ANNALS
OF THE UNIVERSITY OF
PETROŞANI

ELECTRICAL ENGINEERING

VOL. 16 (XXXXIII)

CONTENTS

ENHANCING THE MAINTENANCE OF FLAMEPROOF ELECTRIC MOTORS IN ORDER TO IMPROVE THE RELIABILITY IN EXPLOITATION

MIHAI MAGYARI[1], BURIAN SORIN[2], FRIEDMANN MARTIN[3], LUCIAN MOLDOVAN[4], DRAGOS FOTAU[5], COSMIN COLDA[6]

Abstract: The purpose of the paper is to perform a thorough analysis of the types of breakdowns, both electrical and mechanical, which are likely to occur in the case of electrical drives made up of explosion proof electric motors used in hazardous locations.

Based on this analysis, several solutions are identified, in order to enhance the reliability in exploitation and the maintenance of electrical drives consisting of Ex proof electric motors commonly used in the oil and gas industry.

These solutions can be used both by explosion proof motor manufacturers and the end users of this equipment in oil and gas applications, in order to enhance the safety against explosion hazard.

Key words: electric motor, explosion proof, maintenance, reliability.

1. INTRODUCTION

Presently, the high cost of the electric drives made up of explosion proof electric motors, their higher and higher complexity and technicity, as well as the need of accomplishing an exceptional safety in operation require organizing, at a particularly high level, the operational surveillance of electric drives of machinery employed in atmospheres with explosion hazards, specific to the petrochemical industry, their maintenance and repairs in order to ensure production process continuity and cutting down the maintenance expenses [2].

---

[1] *Ph.D.Eng., senior scientific researcher II, INCD-INSEMEX Petrosani*
[2] *Ph.D.Eng., senior scientific researcher II, INCD-INSEMEX Petrosani*
[3] *Ph.D.Eng., senior scientific researcher I, INCD-INSEMEX Petrosani*
[4] *Ph.D.Eng., senior scientific researcher III, INCD-INSEMEX Petrosani*
[5] *D.Eng,Ph.D.Candidate, assistant scientific researcher, INCD-INSEMEX Petrosani*
[6] *Ph.D.Eng., assistant scientific researcher, INCD-INSEMEX Petrosani*
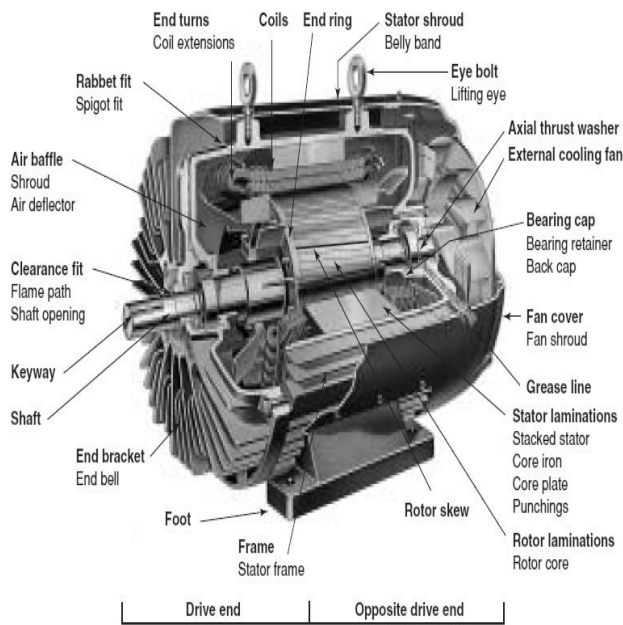
Fig. 1. Components of a flameproof motor

For this reason, the flameproof electric motors maintenance and repair issue, aiming to increase reliability in operation, rise certain specific aspects, both regarding organizing this activity, to maintain the technical potential available to economic agents, and due to the requirement of keeping the explosion proof feature after repairs, in order to maintain safety concerning explosion hazard [1]. Figure 1 shows a section through a flame proof electric motor, specifying its components.

2. INDUCTION MOTORS ENERGY LOSSES
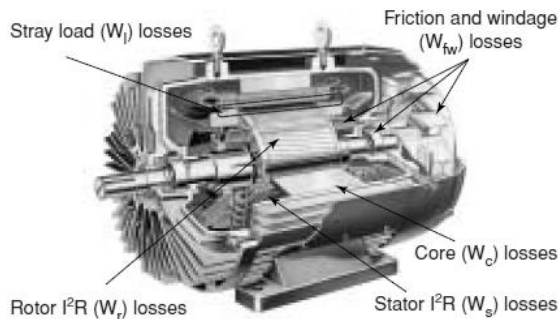
Fig. 2. Losses in the various parts of a motor

There are five types of loses in an induction motor [4]:
- Core losses in the stator and rotor;
- Stator I^2R losses;
- Rotor I^2R losses;
- Friction and windage losses;
- Stray load losses.

The core, friction and winding losses do not significantly change with the motor load, provided the motor is operated from a fixed frequency. The I^2R and stray load losses increase significantly as load is increased.

Both core and I^2R losses (and particularly the rotor losses) may be higher when the motor is supplied from a variable frequency converter.

In many cases, losses can be decreased during the repair process when good practices are followed.

Figure 3 illustrates how the losses vary in relation to load for a typical 4 – pole induction motor [4].
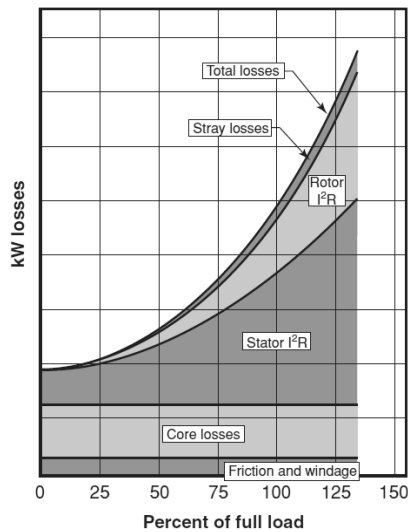
Fig. 3. Typical components
of induction motor loss plotted against load

3. FAULTS ANALYSIS IN EXPLOSION PROOF ELECTRIC DRIVES

3.1. Analysis of the causes producing faults in explosion proof motors

During its serviceable life, the electromechanical equipment may show numerous faults in the electric motors designed for its electric driving, due both to some constructional deficiencies and improper exploitation. These faults could be remedied in some cases by maintenance works whilst in other cases only by repairs performed after taking the equipment out of operation [3].

From analyzing the faults identified, it resulted that these can be systematized in two main categories: mechanical faults and electrical faults, some of them common for any motor and others specific only to certain types of motors. There are also cases where electric motors with faults, taken out for repairs, show simultaneously several mechanical or electrical failures or even mechanical and electrical combined faults.

3.2. Causes inducing mechanical faults in explosion protected electric motors

The main mechanical damages occurring in electric motors operating in petrochemical industry are the following:
- bearing block (jamming), for over 50-60% of the motors, a complex failure consequence of the following causes:
  - inadequate quality of bearings;
  - under-sized bearings compared to the real stresses;
  - inadequate mounting: faulty alignment between the motor shaft and bearings, resulting in vibrations (noise) or shaft clattering in the bearing base, and in some cases even small shifting of the motor in any direction if the clamping bolts were not properly screwed in.

- degradation or premature loss of grease before the technical revision, and in some cases employing an improper grease.

The residual bending of shafts (deformation), most of the times having values that cannot be visually ascertained but high enough to cancel the flameproof joints gaps, occurs due to the following:

- local overheating in all states, inducing bearing jamming (previously mentioned faults);
- mechanical overloading, over the allowable limits for transportation, mounting or during operation;
- dismantling operation following a motor or coupling failure, when forcing the coupling or the fan blades out of the shaft, if they had a too high fastening when assembled.

3.3. Causes inducing electric faults in motors used in potentially explosive atmospheres

The faults occurring in the electromagnetic system of explosion protected electric motors are mainly the following:

- winding deterioration (total or partial), representing a 20-30% of the total faults, due to repeated or long overloads, not disconnected in due time. Besides mechanical failures that can induce these faults, listed in the previous subchapter, the following situations, generating faults, may occur [4]:

- overloading of work mechanisms of the machinery driven by the motor;
- re-winding with electro-insulating materials having an inferior insulation class compared to the one in the original working documentation;
- worsening of cooling conditions, due to multiple causes as: cooling fan airscrew faults, and motor rotation speed lowering due to supply voltage and frequency drop down;
- lack of proper thermal protection of the motor (in the feeding switch or directly on the windings) or its incorrect adjusting (due to frequent start-stop operating or different thermal constants of the thermal relays);
- lack of protection "at tilting" (short-circuit of motors in cases where the operating regime does not allow a correct adjustment of the thermal relays);
- short-circuit in the coils, between the phases or between the phases and mass (magnetic circuit laminations or various elements of the electric motors enclosures) are faults occurring more frequently in windings than overloads. The causes are:
  - improper quality of the winding conductor (manufacture faults);
  - water ingress (resulted from the condense accumulated on windings and on the metallic parts of the electric machine, coming from the outer atmosphere having a high humidity) on the shaft (or on the gaps) in the areas with a weak impregnation;
  - the insulation resistance drop down, between phases or towards the mass;
  - accidental overloads, overheating the insulation and hence breaking down.

Following repairs, respectively dealing with the faults found out, the motors are brought at the initial state, fulfilling the operating conditions at the initial parameters of safety and protection for explosion hazards environments.

4. CONCERNS FOR ENHANCING THE MAINTENANCE AND REPAIRS OF EXPLOSION PROOF ELECTRIC MOTORS

Within operators in petrochemical industry there are serious concerns for improving the maintenance and repair activity of equipment [2], [3]. This is materialized by approaching a new concept in this field, which is the one of "operational maintenance".

The theoretical and practical substantiation of the need of this concept is given by the following aspects:

- the operational maintenance of technological equipment represents a component of the production function, having independent tasks and responsibilities;

- the need of a concordance between the product manufacture technology and the maintenance of equipment and machinery corresponding to a technology, economic efficiency of the maintenance and repair works, correlated with the real productivity of each machinery, as well as with the product quality;

- carrying out a model making use of the experience and ability of specialists in industrial companies, designing institutes and so on.

The model of operational maintenance takes into consideration the technological equipment maintenance as function integrated within the production activity of the company. Thus, accomplishing the tasks of a production unit, under certain quality, expenses, and deadlines conditions, implies analyzing the following factors:

1. Professional training of personnel, both of the ones exploiting the equipment and the ones ensuring its maintenance and repairs, strictly correlated with the professional competency (C_p), due to the following requirements:

- knowledge of the activity specifics, the established norms and solving all the operating problems for the equipment exploited or maintained, all these being part of the elements characterizing the personnel (P);

- ability regarding the task fulfilling correctiveness, and aptitudes of comprising the whole set of obligations comprised in the personnel ability (A_p);

- abilities regarding technical and economical responsibility of personnel (A_t).

Thus, the functional model of the professional training degree may be represented in the following way:

$$C_p = f (P, A_p, A_t) \tag{1}$$

2. The technology used, respectively the technological analysis has in view in particular two large groups:

- the product manufacturing technology;

- the maintenance and repair technology, appropriate to each technological equipment.

3. Production organizing, related to equipment maintenance and repair - this suppose conceiving, designing and applying methods and techniques ensuring fulfilling the fundamental goal of the operational maintenance.

4. Performing statistic tests related to the operational feature of technological equipment:

- using new techniques for equipment surveillance, as for example, vibration measurement, temperatures recording, greasing, cooling elements analysis etc.

5. Designing and carrying out the informational subsystem. This represents the synthesis instrument, offering the possibility of tracking the development of main activities and assesses the risk level for the case, and based upon this, making the decisions ensuring a maximum of efficiency. This sub-system must keep updated the board panel of the maintenance activity responsible - repairs in companies, as follows:

- grouping all significant information regarding development of the scheduled activities;

- shows in a systematized manner the information needed to perform economical-technical analyses;

- contains all information that give the phenomena through their evolution in time;

- provides all information required for decision making in the shown cases.
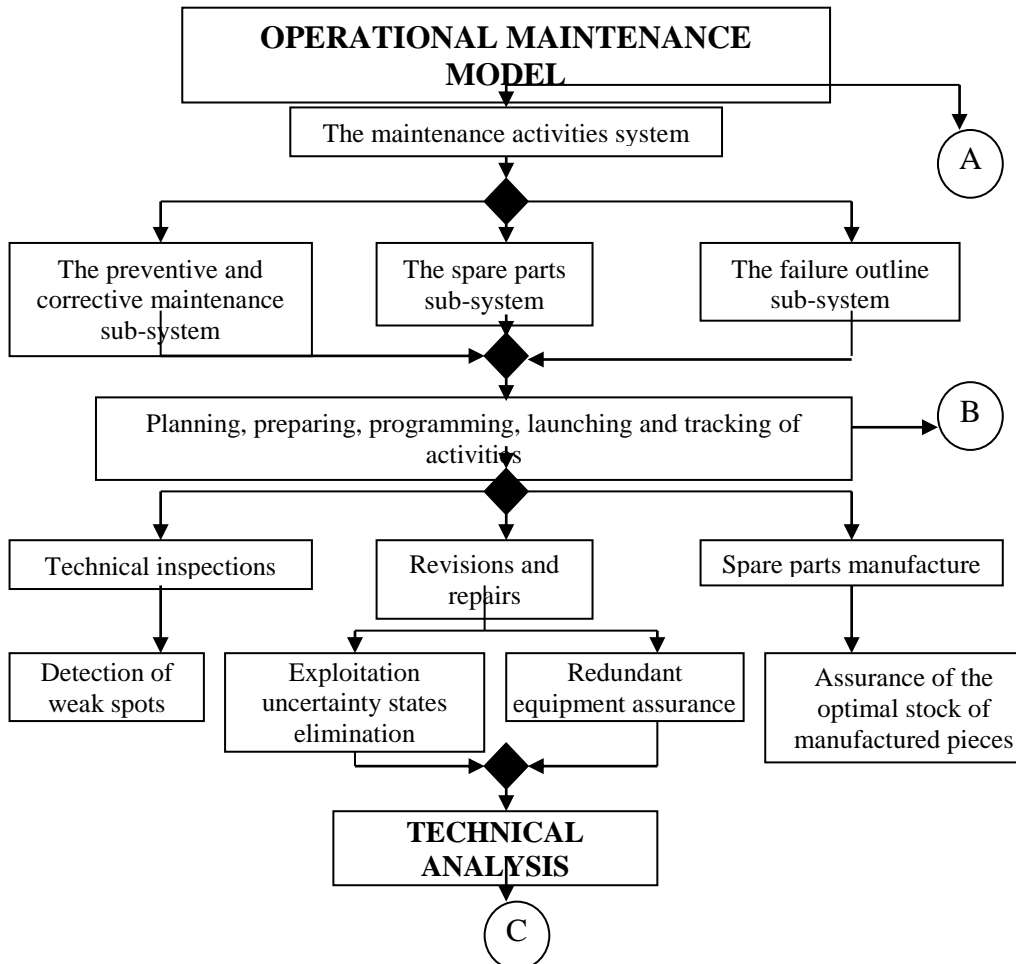
Fig.4. Logical diagram of the operational type of maintenance and repair system

By adopting such a maintenance model, the following results may be obtained:

a) Number of failures lowered at a minimum, which leads to a global efficiency increase, through the following:

- using a preventive maintenance system that ensures knowing the equipment wear out state, finding out the weak spots, prevention of states of uncertainty in exploitation and failures;

- increased quality of maintenance and repair works of equipment;

- optimal exploitation according to the instruction given by the equipment manufacturer.

b) Optimization of repair durations, as consequence of applying the methods based on operational research.

c) Ensuring spare parts in the needed amounts, with required reliability and deadlines. Further on, the paperwork proposes a model structuring the maintenance and repair system, of operational type, through the logic diagrams in figures 4 and 5. Analyzing this, it can be mainly noticed that the model of operational maintenance comprises two sub-systems, as follows:

- the system of maintenance and repair activities, in figure 4, consisting in: preventive and corrective maintenance components; spare parts and failures; programming, preparing and tracking activities, performing specific works; goal fulfilling check-out; technical analysis of the way activities develop;
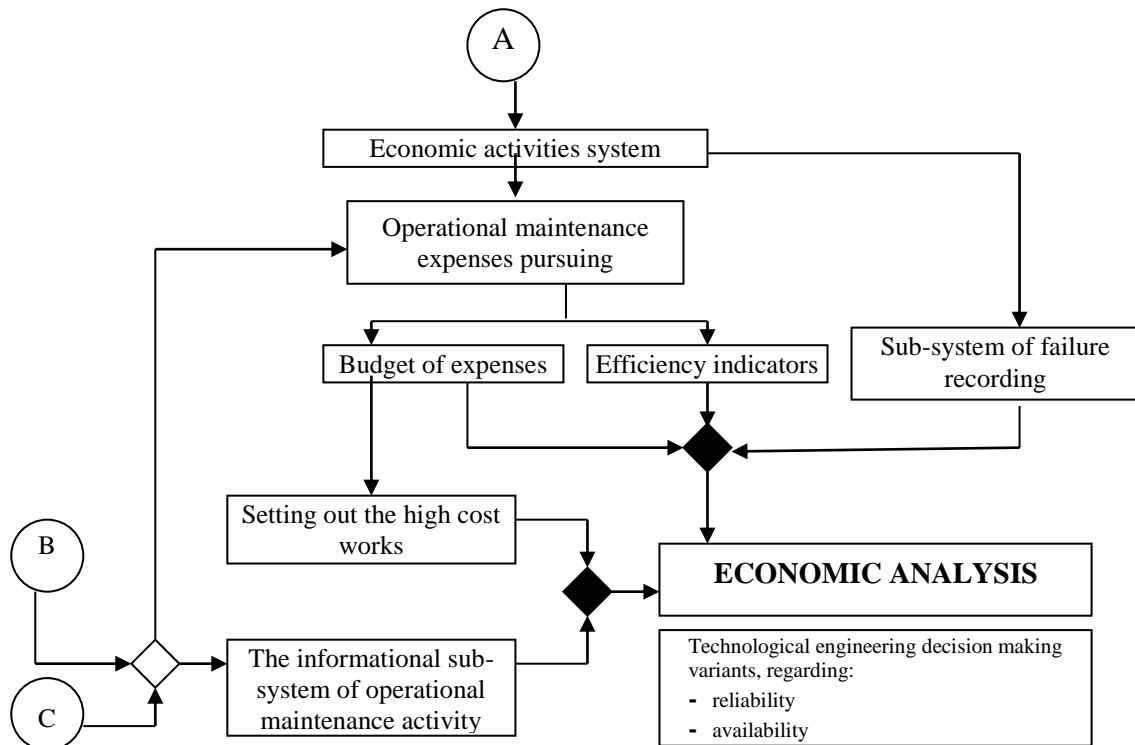
Fig.5. Logical diagram of the economic activity sub-system within the operational type
of maintenance and repair model

- the economic system, in figure 5, comprising: outline of maintenance expenses and fitting into the approved budget, failure expenses and identifying the high cost works, these being comprised in an overall economic analysis;

The two types of analyses: technical and economical ones, would lead to defining the optimal variant in regards of the repair and maintenance decision for each equipment.

5. CONCLUSIONS

The measures to improve the quality and lower the number of failures can be grouped:

1. Technical measures to improve quality and lower the number of failures for the conceiving-constructional stage of the electric motors, whose beneficiaries will be the manufacturers of explosion protected electric motors.

2. Technical and organizational measures, at users of explosion protected electric motors in order to lower the number of failures in the exploitation, maintenance, revisions and repair stages of the electric motors, whose beneficiaries will be the economic agents in the petrochemical industry.

REFERENCES

[1]. SR EN 60079-1: *Atmosfere explozive. Partea 1: Echipamente protejate prin carcase antideflagrante „d".*

[2]. SR-EN 60079-14: *Atmosfere explozive. Partea 14: Proiectarea, selectarea si construirea instalatiilor electrice.*

[3]. SR- EN 60079-19 *Atmosfere explozive. Partea 19: Echipamente pentru reparatii, reparatii generale si revizii.*

[4]. Bala C., *Masini electrice. Teorie si incercari.* Editura Didactica Bucuresti, 1982.

[5]. Magyari M., Burian S., Friedmann M., Moldovan L., Fotău D., Colda C., *Analysis of faults in explosion proof electric drives and concerns for modernizing the maintenance and repairs of motors operating in explosive atmospheres,* SIMPRO 2014, Petroşani 10-17 Octombrie.

IMPORTANCE OF THE TORQUE TEST FOR BUSHINGS AND THERMAL SHOCK TEST, USED FOR THE ASSESSMENT OF ELECTRICAL EQUIPMENTS DESIGNED TO OPERATE IN EXPLOSIVE ATMOSPHERES

MOLDOVAN LUCIAN[1], BURIAN SORIN[2], FRIEDMANN MARTIN[3], MAGYARI MIHAI[4], FOTĂU DRAGOŞ[5], COLDA COSMIN[6]

Abstract: Assessment of electrical equipments designed for use in explosive atmospheres against the ATEX Directive 94/9/EC provisions is made, mostly, by providing conformity against specific technical standards. Thus, samples of electrical equipment are subjected to type tests, in which category are also included the torque test for bushings and thermal shock test.

The purpose of the paper is to highlight the specific requirements of the torque test for bushings and thermal shock test and their importance, and to present the new testing methodology developed based on the specific requirements.

Keywords: electric equipment, explosive atmosphere, type of protection, type test, bushing.

1. GENERALITIES

In order to operate in hazardous explosive atmospheres the equipments must be subjected to certification procedures, according ATEX Directive 94/9/EC[3] [3](transposed in Romanian legislation by Government Decision no. 752/2004).[5]

Assessment of equipments designed for use in explosive atmospheres, in purpose of certification, is very important considering the existing explosion risk which has to be minimized to ensure people's health and safety, as well as to prevent goods damage.

The easiest method that can be used to demonstrate equipment conformity with the requirements of ATEX Directive 94/9/EC is by using harmonized European standards (that are in the scope of the Directive) in the designing process of the equipment.

---

[1] *Sc. Res. IIIrd, PhD.Eng., INCD INSEMEX Petrosani, Lucian.Moldovan@insemex.ro*

[2] *Sc. Res. IInd, PhD.Eng., INCD INSEMEX Petrosani, Sorin.Burian@insemex.ro*

[3] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Martin.Friedmann@insemex.ro*

[4] *Sc. Res. IInd, PhD.Eng., INCD INSEMEX Petrosani, Mihai.Magyari@insemex.ro*

[5] *Sc. Res. , PhD. Student, INCD INSEMEX Petrosani, Dragos.Fotau@insemex.ro*

[6] *Sc. Res. , PhD. Eng., INCD INSEMEX Petrosani, Cosmin.Colda@insemex.ro*

The harmonized standards used to evaluate the electrical equipments are SR EN 60079-0 (Explosive atmospheres. Part 0: Equipment. General requirements) and one or more of the standards containing the specific requirements for the type(s) of protection applied to equipment (ex. SR EN 60079-1 for the type of protection flameproof enclosure "d", SR EN 60079-7 for the type of protection increased safety "e", SR EN 60079-11 for the type of protection intrinsic safety "i", SR EN 60079-2 for the type of protection pressurization).[4] A very important part in the evaluation process of explosion-proof electrical equipment is represented by type tests.

The SR EN 60079-0 standard indicates the type tests to which all the explosion-proof electrical equipments shall be subjected and the order in which these tests shall be performed.

The torque test for bushings and the thermal shock test are also included in type tests category.

