RENEWABLE ENERGY TECHNOLOGIES

MONITORING THE MOTION SYSTEMS

DigiEnergy 4.0

DIGITALIZATION IN ENERGY 4.0 TECHNOLOGIES

2021-1-TR01-KA210-VET000034519

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CONTENTS

EXPLANATIONS

AREA	**Renewable Energy Technologies**
BRANCH/PROFESSION	**Solar Energy Systems**
THE NAME OF THE MODULE	**MONITORING THE MOTION SYSTEMS**
DESCRIPTION OF THE MODULE	This module will cover basic level contents regarding the monitoring of the motion systems in solar energy systems.
DURATION	**40/32**
PRECONDITION	This module has no prerequisites.
COMPETENCY	
PURPOSE OF THE MODULE	**General Purpose: Learn about the basic level monitoring of the motion systems in solar power plants** Differentiate and describe different executions of installing photovoltaic modules Be able to understand and use the management of mobile monitoring systems through Programmable Logic Controllers (PLC) and the logic of their operation Be able to recognize and implement basic steps in the process of PLC programming

EDUCATIONAL ENVIRONMENTS AND EQUIPMENT	**Environment:** Renewable energy technologies field, renewable energy systems workshop **Equipment:** Basic electrical knowledge, basic electronics knowledge, basic PLC programming equipment (hardware and software)
MEASUREMENT AND EVALUATION	You will evaluate yourself with the measurement tools given after each learning activity in the module.At the end of the module, the teacher uses the measurement tool (multiple choice test, true-false test, fill in the blank, matching, etc) to evaluate the knowledge and skills you have gained through module applications.

INTRODUCTION

Dear Students,

With the accelerated development of technology and increased efficiency in the production of electricity, solar power plants with tracking of the movement of the Sun represent the next step of progress in the development of more efficient production of electricity from renewable sources.

Through this module you will learn about the basic methods of installing photovoltaic modules (fixed photovoltaic modules and mobile solar tracking modules) with an emphasis on the detailed description and elaboration of the system development with mobile photovoltaic modules. Some specific systems of movable photovoltaic modules will be presented to you; from the simpler ones to more complex ones that can be rotated along two axes.

Given that mobile photovoltaic systems, in addition to the installation of equipment that enables starting or changing the position of photovoltaic modules, also require logic that will manage the automated system, you will learn about the most suitable circuit for this function, which is a programmable logic controller (PLC). The structure/logic of the PLC will be described with the aim of a better understanding of the operation of the device itself and the functionality of individual parts of the structure.

The practical simulation model which you will encounter describes the process of connecting the PLC to the computer (which is used in order to program the PLC to perform the desired function - controllability, i.e. turning the photovoltaic modules along two axes), programming the PLC, and connecting the components in the program, and connecting the functional blocks that have the task of simulating the execution of real movements, i.e. the rotation of photovoltaic modules.

This module is important for you because the use of PLC is significantly gaining in popularity due to its simplicity and the possibilities it offers, and it is an introduction to the field of correlation between energy, automation, and computing.

LEARNING ACTIVITY –1

PURPOSE

You will learn basic level information about different executions of installing photovoltaic modules:

- Fixed photovoltaic modules
- Movable photovoltaic modules with tracking of the Sun which can include single-axis tracking systems or two-axis tracking systems

You will learn that In the case of mobile photovoltaic modules with sun tracking, the entire system needs to be automated to become manageable and to be able to be controlled or monitored. In addition, the implementation of appropriate software support is required because management, control and supervision require archiving and processing of certain data.

RESEARCH

- Research about the installation of photovoltaic modules
- Research a nearby solar system and check which type of photovoltaic modules do they use.
- Present your findings and comment with your colleagues.

1. different executions of installing photovoltaic modules

1.1 Fixed photovoltaic modules

Fixed photovoltaic modules represent a group of photovoltaic cells (which are connected in a series-parallel combination), and are placed in an adequate position with regard to the angle of incidence of solar radiation.

Photovoltaic modules installed in this way do not follow the movement of the Sun, and their usefulness depends on the position and angle of installation.

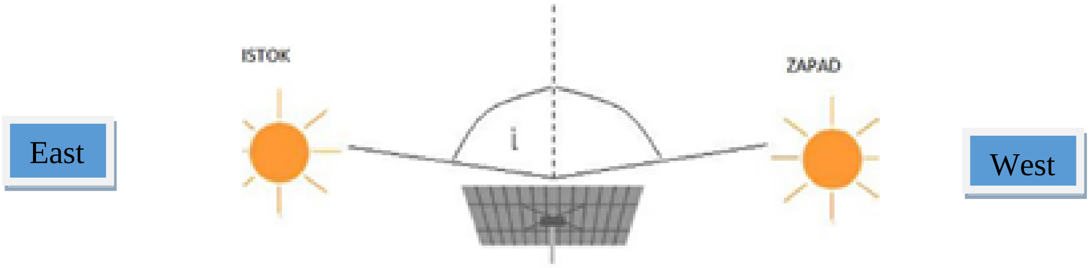


Image 1 Fixed photovoltaic module

1.2 Movable photovoltaic modules with tracking of the Sun

In this way of installing photovoltaic modules, systems are used to monitor the position of the Sun. In other words, it is a set of devices or a drive for directing photovoltaic modules towards the Sun. They require high precision due to the correct directing of solar radiation directly to the photovoltaic modules. Compared to fixed photovoltaic modules, this type of system significantly contributes to the increase in electricity production, improving absorption properties during the day.
There are different versions of mobile solar tracking systems and they can be divided as follows:

- active monitoring systems
- passive monitoring systems
- chronological tracking system

The performance of mobile solar tracking systems can be defined and divided in more detail into:

- polar tracking systems
- tracking systems with a horizontal axis of rotation
- tracking systems with a vertical axis of rotation
- two-axis tracking systems

If the utility of a solar power plant with fixed photovoltaic modules and a solar power plant with mobile photovoltaic modules is considered, the electricity production of the single-axis system is increased by approximately 30%, while the electricity production of the two-axis system is increased by an additional 6%.

In active solar tracking systems, the control unit continuously directs the tracking system using a highly automated electric drive with associated installed equipment (sensors, regulators).

1.2.1 Passive monitoring systems

Passive solar tracking systems use the low boiling point of compressed gas in the system to move from side to side (the sun's heat creates pressure) and thus the tracking system moves in response to the imbalance. They are imprecise, so they are suitable only for common types of photovoltaic systems and do not meet certain criteria of specific photovoltaic systems. They are equipped with shock absorbers for adaptation to strong gusts of wind, shade/reflectors for reflection of early morning sun rays and "starting" photovoltaic modules, i.e. directing them towards the Sun. With such a system, it can be self-released from the position in which it is attached in the evening in order to position the photovoltaic modules slightly above the zenith so that the system is ready for the new day. In addition to the mentioned equipment, a slightly releasing spring is also used, which prevents the release of the drive in windy night conditions.

Image 2 Fixed photovoltaic module

1.2.2 Chronological tracking system

The chronological system bases its work on the rotation of the position in relation to the Sun (in the same relation as the Earth), but in the opposite direction to the rotation of the Earth. It is potentially accurate and simple, and uses data about a rotation of 15 degrees per hour (one rotation of the Earth around the Sun per day). It is theoretically capable of full rotation provided that cross wiring is not a problem or the system can be reset every day to avoid the problem described. Additionally, the system can be automated using electronic control circuits with a real time clock that is turned on clockwise. It is also possible to make adjustments in monitoring which can be intermittent or continuous.

