1 encoder 24V / 1 disk. Entrance EPM-S601 - Connection of 2 24V encoders EPM-S602 - Connection of 1 5V encoder EPM-S603 - Connection of 2 24V encoders EPM-S604 – sensor connection interface with SSI EPM-S620 - PWM output

	EPM-S640 – Module with RS232 interface EPM-S650 - Module with RS422/485 interface EPM-S700 - main power supply (bus connection) EPM-S701 – input/output power supply EPM-S702 - power inputs/outputs and electronics

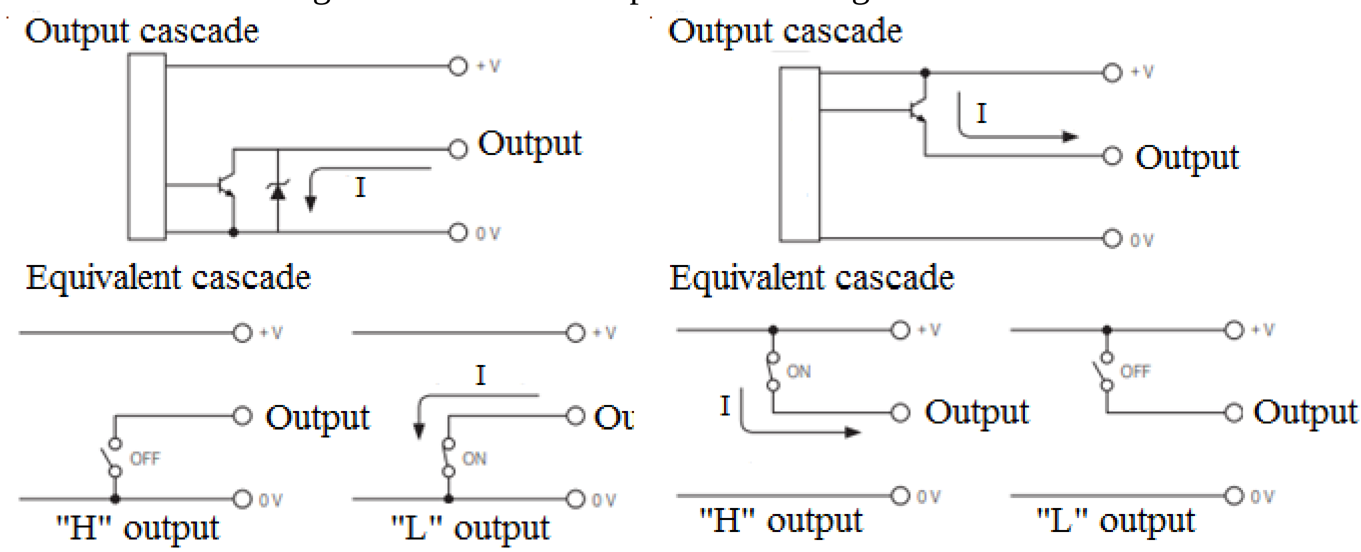
EPM-S1xx communication modules for remote connection of expansion modules are used. Since in our case there is no requirement for remote installation of modules, we will not need them. An exception may be the case when we use a controller with a built-in display, therefore, with the absence of the possibility of connecting modules via bus.

According to the task, we use:

- 3 discrete input signals;
- 2 discrete output signals;
- 2 analog input signals;
- 1 analog output signal.

Discrete inputs form the value "FALSE" and "TRUE" using 2 buttons and an inductive NPN-type sensor. The principle of operation of the NPN-input is that for its operation, a "logical" zero must be applied to the input, in contrast to the PNP-input, in which the input must be applied to a "logical" one.

Connection diagrams have the form presented in Figure 2.3.



NPN – logic PNP – logic

Fig. 2.3. Connection diagrams of sensors with different types of output logic

It should be noted that the button can be connected to any of the inputs according to the corresponding scheme.

Thus, it is advisable to choose the same module for connecting the buttons as for connecting the sensor. So, for discrete inputs, we choose the EPM-S205 module. The connection diagram is shown in Figure 2.4.

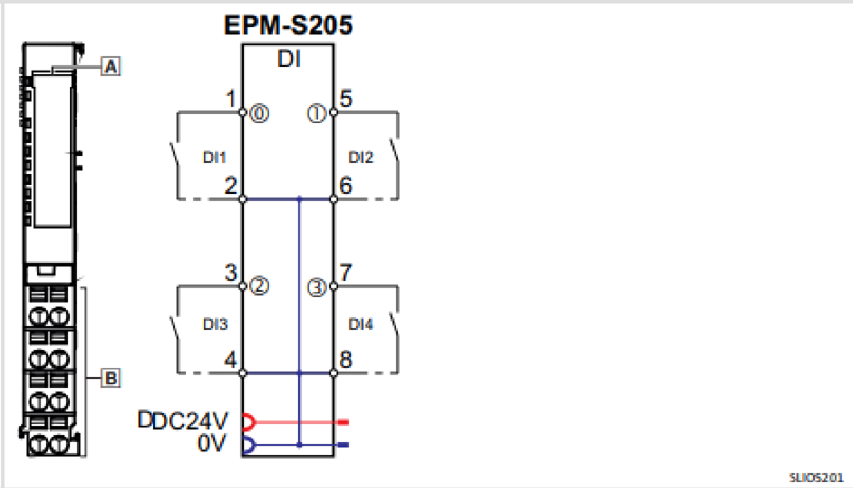


Fig. 2.4. Connection diagram to discrete input modules

Regarding discrete outputs. They must turn on the valves with a voltage of 220V AC. Since the supply voltage of the controller is 24V DC, it is necessary to use either a module with relay outputs or external relays. Since there is a module with two relay outputs in the Lenze range, it is advisable to use it. The connection diagram of such a module is shown in Figure 2.5.