2. CONSIDERATIONS REGARDING THE TORQUE TEST FOR BUSHINGS

2.1 Importance of torque test for bushings

Bushings are used in case of multi-compartmented equipments to which there is a need for the electrical connections to pass from one compartment to another. The compartments connected through bushings may have the same type of protection (for example flameproof enclosure "d"[2]) or different types of protection (for example flameproof enclosure "d" and increased safety "e", flameproof enclosure "d" and intrinsic safety "e", increased safety "e" and intrinsic safety "e" etc.). Examples of such kind of multi-compartmented electrical equipments are: luminaires in which the connecting terminals are placed in a compartment with type of protection increased safety "e", but the light source is placed in a compartment with type of protection flameproof enclosure "d"; electrical motors that are using bushings for the passage from the terminal box (with type of protection increased safety "e") to the main compartment of the motor (with type of protection increased safety "e" or flameproof enclosure "d").[1]

The bushing contains inside a metallic stem that creates the electrical connection between those two compartments. Bushings shall ensure a good fastening, in order not to negatively influence the insulation distances, but also not to facilitate the transmission of mechanical stress from terminal to conductor. Bushings used for connection facilities and which are subjected to torque during connection or disconnection of conductors must be tested for resistance to torque.[2]

The stem in the bushing or the bushing, when mounted, shall be subjected to a torque of the value indicated in table 1, according SR EN 60079-0:2010 (the torque values for other dimensions can be determined from a graph plotted using these values; in addition, the graph may be extrapolated to allow torque values to be determined for stems of bushings larger than those specified).

Table 1. **Torque to be applied to the stem of bushing used for connection facilities**

Stem diameter	Torque Nm
M 4	2,0
M 5	3,2
M 6	5
M 8	10
M 10	16
M 12	25
M 16	50
M 20	85
M 24	130

When mounted, neither the stem in the bushing, nor the bushing itself, shall turn when the stem is subjected to a torque[3].

In case non-metallic materials are used it is necessary that the torque test for bushings to be conducted after their conditioning by tests to thermal endurance to heat and cold.

2.2. Performing the test

Based on the previously described requirements, it was found that before performing the specific test is required that, in case of bushings that use elements made of nonmetallic materials (other than glass and ceramics), to undergo thermal conditioning (thermal endurance to heat and cold). Thermal conditioning is performed in a climatic chamber, capable to achieve the necessary conditions for the test.

The torque test for bushings requires that a torque to be applied to the stem of the bushing. This torque can be applied using a torque wrench that covers the torque range prescribed in the standard SR EN 60079-0: 2010 and to have also the necessary accessories for transmitting torque from the torque wrench to the stem of the bushing.

For the purpose of the test two high precision torque wrenches (Fig. 1 and 2) are used, Stahlwille, Manoskop type 714 (in the range 2-20 Nm) and 730D (in the range 20-200 Nm) with the required accessories[1].

Fig. 1 Torque wrenches Stahlwille, type Manoskop 714

Fig. 2 Torque wrenches Stahlwille, type Manoskop 730D

3. CONSIDERATIONS REGARDING THE THERMAL SHOCK TEST

3.1 Importance of thermal shock test

Explosion-proof electrical equipment containing glass parts (windows or light dispersers) shall maintain explosion protection characteristics even in particular environmental conditions. For example, there is a possibility that in case of a luminare, mounted outside, to reach after a period of operation a specific temperature (maximum service temperature) and, because of some unfavorable environmental conditions, to be exposed at splashing with water at a low temperature (for example cold rain drops). The glass from which the disperser of the luminaire is made shall resist, without breaking or cracking to the thermal shock generated by the rain drops action (cold rain drops) that come in contact with the light disperser (which is at a high temperature, sometimes more than 100°C)[1].

The thermal shock test is part of the thermal tests, as described in the SR EN 60079-0:2010. For the purpose of this test, it is necessary that the glass elements to be verified, to be previously brought to the maximum service temperature. Thus, before performing the thermal shock test, the maximum service temperature shall be determined, in all points in which maximum temperatures can occur (including the temperature on glass parts and plastic materials). Thermal shock test shall be applied on explosion-proof electrical equipment that contains parts made of glass. Glass parts of luminaires and windows of electrical equipment shall withstand, without breaking, a thermal shock caused by a jet of water of about 1 mm diameter at a temperature (10 ± 5) °C sprayed on them when they are at not less than the maximum service temperature. In practice, there are a lot of equipments operating in areas with hazard of explosive atmospheres that use glass parts in their construction (for example: luminaries, analogic or digital measuring instruments for which the local reading of the displayed value is needed, etc.).

3.2 Performing the test

Before performing the thermal shock test, the maximum temperature that can be reached in normal operating conditions (at rated parameters of the device, taking into account the maximum ambient temperature for which the equipment is intended to operate) shall be determined.

In order to determine the maximum temperature in normal operation (at rated parameters) the testing laboratory has the necessary equipment (adjustable power source, multimeter with thermocouples etc.) and specific procedures.

To perform the thermal shock test the glass parts, that are subjected to this test, shall be conditioned (heated) until they reach a temperature at least equal to the temperature reached in normal operation (at rated parameters of the device, taking into account the maximum ambient temperature for which the equipment is intended to operate). For heating of glass parts of the equipment to the maximum temperature reached in normal operation a climatic chamber is used.

The glass parts of luminaires and windows of electrical equipment must withstand, without breaking, a thermal shock caused by a water jet with a diameter of about 1 mm, at a temperature of (10 ± 5) °C, splashed on them when they are at a temperature not lower than the maximum service temperature.

For splashing of glass parts subjected to thermal shock test, a test rig was conceived (Fig. 3). For achieving the test rig were used: water pump, power supply, 1 mm nozzles, water hose, voltage indicator, push button etc.

Spraying the glass part that is intended to be tested can be achieved even within the climatic chamber used for heating through the visiting windows of them (fig. 4).

Fig. 3 Test rig for performing the thermal shock test

Fig. 4 Spraying the light disperser inside the climatic chamber

4. CONCLUSIONS

Explosion proof equipment shall maintain their explosion protection characteristics in the most onerous conditions that can normally occur in practice. In order to verify these safety characteristics all electrical equipments shall be subjected to tests (type tests) in which category are included also the torque test for bushings and the thermal shock test.

The purpose of the thermal shock test is to verify that the glass parts of the equipment can withstand a thermal shock caused by cold water droplets falling onto the heated glass parts (very often in case of luminaires mounted outside).

The purpose of the torque test for bushings is to ensure the maintaining of a good fastening in case of bushings used for connecting facilities which are subjected to torque during connecting or disconnecting of conductors, in order not to negatively influence the insulation distances, but also not to facilitate the transmission of mechanical stress from the terminal to conductor.

The purpose of the paper is to present the testing methodology that was developed and also to underline the importance of the torque test for bushings and thermal shock test.

REFFERENCES

[1]. Moldovan L., Burian S., Friedmann M., Magyari M., et al., *Considerations regarding the torque test for bushings and thermal shock test, applicable to electrical equipment designed for use in explosive atmospheres,* Ediţia a 6-a a Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO, 2014, Petroşani, Universitatea din Petroşani, România ISSN 2344-4754.

[2]. Moldovan L., Friedmann M., Magyari M., et al., *Developing the testing capacity of the laboratory by implementing the testing technology for thermal shock test and torque test for bushings,* Project no. PN 07-45-01-23 – National Research Program, INSEMEX - MEC, Phase II report, 2014.

[3]. Moldovan L., Burian S., Friedmann M., et al., *Specific requirements regarding the torque test for bushings and thermal shock test, used to assess electrical equipments designed to operate in explosive atmospheres*, Al XVI-lea Simpozion Internaţional "Tinerii şi Cercetarea Multidisciplinară" – ISYPMR – Timişoara, 2014, ISSN 1843-6609.

[4]. *** SR EN 60079-0:2013, *Explosive atmospheres - Part 0: Equipment – General requirements*, ASRO, 2013.

[5]. *** *Directive 94/9/EC - on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially Explosive Atmospheres*

DISTRIBUTED SYSTEMS CONTROLLED USING VIRTUAL INSTRUMENTATION

NICOLAE PĂTRĂŞCOIU[1] , IOANA CAMELIA BARBU[2], CECILIA ROŞULESCU [3]

Abstract: In this paper we propose a virtual instrument through which a number of acquisition modules are controlled and these modules realize the initial data processing. Control consists in selection for each of these modules, their inputs selection and retrieves information from them. The physical connection is made by RS-485 bus and the transmission protocol used is MODBUS.

Keywords: data acquisition, RS-485, MODBUS, LabVIEW

1. INTRODUCTION

The notion of distributed control system (or DCS) shall, in the broadest sense, any system of control of a dynamic process characterized by the fact that control elements are located spatially adjacent of the controlled subsystems and these control elements are interconnected in a communication network that allows the monitoring and supervision process.

SCADA is used also to define de control into a distributed system and is an acronym for *Supervisory Control and Data Acquisition* which means level supervisory control and data acquisition system.

Supervisory control level is defined in opposition to real-time control and consists, for example, in charging the set-point values of some smart regulators, whose job is to maintain, in real time, the measured values of some process parameters at levels as close to the prescribed values.[1]

The general structure of a SCADA system (Bailey, 2003), (Dunn, 2006), depicted in fig.1 comprise:

a.   Field equipment comprised all the equipment and the technical systems needed to measure the values of interest variables for this process (pressure transducers, level, temperature, flow meters, analysers etc.) and also comprised the systems to actuate and modify the parameters.

b.   The equipment are connected with the control elements from the higher hierarchy level in order to transmit data and receive the control signals through the local communication bus that use industrial communication protocols (Modbus, Profibus, HART, Ethernet, CAN, etc.);

---

[1] *Assoc.Prof., PhD., University of Petrosani*
[2] *Lecturer, PhD., University of Petrosani*
[3] *Professor, Grigore Geamanu School*
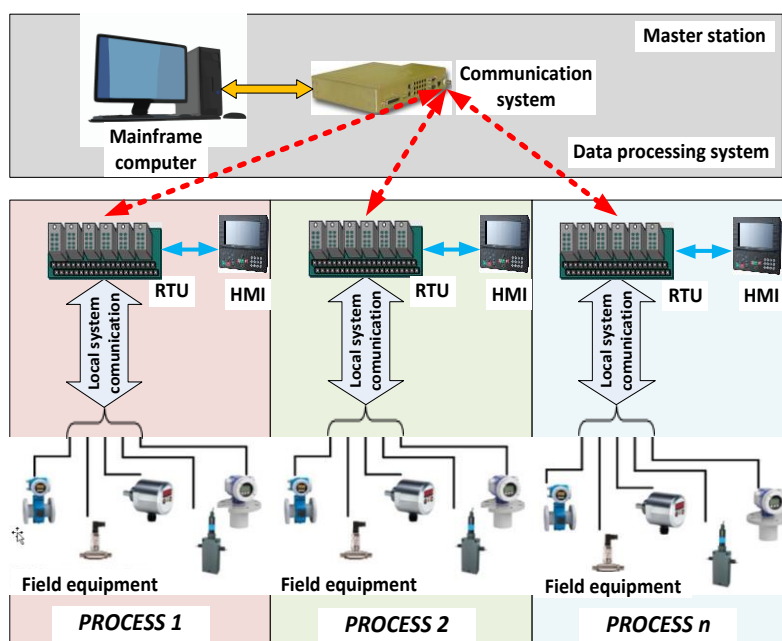
Fig. 1. The general structure of a SCADA system

c. Remote Terminal Units, data distributors and eventually local programming interfaces (Human Machine Interface), that is slave type units and comprise all the equipments and technical systems needed for monitoring and control locally the process. Their number depends to the dimension of the network; every process or work point from a process (pumping station, source, water treatment plant, etc.) has an associated local control unit, which has to be dimensioned corresponding with the number of monitored variables for the process or the work point. All those units are connected and communicate with the higher hierarchy level through different communication systems.

d. The communication system make the necessary connection in order to obtain data and transmit commands towards the local control units and usually such connection suppose long distance communication, full duplex or semiduplex, between local control units and the master system which, most of the cases, reside far away from them. The communication can be achieved through physic channels like telephone line, UTP or STP wire, optic fibre, but a more modern, reliable solution is represented by the wireless communication systems using GSM/GPRS or Radio Modem solutions.

e. The wireless communication system supposes that a GSM/GPRS or Radio Modem is found at each local control unit and also at the master unit.

f. The master unit and the data management system represent the unified command system destined to remote monitoring of all local work points. The SCADA application installed at the central dispatch relay to a SCADA server. When necessary, a configuration with two servers can be used in order to assure the reliability of the system. Beside the server units, at this level computer work stations can be installed on which the real time variable from processes can be observed, the status of the system

can be depicted or where the developers of the application and maintenance personal can undertake different tasks. Most of the cases, the monitoring application will be organized hierarchical with screens depicting the global status of the system and also screens for each process or work point. The application configuration has to fulfill the requirements of the beneficiary in an efficient manner. To assure the scalability of the system and to allow later expansions an OPC server can be installed at the master unit level in order to accept equipment and subsystems from diverse producers.[3]

For each of the subsystems a Remote Terminal Unit (RTU) is used to locally monitor and control the resident process or processes, in each of the subsystems. Those RTU provide communication with the informational elements and also generates the necessary commands towards the execution elements in order to maintain the prescribed parameters. The informational elements, represented by the sensors and transducers, will be specific for the monitored parameters of each process, and their outputs are either voltage levels either electric current value.

For data acquisition and command transmission a local bus is used, this representing the physical level, a RS485 serial bus, and a communication protocol Modbus RTU. The interconnection of field elements (transducers, execution elements) to the bus is realized by specialized interfaces in order to conform to the compatibility parameters from the electric point of view and also from the communication perspective.[2]

The second function of the local RTU is the connection with the centralized dispatch unit. This connection utilizes radio channels either GSM/GPRS or ISM (Industrial, Scientific and Medical band) frequency band. The ISM solution has the definitive advantage that does not require licence and the data transfer do not generate additional costs.

Depending of the chosen solution the radio link implies the existence of a specialized communication modem.

Utilizing the same protocol over the radio link (Modbus over Radio) the communication infrastructure is simplified; the need for convertors between protocols disappear, and the transparency between central dispatch unit, RTU's and field equipment is assured.

The general scheme of a distributed control system with SCADA supervision is shown in Fig.2. We note the presence of several process units or distinct subprocesses, each with sampling devices and transmitting measured data (sensors, conditioning circuits and transmission), actuators (pumps, motors, heaters, etc.) in real-time controls (usually PLC, PID "smart" controllers or RTU), all interconnected by a communication bus to a central monitoring and supervision equipment equipped with an HMI (Human-Machine Interface) that usually is a computer equipped with special software and communication control which can be LabVIEW.[3]

Should be noted that some parameters can be passed directly to supervisory equipment, located in the control room, by means of devices called RTU (Remote Terminal Units). The RTU devices can transmit commands to the PLC or directly to actuators associated to the real-time process control, and these commands sometimes have greatest priority against commands from the local control loop in real time.
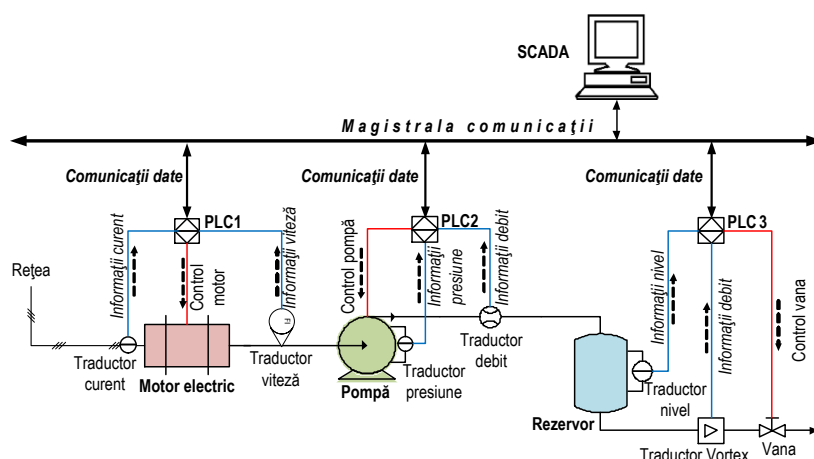
Fig.2. Distributed control system with SCADA

2. HARDWARE STRUCTURE

An RTU unit (sometimes called telemetry unit) is a unit of data acquisition and control system independent in general based on microprocessor or microcontroller which monitors and controls equipment located at a location away from the this unit. Its primary role is to retrieve data and transfer them to the main unit and also to control process equipment located away from the main unit. In general, RTU equipment have the facility to be dynamically configured and programmed from the main unit but the configuration and programming operations can be achieved also through a local programming device. Although usually RTU communicates with the main unit, it is also possible to carry out a communication peer-to-peer to other RTU. RTU unit can also act as a relay unit RTU unit can also act as a relay unit (sometimes called storage and retransmission unit) to another RTU unit, which cannot be accessed directly from the main unit.[5]

Hardware structure of an RTU unit typically includes the following components:

- processing Unit (microprocessor or microcontroller) and associated memory;
- communication interface;
- power supply;
- which may be added one or more of the following functional blocks:
- analog inputs/outputs;
- digital inputs/outputs;
- counter/timer.

A typical configuration of a unit is shown in Fig.3.
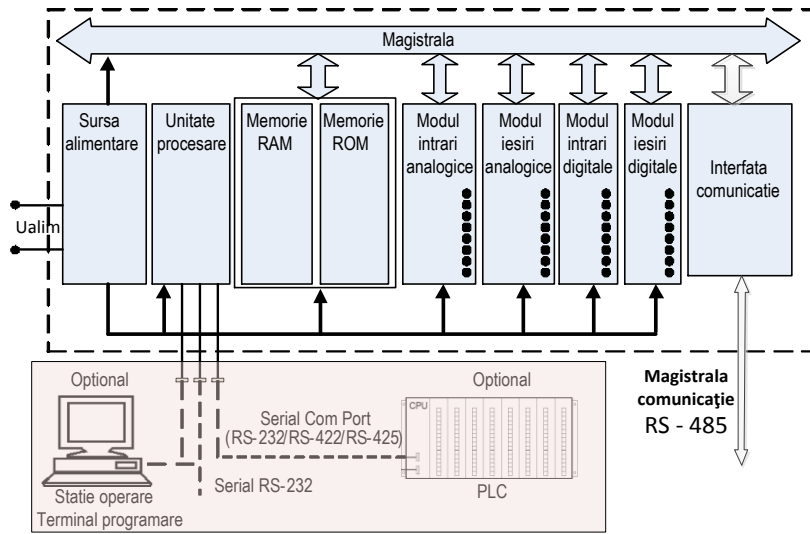
Fig.3. Typical configuration of a RTU unit

Through the virtual instrument that is presented in this paper are controlled the RTU units represented by modules type SM 1 and type P12O.
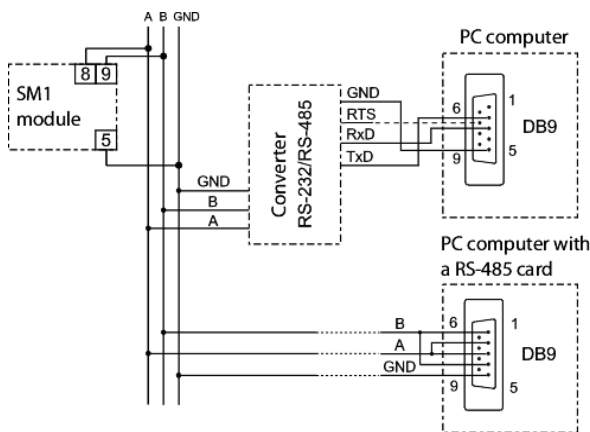
Fig.4. Connecting of module SM1

The SM1 module, shown in Fig. 4., has two analog input channels and is designed to convert standard signals: voltage (0 ... 10 V) or current (4 ... 20 mA) or resistance (0 ... 400 Ω) or temperature signals (collected with Pt100 RTD) into the numerical data which are accessible via bus RS-485 or RS-232. The module has ports to connect to these buses and uses for data communication the MODBUS protocol.

The module SM1 can be connected to an RS-485 serial bus via lines A and B (pins 8 and 9 of connector) to communicate with computer systems or other devices that act as master in a network through asynchronous communication protocol MODBUS.

For module SM1 MODBUS protocol was implemented according to the PI-MBUS-300 Rev. G of the Modicon Company. So, for communication via RS485 serial bus and MODBUS protocol is necessary to set the following parameters:

- Module Address 1 ... 247;
- Transfer rate: 2400, 4800, 9600, 19200, 38400, 57600, 115200 bits/sec.;
- Maximum Response Time: 300 msec.
- mode: ASCII, RTU;

23

- Units of information: ASCII: 8N1, 7E1, 7O1;
                                         RTU: 8N2, 8E1, 8O1, 8N1;

If the connection of the module to the computer is performed by the RS-232 serial bus are set automatically following communication parameters:

- Transfer rate of 9600 bits / s,
- Mode: RTU: 8N1,
- Address: 1.

Implementation of MODBUS protocol is achieved by using the following functions:

Table 1

Function code (hex)	Significance
03 (03 h)	Read n – registers
06 (06 h)	Write single register
16 (10 h)	Write n – registers
17 (11 h)	Slave identification

Based on table of module SM1 registers which can only be read is observed that the values of the two inputs registers can be found at the addresses 7006 and 7008 respectively if are used two successive 16-bit registers or at the address 7503 and 7504 if are used two 32-bit registers.[8]

The module P12O, Fig. 5, is a programmable digital transducer that can convert the number of pulses, number of turns, number of hours of operation, frequency, period and speed of rotation in a unified current signal 4 ... 20 mA or signal DC voltage signal.
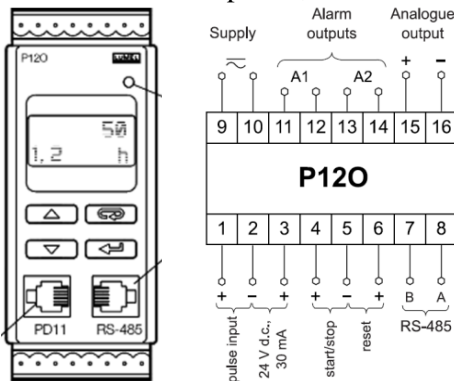
It is preprogrammed to perform certain functions but it can be reprogrammed by the user via the RS-485 interface through a specialized programmer PD14 or keyboard so that it can add new features.

Like SM1 module and P12O module can connect to a RS485 bus via lines A and B (pins

Fig.5. Connecting of module P12O

7 and 8 of connector) to communicate with computer systems or other devices that act as master in a network through asynchronous communication protocol MODBUS.[7]

For communication via RS485 serial bus and MODBUS protocol, like for module SM1 and for module P12O is necessary to set the communication parameters which are the same except of the transfer rate that can be: 2400, 4800 or 9600 bits/sec.

Based on table of module SM1 registers it can observe that the values of the two inputs registers can be found into two successive 16-bit registers beginning address with address 7010 or with address 7505 if are used two 32-bit registers.