1.2.3 Polar tracking systems

Polar tracking systems have a rotation axis in a line that follows the Earth's rotation axis and is perpendicular to the ecliptic plane. In simple single-axis systems, tracking can be initially set to the intended local latitude ecliptic plane. It is possible to adjust the second axis (elevation angle), and the adjustment is performed manually or automatically, in order to possibly compensate for deviations from the ecliptic plane. Adjustments of this type are usually performed at least twice a year (adjustments are best performed during the equinox). One adjustment is made during the autumnal equinox to set the position for the autumn-winter period, and the other during the vernal equinox to set the position for the spring-summer period.

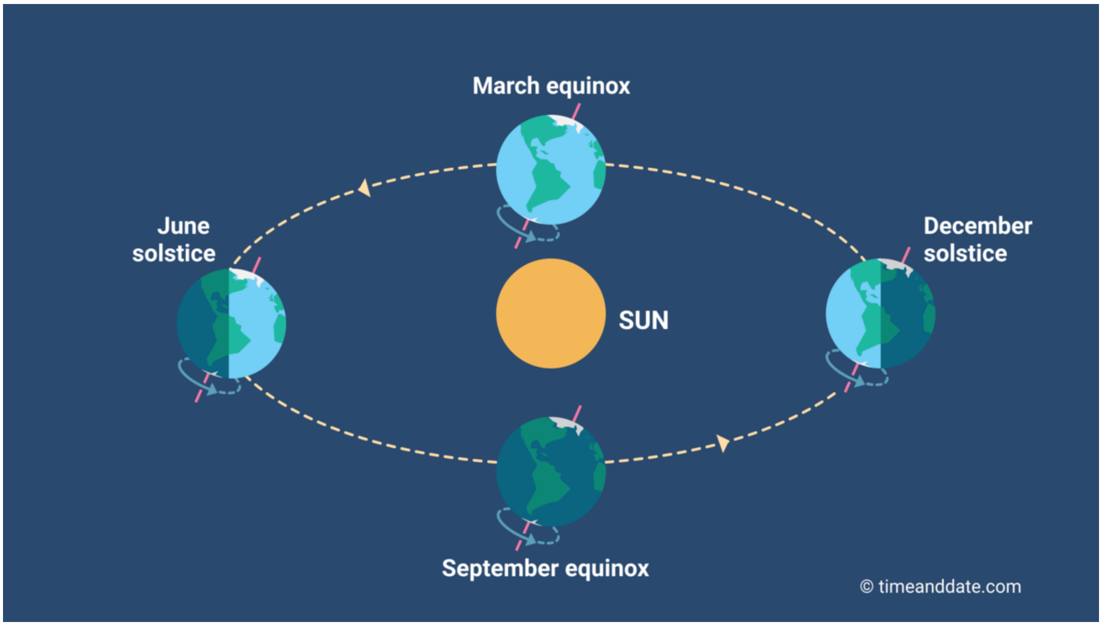


Image 4 Duration of day and night during the seasons


Image 3 solar power plant with a polar tracking system, Greater Sandhill, USA

2 Single-axis tracking systems

Single-axis tracking systems typically use polar tracking for maximum PV efficiency, as previously described (with manual tilt adjustments on the other axis several times a year).

They can be oriented using a passive or active mechanism, depending on the manufacturer and the technical implementation solution. They are composed of a long horizontal pipe oriented linearly in the north-south direction, which is supported by columns or frames on pedestals. Photovoltaic modules are mounted on a pipe and with the rotation of the pipe around its axis, the effect of tracking the apparent movement of the Sun during the day is

achieved. They achieve pronounced productivity during spring and summer when the path of the Sun is high in the sky, while this productivity is reduced during winter and when positioned at high latitudes. The performance characteristic of this system is the strength of the support structure and the simple mechanism. As the photovoltaic modules are mounted horizontally, they can be mounted on the axis tube without the risk of self-shading and are accessible for cleaning and maintenance. For active mechanisms, one controller and motor are sufficient to control several rows of photovoltaic modules.

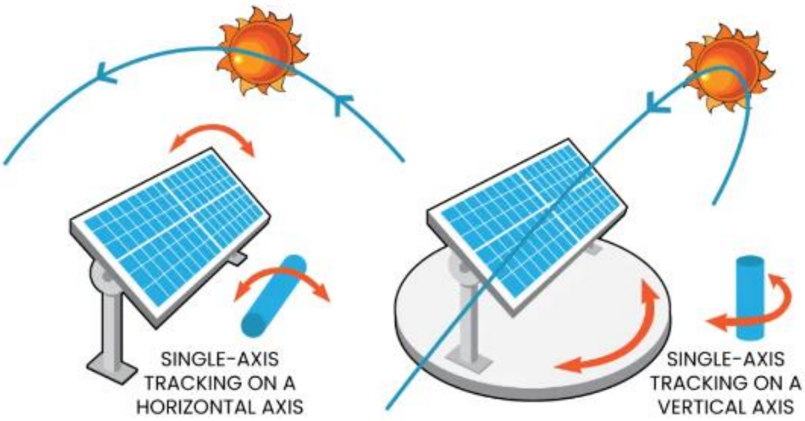


Image 5 A model of a single-axis horizontal tracking system

Vertical single-axis tracking systems rotate on a vertical axis, with PV modules that can be mounted at an angle or vertically. Unlike horizontal ones, they are suitable for assembly and installation at high latitudes, where the angle of the Sun's movement is not particularly high, but they are certainly more useful during long summer days, when the Sun travels along a long arc.

Image 6 A model of a single-axis vertical tracking system

1.2.5 Two-axis tracking systems

Two-axis tracking systems are active systems. The rotation is performed horizontally and vertically, and by combining the two axes of rotation, any location above the hemisphere can be highlighted. Control of the system is achieved in two ways, through a computer system depending on the expected solar orientation or through tracking sensors that control the electric drive to orient the photovoltaic modules towards the Sun.

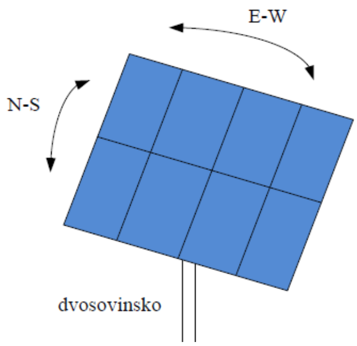


Image 7 A model of a two-axis tracking system

APPLICATION ACTIVITY

Process steps	Suggestions
Sketch the horizonal and vertical movements of the systems	Advise the images in the module

CONTROL LIST

Evaluate yourself by putting an (X) mark in the **YES** box for the skills you have gained from the behaviors listed below within the scope of this activity, and the **NO** for the skills you have not gained.

Evaluation Criteria	YES	NO
1. Did you get general information about different executions of installing photovoltaic modules?		
2. Have you learned about the difference between fixed and moveable photovoltaic modules?		
3. Do you know how single-axis tracking systems function?		
4. Do you know what two-axis tracking systems are?		
5. Have you learned what active, passive and chronological systems are?		

EVALUATION

At the end of the evaluation, review your "No" answers again. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, move on to “Assessment and Evaluation”.

Please read the questions below carefully and tick the correct option.

1. List some of the performance advantages of photovoltaic systems with monitoring of the movement of the Sun (focus on electricity production and the usefulness of such a system).

2. List some of the performance disadvantages of photovoltaic systems with monitoring of the movement of the Sun (focus on the economic justification of investing in more complex equipment, maintenance costs).

3. List some of the basic aspects of the economic profitability analysis of the implementation of such a solution

4. For which areas are vertical axis of rotation suitable while horizontal are not?

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all of your answers are correct, continue to the next learning activity.

LEARNING ACTIVITY –2

PURPOSE

In this module you will learn about the managament of mobile monitoring systems through Programmable Logic Controllers (PLC) and the logic of its operation.