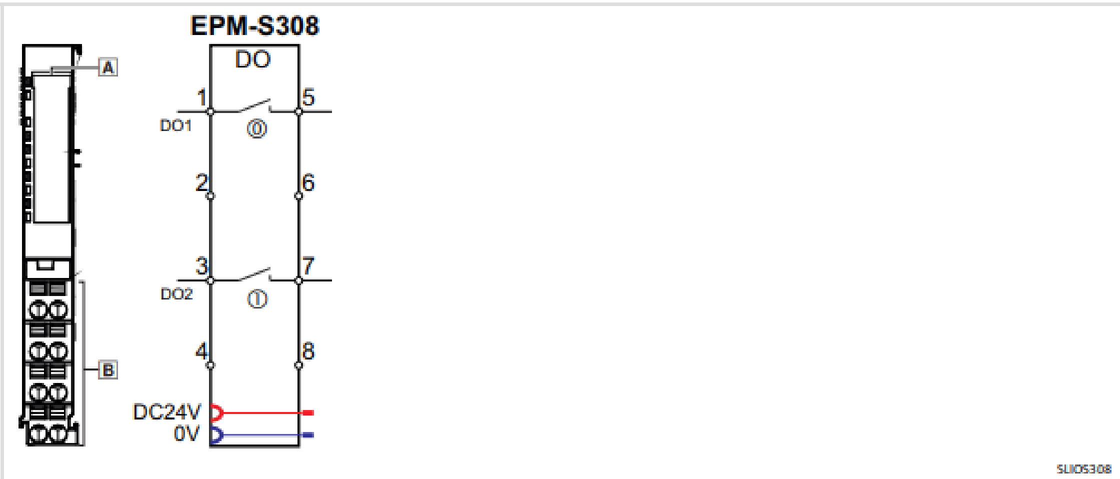


Fig. 2.5. Connection diagram to discrete output modules

This relay has a "dry contact", that means it doesn’t contain voltage potential. To switch the valves, a phase wire must be connected to one of the terminals of these relays.

A specialized EPM−S404 module is used to connect the temperature sensor with thermal resistance principle. The three-wire sensor connection diagram is shown in Figure 2.6.

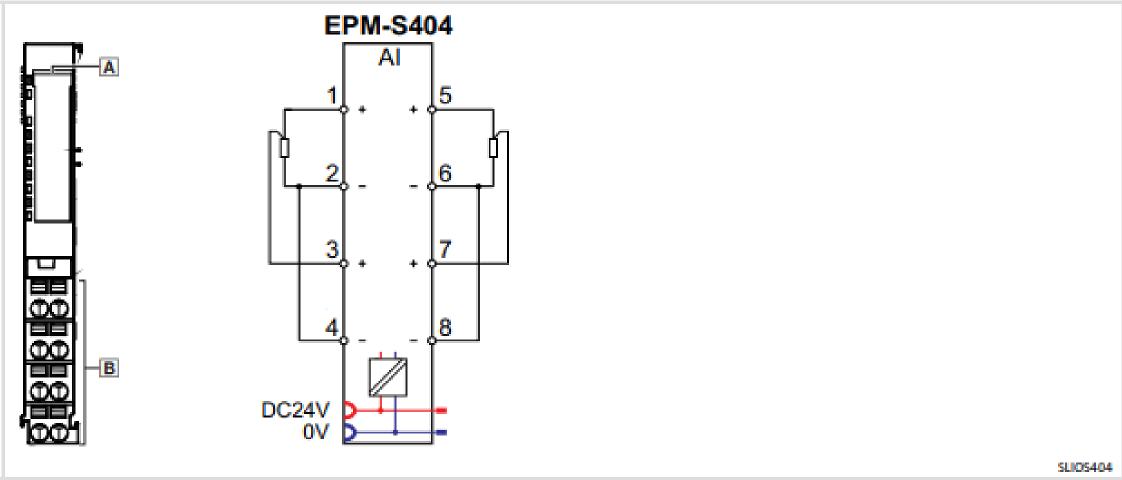


Fig. 2.6. Schematic of connecting thermistors to the analog inputs module

To connect a pressure sensor with an output of 4..20mA, it is necessary to use a corresponding module with inputs of 4..20mA. The experiment of the project developer consists in the correct selection of the input bit rate for a certain technological task. Lenze has two options - 12 bit and 16 bit.

Assume that the maximum measured value of the sensor is 10 bar.

Then, for a 12-bit module, accuracy of pressure measurement might be $\frac{10}{4096} \approx 0{,}0025$bar; and for 16-bits - $\frac{10}{16384} \approx 0{,}0006$ bar.

Since 12-bit resolution is more than enough for pressure regulation process, it is recommended to choose a module with 12-bit input. The connection diagram of the corresponding EPM-S402 module is shown in Figure 2.7.