3. VIRTUAL INSTRUMENT
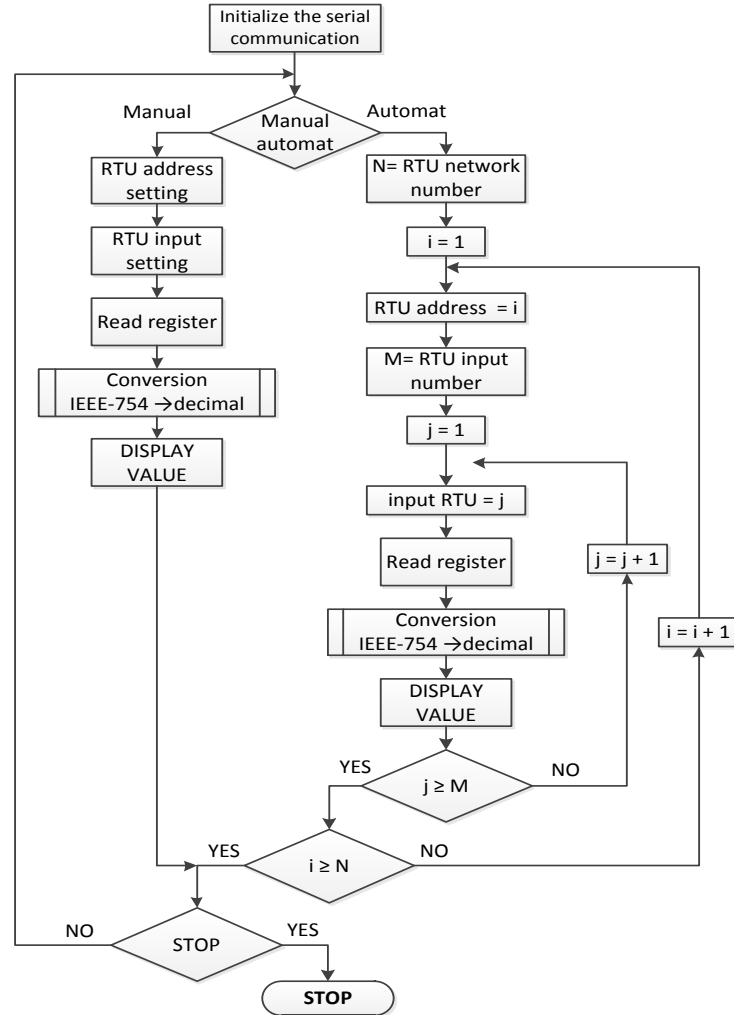
Fig.6. Virtual instrument algorithm

The virtual instrument designed for distributed control system involves gathering information about various physical quantities provided by different transducers. The transducers have different output signals.

In this application there are 3 type SM1 modules with different inputs: voltage, current and resistance and one P12O module, all connected to a RS-485 bus. To the modules are connected sensors and transducers for different physical sizes, collected from different measuring points.

Virtual Instrument operation is described by the algorithm shown in Fig. 5.

Once launched in execution, operation of the virtual instrument starts with the initialization of the serial communication. This means initializing the selected COM port, in this case through the use of RS-485 to USB converter, a virtual serial port with

all appropriate configuration parameters (baud rate, mode, parity, flow control) by opening a VISA session. To these is add a waiting time expressed in milliseconds that is wait time for a response from one of the slave devices. If not received in this wait time is announcing a communication error.

Based on this algorithm is made a block diagram of the virtual instrument, shown in Fig. 7. For communication between devices using MODBUS protocol is necessary that all devices connected to the same communication bus have the same set of communication parameters.
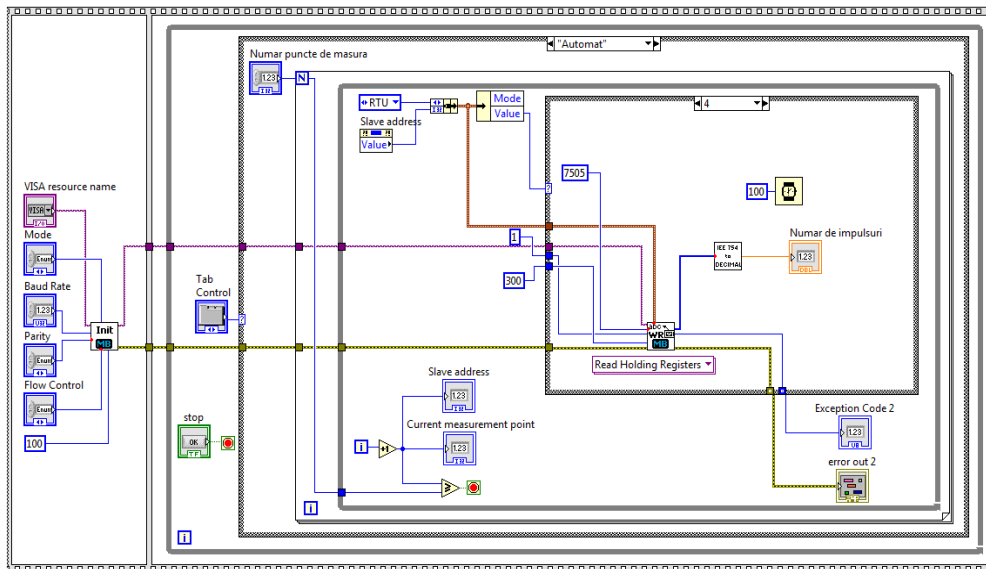
Fig.7. Bloc diagram of the virtual instrument

The block diagram contains a **Sequence** structure and the initialization of the serial communication is performed in the first sequence of a structure. In the second sequence is chosen the operation mode of the instrument that can be Manual or Automat. The second sequence included a **While** loop that will allow the program to run when launched in execution until to activate the STOP control on the front panel.

The selection of the two tracking modes of the measurement means choosing the dialing mode of the slave devices and this choice is made by means of a **Tab** control and a **Case** structure.

For the AUTOMAT operation mode, Fig.8., the slave device addresses are generated consecutively from address 1 to address that corresponds to the number of measuring points. This number is set by the user by control **Number of measurement points** on the front panel.
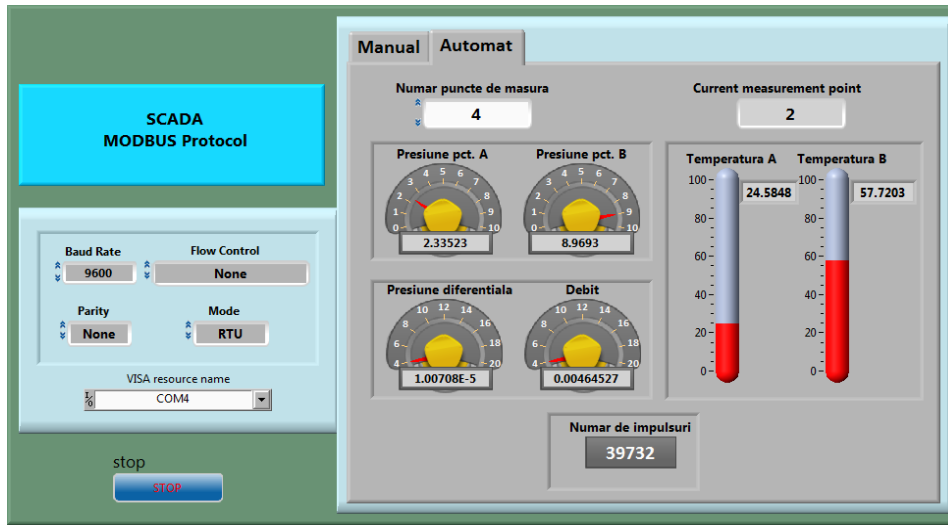
Fig.8. Front panel for AUTOMAT tracking mode

To increment the number representing the slave address is used the counter variable i of a **While loop**. The stop condition of this loop is by achieving the number N of the measurement points. By stopping the **While loop** after each reading cycle full of all slave devices is possible by the user switching to MANUAL tracking or remain in AUTOMAT tracking.

We consider a distributed control system structure containing four slave devices connection. The selection of the each device is made through a **Case** structure with 4 cases which correspond to the addresses of devices to which is added the address 0 for Broadcast call type.

Because each of the SM1 modules have two inputs is used in cases 1, 2 and 3 a **For** loop and each loop having two cycles. The counter variable of each loop is used to select one of the two inputs of modules SM1. It is not used in the address of the number 4 module, which is a P12O module because this has a single input.

Reading value is done via the **MB Serial Master Query Read Holding Registers** function that corresponds to the code 03 of the MODBUS protocol specifications. Measured values, as well at the most RTU devices from the structure of SCADA systems are in floating point format according to IEEE 754 standard because these values are the real numbers.

The decimal value *F* of a real number, expressed as a floating-point in single-precision can be calculated by the formula:

$$F = (-1)^S \cdot 2^{(E-127)} \cdot (1 + M/2^{23})$$
(1)

where E is the decimal value of the exponent and M is decimal value of the mantissa. In this the virtual instrument for conversion from IEEE 754 format to decimal format is implemented the expression (1) by means of **IEEE754 to Decimal SubVI**.

For display on the front panel of the measured values was chosen one indicator corresponding to each device and also for each entry of every device. In Fig.7. is show the complete front panel corresponding to AUTOMAT tracking mode.

Also on the front panel is presented and the setting mode of the parameters of serial communication between devices connected on the RS485 bus. It can be seen choosing the choice of RTU working mode, the 8N1 communication format and the 9600 bps (baud) for transfer rate. Once initialized the communication parameters they will be changed only by the restart of the virtual instrument.

4. CONCLUSIONS

The solution proposed in this paper for control the different devices connected through RS485 serial bus and MODBUS protocol can be extended up to 247 devices.

The virtual instrument proposed also has the advantage of simplicity and flexibility.

The simplicity is due to the fact that the link between devices and between every device and the master is achieved by a twisted pair. The flexibility is due to the fact that the number of devices can be from one to 247 and also every of these can be locate anywhere up to 1200 meters around the master device or computer.

REFERENCES

[1]. **Alan S. M.** *Measurement and Instrumentation Principles* Butterworth-Heinemann, MA, 2009.

[2]. **Bailey D.,** Wright E. *Practical SCADA for Industry*. Elsevier, 2003.

[3]. **Beyon J.Y.,** *LabVIEW Programming, Data Acquisition, and Analysis.* Prentice Hall, New York, 2001.

[4]. **Derenzo E. S.** *Practical Interfacing in the Laboratory Using a PC for Instrumentation, Data Analysis, and Control* Cambridge University Press, NY, 2003.

[5]. **Dunn C. W.** *Introduction to Instrumentation, Sensors, and Process Control.* Artech House, MA, 2006.

[6]. **Patrascoiu N., Barbu I.C., Roşulescu C.,** *Using virtual instrumentation in distributed control systems,* SIMPRO 2014, Petroşani 10-17 Octombrie.

[7]. **Sumathi S., Surekha P.** *LabVIEW based Advanced Instrumentation Systems* Springer-Verlag Berlin Heidelberg, 2007.

[8]. *** *2-Channel Module of Analog Inputs. SM1 Type*. http://www.lumel.com.pl

[9]. ***, *Programmable Transducer of Frequency, Pulses, Period, Worktime and Rotational Speed with RS-485 Interface P12O* http://www.lumel.com.pl

MONITORING SOLUTION OF THE CONDITION FOR ELECTRIC MOTORS USING ARDUINO

ARON POANTA[1], BOGDAN SOCHIRCA[2], COSMIN RUS[3]

Abstract: In this paper is described a cheap and easy to use method of wireless monitoring and data interpreting concerning to the "health" condition for the electric motor. Is very important to know the condition because it can prevent future costly damages, save money, time, all that cause by the potentially damaging vibration found in electric motors.

Key words: vibration, Arduino Mega, accelerometer, electric motors, damaging vibration.

1. GENERALITIES

Monitoring the vibration of the electric motor and use this information in order to obtain the "health" state, is very important because can save a lot of money by preventing and intervene to a future fault or can prevent damaging to other machine. If an electric motor is regular monitored, can be detected some potential problem that can be easy corrected in an early stage when an intervention is very simple, cheap and fast. The vibrating state can occur in several condition like: improper balanced, fault shaft misalign, worn, improper driven machine component, excessive clearance, some loose of the fixing bolts, and even the resonance at a particular rate. [1]

2. STUDY ISSUE

The simplest acquisitions solution of the vibration is with an MEMS accelerometer (Microelectromechanical systems). An accelerometer can be used to measure vibration or acceleration of motion of a subject. [2]

In these days an accelerometer can be found in many devices like: phones, tables, digital camera, and others. Accelerometers can be used in motion detection, orientation sensing, image stabilization, device integrity in laptops, etc. Depending the application the accelerometer specification can vary the number of axes, the amplitude range, shock limits, temperature range, frequency range, sensitivity, resolution, amplitude linearity, and others. [3]

---

[1] *Ph.D. Professor., University of Petrosani*

[2] *Ph.D. Lecturer, University of Petrosani*

[3] *Engineer, University of Petrosani*

The recording and the interpretation of the electric motor vibration, can make an idea about the severity of the vibration. The wireless acquisition of vibration is a good method for motors that cannot be reached easily. Imagine a motor that is placed 10 meters below earth with very hard access path, or a motor as a part of a very complex mechanism almost impossible to be reached. In all this cases a wireless solution will be very good to be implemented, and all with small cost.[4]

On the market are a lot of solution for the problem with price that wary from 200-400 euro only for accelerometer and another 1000 euro for the station where the data are collected. We propose a very cheap and easy to use solution with almost the same results at a price of max 70 euro.

3. SOLUTION

As it was presented earlier, the easiest solution for monitoring the vibration of an electric motor is by using an accelerometer. For data transmission two possibility can be, wired and wireless. It is choose wireless solution because it benefit of mobility advantages. In this days exist a lot of wireless module with vary advantages and disadvantages. One viable solution is Bluetooth. The main advantages is that a lot of devices support Bluetooth connections, like computers and mobile phone, and the cost of the receiving data equipment will be almost zero, and also it assure a good speed for data transfer. The problem with Bluetooth is that can support only a master-slave connection, so only one motor can be monitored a time, so for future expansion will not be the greatest choice.

Another wireless solution on the market is the XBee radio module. The main reason that XBee is a better choice, is the distance, the cheapest XBee is XBee 1mW Chip Antenna - Series 1 with a range of 100m outdoor. The longest distance that an Xbee can transmit and receive is XTend 900 1W RPSMA, with almost 65 km outdoor. In the test phase it is used an XBee Pro 60mW Wire Antenna - Series 1 with the range of 1.5km. For the indoor distance was tested and achieved a distance of 25 meters with 3 walls with 50cm concrete thickness. Xbee also support point to point (a form of mesh networking) and point to multipoint connections. The mesh network is a type of network where each node can serve as a router for other node. If the coordinator can't reach directly to a node for gathering information, it can access that node through another node, so all collaborate for data propagation in the network. The Xbee is suitable for monitoring multiple electric motors or other devices/parameters.

The microcontroller board chose is an Arduino Mega based on the ATmega1280 microcontroller. It is chose because the programming environment is free, the schematic and reference design for the board is also free, so is very easy to develop own devices around this board. It has 54 digital input/output, 16 analogs pins, and runs at 16 MHz, more than enough for the application. The accelerometer used is ADXL 335, a 3 axis accelerometer with low level noise and a low power consumption (320uA). It offer excellent temperature stability, and is used for motion and tilt sensing, widely spread in mobile devices, gaming systems, disk drive protection, image stabilization, sport and health devices and many more, with a minimum full scale range of ±3g.

The schematic connection between microcontroller board, Xbee and accelerometer can be observed in figure 1.
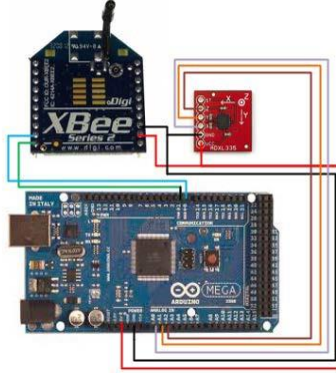
Fig. 1. The schematic drawing of the acquisition system.

Was made several measurements. On the same electric motor, first time when was new, was taken some measurement to have a reference value. The motor speed was controlled using an inverter, at various speed like: 60Hz, 50Hz, 40Hz, 30 Hz, 20 Hz, 10 Hz, and 5 Hz. In the paper is present only at 60 Hz and 30 Hz. The acceleration recorded is passed to a computer where it convert the signal to a velocity signal. To the velocity signal is applied mathematical calculation FFT (Fast Fourier Transform). For each individual measurement is displayed the wave of the accelerometer on axes X and Y, and the FFT of the signal. For each graphical representation was took 1024 value with 1ms between samples.

After the motor was used for a period of the measurement are repeated and apply the FFT on the velocity waves obtained. In order to be accurate it must take in consideration some aspect like: mount the accelerometer as close as possible to a bearing, the accelerometer need to be firmly attached, place it on the same spot on different measurement, the correct orientation of the accelerometer. In the next figures it can be observed the FFT and de acceleration at different speed and on booth x and y axes.

Figure 2 represent the graphic of the acceleration on x axes at motor supply frequency of 60 Hz, when the motor was new.
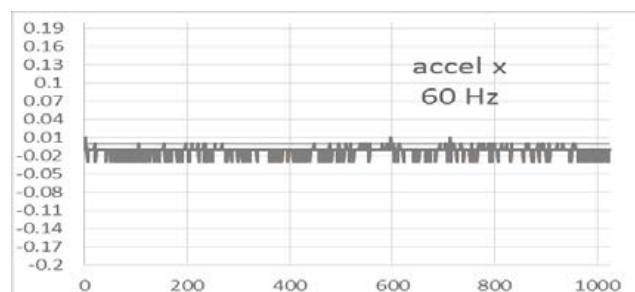
Fig. 2. Acceleration diagram for x axes at motor supply frequency of 60 Hz

For the acceleration represented before, is applied the FFT and was obtained the graph represented in figure 3 where can be observed that the max value of the amplitude is around 1.
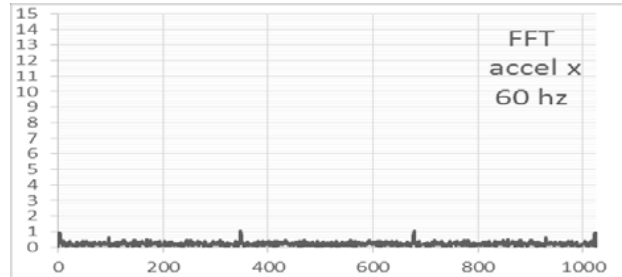
Fig. 3. FFT for motor supply frequency of 60 Hz on x axes with motor in good condition

Figure 4 represent the graphic of the acceleration on y axes at motor supply frequency of 60 Hz, when the motor was new.
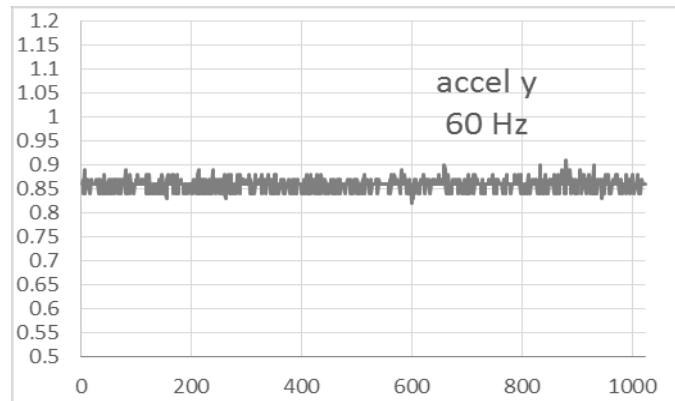
Fig. 4. Acceleration diagram for y axes at motor supply frequency of 60 Hz

Again is applied the FFT and obtain the value of the amplitude with max value around 2.5. (Fig 5)
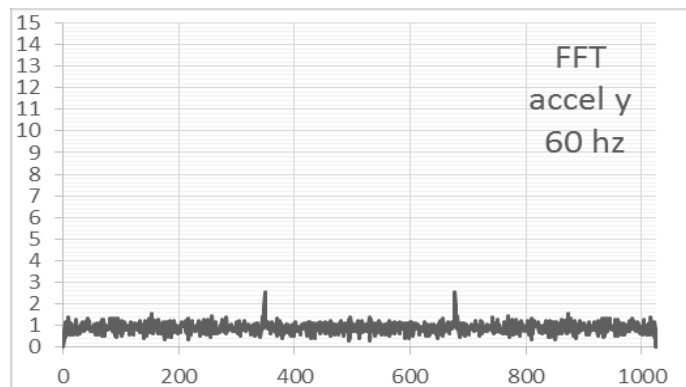
Fig. 5. FFT for motor supply frequency of 60 Hz on y axes with motor in good condition.

The measurements are repeated on the x and y axes this time at motor supply frequency of 30Hz. The acceleration representation can be observed in figure 6 for x axes and 8 for y axes and the corresponding FFT representation in fig 7 for x axes and 9 for y axes with maximum amplitude value of 0.5 and 1.5.
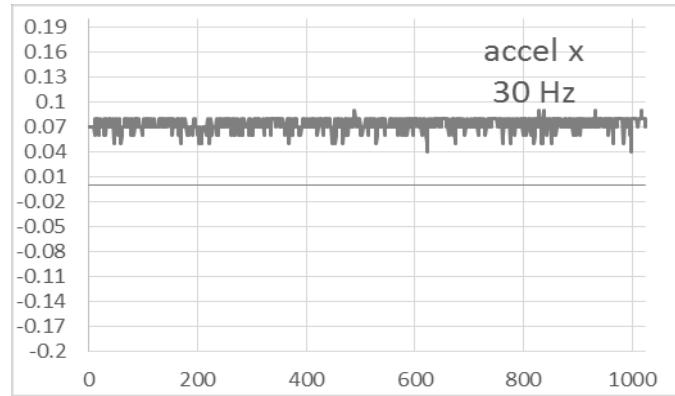
Fig. 6. Acceleration diagram for x axes at motor supply frequency of 30 Hz
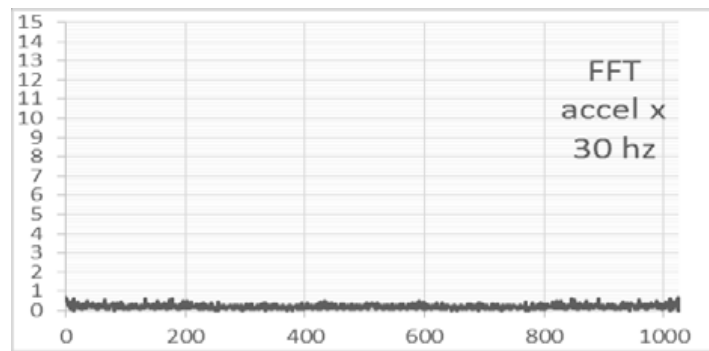
Fig. 7. FFT for motor supply frequency of 30 Hz on x axes with motor in good condition
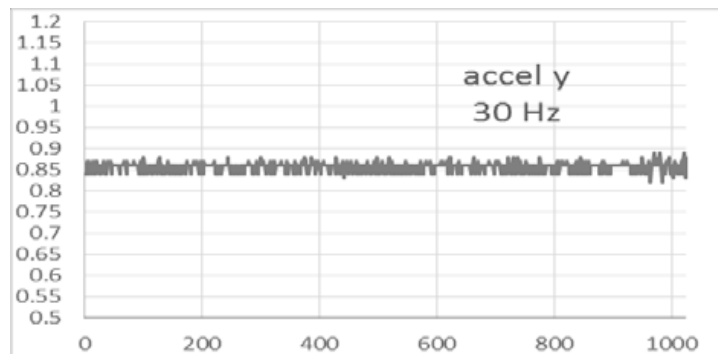
Fig. 8. Acceleration diagram for x axes at motor supply frequency of 60 Hz
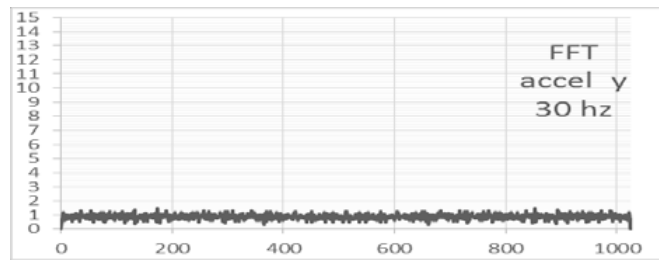
Fig. 9. FFT for motor supply frequency of 30 Hz on y axes with motor in good condition

These data are from a larger set made at vary motor supply frequency in total more than 100.000 data was acquired. After the motor was used and wear appear, the measurement are repeated for the same axes, at the same motor supply frequency, with the accelerometer in the same positions. For the motor supply frequency at 60 Hz and x axes the FFT corresponding is represented in figure 10. The maximum amplitude is 15 and if is compared with the maximum obtained at the same condition but at different wear, from figure 3, can conclude that a significant wear appear in the electrical motor.
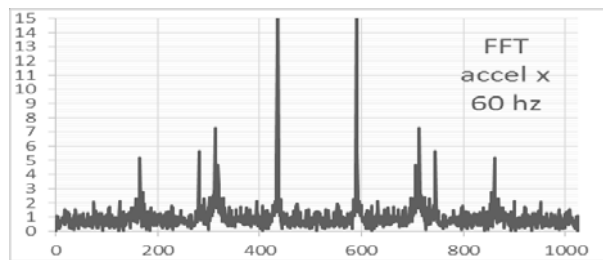
Fig. 10. FFT for motor supply frequency of 30 Hz on y axes with motor in bad condition

The FFT for y axes at motor supply frequency of 60Hz on y axes reveal the maximum amplitude around 9.5, significantly increased from 2.5 when was in good condition (figure 5).
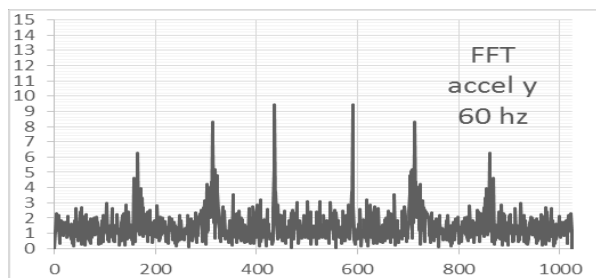
Fig. 11. FFT for motor supply frequency of 60 Hz on y axes with motor in bad condition

The comparing between maximum amplitude on x (figure 12) and y (figure 13) axes at motor supply frequency of 30 Hz when wear appeared with those obtained previously (figure 7 and figure 9), shows that a degree a wear exist.
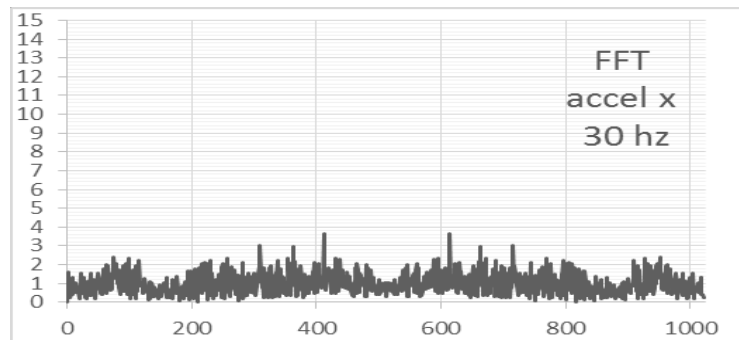
Fig. 12. FFT for motor supply frequency of 30 Hz on x axes with motor in bad condition.
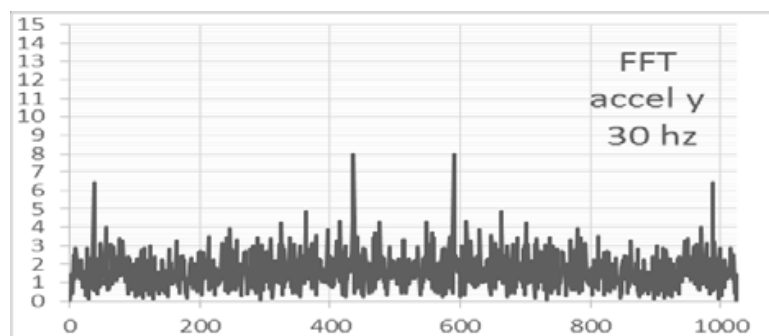
Fig. 13. FFT for motor supply frequency of 30 Hz on y axes with motor in bad condition.