RESEARCH

- Research about the industries in which the PLCs are used
- Record the information you have acquired and share it with colleagues

2. MANAGEMENT OF MOBILE MONITORING SYSTEMS

2.1 Programmable Logic Controllers (PLC)

Installation of rotating systems for monitoring the Sun in order to increase the electricity production of a solar power plant, in addition to the installation of photovoltaic modules, also includes the installation of executive members and equipment (fasteners, equipment carriers, drive mechanisms, drive motors, guides...) that physically performs the work, that is, installs the photovoltaic modules module to the most suitable position in relation to the current position of the Sun. The described results in the realization of the basic prerequisites for the automation of the production process of electricity production. In order for the installed system to fully achieve the desired degree of complete automation, it is necessary to entrust the process operations (turning and tracking the position of the Sun) to the management and control systems and monitoring of the desired process.

The information operations of the process are based on a given program that needs to be programmed or executed using a specific circuit or device.

The most suitable circuit or device for our example is a programmable logic controller (PLC). A PLC can be defined as a miniature industrial computer that contains specific hardware and software for performing control functions. It is most often used for the automation of various industrial electromechanical processes and drives. It enables multiple combinations of digital and analog inputs and outputs with increased temperature ranges. It is immune to electrical noise and is resistant to vibrations and shocks. It consists of two key parts, namely the central control unit (eng. central processing unit - CPU) and the interface for data input and output (eng. input/output - I/O). A schematic diagram showing the structure of a PLC can be seen in the figure below.

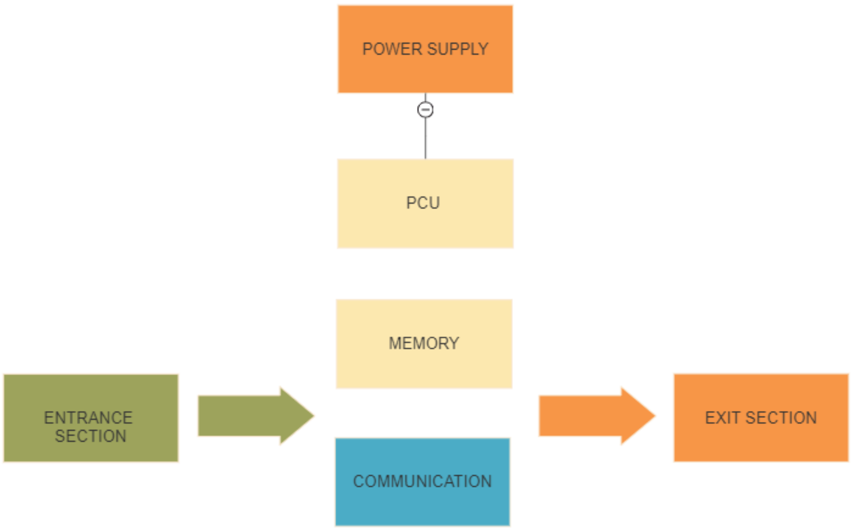


Image 8 PLC structure

The CPU controls the entire system through the processor and memory system. It consists of a microprocessor, memory chip and other integrated circuits for logic control, monitoring and communication. The CPU has different operating modes. In "programmer" mode, it accepts the change of logic from the computer. When the CPU is set in "run" mode, it executes the program, and thus the process navigated by the logic at the output. Input data from connected devices (e.g. sensors) are processed and then the CPU "executes - executes" the control program that is stored in the memory. Being a PLC controller, it executes the program after completion every time again. The time required to execute one cycle of the program is called the scan time and it happens very quickly (in the range of one thousandth of a second, depending on the program and the system to be managed). The memory in the central control unit stores the program, retains the input and output values, and ultimately enables the storage of various variables that have some value.

The input/output of the system is physically connected to the real devices and creates a link between the CPU and the source of information (input) and the controlled devices (output). After the CPU processes the input data, it suggests the necessary changes to the output after the program is executed. There are four basic steps in the operation of all PLC devices, namely:

- input scan – detects the state of all input devices that are connected to the PLC
- program scan – executes user-defined program logic
- output scan – supplies or disconnects the power supply of all devices at the output of the PLC
- housekeeping – includes communication with programming devices and performs internal diagnostics

Standard PLC devices have a wide range of input - output modules available to cover different types of sensors and output devices. One possibility is that discrete input modules are used to detect the presence of objects or events, using devices such as distance sensors or photoelectric sensors, limit switches and various buttons. Such modules can control the switching on and off of loads such as motors, lighting, valves.

Analog input modules can accept signals from instrumentation that measures flow, pressure, temperature or other similar quantities. Such modules can interpret the signal and present the value within the range defined by the electrical specifications of individual devices. Analog outputs can control loads that require different control signals, such as variable frequency drives, different meters or analog flow valves. Many PLCs offer specialized modules such as high-speed I/O, or motion control and serial or Ethernet communication.

The greatest advantage of automating with a PLC is the ability to perform repetitive operations, and change or replicate without change, program-controlled operations. During operation, they enable the continuous collection of essential information.

2.2 PLC Logic

PLC represents a replacement for the classic relay system and offers flexibility in its operation that resembles the operation of a computer using logic similar to relay logic.

Wiring diagrams of physical components in relay technology are developed in the so-called "ladder" form, which can be shown in the figure below, and PLC programming is based on such a logic structure.

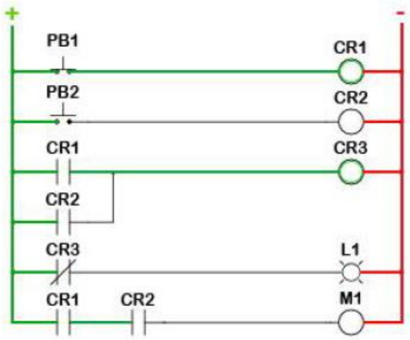


Image 9 Relay structure / logic

The logic structure is called a "ladder diagram" because it resembles a ladder with two basic vertical lines connected by a series of horizontal lines. The positive vertical line (on the left) has flow to the negative vertical line (on the right) through physical devices. In the example shown, "PB" represents a pushbutton; "CR" represents a control relay, while "L1" is a light.

PLC logic is designed to have the same architecture as a relay ladder structure, where memory bits replace physical contacts and coils.

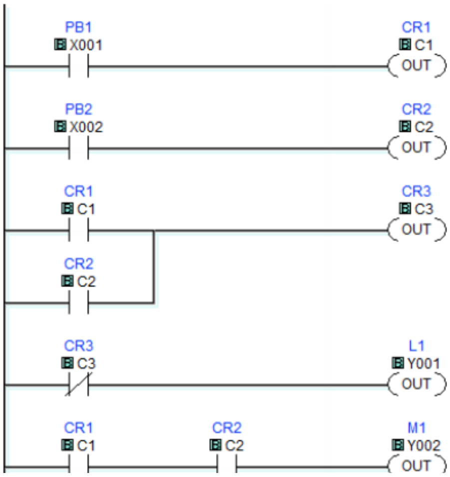


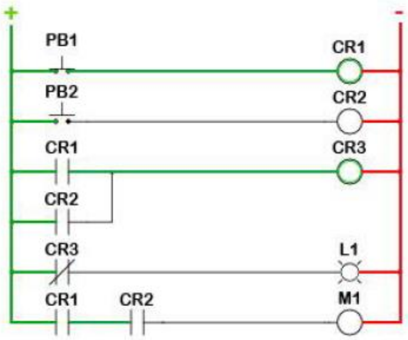
Image 10 Relay structure / PLC logic

For the program in the picture, a relay structure is used, but it is duplicated with ladder logic. The change is that in this case there is no logic to join the two vertical lines, but only memory locations are used. Some of these memory locations are used internally and some with external I/O. In order to monitor and control real devices, they must be connected to input - output modules. For this PLC, inputs and outputs are assigned to X and Y memory addresses such as X001 in the case of the PB1 pushbutton. The state of this normally open contact (normal open - NO) is read from the input of the input - output module where the button is physically connected. On the other hand, each Y will have an output device connected as can be seen with the light controlled by Y001. All other locations are assigned internal bits that can be used as needed.

