

MANAGEMENT OF INDUCTION (ASYNCHRONOUS) MOTORS USING PLC

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Case study

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Abstract: This paper describes the management of an induction (asynchronous) motor using PLC and VSD. For the realization of the practical part of this paper Schneider Electric equipment was used, which makes a complete system that is used in Natron Hayat d.o.o Maglaj, where this experiment was done. For this paper, a Schneider Zelio PLC was used, which with the aid of a 5.5 kW Schneider Altivar ATV312HU55N4 modulator (frequency transformer), managed the work of a 5.5 kW induction motor at speed of 1500 RPM. Managing controls were given for HP mobile working stations, where Windows XP operating system with SCADA software from DAQFactory was installed. The link used between the working stations and the PLC was Ethernet (Modbus TCP/IP).

Keywords: asynchronous, motor, PLC, VSD, frequency, transformer, management, SCADA, software, DAQFactory

THREE PHASE AC ELECTRICAL MOTORS

The first electrical motor was a unidirectional motor (DC motor) made in 1833. Speed regulation of this motor is simple and corresponds to the needs of a number of applications and systems. In 1889, the first alternate motor (AC motor) was made. Even though a lot more robust and simple, the three-phase motors had one huge flaw. Their rotation speed was constant, so were the torque characteristics, and that is the reason why AC motors were not used in special applications where speed regulation was requested. Three-phase motors are electro-magnetic transformers of energy, which convert electrical energy into mechanical (motor mode) or vice versa (generator mode) in accordance with the law of electro-magnetic induction. The law of electro-magnetic induction states that if a conductor is moving in a magnetic induction field B, so that it cuts the field lines, it will induce a voltage. If a conductor is part of a circuit, electricity will flow through it. When a conductor is in motion, force F which is vertical to the magnetic field lines, will act on it. Generator mode (induction

in motion). In the generator mode by moving the conductor in a magnetic field, we generate voltage on its ends, (Figure 1), Motor mode.

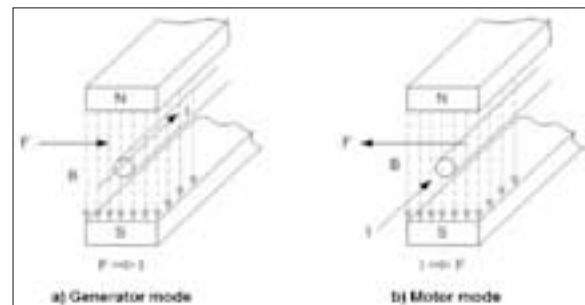


FIGURE 1. THE PRINCIPAL OF ELECTRO-MAGNETIC

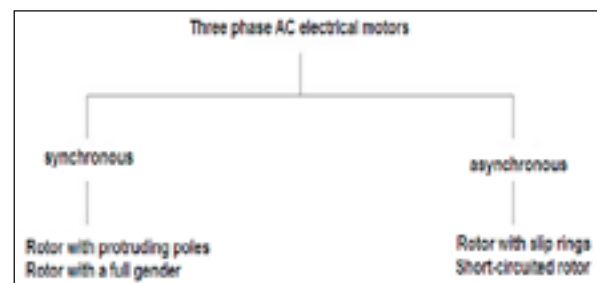


FIGURE 2. TYPES OF THREE-PHASE ELECTRIC MOTORS INDUCTION

In this case, we have a conductor in a magnetic field through which electricity is flowing. Then, there is a force on the conductor which tends to move the conductor out of the magnetic field. In the motor mode, the magnetic field and the conductor with electricity generate movement (Figure 2).

A motors magnetic field produce a static part (stator), and the electro-magnetic force that acts on the conductors is on the mobile part of the machine (rotor). Three-phase motors can be divided into two main groups: asynchronous and synchronous motors. Stators on both motors are alike, but the design and motion of the rotor in relation to with the magnetic field is different. With synchronous motors, the speed of the rotor concedes with the speed of the rotating field, while with asynchronous the speed of the rotor is different.

ASYNCHRONOUS MOTORS

Asynchronous motors are the most used motors and hardly need maintenance. In a mechanical sense, these motors are standard units, so that compatible distributors are always near. There are a few types of asynchronous motors, but the work principle on all is the same. The two main parts of the asynchronous motor are the stator (static part) and the rotor (motional part). Stator is the static part of the motor. It consists of a casing (1), bearing (2) on which the rotor lays (9), side panels, ventilator (4) which is at the end of the casing and used for cooling of the motor and protection cap (5) used as protection from the ventilator. Terminal box (6) is placed and mounted on the stator casing. The stator casing holds the magnetic core (7) made of thin (0.3 – 0.5mm) iron sheets. These sheets contain grooves in which three-phase coils are placed.