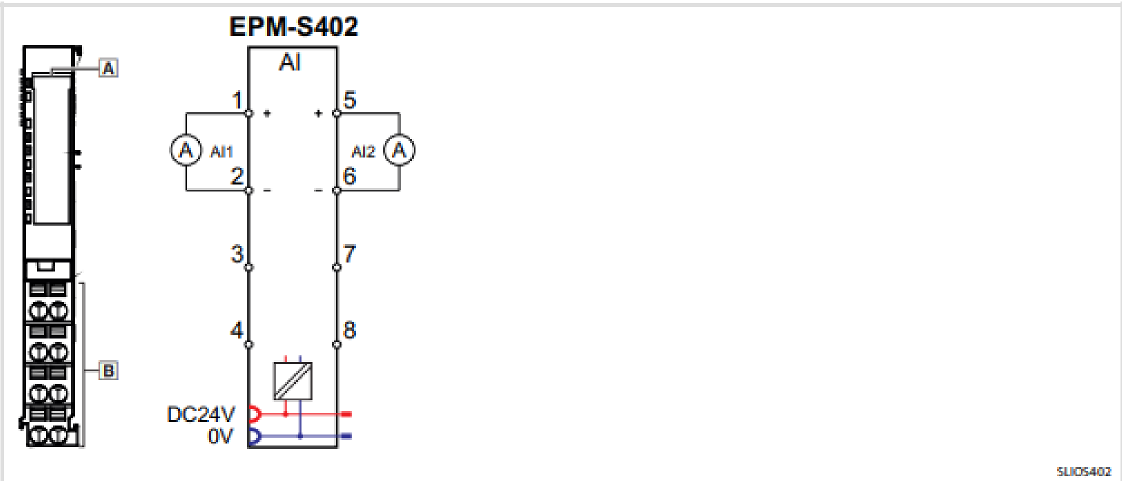


Fig. 2.7. Connection diagram of analog sensors to the analog inputs module

It should be noted that in most cases the pressure sensor has a passive output, that is, it requires the use of additional power supply module. At the same time, it is recommended to use a current loop supply connection.

We use the EPM–S500 module to generate an analog output. The connection diagram is shown in Figure 2.8.

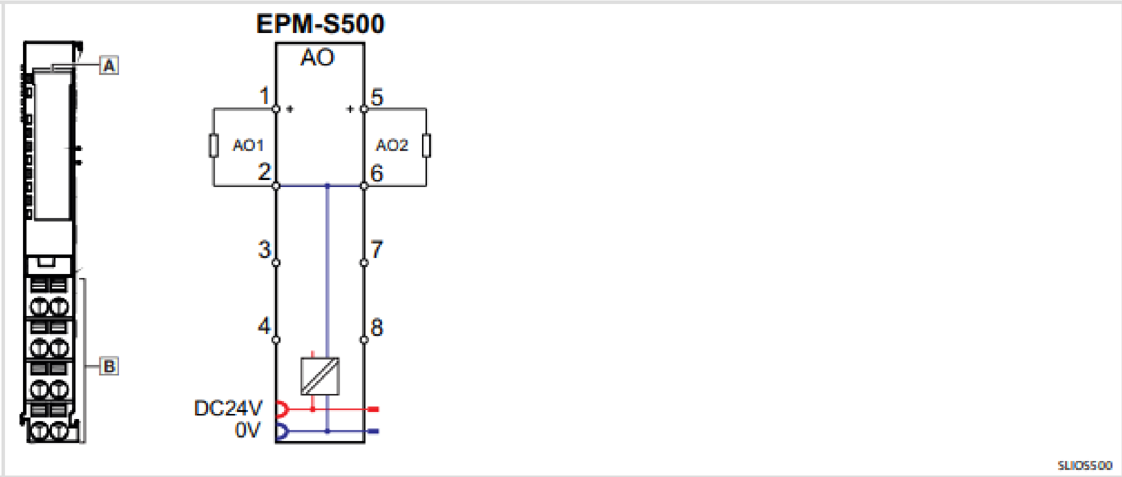


Fig. 2.8. The scheme of connecting executive mechanisms to the analog output module

The selection of expansion modules is completed, it remains to select the power supply module directly of the expansion modules (not to be confused with the power supply module of the controller). It is installed at the beginning of the bus between the controller or communication module and other modules. Survives according to the power consumption of other modules and nodes that will be connected. Since the consumption will be less than 5A, EPM-S701 power supply module have to be chosed. The connection diagram is shown in Figure 2.9.

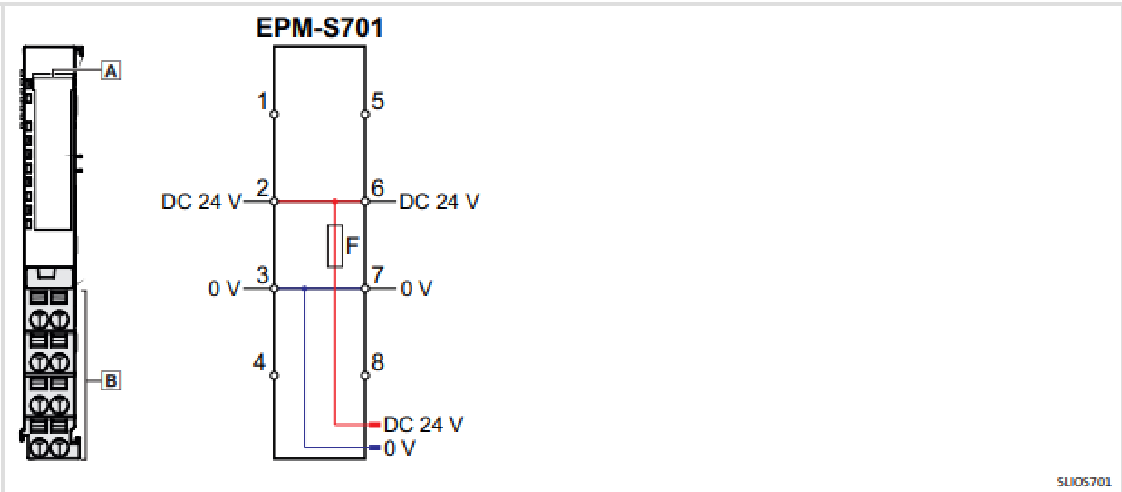


Fig. 2.8. Connection diagram of the power supply module

The general structure of connecting expansion modules to the C300 series controller is shown in Figure 2.10.