The CPU interprets the logic in order, starting from the upper left part of the program down the vertical line direction, executing the instructions from each horizontal line from left to right. In this case, if the PB1 key is pressed, the CPU will turn on the CR1 relay. Since CR1 has changed states, in the third line the CPU will activate relay CR3. The normally closed (NC) state of the CR3 relay is used in the fourth line, so the CPU will turn off the L1 light. Although coils and contacts are still referred to in ladder logic, it is important to remember that these are memory interpretations, not actual devices. When the CPU reaches the last line, it will loop back to the beginning of the program and start it again. This process continues as long as the CPU is powered and in "run" mode. The time it takes for the CPU to loop back to the beginning is called the scan time, which is very important for time-critical applications. Subroutines and special input-output modules can be used to reduce the

time if necessary. In addition to the basic normally open and normally closed contacts, you can use Boolean logic with logical AND, OR and NOT operators (English AND, OR, NOT), various timers, counters, comparators, mathematical functions and many other special functions, all in cooperation with actual physical devices.

APPLICATION ACTIVITY

Process steps	Suggestions
Sketch a schematic diagram showing the structure of a PLC	Advise the schematic diagram from the module
Explain the PLC structure in the picture: 	Carefully follow the steps desribed in the text
Write down what “CR”, “PB”, and “L” represent	Try using visualizations in order to remember the meaning of the terms and abbreviations.

CONTROL LIST

Evaluate yourself by putting an (X) mark in the **YES** box for the skills you have gained from the behaviors listed below within the scope of this activity, and the **NO** for the skills you have not gained.

Evaluation Criteria	YES	NO
1. Have you learned what PLCs are and how they are used?		
2. Have you learned how to draw a PLC structure?		
3. Can you explain what CPU is?		

EVALUATION

At the end of the evaluation, review your answers as “No”. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, proceed to “Assessment and Evaluation”.

MEASUREMENT AND EVALUATION 2

Read the questions below carefully and fill in the blanks.

1. What is a PLC and where is it most often used?
2. What is the PLC scan time?
3. What logic does the PLC use in its work?
4. List the four steps in in the operation of all PLC devices.
5. What is the role of CPU in PLC?

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next learning activity.

LEARNING ACTIVITY–3

PURPOSE

You will learn about the PLC programming.

RESEARCH

- Research about the times of sunset and sunrise in your region
- Research on the Internet a positive example from practice, the implementation of a photovoltaic system with tracking the position of the Sun, and implement the research results in the classroom for all students
- Share and comment on the findings with your colleagues

3. CONNECTING THE CONTROL UNIT (PLC) WITH THE SYSTEM AND PROGRAMMING

In order to create the correct approach to the development and writing of PLC programs, it is necessary to first design what we want to achieve with the PLC program, that is, what we want the system to do. For our observed case, it is important to note that this is a simulation model and that there may be certain deviations in relation to the real situation that needs to be carried out in the field. These deviations include the use of pulse counters instead of "high speed" pulse counters, the use of improvised "kip" switches to provide pulses instead of digital encoders, and instruction parameters within the program that are customized to perform the actual function.

The program that will manage the PLC, with the help of the encoder depending on the selected transfer, will rotate the photovoltaic module along the horizontal and vertical axes. By approximating data on the times of sunrise and sunset in Slavonia (Croatia), the information that the panel rotates by 15° per hour and the data of the optimal monthly angle from the monthly level, the input parameters of the program can be defined.

Table 1 - Input parameters for driver programming

Month	Sunrise time [h]	Sunset time [h]	The angle of incidence of the rays [°]
January	7:30	17:00	58
February	7:00	17:00	50
March	6:30	18:00	39
April	5:30	19:00	22
May	4:30	20:00	8
June	4:00	21:00	1
July	4:00	21:00	4
August	4:30	20:00	17
September	5:30	19:00	36
October	6:00	17:00	49
November	6:30	17:00	57
December	7:00	16:00	57

The photovoltaic module is located in the initial position at 37.5° degrees to the northeast in relation to the horizontal axis. It can be seen from the table that a day can last a maximum of 17 hours and therefore it is necessary to ensure a total daily rotation of 255°. At 4:00 a.m. at the beginning of the day, regardless of the month of the year (since it is the earliest time of sunrise), the panel begins its horizontal movement. One hour passes and then it makes a 15° westward turn using a digital encoder. The digital encoder is a displacement converter, which works in such a way as to convert the obtained pulses into the actual displacement of the motor shaft. Instead of a real displacement transducer, one can choose a transducer whose data can be simulated or programmed, taking into account that the resolution should be such that 1000 pulses correspond to one turn of the potentiometer on the transducer itself.

Given that the planned turn is 15°, the total number of pulses that would correspond to that turn is 990 (slightly less than a full turn), due to the full number of 66 pulses per one degree of turn. Such a device is represented in the program as a pulse counter, which can be further adjusted for simulation purposes. In the actual implementation, high speed counters should be used as functions, due to the inability of the PLC to count such a large number of inputs due to the lower reading

frequency. The turning speed in this case depends on the selection of transmission and the motors themselves for turning the required shaft. When a 15° turn is made, the PV module pauses the turn for one hour and then resumes the 15° turn. The description is repeated until sunset. At 3 o'clock in the morning, the panel begins the initialization process, i.e. turning eastward to the starting position, where then at 4 a.m. it starts again with the execution of the daily westward movement. Horizontal movement is reduced to detecting the current month and the required optimal tilt of the panel. If a wind too strong occurs, which the sensor detects depending on its parameterization, the photovoltaic module returns to a horizontal position in order not to affect the movement or damage the photovoltaic module. When the wind weakens, the photovoltaic module returns to the required position corresponding to the real time. Such a "loop" then repeats itself month after month.

For the purpose of modeling, the licensed program "TIA portal V13" can be used with the help of the following equipment:

- CPU
- HMI Human Machine Interface – KTP 600 monochrome
- Rectifier - Power supply with input 100-240 V AC and output 24 V DC
- Kip switches

Image 11 CPU – Siemens S7 1200

Image 12 HMI KTP 600

Image 11 Rectifier (power supply)

Image 14 Kip switches

When all the devices are connected, it is necessary to create a connection between the CPU, HMI and the computer, through which the program is then created in "TIA portal V13". This is done via the PROFINET (Process Field Network) communication standard, connecting the HMI, CPU and computer using an ethernet cable to the router. When the devices are physically connected, it is necessary to activate the devices we use in the TIA portal program according to the corresponding proposed model and other input parameters.