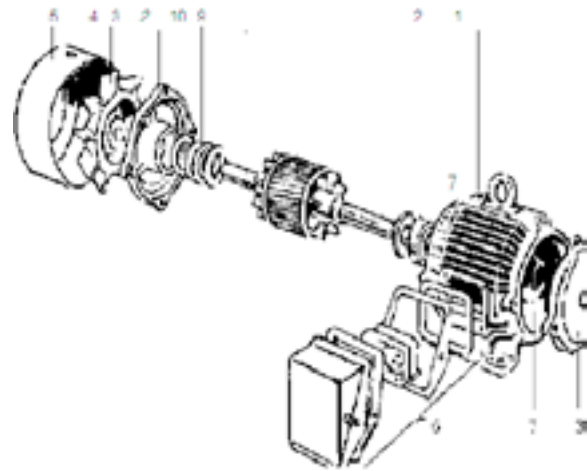


FIGURE 3. MAIN PARTS OF THE ASYNCHRONOUS ELECTRIC MOTOR

Phase coils and stator core produce magnetic flux. The numbers of paired poles determine the rotation speed of the magnetic field. When the motor is connected to a nominal frequency, it is that, that the speed of the magnetic field which is called the synchronous motor speed (n_0) and in Table 1 the connection between the pairs of poles (p) and speed (n_0) is shown.

Magnetic field. A magnetic field rotates in an air space between the stator and rotor. The magnetic field is inducted after the connection of a phase coil to power. The position of this magnetic field in relation to the stator is fixed, but is changing directions. The speed in which the direction is changed is determined by the power frequency of the motor. In a network frequency of 50 Hz, the field changes direction 50 times in a second. If a two-phase coil is connected to an appropriate power, the induction of the two magnetic fields will occur immediately. In the motor with two poles, a movement of 120 degrees exists between the two poles. The maximum that is reached by the two poles is time-shifted. This causes the magnetic field not to be static any more in rela-

TABLE 1. CONNECTION BETWEEN NUMBER OF PAIRS AND POLES

Pairs of poles	1	2	3	4	6
Number of poles	2	4	6	8	12
n_0 [1/min]	3000	1500	1000	750	500

tion to the stator, but starts to rotate. However, this rotating field is highly asymmetrical, until the third phase is connected. Three phases generate three magnetic fields mutually shifted in space for 120 degrees.

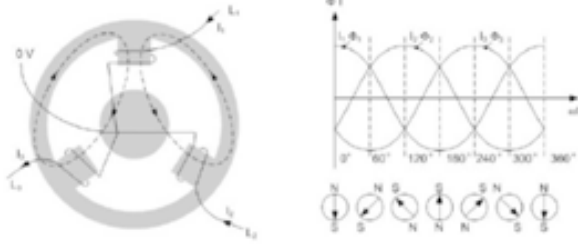


FIGURE 4. INDUCED FIELD OF ONE PHASE

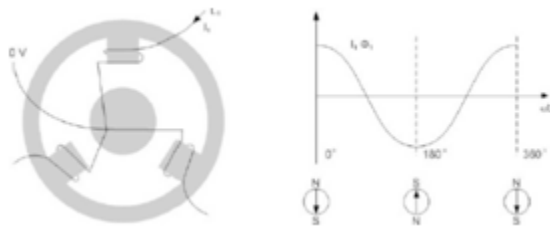


FIGURE 5. TWO-PHASE ASYMMETRICAL ROTATING FIELD

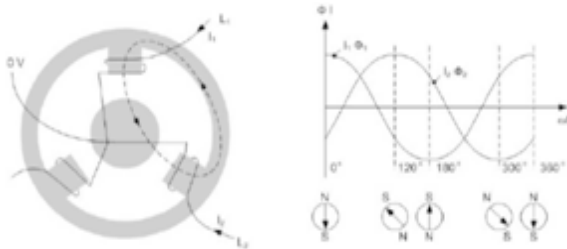


FIGURE 6. THREE-PHASE SYMMETRICAL ROTATING FIELD

The stator is now connected to a three-phase source of power, and the magnetic fields of each of the coils together make a symmetrical rotating magnetic field. Rotating field amplitude is constant and 1.5 times greater than a one-phase magnetic field amplitude.