For all other measurement was obtained encouraging results what prove that the system proposed obtain good performance at a tenth part from a dedicated system.

By analyzing the maximum amplitudes of the FFT in time, can be observed a moment from where the motor need to be replaced in order to assure a safety functioning of the system. The entire system is showed in figure 14.
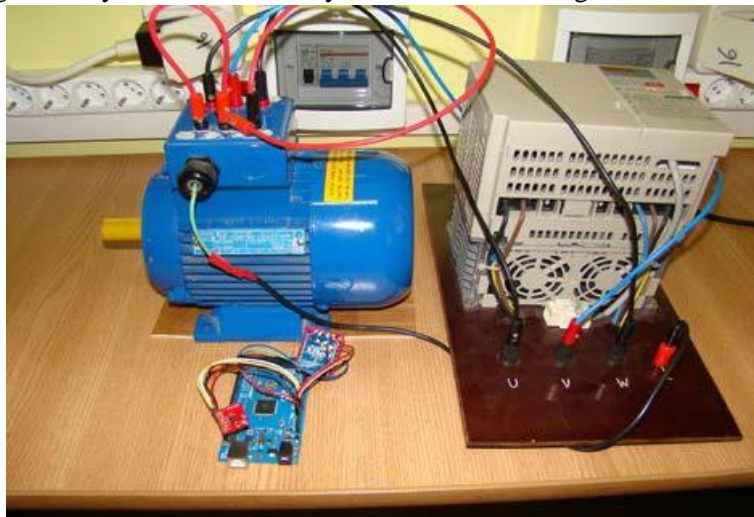
Fig. 14. The equipement used for testing.

4. CONCLUSION

In the future, taking advantages of the Xbee solution can be extend the monitoring solution to a large number of motors not only one, how is presented in the paper. In the future all the calculus will be made in the microcontroller and data will be transmitted over the internet or over the GSM for a better visibility, not only from a computer where is installed the Xbee explorer.

Another research direction will be over a smartphone, to use the accelerometer from that, and only need to touch motor for 5 seconds every week (or maybe more frequently) to see if the motor work properly.

REFERENCES

[1]. GE Energy, *Vibration analysis guide*, New Zeeland, 2013.

[2]. K. McConnell, P. Varoto, *Vibration testing: theory and practice*, John Willey & Sons, Inc., 1995.

[3]. B. Sochirca, A. Poanta, *Proiectarea si dezvoltarea aplicaţiilor cu Microcontroler*, Ed. Universitas, 2012, ISBN 978-973-741-274-4.

[4]. N. Pătrăşcoiu, *Some consideration on understanding the dynamic systems through the use of modeling and simulation technique*, Proceedings of the 12th International Conference on Applied Computer and Applied Computational Science (ACACOS'13), Kuala Lumpur 2013, pag.93-98, ISSN 1790-5109, ISBN 978-1-61804-171-5.

[5]. C. Bouten, K. Koekkoek, M. Verduin, R. Kodde, J, Janessen, *A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity*, Biomedical Engineering, IEEE Transactions on (Volume:44 , Issue: 3), March 1997, Pages 136-147, ISSN 0018-9294.

[6]. B. Sochirca, A. Poanta, *Cheap wireless monitoring solution of the condition for electric motors*, Proceedings of 6th International Multidisciplinary Scientific Symposium „Universitaria Simpro" 2014, 10-11 october 2014, Petroşani, Pages 357-360, ISSN 2344 – 4754.

SOME ISSUES CONCERNING THE PHOTOVOLTAIC ENERGY MANAGEMENT IN ROMANIA

BRANA LILIANA SAMOILA[1], SUSANA LETITIA ARAD [2]

Abstract: European Union energy policy for the next period include the "Energy - Climate Change" package setting the EU targets for 2020, including a 20% increase in the share of renewable energy sources in the total EU energy consumption and a target of 10% bio-fuels in the transport consumption. Romania has a wide range but a reduced amount of fossil primary energy resources and minerals as well as an important usable potential of renewable resources. In terms of the structure of primary energy consumption worldwide, evolution and prognosis highlights for the next decade a rapid growth in the share of renewable resources, such as solar energy. This paper deals with identifying and solving the problems that occurred in constructing photovoltaic power plants in Romania, in connecting them to the National Energy Grid and, last but not least, in their maintenance.

Keywords: photovoltaic, power plant, solar energy, renewable source, energy management

1. INTRODUCTION

The technology of photovoltaic panels and photovoltaic power plants has changed the way we think about energy [1]. This technology has proved since 1970 that people can get a significant amount of energy without consuming fossil fuels or create nuclear reactions. Photovoltaic panels help us avoid most threats associated with current methods of electricity production and have other benefits as well. Photovoltaic plants can bring electricity to rural homes at hundreds of kilometers away from distribution grid and thus can make a significant improvement in living standards and the chance to develop such areas.

A current priority of the European Union is the reduction of carbon emissions and encouragement of renewable energy consumption. The legislative package on climate changes and renewable energies sets on covering 20% of the community consumption from renewable sources until 2020 [7].

---

[1] *Associate Professor, Eng., PhD, University of Petrosani, Romania*
[2] *Associate Professor, Eng., PhD, University of Petrosani, Romania*

2. THE SITUATION OF USING SOLAR ENERGY IN ELECTRICITY GENERATION IN ROMANIA

Mention must be made of the increasing interest in the efficient use of new and renewable power resources: wind, solar, geothermal, biogas, biomass, waves, as well as the hydro power in installations of less than 10 MW power. For the time being and in the near future, the hydro power in installations with less than 10 MW power and wind power may have a more significant contribution to the country's power balance. Their contribution will be higher for electric power production and lesser for ensuring power levels guaranteed for consumption peak coverage [6].

In December 2014, there were 42 companies producing electricity from photovoltaic sources exploiting dispatchable generation units. The number of such companies is increasing. So, at the beginning of April 2015 their number got to 53 [9].

The structure of electricity supplied to the electric grid by producers with dispatchable units in 2014 is shown in Fig. 1.

The evolution of electricity delivered in the past three years generated from different resources is shown in Fig. 2.

In terms of solar energy, Romania is in the European sunshine zone B with substantial potential of using the solar energy.

Fig. 1 Structure of electricity resources in 2014
Source: Monthly reports of producers.
Regulatory Authority for Energy [5]

Romania is located in an area with good solar potential, with 210 days of sunshine per year and an annual solar flux between 1000 kWh / sqm / year and 1300 kWh / sqm / year. Of this amount only 600-800 kWh / sqm / year are used technically.

Regarding solar radiation monthly gap values Romania reaches peak levels in June (1.49 kWh / sqm / day) and minimum values in February (0.34 kWh / sqm / day).

According to the Country Attractiveness Index, launched in November 2011 by Ernst & Young, Romania ranks 31 among the most attractive countries in the world in terms of investment in this area [5].

T

Fig. 2 Evolution of the types of resources structure of the electricity supplied to the network by the producers with dispatchable units

Unfortunately, Romania is no longer as attractive for renewable energy investments as it was four years ago. The country went down 20 places in the renewable energy attractiveness index by Ernst & Young. Back in 2011, Romania enjoyed a good 11th position worldwide and was a hot spot for renewable energy investments. Legislation changes and the lack of legal predictability pushed it down the ranking [11].

Preliminary energy analyzes and field studies have shown that the main areas for the installation of solar power plants are Dobrogea, the Southern Sub-Carpathians, the Romanian Plain, the West Plain and Southern Oltenia.

3. CASE STUDY

The photovoltaic power plant we are talking about is placed in the southern region of Romania and it has an installed capacity of 10 MW (fig. 3 and fig. 4) [2]. In the northern vicinity of the plant and the continuation of this project is namely an additional 8.5 MW plant which has the same technical and operation characteristics.

The installed power is 9989.76 kWp and the total area of photovoltaic panels is 67 717 m².

Observation: Kilowatt peak stands for peak power. This value specifies the output power achieved by a solar module under full solar radiation (under set Standard Test Conditions). Solar radiation of 1,000 watts per square meter is used to define standard conditions. Peak power is also referred to as "nominal power" by most manufacturers. Since it is based on measurements under optimum conditions, the peak power is not the same as the power under actual radiation conditions. In practice, this will be approximately 15-20% lower due to the considerable heating of the solar cells.[10] [2]

Fig. 3 Photovoltaic power plant
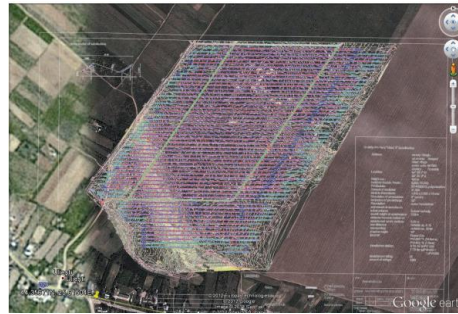
Fig. 4 Satellite image (Google Earth) of the site with overlapping plant

The weather and irradiation characteristics of the specified area are presented in fig. 5 to fig. 9.
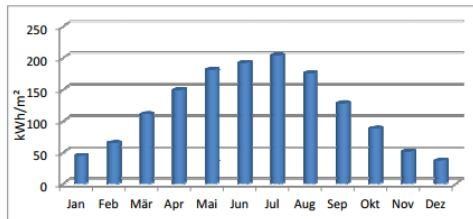
Fig. 5 Average monthly irradiation

Fig. 6 Daily global radiation
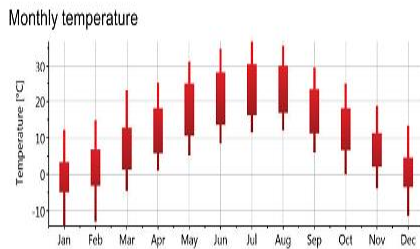
Fig. 7 Monthly temperature values
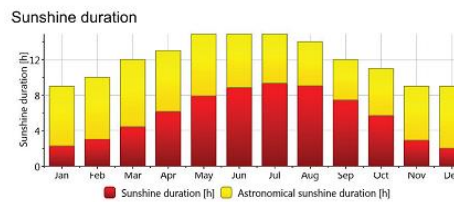
Fig. 8 Sunshine duration

The design software PVSIST was used for study and simulation where we introduced all the technical characteristics of equipment and meteorological data [4].

Follow-up the study, it results an estimated energy of 14,082,057 kWh produced during a year. This energy produced with a clean source of energy can avoid the issue of approximately 9,710,296 kg of CO_2 in the atmosphere that would result if the energy was produced by burning fossil fuels.

3.1. Operating and monitoring station

The power plant is integrated into the National Power Grid through a dispatcher that can control active power and reactive power and the main switch of the plant.

With the aid of iCheckers (Ammeters) mounted at the outlet of the switchboards (DC), groups of 5 or 6 strings can be monitored and thus any defect at the string / photovoltaic panel can be detected and interventions can be made in the shortest time. The communication system is also connected to each inverter and thus can be monitored in real time and also statistically the evolution of each inverter at a power level of 55 kW.
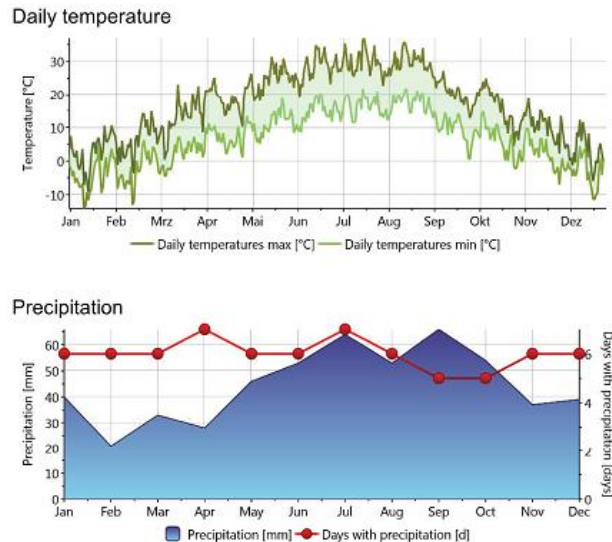
Fig. 9 Daily temperature variation; precipitation and days with precipitation in the power plant area

3.2. SMA Power Plant Controller

With its fast and direct control, the SMA Power Plant Controller (Fig. 10) guarantees the maintenance of setpoints for responding to requirements from the PV power plant and the utility grid to both plant- and grid operators. It controls PV power plants in accordance with the requirements of the grid operator and, through the adaption of active and reactive power, contributes to the stabilization of the utility grid. [12]

It achieves this by:

- Measuring the active/reactive power and voltage at the grid transfer point;

- Translating the transmitted setpoint values and the result of the closed-loop PI/PID-algorithm into control commands;

- And forwarding them to the inverters (via Modbus/UDP broadcast messages).
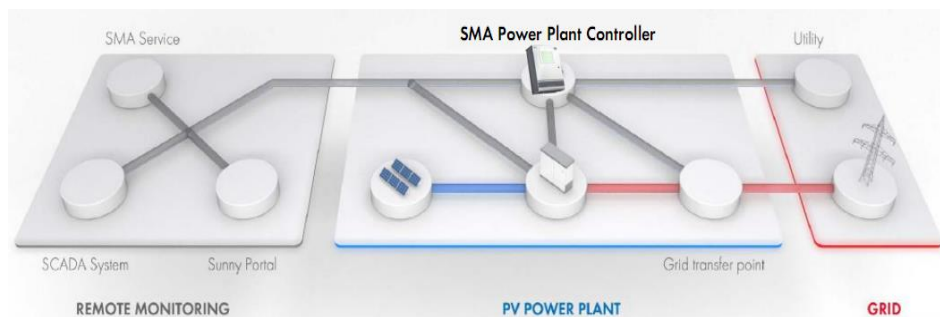
Fig. 10 SMA Power Plant Controller

During this process, changes of status, (diagnosis)-events, set-points, actuating variables and measured data from the grid transfer point are logged and can be read

from a network supervisory control system or stored in a .csv file. Via the integrated web-server it is possible to visualize or configure the system by connecting a web-panel or a PC with a web-browser. The software design of the Power Plant Controller is based on PLC programming standard IEC 61131-3, enabling a scalable solution to grow with the plant. [12]

The monitoring system can send alarms via e-mail or SMS to the personnel responsible for the operation and maintenance of the plant. Active and reactive power, current, voltage and temperature monitoring examples are given in figures 11 to 14.
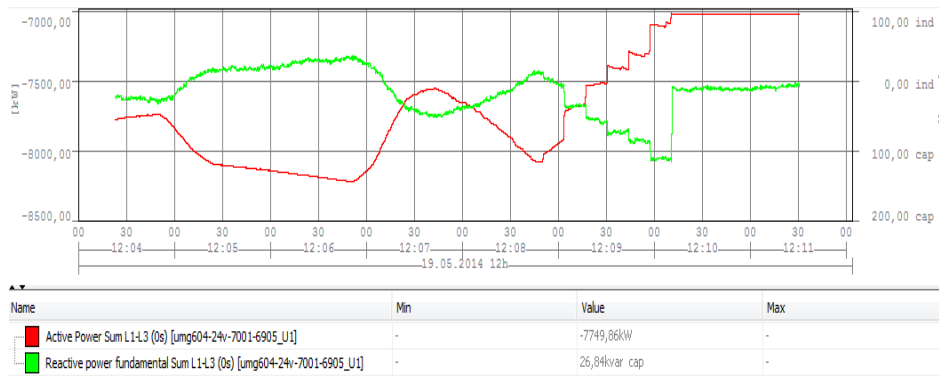
Fig. 11 Active and reactive power monitoring
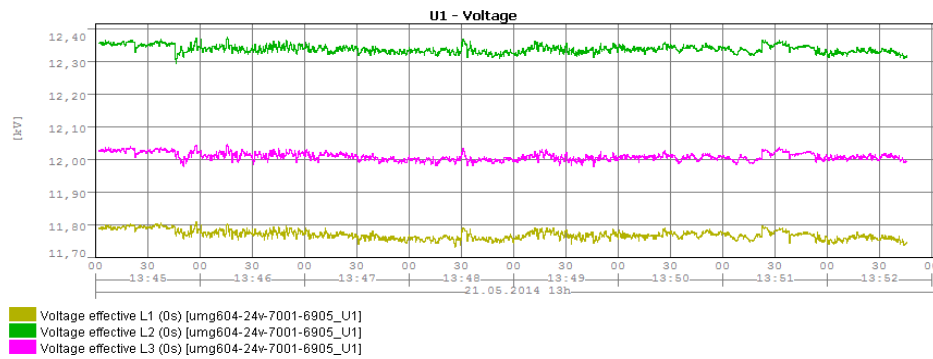
Fig. 12 Voltage monitoring
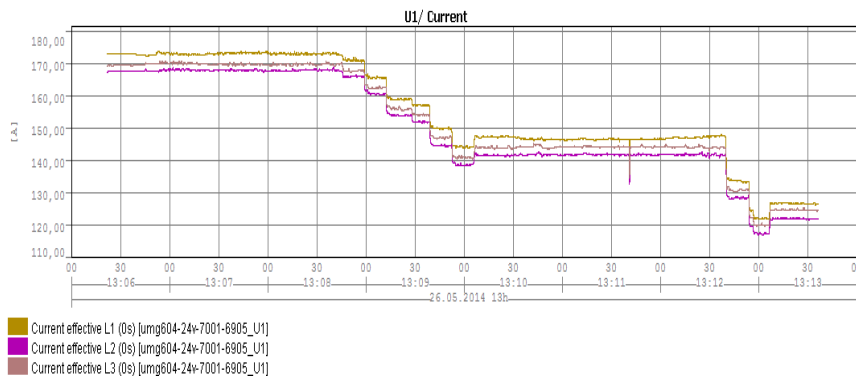
Fig. 13 Current monitoring

42
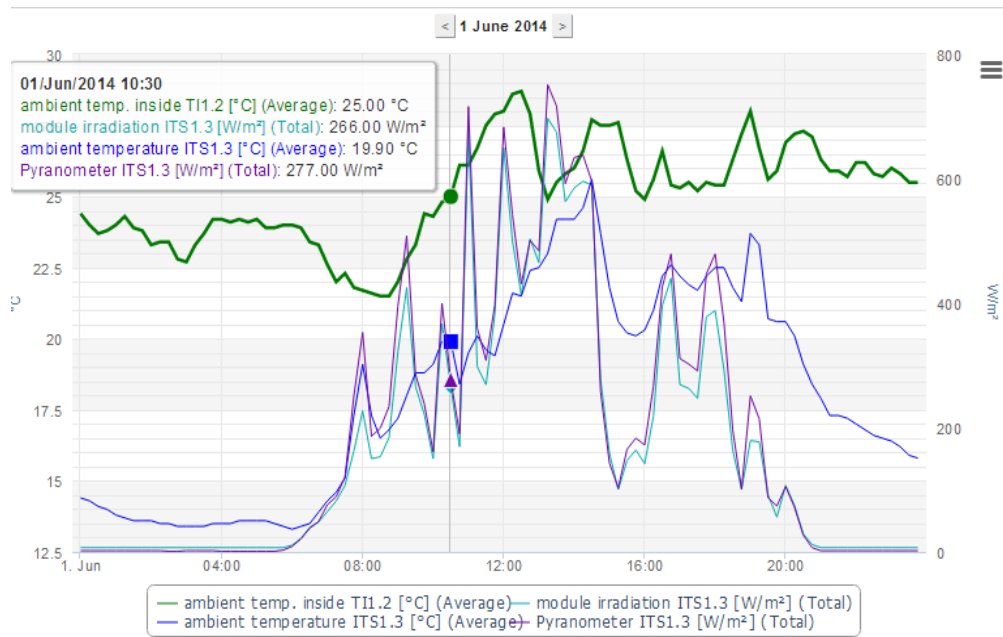
Fig. 14 Temperature and irradiation monitoring

3.3 The dispatching station and the integration into the National Power System

The integration of the plant into the National Power System was done according to the national and European laws. The operating scheme is presented in fig. 15.
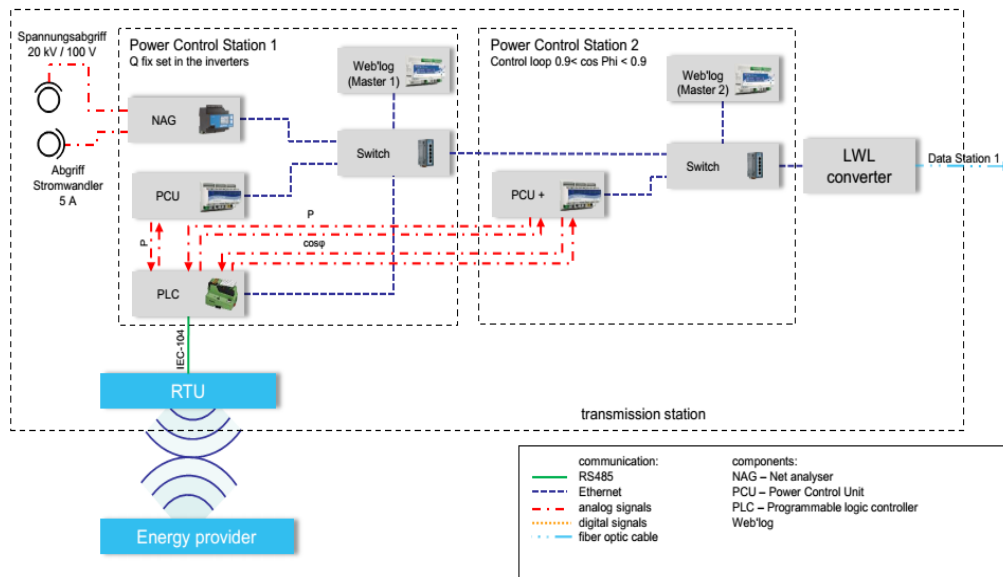
Fig. 15 The photovoltaic power plant dispatching system

4. CONCLUSIONS

According to the studies and measurements of the performance of the plant and the compatibility with the Romanian National Power System, the findings were:

• the connection point of 20 kV is suitable for power supply (9.46 MW, cos φ = 1).