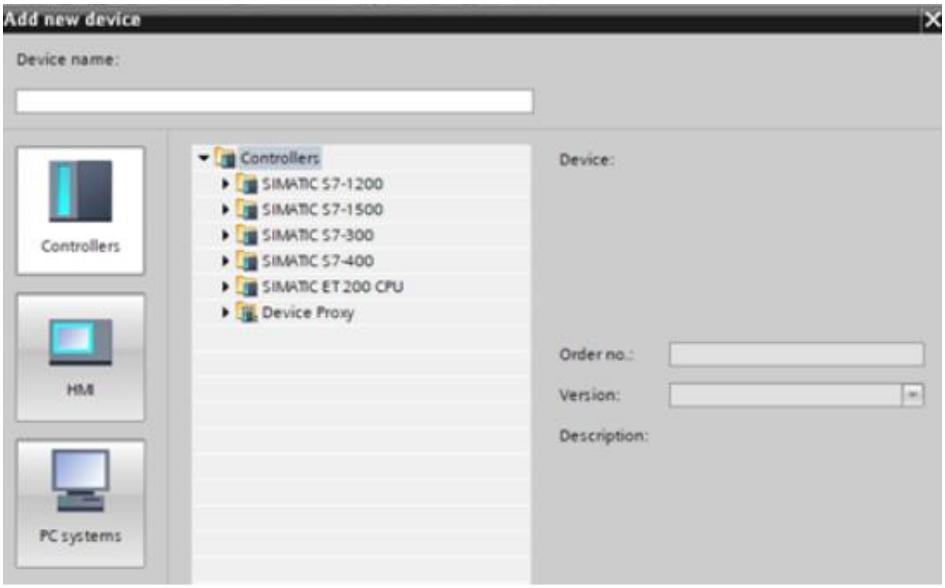


Image 15 Adding a device in the TIA portal V13 program

The next task is to connect the previously selected CPU and HMI in the programming interface and to configure the IP address of each of the devices, so that they are in the same domain and in order to achieve successful communication.

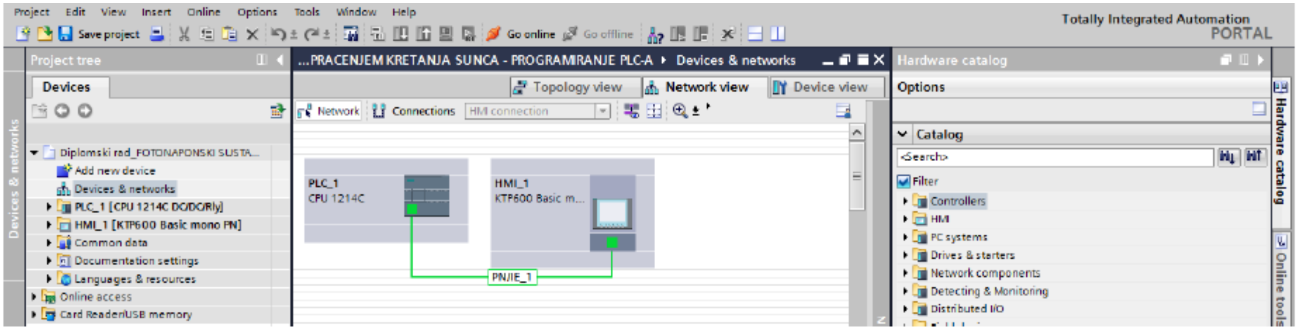


Image 16 Establishing a connection between the CPU and the HMI

After that, everything is ready for the creation of program blocks and networks, that is, the creation of the program itself.

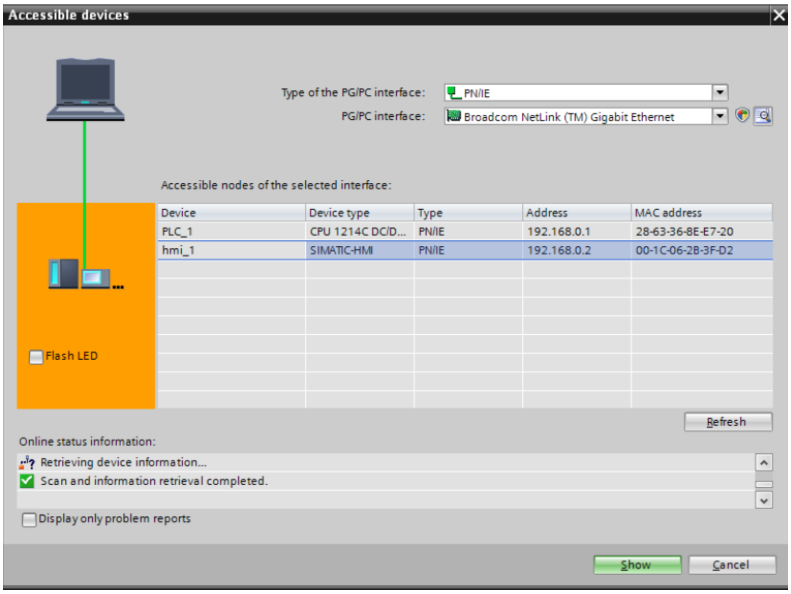


Image 17 The conditions for connecting all devices and their communication have been met

Writing the program itself begins with the creation of program blocks within which specific instructions are executed. Using the "Add new block" option, the user can create new blocks with additional functions. PLC logic is designed to have the same appearance as a relay ladder structure, but almost any physical phenomenon in the designed logic can also be represented as a memory variable in the form of memory bits, which can then be called as needed.

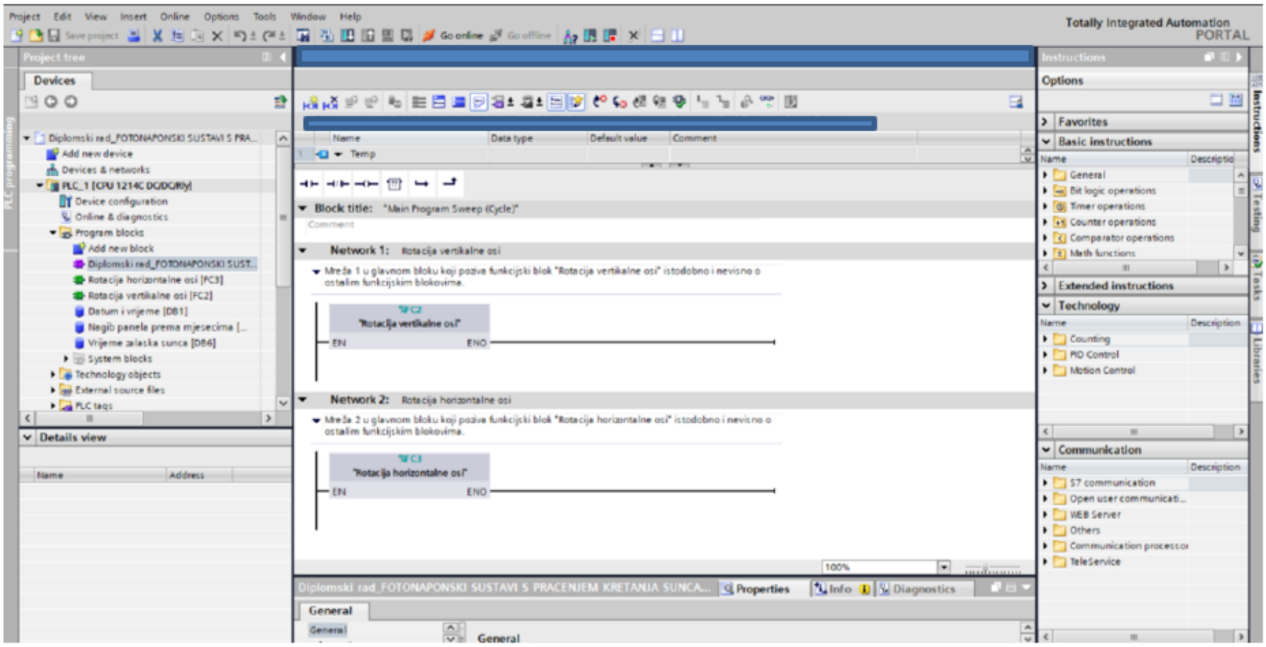


Image 18 The interface of the TIA portal V13 program

In the interface of the TIA portal V13 program, all created devices and blocks are displayed on the left, in the middle is the ladder logic of an individual network, and on the right are the instructions that can be used. There are 4 main types of program blocks. The first in line is the "Organization block" (OB) or more often called the "Main block", which calls other blocks or executes special subroutines. It is most often a "Program cycle" or the main part of the program that is executed cyclically. Next is the "Function block" (FB), which stores values in memory blocks, so that the values remain available even after the instructions of the block have been executed. "Function" (FC) are blocks of code or subroutines without dedicated memory and they are most often used for imaginary actions. "Data block" (DB) has the function of storing certain data that can then be used for subroutines in the blocks.