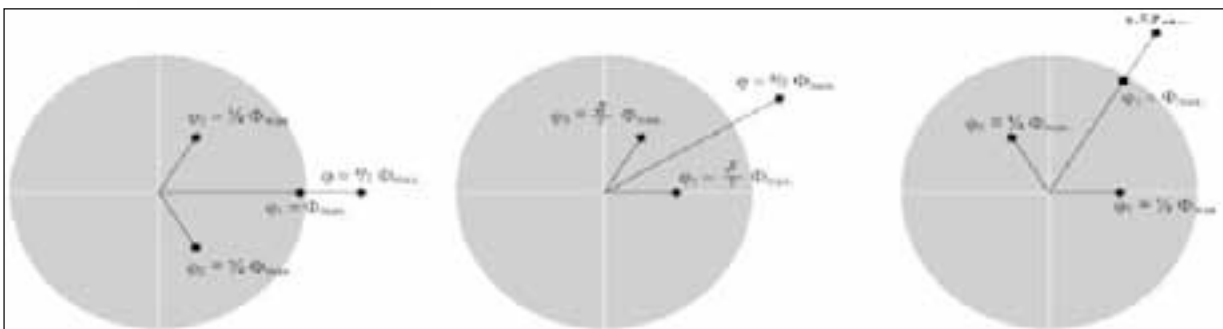
$$n_0 = \frac{f \times 60}{p} \left[\frac{1}{\text{min}} \right]$$

Where: f =frequency, n_0 =synchronous speed, p = number of pole pairs is.

Speed depends on the number of pole pairs (p) and frequency (f) voltage. The illustration shown below, Figure 7. shows vector scales of the magnetic field at three different moments. The diagram of a reverse field with a vector and appropriate angle speed gives a circle. As function of time, in a coordinated system, the rotating field gives a sine curve. If during pole rotation the amplitude changes, then the rotation field would look like an ellipse. The rotor is mounted on the motor shaft (10).

As well as the stator, the rotor is made of grooved thin iron sheets. There are two types of rotors: *rotor with slip rings* and *a short-circuited rotor*; the difference is in the coils placed into the grooves. The rotor with slip rings, as well as the stator, has coils of wire placed in the grooves and for each phase one slip ring onto which coils are connected. After brief joining of the slip rings, the rotor with slip rings will work in the same way as the short-circuit rotor. With short-circuit rotors, aluminium rods are poured into the grooves. Aluminium rings are placed at the ends of the rotor which briefly connect the rods. A short-circuit rotor is used more often. Having in mind that the work principal of both rotors is the same, here we will describe only the short-circuit rotor, because it is the type of electric motor we used for this paper. This flux induces electricity (I_w) in a rotor rod on which force (F) begins to act on. Force on the rod is determined by magnetic induction (6), inducted electricity (I_w), length of the rod (l) between the force vector and magnetic induction vector: $F = B \times I_w \times l \times \sin a$. If we put that $a=90$ degrees, the term for force is then: $F = B \times I_w \times l$ rotor and angle (a) between the

FIGURE 7. MAGNETIC FIELD AMPLITUDE IS CONSTANT



force vector and magnetic induction vector: $F = B \times Iw \times I \times \sin a$. If we put that $a=90$ degrees, the term for force is then: $F = B \times Iw \times I$.

The next pole, whose magnetic field runs through a rotor rod, has an opposite polarity. This magnetic field induces electricity in an opposite direction.

As the direction of the pole is also opposite, the force has the same direction as before (Figure 8). If a whole rotor is now placed in a reversed magnetic field, the force which tends to spin the rotor acts on the rotor rods.

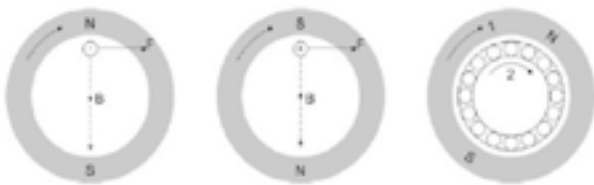


FIGURE 8. INDUCTION IN ROTOR RODS

FREQUENCY TRANSFORMERS

Static frequency transformers are electronic devices that enable the management of the speed of three-phase motors transforming network power and frequency, which are fixed values, into changeable values. While principles stayed the same, a lot has changed since the appearance of the frequency transformer, which contained thyristors, till today's transformer is managed by a microprocessor. Most of the static frequency transformers used nowadays in industry for the regulation or management of speed in three-phase motors were made on the basis of two principals:

1. Frequency transformers without an inter-circuit (known as a direct transformer).
2. Frequency transformers with changeable or constant inter-circuit.