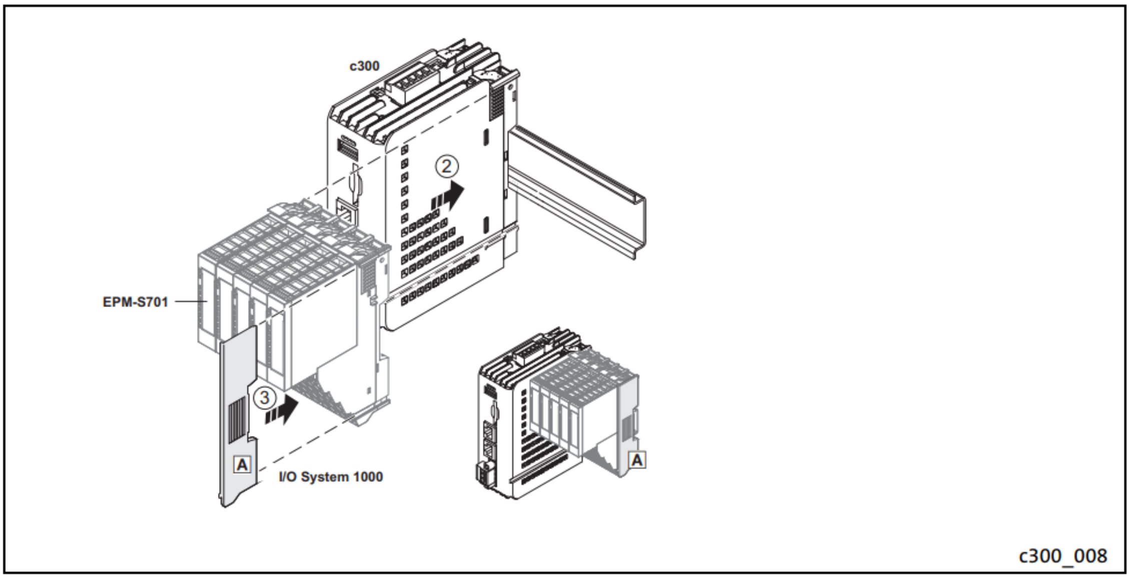


Fig. 2.10. The general structure of connecting expansion modules to the C300 series controller

The general structure of connecting expansion modules to the communication module, which also could be used, is shown in Figure 2.11.

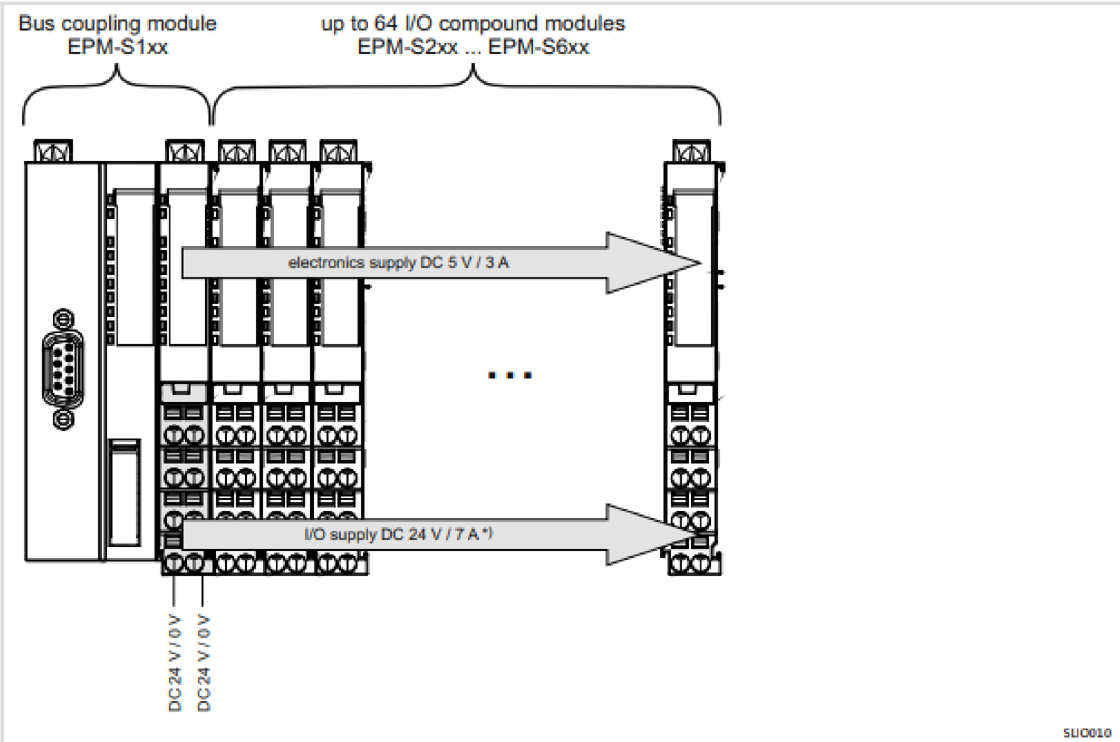


Fig. 2.11. The general structure of the connection of extension modules with the communication module

On the wiring diagram, the modules are located next to the controller or appropriatly marked, as shown in Figure 2.12.