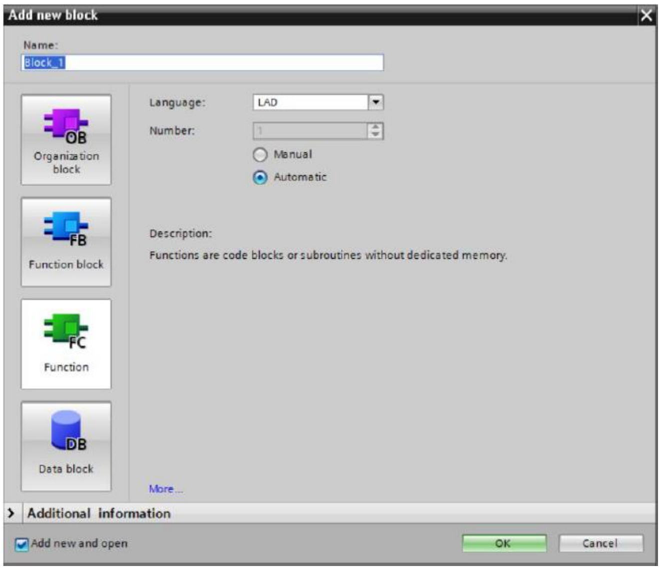


Image 19 Creation of program blocks

The program consists of several blocks. One main block, which performs two functions for rotation of individual axes and from several data blocks.

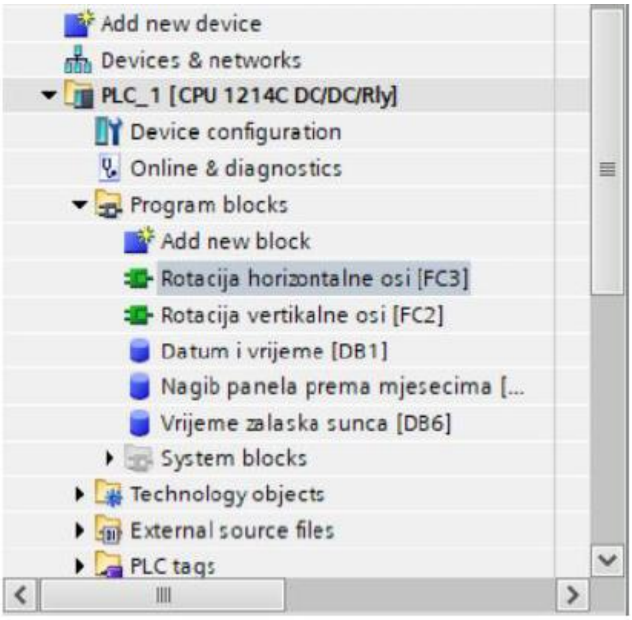


Image 20 Used blocks

The data blocks contain all data related to local and system time, with information on the monthly optimal angle per month and sunset times per month, with which the PLC reads this data and uses it for its work.

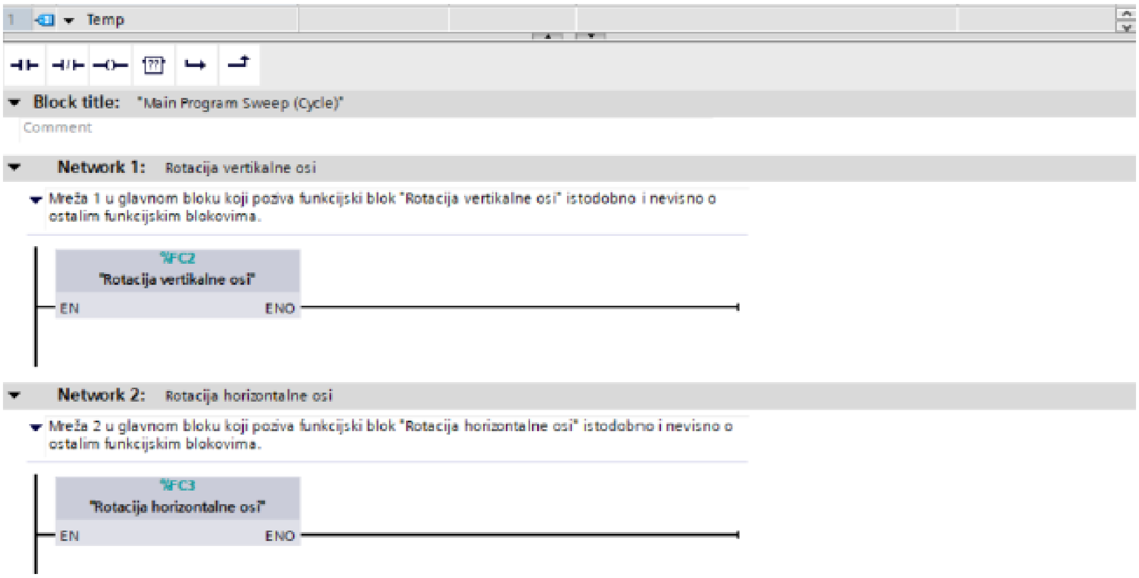


Image 21 The main block

In network 1 (Network 1), the main block of the program calls the function block related to the rotation of the vertical axis, while in network 2 it calls the function block related to the rotation of the horizontal axis. These function blocks are placed each in their own network, because if they were one behind the other in one network, the second function block would be executed only after the execution of the first one. When the signal gets a pass, it is displayed in green during operation.

To explain function blocks, it is necessary to know exactly what each instruction used does. There are bit logic instructions, timing instructions, pulse counter instructions, math instructions, conversion instructions, value conversions, logical operations, and countless others. Each of them uses variables or so-called "Tags", which must be specially created in the appropriate form (Int, Dint, Word, Bool, Byte,

Char, Array, Time, Date, etc.). They can later be used by connecting to the HMI to display some information on the screen or increase user interaction via the screen.

Table 2 - List of used instructions

The name of the instruction	Symbol	Description

NO contact	-||-	When the variable has a value of 1, the contact closes and outputs the value it receives at its input, while at a value of 0 it is not activated and the output is reset to zero
NC contact	-|/|-	When the variable has a value of 1, the contact is opened and the output is reset to zero, while with a value of 0, the contact is closed and the output gives the value it receives at its input
Output set (ON)	-(S)	Sets the signal state to 1
Output reset (OFF)	-(R)	Sets the state of the signal to 0
Purpose (coil)	-( )-	If the result of the logical operation at the input of the coil has a signal state of 1, the specified variable is set to a signal state of 1, and in the opposite case, if the input is zero, the variable is set to 0
Generate ON on delay	TON	When the signal state changes from 0 to 1, a 1 is sent to the output after the timeout
Generate OFF on delay	TONR	When the signal state changes from 0 to 1, after the time has expired, 1 is sent to the output with the possibility of accumulating time and continuing the accumulation if the state of the input changes from 1 to 0
Counter up	CTU	Counts changes of signal states from 0 to 1.
Counter up-down	CTUD	Counts signal state changes from 0 to 1 and from 1 to 0
Comparator equal	CMP ==	Comparing values of variables. If the values are equal, 1 is sent at the output, otherwise 0