Frequency regulator consists of four main components:

1. Adapter, which is connected by the main mono/three-phase AC power and generates pulsing DC power. There are two main types of adapters – controlled and uncontrolled.
2. Inter-circuit. There are three types:
 - a) Convert adapting power to direct electricity
 - b) Stabilize (iron) pulsating DC power and make

it available to the inverter

c) Convert the constant DC power of the adapter into changeable AC power

3. Inverter, which generates power frequency on the motor. Alternatively, some Inverters can also convert constant DC power into changeable AC power.

4. Management circuit, which receives and sends signals from the adapter, inter-circuit inverter. Parts of the regulator which are controlled depend on the design of the regulator itself. What all frequency regulators have in common is that the control circuit uses signals to engage and disengage semiconductor elements. Frequency regulators are divided by their cut-off mode that controls the motors' power. For this paper we used a 5.5 kW Schneider Electric frequency transformer, type Altivar ATV312HU55N4, and 400 VAC of entry power, Figure No. 9.



Figure 9. Schneider Electric Altivar ATV312HU55N4 frequency transformer

The needed adjustment of parameters of the frequency transformer for the 5.5kW, synchronous speed of 1500 RPM, three-phase induction motor that was used, we did with the help of a local control panel which is mounted on the frequency transformer.

SCHNEIDER ELECTRIC ZELIO SMART RELAY/PLC

PLC (Programmable Logic Controller) is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. Zelio falls under the category of sophisticated “smart” relays which have limited abilities of programmable logic controls and are provided for managing smaller systems, electric motor propulsions and such. Advantages of these controls are a modular concept with a low price. Programming logic inside a Zelio control can be established through a function panel, in other words, interfaces on the basic module control or with the aid of a PC, with corresponding cable and software “Zelio Soft”. The starting configuration of the chosen Zelio hardware is shown in Figure 10.

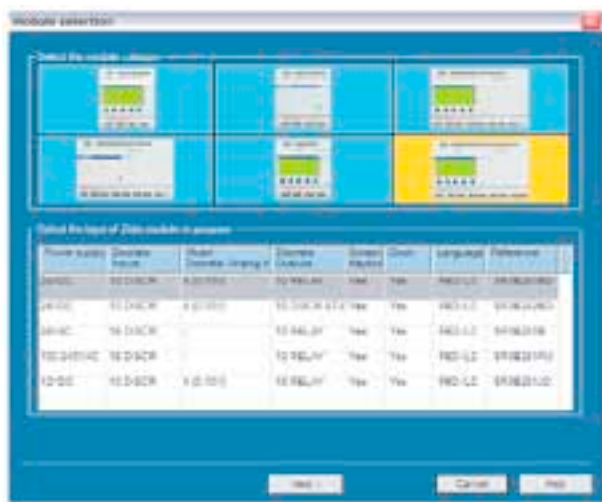


FIGURE 10. SELECTION OF THE BASIC MODULE SR3B261BD

The basic module SR3B261BD has a 24 VDC power source, 10 discrete inputs (input-i from I1 to IA). 6 inputs with the possibility of a discrete or analogue input 0 – 10 V (input-i from IB to IG) and 10 discrete relay outputs (output-i from Q1 to Q8 relays 8A, Q9 to QA relays 5A). This module has the possibility of logic programming in so called FBD mode (Functional Block Diagram) and LD mode (Ladder Diagram). For this paper we used FBD. Ethernet communication module SR3NET01 has 4 integrated 16-bit. inputs and 4 integrated 16-bit. outputs. The Ethernet extension on the network is present as a server.