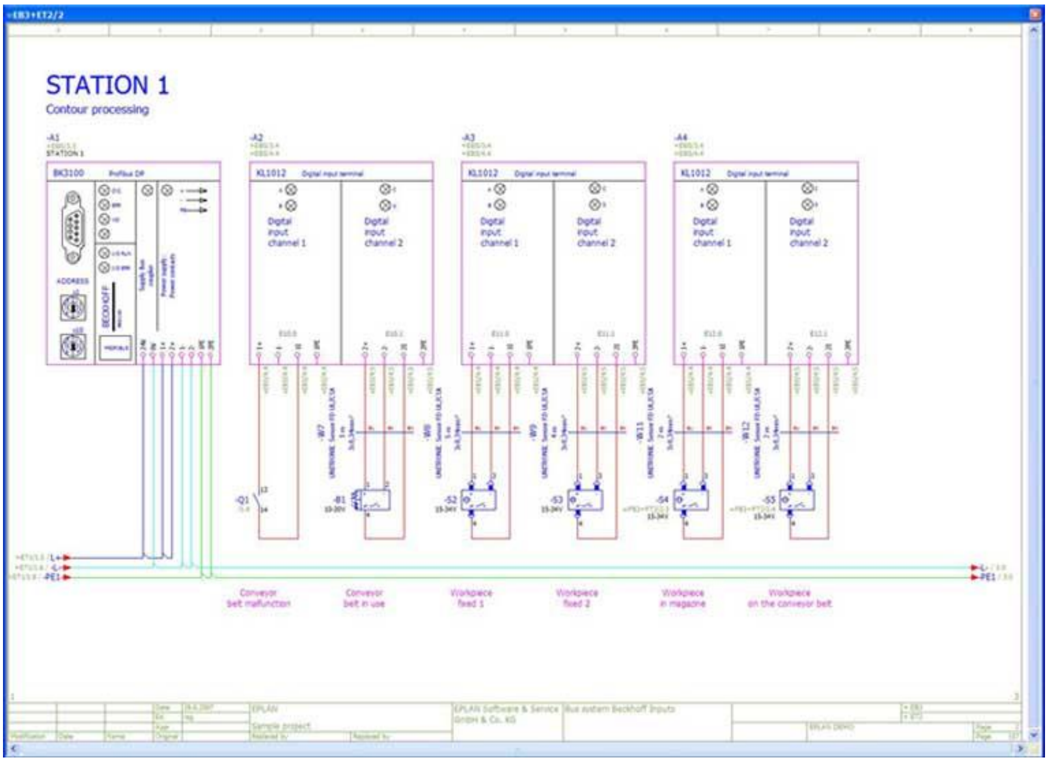


Fig. 2.12. Wiring diagram for automation system with a controller and expansion modules

2.3. Selection of elements of the lower level automation system

Low-level automation elements include sensors, limit switches, discrete-type actuators, non-programmable analog-type actuators, buttons, and control switches.

The selection of sensors is carried out in accordance with the technological conditions of operation, the range and accuracy of the signal measurement, the possible connection scheme, the presence of electromagnetic interference, the design of the sensor, etc.

A) selection of a temperature sensor.

The choice of temperature sensor is mainly carried out in accordance with the maximum temperature and permissible measurement accuracy.

The following types of sensors are distinguished in industrial automation systems:

- Semiconductor resistance sensors (PTC and NTC sensors);
- Thermoresistors (Pt100, Pt50, Pt1000);
- Thermocouples (L – type, K - type).

Only Pt100 thermoresistors and thermocouples can be connected to Lenze expansion modules. To connect other types of sensors, it is necessary to use analog (with 4..20mA output) or digital (with serial interface output) converters. This will greatly complicate the automation system and it is much easier to choose the necessary sensor. Table 4 should be kept in mind when choosing between Pt100 thermoresistors and thermocouples.

Table 4

Comparative characteristics of various temperature sensors

Characteristic	**Thermoresistance**	**Thermocouple**
Accuracy	Class A: 0,015+0,002t Class B: 0,3+0,005t	Typical value 1.1 degrees or 0.4% depending on temperature
Stability	+0,05 of degree during 1000 working hours	2..10 degrees during 1000 working hours
Responce	Lower	Slihtly lower
Calibration	Recalibration is possible	It is compared with the "reference", in case of discrepancy, it is replaced
Temperature range	-200..+850 degrees (up to 250 for platinum sensors without a special housing)	-270..2300 degrees
Term of service	Long term without restrictions	Rising working temperature leads to decreasing of working period
Installation features	Connection with simple copper wires is allowed	It is necessary to connect with expensive compensating cables
The cost of operation during the service	Lower	Higher
Cost	Slightly higher	Lower
Distance to the measuring device	Up to 50m	Up to 20m
Operating characteristics	Always better at temperatures below 650 degrees	It's always worse

Thus, with a small inertia of the technological process, it is recommended to use thermal resistors, which are easier to connect, have a longer service life and higher accuracy.The choice of design can be made according to the catalog at the link https://www.svaltera.ua/upload/iblock/1dd/price_6_sensors.pdf

It should be noted that the list of elements indicates the complete marking of the sensor with all 20 selected positions.

B) Selection of a pressure sensor.

The selection is made according to information from the manufacturer's catalog: https://dwyer-inst.com/PDF_files/626_628_i.pdf

At the same time, the complete marking of the sensor is also indicated, for example: 628-12-GH-P1-E1-S1

C) Selection of lamps, buttons and switches.

Signal lamps are installed on the control panel, cabinets, etc. to visualize the operation of the mechanism in a certain mode. At the same time, it is recommended for important modes such as "Accident", "Operation", "Presence of voltage" to use them even if there is a graphic or touch control panel, as can be seen from Figure 2.13.