Comparator less or equal	CMP <=	Comparing values of variables. If the value of the first variable is less than or equal to the value of the second, 1 is sent to the output, otherwise 0
Comparator more or equal	CMP >=	Comparing values of variables. If the value of the first variable is greater than or equal to the value of the second, 1 is sent to the output, otherwise 0
Comparator less	CMP <	Comparing values of variables. If the value of the first variable is less than the value of the second, 1 is sent to the output, otherwise 0.
Comparator more	CMP >	Comparing values of variables. If the value of the first variable is greater than the value of the second, 1 is sent to the output, otherwise 0
Subtract the value	SUB	Subtracts two variable values at the input and gives the difference at the output
Absolute value	ABS	Forms the absolute value of a specified variable
Move value	MOVE	Copies the value of a variable at the input to the value of another variable at the output
Read the value field	RD_LOC_T	Reads the value of a specific member in the value field and outputs that value

Read local time	FieldRead	reading the current CPU clock time and date with the clock offset and corresponding time zone and outputting that value
Read system time	RD_SYS_T	Read the current time and date from the CPU clock and output that value
Print system time	WR_SYS_T	Instructions for setting the time and date of the CPU clock

Each of these instructions has special branches where specific variables can be placed and each instruction requires a specific type of variable. In order to get an insight into the functioning of the logic itself, it is necessary to observe several networks of one function block. Taking as an example the network 12 in which all the conditions for turning on the output of the CPU unit that activates the drive of the photovoltaic module to the left side towards the east are stated, it can be noted that the fulfillment of a large number of conditions is necessary to activate the output. The variables QM3, Initialization and KP1 on the left are represented by NO contacts, which means that if they receive a value of 1 at their input, they will pass the signal on. The reverse case is valid for the variables R1 right and Zero position horizontal which are represented by NC contacts and which pass the signal if they receive the value 0 at the input. It can be said that if the protection QM3 does not turn off, which is represented by the NO contact, the memory variable and which receives the value 1 at the input, passes the signal further. In a similar way, if the conditions for fulfilling the variable R1 to the right do not apply (because driving to the left and to the right cannot be switched on at the same time), the NC contact receives a 0 at the input and passes the signal on. In order for the Initialization to pass the signal, the conditions for its fulfillment must be valid, and they are defined in grid 6. If the clock currently read from the CPU clock using the comparator instruction is equal to 3 am, the value 1 is passed to the output, which then activates the SET instruction (ON) associated with the memory variable. That memory variable then has a value of 1 in network 12 and since it is represented by the NO contact, it therefore passes the signal on.

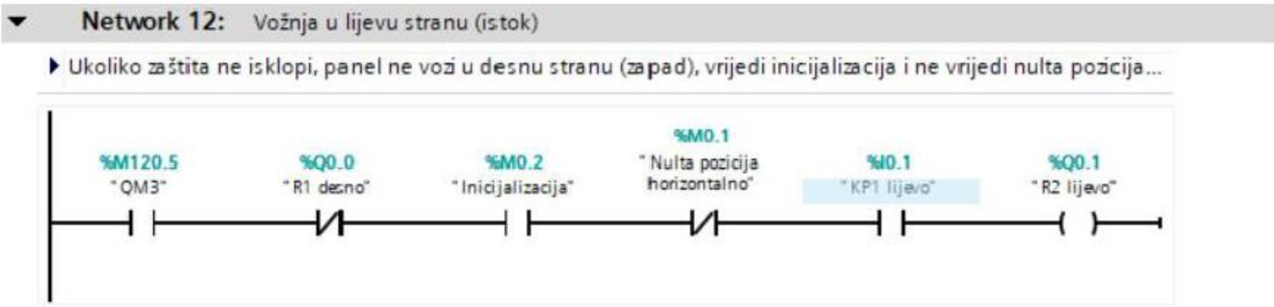


Image 22 Network 12

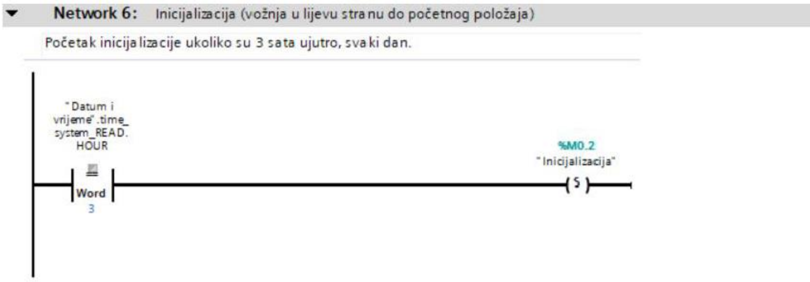


Image 23 Network 6

The same is true for the Zero horizontal position, which passes the signal on if it receives the value 0 at the input. If the physical limit switch KP1, represented by the NC contact, is stepped on, it receives the value 0 at the input and sends a signal further that activates the memory variable Zero position horizontal and Initialization. Zero position horizontally then has the value 1 while Initialization has the value 0 because it is represented by the reset instruction. In this case, the limit switch is not pressed and it is valid that the zero position horizontally has the value 0. The zero position horizontally is represented by the NC contact in network 12 and with the value 0 of the zero position horizontally from network 7, the signal passes on.

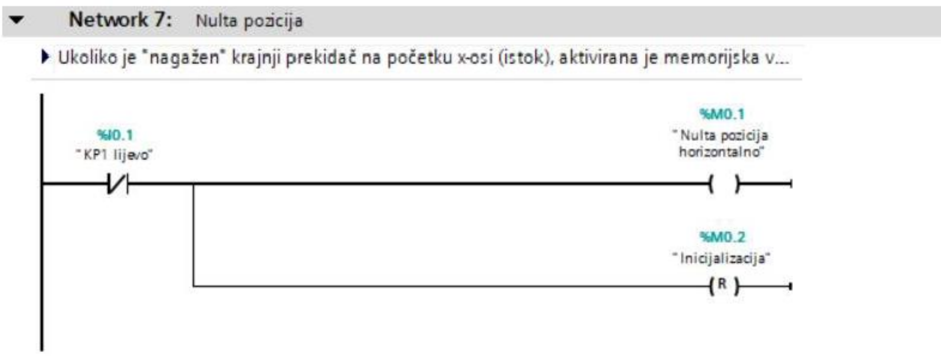


Image 24 Network 7

The variable KP1 on the left is a physical variable that indicates one of the kip switches. Since it is in the upper position (ON), that variable has a value of 1 and the NO contact shown in the network lets the signal go. Ultimately, R2 left is activated, which is the physical output that activates the motor to drive in the right direction. It is important to note that all these conditions must be met in order to only activate driving in one direction, while it is also necessary to ensure that the values of individual variables do not collide and the fact that each variable has branching conditions of its own for its fulfillment.

APPLICATION ACTIVITY

Working with clumps and other hand tools.

Process steps	Suggestions
Create a connection between CPU, HMI and the computer	Follow the instructions for the connection of the devices as described in the module
Adding a device in the TIA portal V13 program	Activate the devices we use in the TIA portal program according to the corresponding proposed model and other input parameters.
Establish a connection between the CPU and the HMI	Connect the previously selected CPU and HMI in the programming interface and to configure the IP address of each of the devices, so that they are in the same domain and in order to achieve successful communication
Create a program block	Use the "Add new block" option, in order to create new blocks with additional functions

CONTROL LIST

Evaluate yourself by putting an (X) mark in the "Yes" box for the skills you have gained from the behaviors listed below, and the skills you have not gained by placing a "No" box within the scope of this activity.

Evaluation Criteria	Yes	No
1. Can you name the equipment to be used for the purpose of modeling using the TIA portal V13 program?		
2. Can you describe the steps of working in the TIA portal V13 program		
3. Can you name and describe at least five instructions?		

EVALUATION

At the end of the evaluation, review your answers as “No”. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, proceed to “Assessment and Evaluation”.