• the block transformer structure provides sufficient voltage to connect to the low voltage inverter; so the inverter voltage and reactive power control is guaranteed.

• the voltage increase at the point of connection of 20 kV is within the allowed range Delta U <2%.

• transport loss is within accepted range.

• the voltage decrease generated by switch inrush is within accepted range.

• at maximum short-circuit power the harmonic load is below the limit.

• P-Q diagrams show on the one hand the possible operating range of converters with cos φ value control and on the other hand the working range of converters with adjustable cos φ at the point of connection to the network.

• reactive power adjustment range of the PV system is between 0.90 inductive and 0.90 capacitive.

• in the switching phase operating mode, the reactive power is compensated during the night at the point of connection to the network.

• selection and regulation of protective devices ensure sufficient selectivity in the 20 kV network.

REFERENCES

[1]. **Arad**, **S.,** *Surse regenerabile*, Universitas Publishing House, Petrosani, 2014.

[2]. **Crisnic, A.,** Solutii constructive si de functionare in realizarea unei centrale fotovoltaice in judetul Giurgiu, Disertation Thesis, Petrosani, 2014.

[3]. **Marcu, M.D., Popescu, F.G., Pana, L., Stepanescu, I., Slusariuc, R.**, *Modeling and Simulation of a Photovoltaic Module Using the Two Diode Module*, SGEM2014, Conference Proceedings, Vol. Energy and clean technologies, pg.353 - 360.

[4]. Marcu M., Popescu F., Pană L., Slusariu I.R., "*Modeling and simulation of solar radiation*", 3rd International Conference on Nanotechnology, Technology and Advanced Materials ICNTAM, 2014.

[5]. **Jones, J.,** *Europe: enablement and beyond*, RECAI Renewable energy country attractiveness index, Issue 42, September 2014, pg. 6-11.

[6]. *Power Tranmission Grid (PTG) Perspective Plan Period 2008-2012 and 2017 as a guide*, Romanian Power Grid Company Transelectrica, 2009.

[7]. http://www.minind.ro/energie/STRATEGIA_energetica_actualizata.pdf

[8]. http://www.anre.ro/

[9]. http://www.transelectrica.ro/

[10]. http://www.solar-is-future.com/

[11]. http://www.energyworldmag.com/12/03/2015

[12]. http://www.sma-america.com/

MODERN HIGH EFFICIENCY MOTORS FOR DRIVES TO THE MINING CONVEYOR BELTS IN LIGNITE OPEN PIT

STOCHITOIU MARIA DANIELA[1], UTU ILIE[2]

Abstract: The paper presents the improvements of electrical drives to the belt conveyors using the high efficiency motors and their advantages. An efficient, economic transport system is a key element in the viability of coal open pit in Romania

Keywords: open pit, automation, controllers, electrical energy

1. INTRODUCTION

The lignite open pits activity is only justified in some conditions when the lignite costs are attractive in the market competition. To assure the lignite competition with another primary energy fuels it is necessary the correlation between transport, excavation activity with the market requests for increase the economic efficency, incrase the productivity and for reduction the stuff and energy consumption.[2]

Electrical energy consumption is an important part on the lignite structure cost so it must achieve a detailed study about losses of energy and to establish a measurements plan. The following measurements and programme on short and average time are applied: limitation of peak loading which is based on the direct relations between programmed mechanical torque to be used and the effective mechanical torque; electromagnetical monitoring to determ some levels for electrical measurements to be used; the adjustable electrical drives used in the open pit`s equipments through power electronics and adequated comand represent a method to diminuate the electrical energy consumption and the financial effort is not important because the actual motors are kept in function working with static converters.[3]

The energy production based on lignite has the following advantages:
- the production costs are approximately the fuel oil production costs;
- diminution of hydrocarbons imports through ht own resources using;
- the investments for lignite are smaller than nuclear energy investments at the same installed power;
- assuring the occupation work forces like an important social aspect;
- the dependence of electrical energy import is eliminated, it can even produce thermal energy in cogeneration;
- environmental problems are solving with actual used technologies.

---

[1] *Associate Professor, Eng., PhD, University of Petrosani, Romania*
[2] *Associate Professor, Eng., PhD, University of Petrosani, Romania*

The bucket wheel excavator is continuous flow complex machinery that excavates the coal using the buckets fitted on the wheel and in the same time conveys the material to the transportation facility. The working element – bucket wheel executes horizontal and vertical movements, the basic one being the rotation.

The bucket wheel turns and in the same time swivels so a bucket moves on a helical trajectory (helix). The asynchronous motors in schortcut or induction motors are frequently used in electrical drives for open pits machines. The motor `s power are from 100 to 630 kW and the open pits costumers are supplied from transformer stations about 2x6300kVA, 20/6 kV using different electrical cables (fig.1).
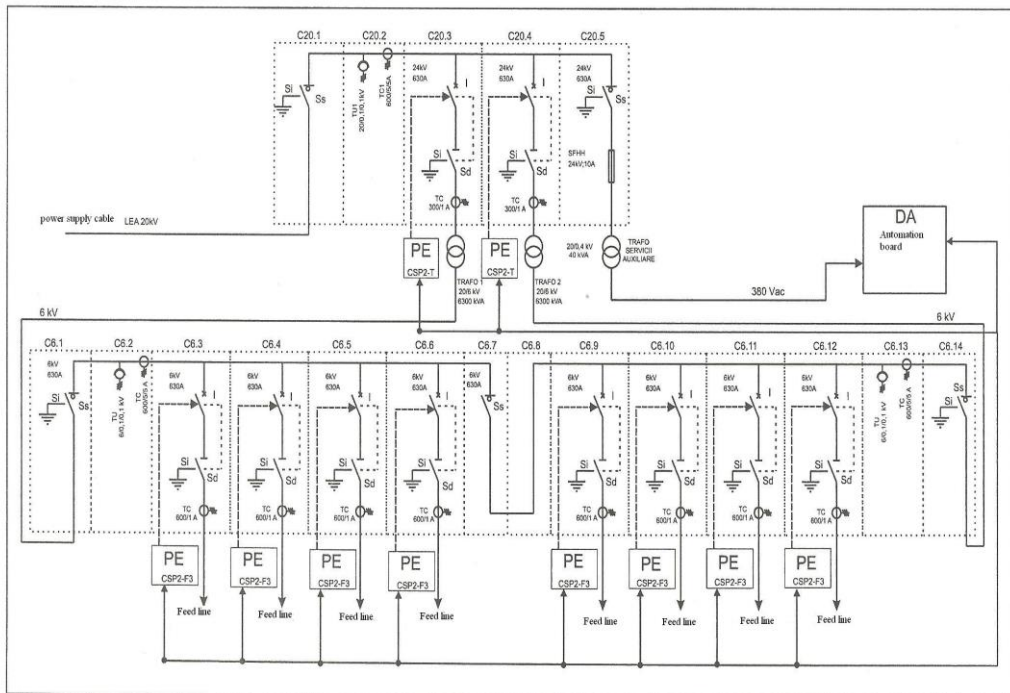
Fig 1. Power supply station

The lignite open pits from Oltenia are equipped with technologies in continuous flux characterized by: the lignite deposits are excavated by bucket wheel excavators (BWE) with the following capacities 470 l, 1300 l, 1400 l, 2000 l and productivity about 1680 m^3/h - 6500 m^3/h; the belts conveyor have the productivity about 1400 -12500 m^3/h ; the laying down machines have capacity about 2500 -12500 m^3/h.

An efficient, economic transport system is a key element in the viability of coal open pit in Romania. The development of the power semiconductor elements has revolutionized the field of electric power control and has permitted the improvement and the diversification of the electric energy converter. As electronic power components improve in reliability and decrease in size, the cost and size of variable

drives will continue to decrease but their maintenance requirements fall into three basic categories: keep it clean; keep it dry; and keep the connections tight.

2 ABOUT HIGH EFFICIENCY MOTORS

The induction motors with squirrel cage rotor are classified according to IEC 60034-30:2008 in three efficiency classes:
   a. Standard Efficiency IE1;
   b. High Efficiency IE2;
   c. Premiu Efficiency IE3.

These motors must be executed respecting the standard power-frame size assignment. To increase the efficiency of induction motors there were looked methods to reduce the losses. In the conductors of the stator winding appear principal and supplementary losses.

To reducing of the principal losses in the stator winding was achieved by reducing the stator winding resistance. To this aim the winding diagram with concentric coils was replaced with a winding diagram with equal, displaced coils. The losses in the magnetic core are the main losses (which are taking place only in the stator) and supplementary losses. For the reducing of the losses in the core the use of electromagnetic steel sheet, having lower specific losses ps=1.1W/kg (M270-50) and ps=1.7 W/kg (M400-50) instead of that with specific loss of ps=3.6 W/kg (M800-50).

By adopting certain constructions and design methods, one can obtain motors with high energetic indexes. The energetic parameters of the asynchronous motor are defined by efficiency (η) and power factor (cosφ), which help calculating the loss of active power and the loss of reactive power.

For an asynchronous motor, the loss of active energy (Δp_a) is calculated by the following relation:

$$\Delta p_a = (1 - \eta) \cdot \frac{P_N}{\eta} \quad \text{(kW)} \tag{1}$$

where: η = nominal efficiency; P_N =nominal power

The loss of reactive energy (Q) is calculated by the following relation:

$$Q = P_N \cdot tg\varphi \quad \text{(kVAR)} \tag{2}$$

Out of the losses generated in an asynchronous motor, the mechanical losses Pm are practically independent from the charging power, and only the losses from the wrappings and the ferromagnetic core remain variable according to the electrical and mechanical variations.

The losses from the wrappings are practically dependent only on the charge and the quantity of the materials.

The electro-caloric effect in the mass unit is p_{J2}, which for the whole resistance wrapping R, length L_{Cu}, with section S_{Cu} and current I becomes:

$$p_{Cu} = \frac{\rho \cdot L_{Cu}}{S_{Cu}} \cdot I^2 = R \cdot I^2 \tag{3}$$

we can notice that for a given current , the only measure is to increase the section of the conductor, and so to decrease the density of electricity.

For the asynchronous motors with contact rings, this measure can be applied for both rotor and static armatures. The limit is given only by the possibility to place spires, limited by the exterior diameter of the machine.

In the case of asynchronous motors with a caged rotor, the measure can be applied only at the static wrapping. The rotor wrapping must satisfy other requests corresponding to the rotation moment necessary to accelerate and the starting current, as compared to the one with rings, so the degrees of freedom for this motor are lower.

Usually, the asynchronous motor with a squireel cage rotor requires relatively big starting moments and low starting currents. This requires a certain shape of the rotoric notch, which must have a pronounced refutation of the current from the rotoric bar, in order to increase the apparent resistance.

The supplementary losses in the core appear both at no load and full load status of the machine. According to the literature, the supplementary losses can reach up to 8-25% from the total losses.

The supplementary losses in the induction motor with squirrel cage rotor are:
-     surface losses (representing 40%from the total supplementary losses);
-     losses caused by transversal currents between the rotor bars (30% from the total supplementary losses;
-     pulsation losses (represent 17% from the total supplementary losses);
-     losses produced by the high frequencies (10%); losses produced by the stray fluxes.

Therefore, in order to reduce the supplementary losses and implicitly to increase the efficiency, first of all must be reduced the surface losses and the losses produced by the transversal currents between the rotor bars. For the reducing of the losses produced by the transversal currents (cross-currents), the resistance between the bars must be increased. It was shown above theoretically that the decreasing of the supplementary surface losses and of those produced by the transversal currents can be achieved by the increasing of the resistivity of the rotor surface respectively by the increasing the resistance between the bars. This can be achieved by thermal treatment of the squirrel cage by the so called flaming (thermal shock).

This treatment is made as follows: the rotor (with machined shaft, but not finished on the bearing-seats) having the surface of the rotor core machined, is introduced in an oven and the temperature is increased at 400° C and then maintained for 2 hours. Then the rotor is cooled suddenly in water up to maximum 30⁰C. Using copper instead of aluminum in the execution of the squirrel cage leads to the decreasing of the rotor resistance, of the losses in cage and, also, leads to increasing of

efficiency. For increasing the efficiency it was worked on the ventilation losses by using fans with smaller external diameter.

For example, taking into acount, the belt conveyor drived by 2x630kW from open pit, the following measurements are:

U_{abs} (V)	I_{abs} (A)	k cos φ	η %	k load	P_{abs} kW	Q_{abs} kVAR	Δp kW	Δp_v kW	Δp_{ct} kW	h	W_{abs} kWh	ΔW_{abs} kWh
6145	24,2	0,8	90	0,33	201	150,9	40,2	22,6	17,6	6	1206	120,72
6215	24,8	0,8	90	0,36	206	154,6	40,2	22,2	18.1	6	1236	120,6

Using electrical motors having reduced speed and a higher torque to the shaft the cinematic reductor is eliminated as well as the weakness due to maintenance costs and the low efficiency.

Using an IE2 motor, the Δp_a= 13,5 kW and ΔW_{abs} = 81 kWh, the economicitz is about 40kWh.

3. CONCLUSIONS

An efficient, economic transport system is a key element in the viability of coal open pit in Romania. The development of the power semiconductor elements has revolutionized the field of electric power control and has permitted the improvement and the diversification of the electric energy converter. As electronic power components improve in reliability and decrease in size, the cost and size of variable drives will continue to decrease.

In a modern open pit coal mine the technological, mechanical, electrical and economical elements of the production process are in a direct interdependency, the modernization of any of these components (mainly the electrical one) is necessary.

In the scientific research evolution for the automation of the conveyor belts and its control, the challenge is the implementation of a rational mode of operation and the optimizing of the working parameters, for obtaining superior techno-economical indicators, especially the power saving. This goal is very important, as the electric energy cost has significantly increased in the last years, being expansive than a few years ago.

Usually, the asynchronous motor with a squireel cage rotor requires relatively big starting moments and low starting currents. This requires a certain shape of the rotoric notch, which must have a pronounced refutation of the current from the rotoric bar, in order to increase the apparent resistance. The supplementary losses in the core appear both at no load and full load status of the machine.

4. REFERENCES

[1]. Dordea T., Campeanu A. *Necesitatea maririi randamentului masinilor electrice* Conferinta Nationala a Energiei, CNE-2004, Neptun 13-17 06. 2004.

[2]. Huidu E., s.a. *Utilaje pentru carierele de lignit din Oltenia,* Ed.Maiastra Tg.Jiu, 2011.

[3]. Marcu M., Popescu F., Slusariuc I.R., "*Performance improvement of ac electric drives using field oriented control and digital speed transducers*", Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO 2012, Petroşani, ISSN 2344-4754.

[4]. Mircea I., s.a. *Solutii de eficientizare a sistemelor de transport cu banda de mare capacitate,* prezentare- Universitatea din Craiova, 2013.   .

[5]. Popescu N., Mircea I., *Analiza energetica ua unui sistem de benzi transportoare din cadrul unei cariere de extracţie a lignitului,Workshop , Craiova* 2012.

[6]. Sandru M., *Imbunatatirea actionarilor electrice la unele utilaje principale din Exploatarea miniera de cariere Jilt in vederea cresterii eficientei energetice*, teza de doctorat, Petrosani, 2012.

[7]. Stochitoiu M.D., Gruber A., *The possibility to produce asynchronous motors with high energetically parameters,* Simpozion National de Electrotehnica Teoretica, Bucuresti, oct.2012.

[8]. Stochitoiu M.D., Uţu I., *Using the easy programablle logic controllers to the mining conveyors belt in Jilt open pit,* Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO, 2014, Petroşani, ISSN 2344-4754.

MODELING AND SIMULATION OF THE VECTORIAL CONTROL SYSTEM WHICH CONTAIN AN EXTENDED GOPINATH OBSERVER

CORNELIU MÂNDRESCU[1], OLIMPIU STOICUȚA[2] NADIA STOICUȚA[3]

Abstract: This paper presents a new flux and rotor resistance observer called an Extended Gopinath observer (EGO). The design of the EGO observer is done based on an adaptive mechanism using the notion of Popov hyperstability. The analysis of the new speed control system is released by simulation.

Key words: Extended Gopinath Observer (EGO), induction motor, control system.

1. INTRODUCTION

This paper presents a new flux and rotor resistance observer called an Extended Gopinath observer (EGO). The design of the EGO observer is done based on an adaptive mechanism using the notion of Popov hyperstability [11].

Thus, this type of observer is included in the estimation methods based on an adaptation mechanism, along with the Extended Luenberger Observer (ELO) proposed by Kubota [4] and the Model Adaptive System (MRAS) observer proposed by Schauder [3].

In the second part of the paper is presented the analysis of the new speed control system, released by simulation.

2. THE GOPINATH EXTENDED OBSERVER

The EGO observer in composed of a low grade Gopinath rotoric flux observer and an adaptation mechanism used for the rotor resistance estimation.

The equations that define the rotoric flux Gopinath observer are [9]:

$$\begin{cases} \dfrac{d}{dt}\hat{\underline{i}}_s = a_{11}^* \cdot \underline{i}_s + a_{12}^* \cdot \underline{\hat{\psi}}_r + b_{11}^* \cdot \underline{u}_s \\[2mm] \dfrac{d}{dt}\underline{\hat{\psi}}_r = a_{21}^* \cdot \underline{i}_s + a_{22}^* \cdot \underline{\hat{\psi}}_r + \underline{g} \cdot \left(\dfrac{d}{dt} \cdot \underline{i}_s - \dfrac{d}{dt} \cdot \hat{\underline{i}}_s \right) \end{cases} \tag{1}$$

---

[1] *Associate Professor, Ph.D. at the University of Petrosani*

[2] *Associate Professor, Ph.D. at the University of Petrosani*

[3] *Lecturer, Ph.D. at the University of Petrosani*

where:

$$a_{11}^* = -\left(\frac{1}{T_s^* \cdot \sigma^*} + \frac{1-\sigma^*}{T_r^* \cdot \sigma^*} \right); \; a_{11}^* = a_{13}^* - j \cdot a_{14}^* \cdot z_p \cdot \omega_r; \; T_s^* = \frac{L_s^*}{R_s^*};$$

$$a_{13}^* = \frac{L_m^*}{L_s^* \cdot L_r^* \cdot T_r^* \cdot \sigma^*}; \; a_{14}^* = \frac{L_m^*}{L_s^* \cdot L_r^* \cdot \sigma^*}; \; a_{33}^* = -\frac{1}{T_r^*}; \; T_r^* = \frac{L_r^*}{R_r^*};$$

$$a_{21}^* = a_{31}^* = \frac{L_m^*}{T_r^*}; \; a_{22}^* = a_{33}^* + j \cdot z_p \cdot \omega_r; \; b_{11}^* = \frac{1}{L_s^* \cdot \sigma^*}; \; \sigma^* = \frac{\left(L_m^* \right)^2}{L_s^* \cdot L_r^*}$$

In the above relations i marked with "*" the identified electrical sizes of the induction motor.

The block diagram of the EGO is presented in Figure 1.

The essential element that determines the flux observer's stability, and also his lack of sensibility to the motor parameters variation, is a g gate, which is a complex number of the form: $\underline{g} = g_a + j \cdot g_b$.
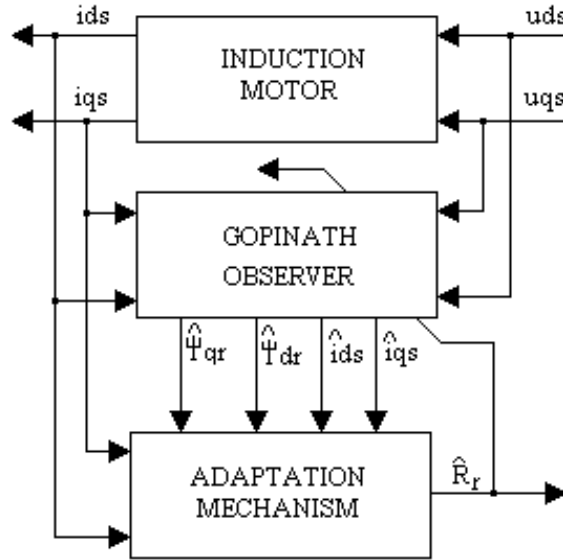
Fig.1. The Principle Schematic of the EGO Estimator

In order to design this type of estimator we need to position the estimator's poles in the left Nyquist plane so that the estimator's stability is asured. The expresions g_a and g_b after the pole positioning are [9]:

$$\begin{cases} g_a = \frac{1}{a_{14}^*} \cdot \left[\frac{\omega_r \cdot z_p \cdot \beta - \alpha \cdot a_{33}^*}{\left(\omega_r \cdot z_p \right)^2 + \left(a_{33}^* \right)^2} - 1 \right] \\ \\ g_a = \frac{1}{a_{14}^*} \cdot \frac{\omega_r \cdot z_p \cdot \alpha + \beta \cdot a_{33}^*}{\left(\omega_r \cdot z_p \right)^2 + \left(a_{33}^* \right)^2} \end{cases} \qquad (2)$$

The optimum position of the poles, the α and β values respectively, are obtained by the minimization of the induction motor's rotoric resistance variation over the stability of the flux observer. We get the following [9]:

$$\beta = 0 \, ; \alpha = k \cdot \sqrt{\left(\omega_r \cdot z_p\right)^2 + \left(a_{33}^*\right)^2} \, ; k > 0 \, . \tag{3}$$

In these conditions the Gopinath rotoric flux observer is completely determined.