Fig. 2.13. The appearance of the control cabinet with a built-in controller

Light lamps mainly for installation in control cabinets and are selected by color and power supply voltage are intended. It should be noted that the color used to inform staff is standardized. Main colors appointment is shown at Table 5.

Table 5

Functional assignment of colors in industry

Color	Purpose
Red	It is used only to generate signals about a critical accident that led to a stoppage of equipment, a subsequent emergency situation in production
Orange	It is used to inform the personnel about the occurrence of a situation that can lead to a stoppage of the equipment and a subsequent emergency situation in the production
Yellow	Informs about the presence of a dangerous situation, attracts the attention of personnel. It is used to inform personnel about the presence of voltage in circuits dangerous for humans

Green	It is used to inform personnel about the normal operation of the equipment
Blue, White	They are used to generate additional signals for personnel (transition to certain operating modes, for example manual)

The choice of light signal armature is carried out according to the excerpt from the manufacturer's catalog:

Type	Voltage	Colour
LPMLB3	24V AC/DC	
LPMLB4		
LPMLB5		
LPMLB6		
LPMLB7		
LPMLE3	110V AC	
LPMLE4		
LPMLE5		
LPMLE6		
LPMLE7		
LPMLM3	230V AC	
LPMLM4		
LPMLM5		
LPMLM6		
LPMLM7		

Selection of buttons and switches:

For ease of use in industry, prefabricated buttons consisting of a pusher are used; mounting plate; the required number and type of switching contacts of the light signaling module.

The rules for choosing a color are similar to choosing a lighting fixture.

Consider the example of selecting the button shown in Figure 2.14.

It consists of a red pusher without locking, a mounting plate and a normally open contact. The selection is made from the catalog by following the link:

https://www.svaltera.ua/upload/iblock/9a5/price_3_upravl_signal.pdf

The connection diagram of inputs and outputs with selected elements using Lenze expansion modules of the EPM series has the form presented in Figure 2.15.

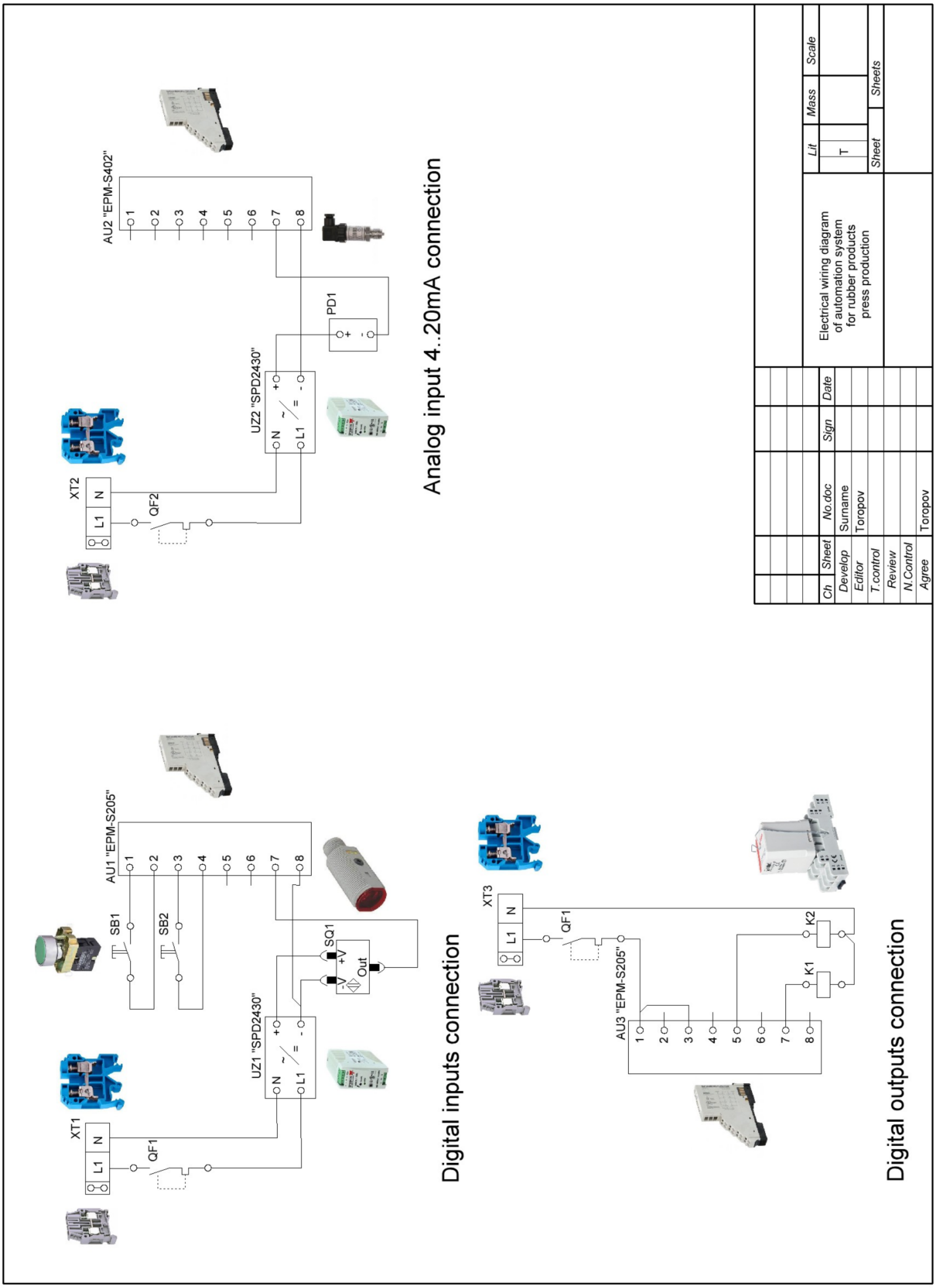


Fig. 2.15. Connection diagram of actuators, buttons and sensors to Lenze expansion modules of the EPM series

2.4. Recommendations for the development of an electrical installation scheme

Let's consider an example of the development of an electrical circuit using the example of a control cabinet using the example of an induction motor start/stop control cabinet. The connection is made to the power supply network with a solidly grounded neutral, that is, where the neutral is connected to the ground. Since the used control scheme is small, let's draw it on a sheet of A4 format. At the same time, a frame for the appropriate format should be selected, as can be seen from Figure 2.16.