MEASUREMENT AND EVALUATION

Connect the name of the instructions and the functionality of the instructions, used when creating the program for managing the photovoltaic system in the TIA portal V13 program.

INSTRUCTION NAME	INSTRUCTION FUNCTIONALITY
1. Output set (ON)	A. It reads the value of a specific member in the value field and outputs that value
2. Generate ON on delay	B. When the signal state changes from 0 to 1, a 1 is sent to the output after the timeout
3. Counter up	C. Sets the signal state to 1
4. Greater than or equal to comparator	D. Counts changes of signal states from 0 to 1.
5. Read the value field	E. Comparing values of variables. If the value of the first variable is greater than or equal to the value of the second, 1 is sent to the output, otherwise 0

1. – _______
2. – _______
3. – _______
4. – _______
5. – _______

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next learning activity.

• MODULE EVALUATION

1. In the bracket next to the statement number, write the letter T if you think the statement is true, or the letter F if you think the statement is false.

1. ( ) In practice, there are 2 key versions of installing photovoltaic modules, which are fixed installation of photovoltaic modules and installation of photovoltaic modules with a mobile system for tracking the position of the Sun.
2. ( ) The fixed photovoltaic modules are placed in an adequate fixed position considering the angle of incidence of solar radiation, and their usefulness depends on the monitorining of the movements of the Sun.
3. ( ) In active solar tracking systems, the control circuit continuously directs the tracking system using highly automated electric drive associated installed equipment (sensors, regulators).
4. ( ) Single-axis tracking systems typically use polar tracking for maximum photovoltaic efficiency, without adjusting the slope on the other axis several times during the year.
5. ( ) Two-axis tracking systems are active systems where the rotation is performed horizontally and vertically, by combining both axes of rotation.
6. ( ) Control of two-axis systems is achieved in two ways, through a computer system depending on the expected solar orientation or through tracking sensors that control electric drive for orientation of photovoltaic modules towards the Sun.

2. Answer the following questions using key words

1. What is the most suitable circuit or device for managing a moving system of photovoltaic modules for tracking the position of the Sun?
2. Which electrical machine physically performs the work, that is, installs the photovoltaic modules in the most suitable position in relation to the current position of the Sun?
3. What 2 key parts does a PLC consist of?
4. Which devices are most often used to detect the presence of objects or events, displacement, change of position...?
5. In what order does the CPU interpret logic in one horizontal line, executing commands from that horizontal line?
6. What is the name of the time it takes for the CPU to return the loop to the beginning, which is very important for applications where time is of critical importance?

3. In the bracket next to the statement number, write the letter T if you think the statement is true, or the letter F if you think the statement is false.

1. ( ) To program the PLC that will manage the automated photovoltaic system the module for tracking the position of the Sun requires appropriate software and a computer.
2. ( ) The program controls the PLC and rotates the photovoltaic module horizontally and vertically axes without the help of other elements such as executive members and equipment (fasteners, equipment carriers, drive mechanisms, drive electric motors, guides).
3. ( ) Approximation of data on sunrise and sunset times in a region, and information about the possible angle of rotation of a photovoltaic module is not essential data for parameterizing the driver program and do not represent input parameters program.
4. ( ) When a 15° turn is made, the photovoltaic module pauses the turn for one hour and after this is done again by turning it by 15°. It is repeated as described until the time of sunset The sun.
5. ( ) If there is an occurrence of too strong wind detected by the wind sensor, photovoltaic the module does not return to the horizontal position, but the rotation continues as planned, because the wind does not affect the movement of photovoltaic modules.
6. ( ) Writing programs in the "TIA portal V13" program begins with the creation of program files blocks within which certain instructions are executed.

4. Answer the following questions

1. Can the memory variable of some physical phenomenon in the designed PLC logic represented in the form of memory bits be called as needed or only once?
2. Which block in the "TIA portal V13" program stores values in memory blocks, so that the values remain available even after the instructions of the block have been executed?
3. In which network of the "TIA portal V13" program are the conditions for starting the initialization process defined? If they are satisfied, the initialization process starts at 3 am.
4. Which value at the output of the "comparator equals" instruction is omitted if the comparison process determines that the currently read time value from the CPU clock is equal to the set initialization start time (3 am)?
5. Which instruction was used in the process of comparing time values from question no. 4?
6. The missed value of the "comparator equal" instruction (value 1) in case the conditions for starting the initialization are met, activates the SET (ON) instruction associated with the memory variable, which then has the value 1 in network 12. Which instruction should be acted upon in order to have the same value signal missed further?

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next performance test.

CONTROL LIST

Evaluate yourself by placing a check mark (X) in the YES box for the skills you have gained from the behaviors listed below within the scope of this module, and No for the skills you have not gained.

Evaluation Criteria	Yes	No
1. Can you make a short presentation about the motion systems in solar power plans systems?		
2. Can you differentiate and describe different executions of installing photovoltaic modules?		
3. Do you understand the baics of managament of mobile monitoring systems through Programmable Logic Controllers (PLC) and the logic of its operation?		
4. Can you understand the meaning and describe different instructions used for PLC programming		
5. Are you able to implement basic steps in the process of PLC programming		

EVALUATION

At the end of the evaluation, review your answers as “No”. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, contact your teacher to move on to the next module.

ANSWER KEYS

ANSWER KEY TO LEARNING ACTIVITY-1

1	- a significant increase in the use of photovoltaic systems has led to the development of modern technology for harnessing the energy of the Sun, so it is not difficult to implement an automated system that places photovoltaic modules in a vertical position in relation to the position of the Sun - increase in electricity production - an increase in the economic profitability of the investment due to the higher amount of electricity produced, with the subsidization of electricity production from renewable sources, which is in effect in all countries - an increase in the number of employees because the implemented system requires additional maintenance, thus reducing unemployment in some countries
2	- higher initial investment costs than benefits (a scenario can easily occur where the ratio of costs due to the implementation of the system for monitoring the position of the Sun and the increase in income from additional electricity production will be negative) - lack of equipment to implement a system for monitoring the position of the Sun due to various disturbances in the market - lack of skilled workers who can implement the system, that is, work on later maintenance
3	- the size of the photovoltaic system - position and ease of performance - efficiency and orientation - solar radiation - tariff items and the price of electricity - stimulation of electricity production - interest rates and tax benefits
4	Systems with vertical axis of rotation are, unlike the horizontal ones, suitable for high latitude areas.

ANSWER KEY TO LEARNING ACTIVITY-2

1	PLC can be defined as a miniature industrial computer that contains specific hardware and software for performing control functions. It is most often used for the automation of various industrial electromechanical processes and drives
2	The scan time is the time required to execute one cycle of the program
3	The PLC logic is designed to have the same architecture as the relay ladder structure, using memory bits and memory locations.
4	- input scan– detects the state of all input devices that are connected to the PLC - program scan – executes user-defined program logic - output scan – supplies or disconnects the power supply of all devices at the output of the PLC - housekeeping – includes communication with programming devices and performs internal diagnostics
5	The CPU controls the entire PLC system through the processor and memory system

ANSWER KEY TO LEARNING ACTIVITY-3

1	**C**
2	**B**
3	**D**
4	**E**
5	**A**

ANSWER KEY TO MODULE EVALUATION

Task 1

Question No.	Correct answer
1.	T
2.	F
3.	T
4.	F
5.	T
6.	T

Task 2

Question No.	Correct answer
1.	PLC
2.	Electromotor
3.	CPU, I/O interface
4.	Sensors
5.	from left to right
6.	scan time

Task 3

Question No.	Correct answer
1.	T
2.	F
3.	F
4.	T
5.	F
6.	T

Task 4

Question No.	Correct answer
1.	can be called upon as needed
2.	Function block (FB)
3.	Network 6
4.	Value 1
5.	Comparator equally
6.	NO contact

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