Next, in order to determine the adaptation mechanism used to estimate the rotoric resistance, we will consider as a reference model the „statoric curents - rotoric fluxes" model of the induction motor and as an ajustable model, the model of the Gopinath rotoric flux observer. The equations mentioned above written under the input-state-output canonic form are:

- Reference model:

$$\begin{cases} \dfrac{d}{dt} x = A \cdot x + B \cdot u \\ y = C \cdot \dfrac{d}{dt} x \end{cases} \tag{4}$$

- Ajustable model:

$$\begin{cases} \dfrac{d}{dt} \hat{x} = \widetilde{A} \cdot \hat{x} + \widetilde{A}_1 \cdot x + B \cdot u + \widetilde{G} \cdot \left(y - \hat{y}\right) \\ \hat{y} = C \cdot \dfrac{d}{dt} \hat{x} \end{cases} \tag{5}$$

where:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} ; \widetilde{A} = \begin{bmatrix} 0 & a_{12}^* \\ 0 & a_{22}^* \end{bmatrix} ; \widetilde{A}_1 = \begin{bmatrix} a_{11}^* & 0 \\ a_{21}^* & 0 \end{bmatrix} ; \widetilde{G} = \begin{bmatrix} 0 \\ g \end{bmatrix} ;$$

$$x = \begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \end{bmatrix} ; \hat{x} = \begin{bmatrix} \hat{\underline{i}}_s \\ \hat{\underline{\psi}}_r \end{bmatrix} ; u = \underline{u}_s ; B = \begin{bmatrix} b_{11} \\ 0 \end{bmatrix} ; C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

In the above relations we marked with "~" the Gopinath estimator's matrices which are dependent upon the rotoric resistance, which in turn needs to be estimated based on the adaptation mechanism

Next, in order to determine the expresion that defines the adaptation mechanism we will asume that the identified electric sizes are identical with the real electric sizes of the induction motor. In other words:

$$a_{ij} = a_{ij}^* \, ; i, j = 1,2 \text{ and } b_{11} = b_{11}^*$$

In order to build the adaptive mechanism, for start we will calculate the estimation error given by the difference:

$$e_x = x - \hat{x} \tag{6}$$

Derivation the relation (6) in relation with time and by using the relations (4) and (5) the relation (6) becomes:

$$\frac{d}{dt}e_x = \left(A - \tilde{A}_1\right) \cdot x - \tilde{A} \cdot \hat{x} - \tilde{G} \cdot C \cdot \frac{d}{dt}e_x \tag{7}$$

If the determinant $\left|I_2 + \tilde{G} \cdot C\right| \neq 0$ then it exists a unique inverse matrix $M = \left(I_2 + \tilde{G} \cdot C\right)^{-1}$ so that the expression (7) can be written like this:

$$\frac{d}{dt}e_x = M \cdot \left(A - \tilde{A}_1\right) \cdot e_x + M \cdot \left(A - \tilde{A}_1 - \tilde{A}\right) \cdot \hat{x} \tag{8}$$

Equation (8) describes a linear system defined by the term $M \cdot \left(A - \tilde{A}_1\right) \cdot e_x$ in inverse connection with a nonlinear system defined by the term $\Phi(e_y)$ which receives at input the error $e_y = C \cdot e_x$ between the 2 models and has at the output the term:

$$\rho = -M \cdot \left(A - \tilde{A}_1 - \tilde{A}\right) \cdot \hat{x} \tag{9}$$

The block diagram of the system that describes the dynamic evolution of the error between the state of the reference model and the state of the adjustable model is presented in Figure 2.

As one may notice, this problem is frequently treated in the literature of the non-linear systems, being exactly the configuration of the Lure problem, and of one of the problems treated by Popov.
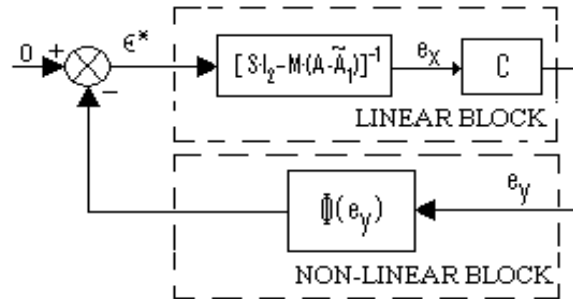
Fig. 2 The block diagram of the system (7)

Considering, according to the Popov terminology, the non-linear block described by $\Phi(e_y)$ the integral input- output index associated to it is:

$$\eta(t_0, t_1) = \mathrm{Re}\left[\int_0^{t_1} e_y^T \cdot \rho(t) \cdot dt\right] \tag{10}$$

In order for block to be hyper-stable a necessary condition is:

$$\eta(0,t_1) = \mathrm{Re}\left[\int_0^{t_1} e_y^T \cdot \rho(t) \cdot dt\right] \geq -\gamma^2(0) \tag{11}$$

for any input-output combination and where $\gamma(0)$ is a positive constant.

In the above relation we marked with e_y^T the following expression:

$$e_y^T = \begin{bmatrix} \bar{e}_y & 0 \end{bmatrix} \tag{12}$$

obtained in order to keep the compatibility between the input and output dimensions, and $\bar{e}_y$ represents the conjugate of the complex variable e_y.

Under these circumstances, using the relation (9) the expression (11) becomes:

$$\eta(0,t_1) = \mathrm{Re}\left[\int_0^{t_1} e_y^T \cdot M \cdot \left(A - \tilde{A}_1 - \tilde{A}\right) \cdot \hat{x} \cdot dt\right] \geq -\gamma^2(0) \tag{13}$$

Next we asume that the error $M \cdot \left(A - \tilde{A}_1 - \tilde{A}\right)$ is determined only by the rotor resistance estimation of the induction machine. In this case we may write:

$$M \cdot \left(A - \tilde{A}_1 - \tilde{A}\right) = \left(R_r - R_r^*\right) \cdot A_{er} \tag{14}$$

where:

$$A_{er} = \frac{1}{L_r} \cdot \begin{bmatrix} -\dfrac{1-\sigma}{\sigma} & a_{14} \\ L_m + \dfrac{1-\sigma}{\sigma} \cdot \underline{g} & -\left(1 + \underline{g} \cdot a_{14}\right) \end{bmatrix}$$

For any positive derivable f function we can demonstrate the following inequality:

$$K_1 \cdot \int_0^{t_1} \left(\frac{df}{dt} \cdot f\right) \cdot dt \geq -\frac{K_1}{2} \cdot f^2(0) \tag{15}$$

On the other hand, using the relation (14), the expression (13) becomes:

$$\eta(0,t_1) = -\mathrm{Re}\left[\int_0^{t_1} e_y^T(t) \cdot A_{er} \cdot \hat{x} \cdot \left(R_r - R_r^*\right) \cdot dt\right] \geq -\gamma^2(0) \tag{16}$$

By combining the relations (15) and (16) we can write the following relations:

$$\begin{cases} f = R_r - R_r^* \\ -\mathrm{Re}\left(e_y^T \cdot A_{er} \cdot \hat{x}\right) = K_1 \cdot \dfrac{df}{dt} \end{cases} \tag{17}$$

Because K_1 is a constant and then, in case of a slower R_r parameter variation related to the adaptive law, we can write:

$$R_r^* = K_i \cdot \int \mathrm{Re}\left(e_y^T \cdot A_{er} \cdot \hat{x}\right) \cdot dt \tag{18}$$

After replacing the variables that define the above expression (18) and taking into account the arbitrary nature of the K_i positive constant we obtain:

$$R_r^* = K_i \cdot \int \left[e_{yd} \cdot \left(\tilde{\psi}_{dr} - L_m \cdot \hat{i}_{ds} \right) + e_{yq} \cdot \left(\tilde{\psi}_{qr} - L_m \cdot \hat{i}_{qs} \right) \right] \cdot dt \qquad (19)$$

where: $e_{yd} = i_{ds} - \hat{i}_{ds}$ and $e_{yq} = i_{qs} - \hat{i}_{qs}$.

Sometimes, insted of the adaptation law (19) we can use the following form:

$$\begin{aligned} \tilde{R}_r = {} & K_R \cdot \left[e_{yd} \cdot \left(\tilde{\psi}_{dr} - L_m \cdot \hat{i}_{ds} \right) + e_{yq} \cdot \left(\tilde{\psi}_{qr} - L_m \cdot \hat{i}_{qs} \right) \right] + \\ & + K_i \cdot \int \left[e_{yd} \cdot \left(\tilde{\psi}_{dr} - L_m \cdot \hat{i}_{ds} \right) + e_{yq} \cdot \left(\tilde{\psi}_{qr} - L_m \cdot \hat{i}_{qs} \right) \right] \cdot dt \end{aligned} \qquad (20)$$

From the above relation we ca observe that a new proportional component apears from the desire to have 2 coefficients that can control the speed estimation dynamics. This fact isn't always necesary because we can obtain very good results by using only expresion (19). Thus expresion (20) represents the general formula of the adaptation mechanism where K_R represents the proportionality constant and $K_i = K_R / T_R$ where T_R represents the integration time of the proportional-integral controller that defines the adaptation mechanism.

3. THE MATHEMATICAL DESCRIPTION OF THE VECTOR CONTROL SYSTEM

The block diagram of the control system of the mechanical angular speed ω_r of the induction motor with a discreet orientaion after the rotoric flux (DFOC) is presented in Figure 3.

Fig. 3. The block diagram of the vector control system which contains an EGO loop

In Figure 3 we marked with B2 the control block of the speed control system with direct orientation after the rotoric flux (DFCO) and with B1 the extended Gopinath estimator block (EGO).

In order to mathematically describe the DFOC control system the following hypotheses have been considered:

- The static frequency converter (CSF) is assumed to contain a tension inverter.
- The static frequency converter is considered ideal so that the vector of the command measures is considered to be the entry vector of the induction motor.
- The dynamic measure transducers are considered ideal.

The mathematical model of the vector control system will be written in an $d\lambda_e - q\lambda_e$ axis reference bounded to the stator current.

Some of the equations that define the vector control system are given by the elements which compose the field orientation block and consist of:

- stator voltage decoupling block (C_1U_s):

$$\begin{cases} u_{dr\lambda_r}^* = \dfrac{1}{b_{11}^*} \cdot \left[b_{11}^* \cdot v_{dr\lambda_r}^* - a_{13}^* \cdot |\psi_r| - a_{31}^* \cdot \dfrac{i_{qs\lambda_r}^2}{|\psi_r|} - z_p \cdot \omega_r \cdot i_{qs\lambda_r} \right] \\[4mm] u_{qs\lambda_r}^* = \dfrac{1}{b_{11}^*} \cdot \left[b_{11}^* \cdot v_{qs\lambda_r}^* + a_{14}^* \cdot z_p \cdot \omega_r \cdot |\psi_r| + a_{31}^* \cdot \dfrac{i_{ds\lambda_r} \cdot i_{qs\lambda_r}}{|\psi_r|} + z_p \cdot \omega_r \cdot i_{ds\lambda_r} \right] \end{cases} \quad (21)$$

- PI flux controller (PI_ψ) defined by the K_ψ proportionality constant and the T_ψ integration time:

$$\begin{cases} \dfrac{dx_6}{dt} = \psi_r^* - |\psi_r| \\[4mm] i_{ds\lambda_r}^* = \dfrac{K_\psi}{T_\psi} \cdot x_6 + K_\psi \cdot \left(\psi_r^* - |\psi_r| \right) \end{cases} \quad (22)$$

- torque PI controller (PI_M_e) defined by the K_M proportionality constant and the T_M integration time:

$$\begin{cases} \dfrac{dx_7}{dt} = M_e^* - M_e \\[4mm] i_{qs\lambda_r}^* = \dfrac{K_M}{T_M} \cdot x_7 + K_M \cdot \left(M_e^* - M_e \right) \end{cases} \quad (23)$$

- mechanical angular speed PI controller (PI_W) defined by the K_ω proportionality constant and the T_ω integration time:

$$\begin{cases} \dfrac{dx_8}{dt} = \omega_r^* - \omega_r \\[4mm] M_e^* = \dfrac{K_\omega}{T_\omega} \cdot x_8 + K_\omega \cdot \left(\omega_r^* - \omega_r \right) \end{cases} \quad (24)$$

- current PI controller (PI_I) defined by the K_i proportionality constant and the T_i integration time:

$$\begin{cases} \dfrac{dx_9}{dt} = i^*_{ds\lambda_r} - i_{ds\lambda_r} \\ v^*_{ds\lambda_r} = \dfrac{K_i}{T_i} \cdot x_9 + K_i \cdot \left(i^*_{ds\lambda_r} - i_{ds\lambda_r} \right) \end{cases} \tag{25}$$

$$\begin{cases} \dfrac{dx_{10}}{dt} = i^*_{qs\lambda_r} - i_{qs\lambda_r} \\ v^*_{qs\lambda_r} = \dfrac{K_i}{T_i} \cdot x_{10} + K_i \cdot \left(i^*_{qs\lambda_r} - i_{qs\lambda_r} \right) \end{cases} \tag{26}$$

- Flux analyzer (AF):

$$\begin{cases} |\psi_r| = \sqrt{\widetilde{\psi}_{dr}^2 + \widetilde{\psi}_{dr}^2} \\ \sin \lambda_r = \dfrac{\widetilde{\psi}_{qr}^2}{|\psi_r|} ; \cos \lambda_r = \dfrac{\widetilde{\psi}_{dr}^2}{|\psi_r|} \end{cases} \tag{27}$$

- The calculate of the torque block (C_1M_e):

$$M_e = K_a \cdot |\psi_r| \cdot i_{qs\lambda_r} \tag{28}$$

The other equations that define the mathematic model of the speed's vectorial control system are:

- The equations that define the stator currents – rotor fluxes mathematical model of the induction motor; 4 equations defined based on the first relation in the canonic system (4) to which we can add the induction machine's motion equation defined by the following expression:

$$\frac{d}{dt} \omega_r = K_{m1} \cdot \left[\psi_{dr} \cdot i_{qs} - \psi_{qr} \cdot i_{ds} \right] - K_{m2} \cdot \omega_r - K_{m3} \cdot M_r \tag{29}$$

where:

$$K_{m1} = \frac{3}{2} \cdot \frac{z_p}{J} \cdot \frac{L_m}{L_r} ; K_{m2} = \frac{F}{J} ; K_{m3} = \frac{1}{J}$$

The equations that define the extended Gopinath observer defined by the 4 relations that can be written based on system (1) with the equation that defines the speed adaptation mechanism (20). Expresion (20) can also be written like below:

$$\begin{cases} \dfrac{d}{dt} x_{15} = e_{yd} \cdot \left(\widetilde{\psi}_{dr} - L_m \cdot \hat{i}_{ds} \right) + e_{yq} \cdot \left(\widetilde{\psi}_{qr} - L_m \cdot \hat{i}_{qs} \right) \\ R^*_r = \dfrac{K_R}{T_R} \cdot x_{15} + K_R \cdot \left[e_{yd} \cdot \left(\widetilde{\psi}_{dr} - L_m \cdot \hat{i}_{ds} \right) + e_{yq} \cdot \left(\widetilde{\psi}_{qr} - L_m \cdot \hat{i}_{qs} \right) \right] \end{cases} \tag{30}$$

All these expressions form a 15 differential equations system with 15 unknown values. In order to offer a coherent presentation of this differential equations system, we have used the following notations:

The state vector of the control system will be:

$$x = [x_i]_{i=\overline{1,15}} \tag{31}$$

where: $x_1 = i_{ds\lambda_e}$; $x_2 = i_{qs\lambda_e}$; $x_3 = \psi_{dr\lambda_e}$; $x_4 = \psi_{qr\lambda_e}$; $x_5 = \omega_r$;

$x_{11} = \hat{i}_{ds\lambda_e}$; $x_{12} = \hat{i}_{qs\lambda_e}$; $x_{13} = \tilde{\psi}_{dr\lambda_e}$; $x_{14} = \tilde{\psi}_{qr\lambda_e}$

The input vector of the of the control system will be:

$$u = \begin{bmatrix} u_1 & u_2 & u_3 \end{bmatrix}^T \tag{32}$$

where: $u_1 = \psi_r^*$; $u_2 = \omega_r^*$; $u_3 = M_r$

Under these circumstances the 15 differential equations system that define the mathematical model of the vector control system can be written as follows:

$$\frac{d}{dt}x = f(x,u) \tag{33}$$

where $f(x,u) = [f_i(x,u)]_{i=\overline{1,15}}$ and the $f_i = f_i(x,u)$ function are:

$$f_1(x,u) = a_{11} \cdot x_1 + \omega_e \cdot x_2 + a_{13} \cdot x_3 + a_{14} \cdot z_p \cdot x_5 \cdot x_4 + b_{11} \cdot u_a \tag{34}$$

$$f_2(x,u) = -\omega_e \cdot x_1 + a_{11} \cdot x_2 + a_{13} \cdot x_4 - a_{14} \cdot z_p \cdot x_5 \cdot x_3 + b_{11} \cdot u_b \tag{35}$$

$$f_3(x,u) = a_{31} \cdot x_1 + a_{33} \cdot x_3 + (\omega_e - z_p \cdot x_5) \cdot x_4 \tag{36}$$

$$f_4(x,u) = a_{31} \cdot x_2 - (\omega_e - z_p \cdot x_5) \cdot x_3 + a_{33} \cdot x_4 \tag{37}$$

$$f_5(x,u) = K_{m1} \cdot (x_3 \cdot x_2 - x_4 \cdot x_1) - K_{m2} \cdot x_5 - K_{m3} \cdot u_3 \tag{38}$$

$$f_6(x,u) = u_1 - g_1 \tag{39}$$

$$f_7(x,u) = \frac{K_\omega}{T_\omega} \cdot x_8 + K_\omega \cdot (u_2 - g_2) - K_a \cdot g_3 \tag{40}$$

$$f_8(x,u) = u_2 - g_2 \tag{41}$$

$$f_9(x,u) = \frac{K_\psi}{T_\psi} \cdot x_6 + K_\psi \cdot (u_1 - g_1) - \frac{g_4}{g_1} \tag{42}$$

$$f_{10}(x,u) = \frac{K_M}{T_M} \cdot x_7 + K_M \cdot f_7(x,u) - \frac{g_3}{g_1} \tag{43}$$

$$f_{11}(x,u) = a_{11}^* \cdot x_1 + \omega_e \cdot x_2 + a_{13}^* \cdot x_{13} + a_{14}^* \cdot z_p \cdot g_2 \cdot x_{14} + b_{11}^* \cdot u_a \tag{44}$$

$$f_{12}(x,u) = -\omega_e \cdot x_1 + a_{11}^* \cdot x_2 + a_{13}^* \cdot x_{14} + a_{14}^* \cdot z_p \cdot g_2 \cdot x_{13} + b_{11}^* \cdot u_b \tag{45}$$

$$f_{13}(x,u) = b_1 \cdot x_{13} + b_2 \cdot x_{14} - g_a \cdot b_{11}^* \cdot u_a + g_b \cdot b_{11}^* \cdot u_b + \\ + b_3 \cdot x_1 + b_4 \cdot x_2 - g_a \cdot f_1(x,u) + g_b \cdot f_2(x,u) \tag{46}$$

$$f_{14}(x,u) = -b_2 \cdot x_{13} + b_1 \cdot x_{14} - g_b \cdot b_{11}^* \cdot u_a - g_a \cdot b_{11}^* \cdot u_b - \\ - b_4 \cdot x_1 + b_3 \cdot x_2 + g_b \cdot f_1(x,u) + g_a \cdot f_2(x,u) \tag{47}$$

$$f_{15}(x,u) = e_{yd} \cdot \left(x_{13} - L_m^* \cdot x_{11}\right) + e_{yq} \cdot \left(x_{14} - L_m^* \cdot x_{12}\right) \tag{48}$$

where:

$$g_1 = \sqrt{x_{13}^2 + x_{14}^2}\,;\; g_2 = x_5\,;\; g_3 = x_2 \cdot x_{13} - x_1 \cdot x_{14}\,;$$

$$g_4 = x_1 \cdot x_{13} + x_2 \cdot x_{14}\,;\; b_1 = a_{33}^* - g_a \cdot a_{13}^* - g_b \cdot a_{14}^* \cdot z_p \cdot g_2\,;$$

$$g_5 = \frac{K_R}{T_R} \cdot x_{15} + K_R \cdot \left[e_{yd} \cdot \left(x_{13} - L_m^* \cdot x_{11}\right) + e_{yq} \cdot \left(x_{14} - L_m^* \cdot x_{12}\right)\right];$$

$$b_2 = g_b \cdot a_{13}^* - \left(1 + g_a \cdot a_{14}^*\right) \cdot z_p \cdot g_2 + \omega_e\,;\; b_3 = a_{31}^* - g_a \cdot a_{11}^* - g_b \cdot \omega_e\,;$$

$$b_4 = g_b \cdot a_{11}^* - g_a \cdot \omega_e\,;\; \omega_e = z_p \cdot g_2 + a_{31}^* \cdot \frac{x_2}{x_{13}}\,;\; \varepsilon = k \cdot \sqrt{\left(z_p \cdot g_2\right)^2 + \left(a_{33}^*\right)^2}\,;$$

$$g_a = \frac{-1}{a_{14}^*} \cdot \left[1 + \frac{\alpha \cdot a_{33}^*}{\left(z_p \cdot g_2\right)^2 + \left(a_{33}^*\right)^2}\right];\; g_a = \frac{1}{a_{14}^*} \cdot \frac{g_2 \cdot z_p \cdot \alpha}{\left(z_p \cdot g_2\right)^2 + \left(a_{33}^*\right)^2}\,;$$

$$v_a = \frac{K_i}{T_i} \cdot x_9 + K_i \cdot f_9(x,u)\,;\; v_b = \frac{K_i}{T_i} \cdot x_{10} + K_i \cdot f_{10}(x,u)\,;$$

$$h_1 = a_{13}^* \cdot g_1 + a_{31}^* \cdot \frac{g_3^2}{g_1^3} - z_p \cdot g_2 \cdot \frac{g_3}{g_1}\,;$$

$$h_2 = a_{13}^* \cdot z_p \cdot g_2 \cdot g_1 + a_{31}^* \cdot \frac{g_3 \cdot g_4}{g_1^3} + z_p \cdot g_2 \cdot \frac{g_4}{g_1}\,;$$

$$u_a = \frac{1}{b_{11}^* \cdot g_1} \cdot \left[x_{13} \cdot \left(b_{11}^* \cdot v_a - h_1\right) - x_{14} \cdot \left(b_{11}^* \cdot v_a - h_2\right)\right];$$

$$u_b = \frac{1}{b_{11}^* \cdot g_1} \cdot \left[x_{14} \cdot \left(b_{11}^* \cdot v_a - h_1\right) + x_{13} \cdot \left(b_{11}^* \cdot v_a - h_2\right)\right];$$

$$e_{yd} = x_1 - x_{11}\,;\; e_{yq} = x_2 - x_{12}\,;\; a_{11} = -\left(\frac{1}{T_s \cdot \sigma} + \frac{1 - \sigma}{T_s \cdot \sigma}\right);$$

$$a_{13} = \frac{L_m}{L_s \cdot L_r \cdot T_r \cdot \sigma}\,;\; a_{14} = \frac{L_m}{L_s \cdot L_r \cdot \sigma}\,;\; a_{31} = \frac{L_m}{T_r}\,;\; a_{33} = \frac{1}{T_r}\,;\; b_{11} = \frac{1}{L_s \cdot \sigma}\,;$$

$$T_s = \frac{L_s}{R_s}\,;\; T_r = \frac{L_r}{R_r}\,;\; \sigma = 1 - \frac{L_m^2}{L_s \cdot L_r}\,;\; K_a = \frac{3}{2} \cdot z_p \cdot \frac{L_m^*}{L_r^*}\,;$$

$$a_{11}^* = -\left(\frac{1}{T_s^* \cdot \sigma^*} + \frac{1 - \sigma^*}{T_s^* \cdot \sigma^*}\right);\; a_{13}^* = \frac{L_m^*}{L_s^* \cdot L_r^* \cdot T_r^* \cdot \sigma^*}\,;\; a_{14}^* = \frac{L_m^*}{L_s^* \cdot L_r^* \cdot \sigma^*}\,;$$

$$a_{31}^* = \frac{L_m^*}{T_r^*}\,;\; a_{33}^* = \frac{1}{T_r^*}\,;\; b_{11}^* = \frac{1}{L_s^* \cdot \sigma^*}\,;\; T_s^* = \frac{L_s^*}{R_s^*}\,;\; T_r^* = \frac{L_r^*}{g_5}\,;\; \sigma^* = 1 - \frac{\left(L_m^*\right)^2}{L_s^* \cdot L_r^*}\,.$$

Under these circumstances the mathematical model of the speed vector control system is fully determined as being defined by the non-linear differential equations system given by (33) whose initial condition is $x(0) = 0$.