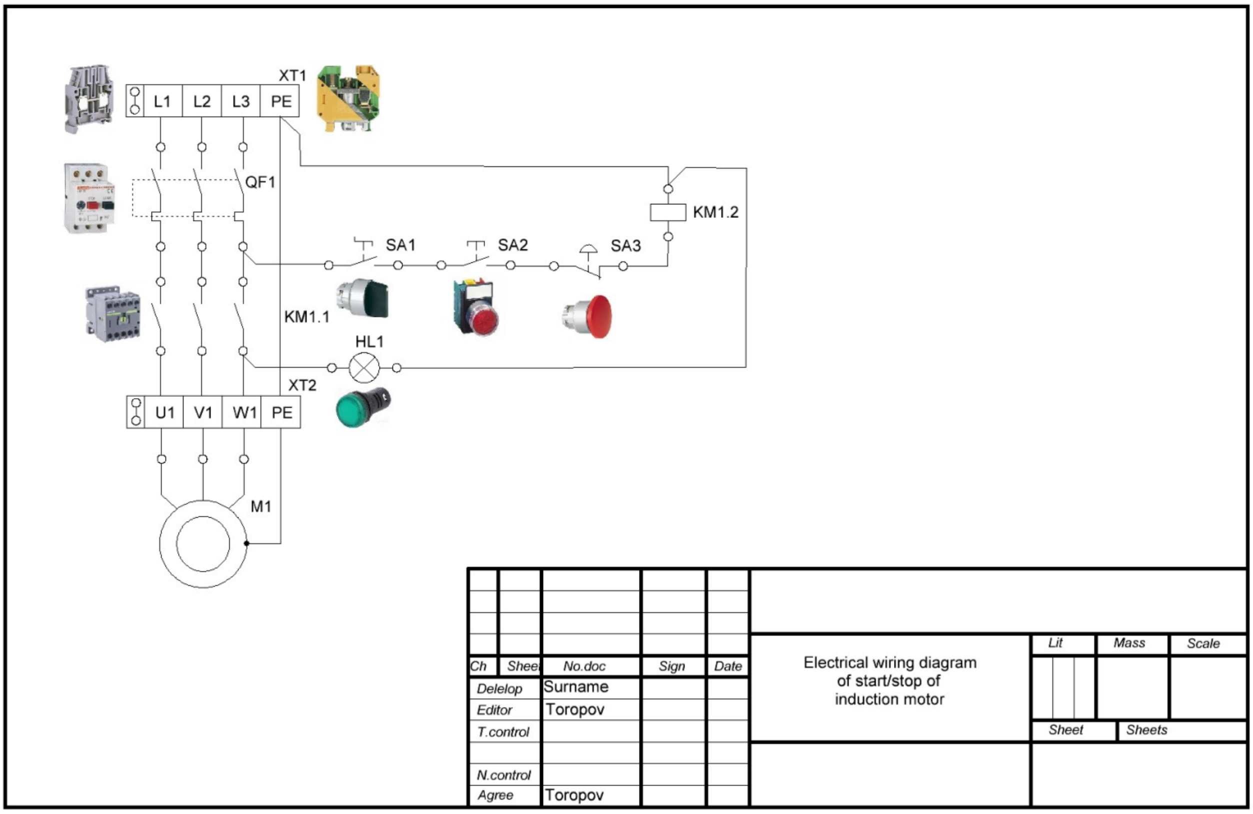


Fig. 2.16. Diagram of an electrical diagram for controlling the start/stop of induction motor

The control scheme consists of:

- Automatic motor protection switch QF1;
- electromagnetic contactor KM1;
- Switches SA1, SA2;
- SA3 "mushroom type" emergency stop button;
- “Run mode” indication lamp HL1;
- XT1 and XT2 terminals with grounding terminal.

The M1 motor does not belong to the cabinet, but to understand the operation of the system, it is still recommended to draw it at diagram.

The principle of operation of the scheme:

1. It is used supply voltage 3 phases 400V, 50Hz for energy supply of system.

2. Power supply to the control cabinet is made by switching on the automatic motor protection switch with thermal protection function. This switch provides protection of the electric motor and the control circuit as a whole from short circuit, as well as from the permissible overload of the motor current.

IMPORTANTLY! To protect the motor from overheating, you should use one of components listed below:

- Automatic switch with a separate thermal relay;
- Automatic motor protection switch with a built-in thermal relay;
- Semiconductor motor protection devices (electronic thermal relays, softstart devices, frequency inverters).

3. Motor operation starts when switches SA1 and SA2 are turned on while SA3 is closed. When the motor is running, the green light signal lamp HL1 lights up.

4. Stopping the motor by coasting is carried out when any of the switches SA1..SA3 is opened.

The list of elements listed below must be attached to the electrical wiring diagram.