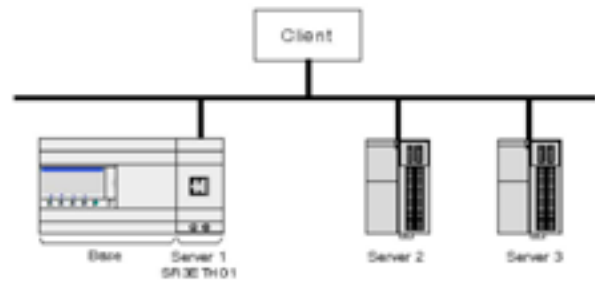


FIGURE 11. NETWORK ARCHITECTURE OF THE ETHERNET COMMUNICATION MODULE SR3NET01

The analogue module SR3XT43BD has two analogue inputs and two analogue outputs with the resolution of 10 bits. In this Zelio Soft programme configuration, a choice between current (0-20mA) or voltage (0-10V) input and output is made possible. Such complex modules are ready for wiring with other elements for the production of this MCC (Motor Control Centre). Electric scheme of the energy and management circuit of the electric motor is shown in Figure 12.

The chain of management is as follows: the Zelio controller on the basis of already made logic will send control signals to the VSD (Variable Speed Drives), from which it will receive feedback information on the state of the VSD and motor speed, so the VSD itself, with an appropriate modulation of voltage and frequency, control the electrical motor.