4. CONTROL SYSTEM ANALYSIS

In order to accomplish the above mentioned control system analysis, we shall consider an induction motor with a short-circuited rotor having the following electrical and mechanical parameters:

• electrical parameters:

$$R_s = 0.371\,\Omega;\ R_r = 0.415\,\Omega;\ L_s = 0.08694\,\text{H};\ L_r = 0.08762\,\text{H};\ L_s = 0.08422\,\text{H}$$

• mechanical parameters:

$$z_p = 2;\ J = 0.15\,\text{kg}\cdot\text{m}^2;\ F = 0.005\,\text{N}\cdot\text{m}\cdot\text{s/rad}$$

On the other hand, following the controllers tuning within the speed control system the following constants have been obtained:

$$K_\psi = 501.3834;\ T_\psi = K_\psi/2374.7;$$

$$K_i = 5.9881;\ T_i = K_i/754.4176;$$

$$K_M = 10.1988;\ T_M = K_M/1020;$$

$$K_\omega = 10;\ T_\omega = K_\omega/350;\ K_R = 6;\ T_R = K_R/4000$$

In the relations above, K_R represents the proportionality constant and T_R represents the integration time of the PI control from the speed estimator designed based on the Popov hyperstability.

Next, the performances of the extended Gopinath estimator are presented in a variety of functional conditions.

Thus the image below will present the graphics for the real and estimated rotors fluxes and also the graphics for the imposed speed, real speed and the estimated speed for small, medium and large imposed speeds.
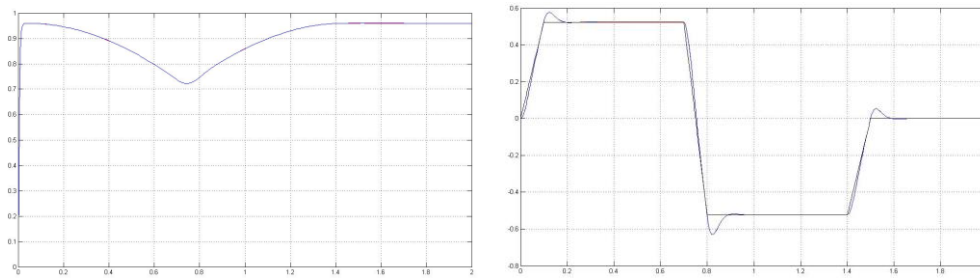
Fig. 4. ψ_{dr} real flux compared to the $\tilde{\psi}_{dr}$ estimated flux (left);

ω_r real speed compared to the $\tilde{\omega}_r$ estimated speed and reference speed (right) ;

$$\omega_r^* = 5\cdot\pi/30\,\text{rad/s} ;\ M_r = 0$$
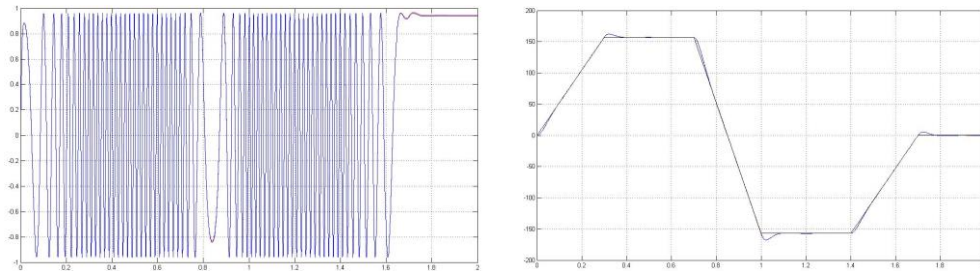
Fig. 5. ψ_{dr} real flux compared to the $\tilde{\psi}_{dr}$ estimated flux (left);

ω_r real speed compared to the $\tilde{\omega}_r$ estimated speed and reference speed (right) ;

$$\omega_r^* = 1500 \cdot \pi / 30 \, \text{rad/s} \, ; M_r = 0$$
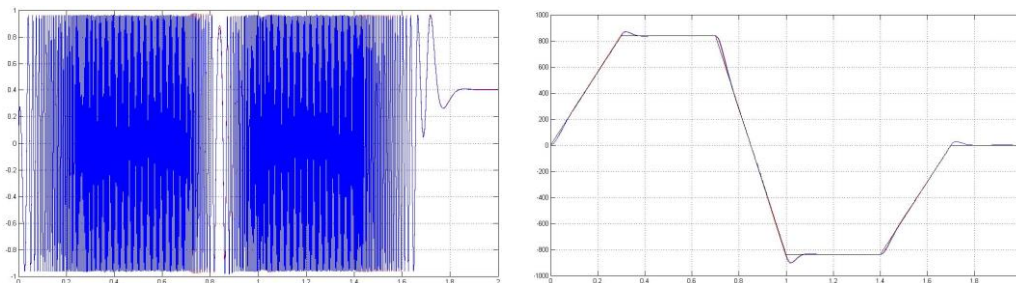
Fig. 6. ψ_{dr} real flux compared to the $\tilde{\psi}_{dr}$ estimated flux (left);

ω_r real speed compared to the $\tilde{\omega}_r$ estimated speed and reference speed (right) ;

$$\omega_r^* = 3000 \cdot \pi / 30 \, \text{rad/s} \, ; M_r = 0$$

5. CONCLUSIONS

This paper presents a new flux and rotor resistance observer called an Extended Gopinath Observer (EGO). The design of the EGO observer is done based on an adaptive mechanism using the notion of Popov hyperstability.

The EGO observer designing using the method presented in this paper ensures the control system with a very good dynamics and robustness. This net avantage, recomend the succesful use of this method in practice.

REFERENCES

[1]. Fransua, A., Măgureanu, R., *Electrical Machines and Drive Systems,* Oxford Technical Press, 1984.

[2]. Kelemen, A., Imecs, M., *Field-Oriented AC Electrical Drives*, Editura Academiei, Bucharest, 1989.

[3]. Schauder, C., *Adaptive Speed Identification for Vector Control of Induction Motors without Rotational Transducers*, IEEE Trans. Ind.Applicat., vol.28, no.5, pages 1054-1061, Sept-Oct., 1992.

[4]. Kubota, H., Matsuse, K., Nakano, T., *New Adaptive Flux observer of Induction Motor for Wide Speed range Motor Drives*, in Proc. Int. Conf. IEEEIECON, pp. 921-926, 1990.

[5]. Vas, P., *Vector Control of AC Machines*, Clarondon press, Oxford, 1990.

[6]. Mandrescu, C., Stoicuta, O., Stoicuta, N., *Modeling and simulation of the vectorial control system which contain an extended gopinath observer*, Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO, 2014, Petroşani, ISSN 2344-4754.

[7]. Nasar, S. A., Boldea, I., *Electrical Machines: Dynamics and Control,* CRC Press, 1993.

[8]. Pana, T., *Vector Control of Induction Motor Drive Systems*, Mediamira Publ. Cluj-Napoca, Romania, 2001.

[9]. Pana, T., *Matlab Application Toolbox – Electrical Drives – Induction Motor*, Mediamira Publishers, 1997.

[10]. Pana, T., Stoicuta, O., *Small Speed Asymptotic Stability Study of an Induction Motor Sensorless Speed Control System with Extended Gopinath Observer*, Advances in Electrical and Computer Engineering, vol. 11, no. 2, pp. 15-22, 2011 .

[11]. Pana, T., Stoicuta, O., *Controllers tuning for the speed vector control of induction motor drive systems*, Proc. IEEE AQTR, Cluj-Napoca, 2010.

[12]. Popov, V. M., *Hyperstability of Control Systems*, Springer Verlag, New York, 1973.

ELECTRIC DRIVE FOR WINDING MACHINES OPERATED BY A DIGITAL SIGNAL PROCESSOR

ILIE UŢU[1], STOCHITOIU MARIA DANIELA[2]

Abstract: This paper propose a new electric drive system for winding machines. Most electric drives used in mining plants are operated by induction motors due to their robustness, low cost and simple maintenance. Such electric drive systems require high performance, high precision and superior function of maintenance. For that are necessary controlled drive systems with frequency converters. Its stable operation and highly precise torque control are implemented through a number of techniques such as CPU system and a Digital Signal Processor (DSP), current detection, and voltage model method.

Key words: electric drive systems, induction motor, Digital Signal Processor, PWM converter.

1. INTRODUCTION

In mining plants from Jiu Valley there are many winding machines operated with asynchronous motors, where starting and speed control is achieved by means of a rheostat metallic gear [8].

The drive systems of mining equipment have been required to compose of ac motors because of their simple maintenance. Transistor inverters are usually used in small plants. However, they cannot be applied to larger drive systems, such as winding machine drives, because the maximum capacity of those currently available for AC drives is only 200-300 kVA.

Therefore, there has been demand for an inverter with a large capacity to enable AC drive systems to be used for all process lines. On the other hand, high performance, high precision and superior function of maintenance and fault diagnosis are needed to improve the quality of drive system without additional cost. Hence, there is a strong requirement for a fully digital controlled inverter.

In order to ensure winding machine operation speed, we proposed the use of asynchronous motor drives fed by a fully digital, vector controlled GTO PWM inverter for driving induction motors.

This allows operation of the electric drive speed extraction set eliminating loss of electricity rheostat rotor circuit by operating the existing solution. The management system can be realized by means of a microprocessor system intended for such an application.

[1] *Ph.D. Associate Professor Eng., University of Petrosani*
[2] *Ph.D. Associate Professor Eng., University of Petrosani*

The relatively low cost, ease maintenance, high performance technical features, require the use of the technical solutions for the new operating conditions of extraction machine.

Of the many issues regarding equipment in mining in this paper deepened use of new types of electric drives by applying power electronics as a measure to reduce electricity consumption.

2. DRIVE SYSTEM WITH AC INVERTER

2.1. Main circuit

In figure no.1 is shown the main circuit scheme. The element used in the inverter is a 2500 V, 2000 A reverse conducting GTO. By the use of reverse conducting GTO, the need for a diode, connected in reverse parallel to the GTO, resulted in a simplified circuit. This inverter uses a direct current distribution system [1].

To realize a larger capacity of the inverter, the parallel-set operation of the inverter was reported. This method presents the problem of a complex control structure to suppress any cross current between the two inverters.

For solve this problem, it can be used a large capacity system with six-phase motor [3], [4]. In figure no.2 is shown the diagram of the inverter, motor and reactor.

The induction motor stator windings consist in two of three-phase groups displaced by 30 degrees each being supplied by one inverter. The phase current is shifted by 30 degrees between the two inverters.

IM - Induction Motor C - Capacitor S - Snubber
F - Fuse   Th - Reverse conducting GTO

Fig.1. Main circuit scheme of inverter
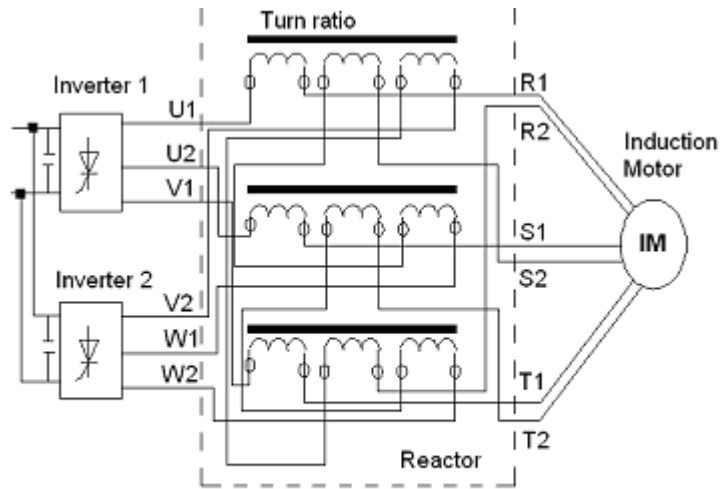
Fig.2. Diagram of the inverter, motor and reactor

2.2. Microsystem block diagram

In figure no. 3 a microsystem block diagram is shown. This diagram can be divided into three parts.
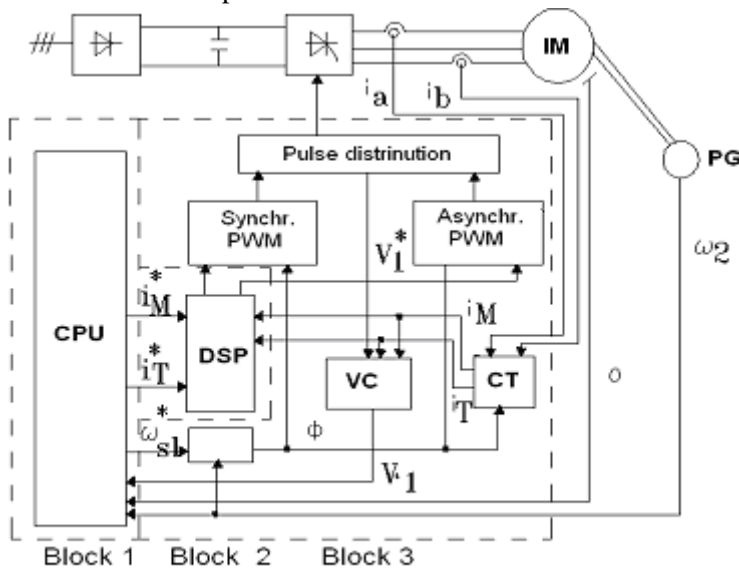
Fig.3. Discrete circuits for generation the PWM pulse

In block no. 1 is a 16-bit microprocessor for the speed control, flux control, slip frequency operation, voltage model operation, and so on.

In block no.2, the Digital Signal Processor (DSP), provides current control and PWM operation at high speed, according to his software.

In block no.3 is shown the discrete circuits for generation the PWM pulse, distribution of the PWM pulse to each GTO, detection of the voltage and current, other interface processing [3], [4].

67

3. ASYNCHRONOUS ELECTRIC MOTOR DRIVES FED FROM AN PWM INVERTER FOR THE WINDING MACHINES

3.1. General data

Since almost all mines in the Jiu Valley mining facilities are operated motors with rheostat rotor circuit, the problem of finding more efficient ways to achieve the speed setting in being intricate so as to reduce electricity losses [1], [5].

A very modern method is the introduction of electric drives induction motor powered by an inverter, whose calculation is shown below.

In order to highlight the advantages of using such electrical drives, have made some calculations on the operation of the existing plant operation conditions, showing that energy losses occurring in the rotor circuit resistances.

The calculations will take into account the rated motor drive type AKH-2-16-48-12:

- Nominal power: 630 kW;
- Supply voltage: 6000 V;
- Power factor: $\cos \varphi = 0.8$;
- Stator current: 81 A;
- Rotor current: 466 A;
- Rotor voltage: 810 V;

Features extraction machine are:
- Maximum static load: 176,5 kN;
- Maximum static imbalance: 147,1 kN;
- Maximum weight of equipment carried in or under cage: 102.9 kN;
- The weight of the heaviest machine with special frame cage: 176.5 kN;
- Gear transmission ratio of 1:10.5;
- The extraction rate: 5,8 m / s;
- 4 buildings for 1 m^3 of sterile 1800 Kg / conveyance;
- Extraction time t = 59 s;
- The cycle: $T_0 = 119$ s;

The method of calculation used assumes a functioning extraction system diagram 3 times to double cages.

Initial data for determining starting resistances are:
a) The ratio of maximum torque and nominal;
b) The nominal voltage of the rotor, E_{2N};
c) The rated rotor I_{2N};
d) Motor efficiency;
e) rated speed n_N and synchronicity, n_0;
f) Theoretical values of M_{min} and M_{max} starting time

To determine the actual values starting rheostat steps can be applied analytical method of calculation or graphical method. I thought the graphic method is most suitable for this application [5].

According to this method, it is necessary to be constructed of natural or artificial mechanical properties formed by the coupling to the rotor circuit of the power levels of the resistance.

It should be given limit values (minimum and maximum) of torque variation during startup. The range of these variations is inversely proportional to the number of steps starting rheostat and can reach 30% of the theoretical starting time.[6]

This should be borne in mind that the higher values of starting torque not reach the maximum moment due to a reduction in blood supply to the engine, leading to decreased torque proportional to the square of supply voltage.

The starting torque lower values may not fall below the static moment resistance as during startup with system acceleration would take place and the phenomenon of slowing appropriate time during descent time starting below the static moment resistant.

3.2. Cinematic and dynamic parameters for extraction plant shareholders

Extraction unit for projecting the drive system is a system of the type 2T-3,5x1,7A extract the following information [5]:
- Static permissible cable extraction: $Q_{st\ max\ adm} = 15,000$ daN;
- Nominal body wrap: $D_t = 3,400$ mm;
- Width of the drum: $B = 1,700$ mm;
- Cable diameter extraction: $d_c = 44$ mm;
- Maximum depth of extraction: $H_{max} = 337$ m;
- Cage with 2 floors of 2 buildings on the floor;
- Power drive motor (electric motor type AKH-2-16-48): $P_n = 630$ kW;
- Synchronous speed: $n_0 = 600$ rev / min;
- Rated: $n_n = 590$ rev / min;
- Return drive motor: $\eta = 0.925$;
- T2S gear type transmission ratio: $i_{red} = 20$.

Cinematic extraction facility
Vertical transmission speed is:

$$v = \frac{\pi\,D_t\,n_t}{60} = 5{,}25\ \ [m/s] \tag{1}$$

where:
$n_t = n_n / i_{red} = 29.5$ rev / min; speed spindle drum.
Diagram elements of the installation of extraction are:
The period of time that acceleration and deceleration:

$$t_1 = t_3 = \frac{v}{a_1} = 7\ \ [s]; \tag{2}$$

with $a = 0.75$ m / s^2 acceleration or deceleration;
Space traveled during acceleration or deceleration:

$$h_1 = h_3 = 0{,}5 \cdot v \cdot t_1 = 19\ \ [m] \tag{3}$$

$$h_2 = H_{max} - (h_1 + h_3) = 299 \ [m]; \tag{4}$$

$$t_2 = \frac{h_2}{v} = 57 \ [s]; \tag{5}$$

Actual time of an extraction:

$$t = t_1 + t_2 + t_3 = 71 \ [s]; \tag{6}$$
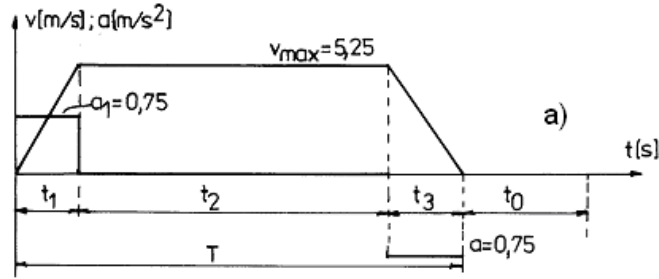
Fig.4.a. Angular velocity variation

Residence time consists of the time required to introduce two buildings on the floor of the cage and the time needed to change the floor of the cage:

$$t_0 = 60 \ [s]. \tag{7}$$

The diagram of operation of extraction is shown in fig.4.a at another scale the change in angular velocity of the induction motor function of time [5].

Dynamic extraction plant

In order to increase graphics force variation with respect to time (fig.4.b) were determined following forces:

Force at the beginning of acceleration:

$$F_1 = k \cdot Q_{ut} + h_{max} \cdot p_c + m_{red} \cdot a_1 = 18.371 \ [daN]; \tag{8}$$

Force at the end of the acceleration:

$$F_2 = k \cdot Q_{ut} + h_2 \cdot p_c + m_{red} \cdot a_1 = 18.183 \ [daN]; \tag{9}$$

The beginning of the drive force stabilized:

$$F_3 = k \cdot Q_{ut} + h_2 \cdot p_c = 10.895 \ [daN]; \tag{10}$$
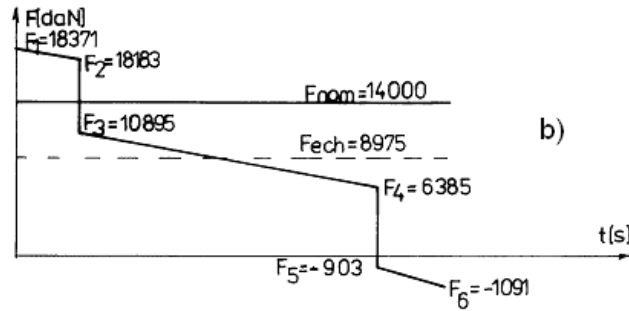
Fig.4.b. Force variation

The end of the drive force stabilized:

$$F_4 = k \cdot Q_{ut} - h_2 \cdot p_c = 6.385 \ [daN]; \qquad (11)$$

$$F_5 = k \cdot Q_{ut} - h_2 \cdot p_c - m_{red} \cdot a_1 = \_903 \ [daN]; \qquad (12)$$

$$F_6 = k \cdot Q_{ut} - h_{mx} \cdot p_c - m_{red} \cdot a_1 = 1.091 \ [daN]; \qquad (13)$$

where:
- Aerodynamic drag coefficient k = 1.2;
- Q_{UT} = 7200 kg total payload cage;
- p_c = 7.25 kg / m linear weight of the cable;
- m_{red} = 9717 kg reduced mass of the entire system periphery drums extraction.

With these forces will determine the appropriate power points of interest: P_1=0; P_2 = 818 kW; P_3 = 490 kW; P_4 = 288 kW; P_5 = -41 kW; P_6 = 0; representing the variation with time in fig.4.c. [5]

Fig.4.c. Power variation

Torque developed by the engine needed to be shown graphically in fig.4.d.

Fig.4.d. Torque variation

71

The values of the angular velocity and the torque with respect to time are input quantities for the microcontroller (prescribed value), and are previously stored in the micro memory.

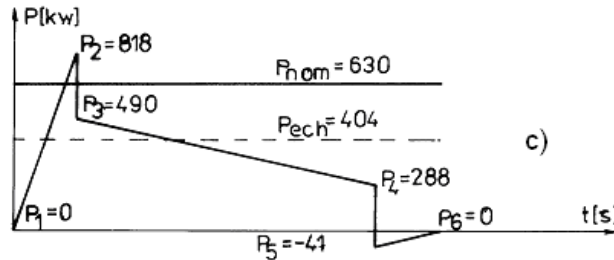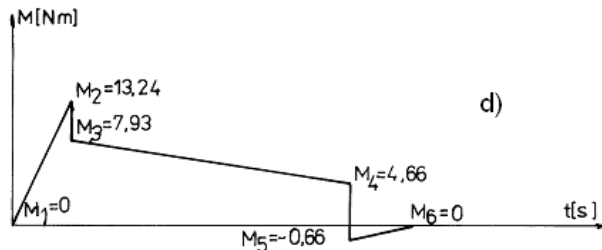Kinematics and dynamics calculations extraction plant were extracted from contract research which aimed at improving the technical and functional parameters of the extraction plants operated asynchronous contract which I was coauthor [5].

3.3. Energy consumption calculation functioning machine rotor resistance extraction steps

We are considering the following parameters that characterize electric drive:
- Nominal torque M_N = 1.229.75 daN;
- Rated slip S_n = 2%;
- Nominal resistance rotor R2N = 1 Ω;
- Rotor resistance, $R_2 = s_N$ x R2N = 0.02 Ω;
- Minimum torque, M_{min} =1.05 M_N = 1,291.22 daN;
- Maximum static force, F_S = 10,588.24 daN;
- Torque resistant, M_{st} = 1,926.02 daN;
- Report, M_{st} / M_N = 1.57;
- Maximum torque M_{max} = 1,755M_N = 2,158.44 daN;

Resistant torque values and maximum starting torque oscillations in the types of transport are given in Table 1.

Resistance values for each step are calculated using:

$$r_i = R_i - R_{i+1},\qquad(14)$$

where i is the step number rheostat.