Sign	Title	Quant.	Notes
	List of elements		
HL1	Light signal monoblock of constant light LPMLM3		
KM1	Contactor BF1801A220	1	Iн=18 A
M1	Induction motor IE2 WEG W22 132M 4p 1500 rpm	1	P=7,5 kW
QF1	Automatic motor protection switch SM1P0016	1	In=16 A
SA1	The switch is complete (The button is red with fixing LM2T Q104+ Mounting plate LPXAU120+Contact open LPXC10)	1	
SA2	Complete switch (LPCS120+ two-position rotary button Mounting plate LPXAU120+Contact open LPXC10)	1	
SA3	Complete switch (Mushroom button LPCB6144+ Mounting plate LPXAU120 + Contact closed LPXC01)	1	
XT1,XT2	Complete terminal block (Through terminal, with screw fixation on a DIN rail, open 3pcs + Grounding terminal with screw fixation, closed version 1pc)	8	

Ch.	Sh	No.doc	Sign	Date	CGW IEE OA-xxmp(n)-xx			
Developer					List of elements. Name of electrical diagram according to automation task.	Літ.	Лист	Листів
Editor		A.Toropov					1	1
T.control						Igor Sykorsky KPI ES IEE, OA-xx group		
N.control								
Agreed		A.Toropov						

3. AUTOMATED SYSTEM ALGORITHM FOR CALCULATIONAL GRAPHICS WORK

Select the equipment for the automation scheme of the pumping station and make a synthesis procedure of control algorithm.

In the water supply system, several pumps are used to maintain the pressure in the hydraulic system. At the same time, one of the pumps is used with a frequency converter and a pressure feedback sensor. At the same time, smooth control of the pump speed and, accordingly, maintaining the pressure at a given level is implemented. If the motor speed have reached a maximum, and the required pressure level has not been reached during defined time, then procedure for starting another motor should be carried out. At the same time, the procedure is as follows. To reduce the hydraulic shock caused by the direct start of the non-controlled pump in the water supply system, the speed of the regulated pump is reduced to 40% of the nominal one, after a while the auxiliary pump is started and after a while the regulation with the help of the controlled pump is switched on. When the controlled pump reaches the minimum operating frequency of rotation (about 20% of the nominal), the auxiliary pump is turned off and regulation continues only with the help of the controlled pump. Similarly, several auxiliary pumps can be switched on. When designing the system, alternate switching on of the auxiliary pumps should be provided, that is, after some time, the order of switching on the standby pumps changes. So, for example, at the initial moment of control, the pumps are turned on in the sequence No.1-No.2-No.3. Ater defined time, the sequence changes and the pumps will be turned on in the sequence No.2- No.3- No.1, etc. This is done to ensure uniform wear of the equipment. Visualization of the operation of the pumps on the operator's panel located at a distance of more than 1000 meters from the control cabinet should also be provided.

All datas for variants in Tables 6 are presented.

Table 6

Datas for various variants for automation task

№	Controlled pump power	Uncontrolled pump power	Uncontrolled pumps quantity	Requriments for visualization and archievation
1	10kW	3 kW	4	Visualization and archiving on a PC
2	30 kW	10 kW	3	Visualization only on the operator panel
3	50 kW	5 kW	4	Visualization and archiving on a PC

4	40 kW	10 kW	3	Visualization only on the operator panel
5	20 kW	15 kW	2	Visualization and archiving on a PC
6	15 kW	5 kW	4	Visualization only on the operator panel
7	11kW	7,5kW	2	Visualization and archiving on a PC
8	7,5kW	5,5kW	3	Visualization only on the operator panel
9	45kW	15kW	4	Visualization and archiving on a PC
10	20kW	15kW	2	Visualization only on the operator panel

4. EXECUTION PROCEDURE OF CALCULATIONAL GRAPHIC WORK

The following tasks ought to be completed for all variant of calculational graphic work:

1. Carring out the synthesis of the automation system, according variant number using one of the well-known methods of synthesis of logic schemes (Carnot map method, clock divider method, RS-trigger method, graph method using conditional transition commands).
2. Development of automation program for programmable logic controller using Codesys v.x.x application software and visualization of the technological process.
3. Development of technical solution for the implementation of data visualization and archiving, according to the variant.
4. Choosing of equipment that allows to solve the task of automation.
5. Development an installation electrical diagram of the equipment.
6. Providing a list of elements for the electrical circuit.
7. Making conclusions on the implemented automation system with a description of the advantages of the proposed solution, possibilities for further improvement, features of commissioning.

Recommended content of calculational graphic work.

1. Introduction.
2. Description of the synthesis procedure of the automation system algorithm.
3. Description of the algorithm of the automation system.
4. Description of the technological process visualization screen.
5. Description of the equipment that will be used to solve the problem.
6. Electrical assembly diagram.
7. List of elements.
8. Conclusions from the work.
9. A file with the program of the automation algorithm (on a flexible disk, on a USB drive), which could be run in emulation mode in Codesys x.x.

5. CONTROL QUESTIONS FOR CALCULATIONAL GRAPHICS WORK

1. What methods do you know of synthesizing logical automation schemes?

2. What conditional transition operators of the ST programming language do you know?

3. How to connect sensors with a passive output of 4..20mA to measuring device?

4. What is "dry contact"?

5. How does a PNP output differ from an NPN output?

6. Which temperature sensors according to the principle of action do you know?

7. How is the actuator connected to a discrete module with a "dry contact"?

8. What types of serial industrial interfaces allows to transmit a numerical signal more than 1 km?

9. Name the advantage of the method of graphswith conditional transitions, in comparison with the method of RS-triggers.

10. What are the advantages of using automation systems with thermoresistors, compared to thermocouples?

RECOMMENDED LITERATURE

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