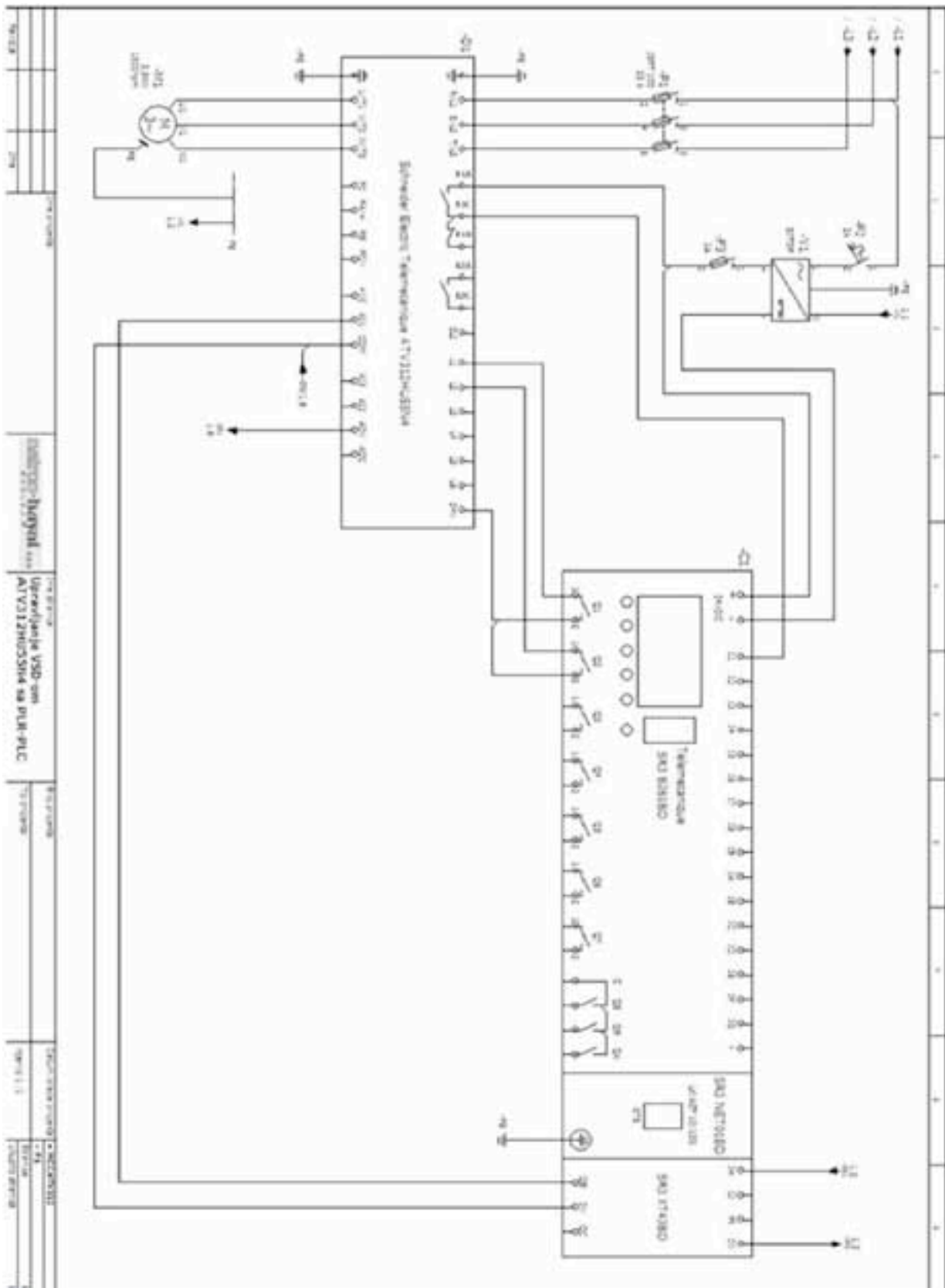


FIGURE 12. ELECTRIC SCHEME MADE IN CAE SOFTWARE EPLAN P8 ELEC

INTEGRATION OF ZELIO CONTROLS AND DAQFACTORY SOFTWARE

After we manufactured the logic of managing VSD and electric motor, we need to enable visualisation of parameters of controlling and overseeing work of the whole system inside a Zelio controller. For that, with the aid of Ethernet, we enabled communication between Zelio controls and a PC with installed DAQFactory software.

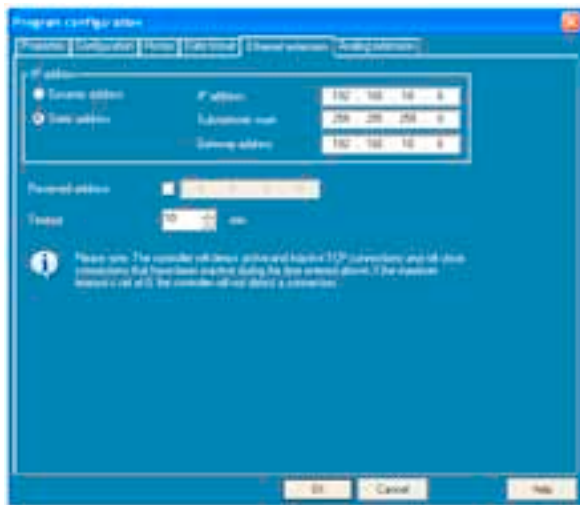


FIGURE 13. SETTING OF IP ADDRESS OF THE ePLAN P8 ELEC ZELIO ETHERNET EXTENSION

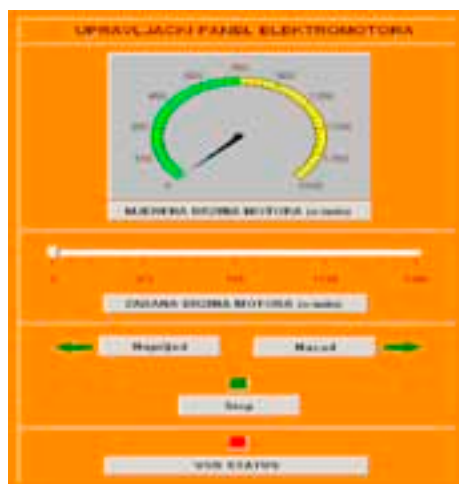


FIGURE 14. CONTROL PANEL (FACEPLATE)

TABLE 2. ZELIO ETHERNET EXTENSIONS

Zelio Ethernet input words	Zelio Ethernet output words
J1 (adress 16)	O1 (adress 20)
J2 (17)	O2 (21)
J3 (18)	O3 (22)
J4 (19)	O4 (23)

Entry words are entirely in write mode while output words are entirely in read mode; meaning, in the register of the input words it is possible to “write” values, while in the registers of the output words it is possible only to “read” values inside the register. As it can be seen from the logic control of the input words we used J1 and J2, in other words, addressed 16 and 17 respectively, while with the output words we used O1 and O2, in other words, addressed 20 and 21 respectively. With the input word J1 we control VSD (forward, back, stop) while with the input word J2 we assign a reference speed value. With the aid of output word O1 we receive information on the current measured motor speed while the output word O2 is used to receive status information of VSD (ready or fault).



FIGURE 15. IMPLEMENTATION

CONCLUSION

It is very easy to assume the role and importance of induction motors by monitoring the development of technological advances from their beginnings to the present date. As the time goes by, industrial development is increasing, and therefore the induction motor is gaining an advantage over the DC motor due to the transmitting it has. What we can have concluded and presented in this paper, is to successfully manage asynchronous motor with programmable logic controller (PLC) and VSD in a way that controller based control logic sends signals and receives information about the state and the speed of the motor. It also enables the visualization of the process control using electric motors and a complete software that manages processes and data in the system.

Authorship statement

Author(s) confirms that the above named article is an original work, did not previously published or is currently under consideration for any other publication.

Conflicts of interest

We declare that we have no conflicts of interest.

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