The results are shown in Table 3.
The total resistance is R_T = 0.897 Ω.

Binding phase two parallel triangles, the total equivalent resistance is $R_{T\Delta}$ = 4.657 Ω.

Resistances on the steps for connecting the star are as follows (see Table 4) [5].

Table 1. **Resistant torque values and maximum starting torque oscillations**

Version	A	B	C	D	E	F	G	H	I	J	K
M_{st}	1964	641	363	806	1351	286	959	653	2530	1798	1464
M_{min}/M_N	1,05	0,30	0,18	0,38	0,65	0,14	0,46	0,31	1,20	0,86	0,70
M_{max}/M_N	1,57	0,51	0,30	0,64	1,08	0,22	0,76	0,52	2,01	1,43	1,17

The values for the total resistance of the rotor circuit of the motor drive of the plant extract are shown in Table. 2.

Table 2. **Resistance of the rotor circuit**

Step	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Value [Ω]	0,917	0,580	0,343	0,231	0,145	0,085	0,052	0,033

Table 3. **Resistance values for each step**

Step	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
Value[Ω]	0,336	0,237	0,112	0,085	0,059	0,033	0,019	0,013

Table 4. **Total resistance values**

Step	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
Equation	$1,4R_{2N}$	$0,5R_{2N}$	$0,3R_{2N}$	$0,2R_{2N}$	$0,12R_{2N}$	$0,07R$	$0,04R_{2N}$	$0,02R_{2N}$
Value [Ω]	1,4	0,5	0,3	0,2	0,12	0,07	0,04	0,02

The total resistance is $R_T = 2.67\ \Omega$.

The equivalent resistance delta binding is $R_{T\Delta} = 4.619\ \Omega$.

Existing total resistance is composed of two branches connected in parallel delta of 9.28 Ω. We obtain a total resistance $R_{T\Delta} = 4.64\ \Omega$.

The operating time is determined on each step bearing in mind that the engine operates on artificial mechanical rheostat. The first feature allows the actual start of the engine, resulting in a slow-motion necessary to carry out the revision of the extraction wire,[2], [5].

Running the engine at a speed of extraction of 5.8 m / s takes place on the fourth stage of resistance at an engine speed of 342 rev / min.

The plant can operate after shorting resistance at a speed of 8.3 m / s.

For the first step of the rheostat, to achieve regime overhaul cable pit mining or choose: $\Delta_{t1} = 0.75$ s.

Intervals between the steps of resistors to meet start time 8 s at a speed of 5.8 m / s are:

$\Delta t_2 = 3.95$ s;

$\Delta t_3 = 2.10$ s;

$\Delta t_4 = 1.20$ s.

The total time between steps will be:

$$\Delta t = \sum_{i=2}^{i=4} \Delta t_i = 7{,}25\ s \qquad (15)$$

Times after which engages every one steps will be:

$\sigma_1 = 0.75$ s;

$\sigma_2 = 4.70$ s;

$\sigma_3 = 6.80$ s;

$\sigma_4 = 8.0$ s.

By means of the above-values are determined by setting time of the time relay. Calculate the time of the relay control for the extraction of plants is based on the kinematics of the system, the start time t1 is given size, unlike the calculation method it is necessary to determine in advance the period of acceleration of the motor according the low moment of inertia of the engine shaft.

The methodology for determining the adjustment times of relays is simplified considerably. Knowing the values of time the gear coupling occurs neighboring rheostat resistance and proper time of the engagement of the contactor, t_k, t_{pi} time setting is obtained by the relationship:

$$tp_i = \sigma_i - t_k \tag{16}$$

Embracing the value of $t_k = 0.15$ s, we obtain the following values:

$t_{p1} = 0.6$ s;
$t_{p2} = 3.2$ s;
$t_{p3} = 2.0$ s;
$t_{p4} = 1.1$ s.

Then it will calculate the currents on each step. To determine the current value of each step of the starting rheostat is necessary to know the relative coupling length and size of the starting current of the rotor.

The relative length of the coupling for each step is $PR_1 = 0.7\%$, $PR_2 = 4\%$, $PR_3 = 6\%$, $PR_4 = 7\%$.

Starting current of the rotor size is calculated knowing the ratio M / MN for each step. Engine mechanical diagram is determined $M_{min} = 1,290.5$ daN and $M_{max} = 2,158.4$ daN and can be considered constant for each step because the variations are small.

The result will therefore:

$$Ip_i = I_2 \cdot \frac{MP_{max\,i}}{Mp_{min\,i}} \ [A] \tag{17}$$

Performing calculations resulting $I_p = 779$ A.

Equivalent amount of current for the rheostat steps is determined by the equation:

$$Ief_i = Ip \cdot \sqrt{PR_i} \ [A], \tag{18}$$

resulting in the following numerical values:

$Ief_1 = 65$ A;
$Ief_2 = 155$ A;
$Ief_3 = 190$ A;
$Ief_4 = 206$ A.

Knowing that at a time of driving DA = 15% of the permitted load resistance is about three times larger than the permissible charging DA = 100%, the steps of stress currents are $I_1 = 22$ A, $I_2 = 52$ A, $I_3 = 63$ A, $I_4 = 69$ A. These currents must be less than the allowable currents of resistance rheostat steps.

Based on the above calculation we made the actual electricity that is lost rheostat rotor circuit of induction motor drive system of extraction. We have the following data:

- Resistance of the rotor circuit at v = 5.8 m / s, $R_2 = 2.225$ Ω;
- Current in the rotor circuit, $I_2 = 330$ A;
- TEF - effective operating time of 24 hours at a speed of 5.8 m/s: - often during a cycle, t = 59 s;
- During a cycle, T0 = 119 s;

- K = 0.75 - coefficient ratio of common and rare regimes or breaks

$$t_{ef} = 24 \cdot \frac{t}{T_0} \cdot K \tag{19}$$

The calculations will result - t_{ef} = 8.93 hours

Energy consumed per day:

$$E = \sqrt{3} \cdot R \cdot I^2 \cdot t_{ef} \tag{20}$$

Substituting the resulting data and performing calculations: E = 3743.3 kWh/day.

Energy consumption per year is calculated by the formula:

$$E_{an} = 300 \cdot E \tag{21}$$

So, we obtain E_{an} = 1,122,990 kWh/year.

For the consumer, the less shift operation or implement a different pricing system, the equivalent energy consumed on the steps rheostat will refresh accordingly [2].

The entire energy consumption resulting from the above calculations will be saved using asynchronous motor drive system powered by an inverter.

4. CONCLUSIONS

A fully digital, vector controlled GTO PWM inverter for driving induction motors has been developed. With the techniques described in this paper, this drive system has enabled the following improvements:

1. High precision torque control.
2. High speed response by current detection without the effect of current ripple and decoupling control.
3. Improvement of reliability and maintainability through full digital control.

This inverter system can be applied to driving a bucket wheel of a bucket wheel excavator in an open pit mine. This inverter allows the process to be entirely operated by ac machines.

REFERENCES

[1]. Bitoleanu, Al., şa. *Convertoare statice.* Infomed Publishing House, Craiova, 1997.

[2]. Chiuţă, I. *Compensarea regimului energetic deformant.* Technical Publishing House, Bucharest, 1989.

[3]. Hashii, K., Kousaka, K. & Kaimoto, M. *New approach to a high power GTO PWM inverter for ac motor drives.* IEEE Trans. Ind. Appl., vol. IA-23, Mar./Apr. 1987.

[4]. Ohsawa, C. & Ohara, M. *A digital control system with grafic language and its applications to variable speed drives.* IEEE Conf. Rec. 1988 IAS Annu. Meeting.

[5]. Marcu, M., Utu, I., Pana, L., Orban, M.D. *Computer Simulation of Real Time Identification for Induction Motor Drives.* Proceedings of the International Conference on Theory and Applications of Mathematics and Informatics - ICTAMI 2004, Thessaloniki, Greece.

[6]. Marcu M., Popescu F., Slusariuc I.R., "*Performance improvement of ac electric drives using field oriented control and digital speed transducers*", Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO, 2012, Petroşani, ISSN 2344-4754.

[7]. Uţu, I. *Reducerea consumului de energie electrică în acţionările electrice de mare putere din industria minieră.* Doctoral Thesis, Petroşani 1998.

[8]. Uţu, I., Stochitoiu M.D., *Reducing electricity consumption at winding machines operated by induction motor using power electronics*, Simpozionului multidisciplinar internaţional UNIVERSITARIA SIMPRO, 2014, Petroşani, ISSN 2344-4754.

BIOMASS – A SOLUTION FOR BUILDING'S HEATING IN A MOUNTAIN AREA

ADRIAN NICOLAE DINOIU [1] **EMIL POP** [2] **IOANA CAMELIA BARBU** [3] **MARIA POP** [4]

Abstract: Systems based on biomass for energy production may increase economic development without contributing to the greenhouse effect, because biomass is not a net emitter of CO_2 into the atmosphere when it is produced and used sustainably. In this paper, we analyzed a bioenergetic system and also implementation issues. The simulation was performed for an educational buildings in a mountainous area. The proposed bioenergy system is combined with one by natural gas used for peak loads. The modeling and simulation performed for this energy system can be customized for different areas where biomass is available.

Key words: biomass, energy, environment, Jiu Valley, mining, modeling, renewable, simulation, mountain.

1. INTRODUCTION

In the atmosphere, human emissions of CO_2 exceed natural fluctuations and these activities have altered seriously the global carbon cycle.[7] Changes in the amount of atmospheric CO_2 have significantly changes for the weather patterns and indirectly influence of the ocean chemistry.[3]

The use of biomass in larger commercial systems based on sustainable resources and waste can help the improvement of the natural resource management. Biomass systems for energy production may increase economic development without contributing to the greenhouse effect, because biomass is a net emitter of CO_2 in the atmosphere when it is produced and used sustainably.[11]

2. BIOMASS

Biomass energy can be a sustainable source, environmentally friendly and economical. The biomass is all vegetal organic materials also participating in carbon cycle, such as plants, trees and the crops that ends its life cycle. Using biomass as a primary source of electricity, means to interrupt the normal carbon in nature by accelerating its development, extracting in a usable form, the energy that would otherwise be emitted to the environment by oxidation.

---

[1] *Ph.D. Assistant lecturer Eng., University of Petrosani*
[2] *Ph.D. Professor Eng., University of Petrosani*
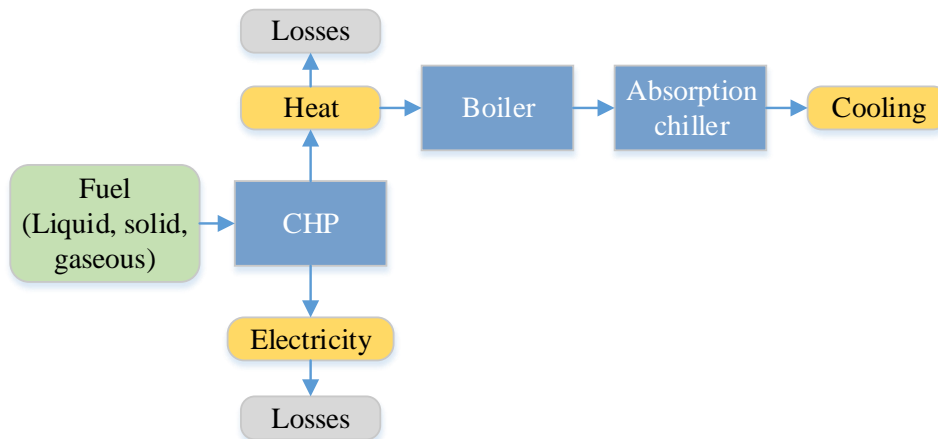[3] *Ph.D. Lecturer Eng., University of Petrosani*
[4] *Ph.D. Professor Eng., University of Petrosani*

Fig. 1. Forest and agricultural biomass

A general scheme of a biomass energy system suitable for the Jiu Valley is shown in Fig. 2, relying on a trigeneration system, where biomass is used to generate electricity, but also heat and cooling, thus high efficiency.

Fig. 2. The general scheme of a trigeneration system [5]

Biomass is the most important source of increasing energy production based on renewable energy. Biomass energy is the conversion of biomass into useful forms of energy, such as heat, electricity and liquid fuels. The biomass assimilates solar energy by photosynthesis.

The main sources of biomass are dedicated energy crops, crop residues generated in food processing, wood industry, and waste. Through conversion process, the biomass is transformed into biofuels liquid, gaseous or solid form. So we get bioenergy from biomass by burning solid biomass, creating steam to set in motion turbines or engines, or using biofuels.

Biomass is a renewable energy source, sustainable and relatively environmentally friendly, is not uncertainty of supply of imported fuels, it reduce

consumption of fossil fuels and biomass fuels have a sulfur content not negligible contribute to sulfur dioxide emissions.

Burning agricultural and forestry residues and municipal solid waste for energy production is an efficient use of waste which significantly reduces waste disposal problem, especially in municipal areas. Biomass provides a clean source of renewable energy that could improve the environment, economy and energy security.

2. MATERIAL AND METHODS - PROBLEM FORMULATION

We wanted to evaluate the feasibility of installing a biomass system, combined with the current with natural gas used for periods when the load reaches a peak. The simulation was performed for an educational building in Petrosani. The city Petrosani is situated near Parang Mountain. The climatic conditions of chosen location can be seen in Fig. 3.

Climate data location		Petrosani	
	Unit	Climate data location	Project location
Latitude	°N	45,4	45,4
Longitude	°E	23,4	23,4
Elevation	m	599	599
Heating design temperature	°C	-11,3	
Cooling design temperature	°C	27,1	
Earth temperature amplitude	°C	21,0	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-1,8	87,7%	1,46	96,0	0,6	-3,8	614	0
February	-0,8	83,6%	2,27	95,8	0,9	-2,4	526	0
March	2,9	80,0%	3,32	95,7	1,3	3,3	468	0
April	8,1	81,2%	4,01	95,3	1,2	10,1	297	0
May	13,0	82,3%	4,94	95,5	1,2	16,0	155	93
June	16,0	83,3%	5,40	95,5	1,2	19,3	60	180
July	17,8	81,5%	5,55	95,6	1,1	21,9	6	242
August	17,2	81,6%	5,07	95,6	1,0	21,9	25	223
Septembe	13,1	83,6%	3,62	95,7	0,9	16,6	147	93
October	8,5	84,6%	2,48	96,0	1,0	10,1	295	0
November	2,6	85,9%	1,51	95,9	0,8	2,9	462	0
December	-0,9	90,4%	1,16	96,0	0,5	-2,6	586	0
Annual	8,0	83,8%	3,41	95,7	1,0	9,5	3.641	831
Measured at	m				10,0	0,0		

Fig. 3. Climatic conditions of the location

RETScreen ® International[12] is a standardized software and integrated for analysis of renewable energy projects. It can be used to evaluate the energy production, life circuit costs and the reduce emissions of greenhouse gases for different renewable energy technologies.

3. EXPERIMENTAL – PROBLEM SOLUTION

In the reference system, the heating is done using a plant operating on natural gas and in the proposed system, the heating will be using a wood biomass power plant.

The building has two parts, so we split the building into two parts. The building has 5 floors with a total area of approximately 9000 m^2 (Fig. 4), where are about 310 people. The maximum load that we took into account is 605 kW (Fig. 5).

RETScreen Load & Network Design - Heating project

Heating project	Unit		Building zones	
			1	2
Base case heating system		Single building - multiple zones - space heating		
Heated floor area per building zone	m²	9.000	6.200	2.800
Fuel type			Natural gas - m³	Natural gas - m³
Seasonal efficiency	%	-	65%	65%
Heating load calculation				
Heating load for building zone	W/m²	-	75	50
Domestic hot water heating base demand	%	10%		
Total heating	MWh	1.512	1.162	350
Total peak heating load	kW	605	465	140
Fuel consumption - unit		-	m³	m³
Fuel consumption - annual		-	189.466	57.043
Fuel rate - unit		-	€/m³	€/m³
Fuel rate		-	0,350	0,350
Fuel cost	€	86.278	€ 66.313	€ 19.965
Proposed case energy efficiency measures				
End-use energy efficiency measures	%	0%	0%	0%
Net peak heating load	kW	605	465	140
Net heating	MWh	1.512	1.162	350

Fig. 4. The reference case of heating project

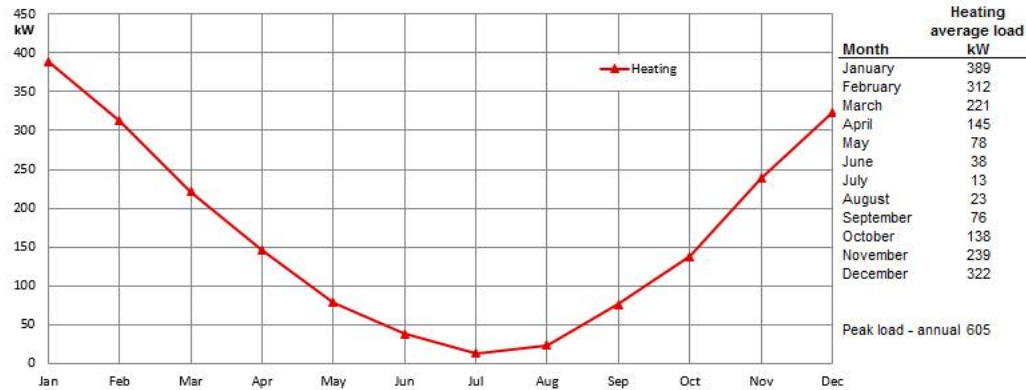| Month	Heating average load kW
January	389
February	312
March	221
April	145
May	78
June	38
July	13
August	23
September	76
October	138
November	239
December	322
Peak load - annual	605

Fig. 5. Proposed case system load characteristics graph

One aspect of this simulation is the importance of improving energy efficiency in buildings and investing in sustainable technologies.

It also represents a starting point in the development of other projects with woody biomass heating in the area. Funds for the development of these projects can be obtained from the European Commission, the Ministry of Education or Ministry of Environment.

RETScreen Energy Model - Heating project

Proposed case heating system			
System selection		Base load system	
Base load heating system			
Technology		Biomass system	
Fuel selection method		Single fuel	
Fuel type		Biomass	
Fuel rate	€/t	100,000	
Biomass system			
Capacity	kW	300,0	49,6%
Heating delivered	MWh	1.379	91,2%
Manufacturer		Dan Trim	
Model		Uzual	
Seasonal efficiency	%	70%	
Boiler type		Hot water	
Fuel required	GJ/h	1,5	

Fig. 6. The energy model of the proposed heating project

80

The biomass heating system is based on a boiler with an output of 300 kW (Fig. 7a) to meet the basic needs of the heating of the two dormitories.

The boiler is produced by DanTrim Ltd. and it can be supplied with different woody biomass, such as sawdust, pellets, wood chips.
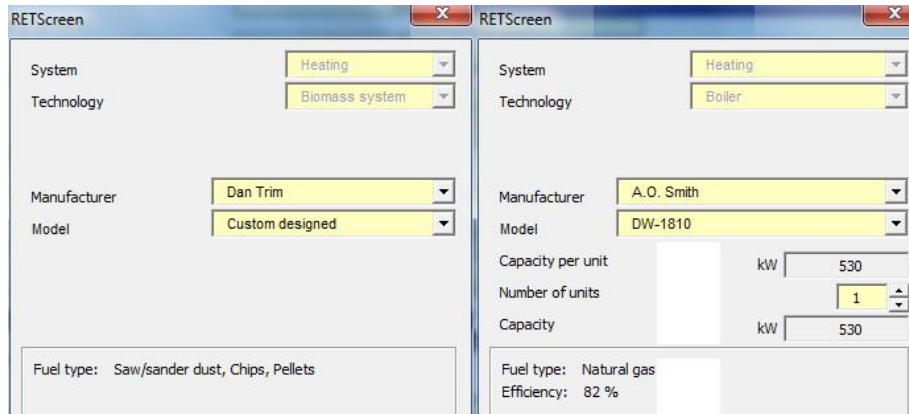

Fig. 7. a) Biomass heating system   **b)** Natural gas heating boiler

A reserve system based on natural gas of 530 kW (Fig. 7b) is used to cover periods when load peaks are recorded, or in case of failure of the main system. As shown in Figure 3, the main system can meet the heating load for most of the year, without the secondary. For the winter months and coldest days, but mostly to have energy security, we need the both systems.

Proposed case system characteristics	Unit	Estimate	%
Heating			
Base load heating system			
Technology		Biomass system	
Capacity	kW	300,0	49,6%
Heating delivered	MWh	1.379	91,2%
Peak load heating system			
Technology		Boiler	
Fuel type		Natural gas - m³	
Fuel rate	€/m³	0,340	
Suggested capacity	kW	305,0	
Capacity	kW	530	87,6%
Heating delivered	MWh	132,9	8,8%
Manufacturer		A.O. Smith	See PDB
Model		DW-1810	1 unit(s)
Seasonal efficiency	%	65%	
Back-up heating system (optional)			
Technology			
Capacity	kW	0,0	

Fig. 8. Proposed case system characteristics

The biomass that will supply the energy system will be stored in a silo built specifically for this task and will be supplied as needed. Being a mountain area, logging is one of the economic activities in the area. There are sawmills and factories dealing with wood and using only some parts of the wood collected from the forest. Waste wood can be obtained from them and used for this biomass heating system, even at a very low price.
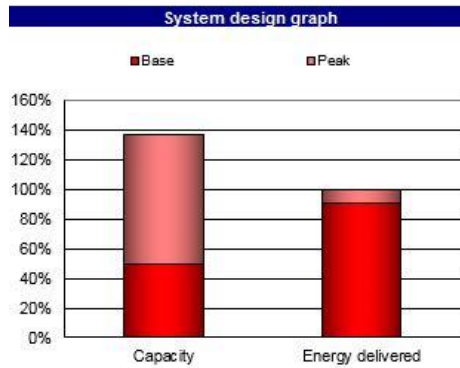
Fig. 9. System design graph

The amount of wood available can be increased if takes into account the planting of energy crops with short rotation time. If the type of the waste is unknown, it is assumed average heating value and moisture content of about 40%.

4. RESULTS AND DISCUSSION

The biomass that will supply the energy system will be stored in a silo built specifically for this task and will be supplied as needed.

Project costs and savings/income summary				Yearly cash flows			
Initial costs				Year	Pre-tax	After-tax	Cumulative
Feasibility study	3,9%	€	4.000	#	€	€	€
Development	3,9%	€	4.000	0	-20.372	-20.372	-20.372
Engineering	6,9%	€	7.000	1	25.075	25.075	4.703
				2	25.820	25.820	30.523
Heating system	71,1%	€	72.400	3	26.579	26.579	57.102
				4	27.353	27.353	84.455
				5	28.143	28.143	112.598
				6	28.949	28.949	141.547
Balance of system & misc.	14,2%	€	14.460	7	26.325	26.325	167.872
Total initial costs	**100,0%**	**€**	**101.860**	8	30.609	30.609	198.481
				9	31.464	31.464	229.945
				10	32.336	32.336	262.282
				11	45.370	45.370	307.652
Annual costs and debt payments				12	46.278	46.278	353.929
O&M		€	3.960	13	47.203	47.203	401.132
Fuel cost - proposed case		€	45.829	14	44.189	44.189	445.321
Debt payments - 10 yrs		€	12.144	15	49.110	49.110	494.431
Total annual costs		**€**	**61.933**	16	50.092	50.092	544.523
				17	51.094	51.094	595.617
Periodic costs (credits)				18	52.116	52.116	647.733
User-defined - 7 yrs		€	3.000	19	53.158	53.158	700.892
				20	54.221	54.221	755.113
				21	50.759	50.759	805.872
				22	56.412	56.412	862.284
Annual savings and income				23	57.540	57.540	919.824
Fuel cost - base case		€	86.278	24	58.691	58.691	978.515
				25	59.865	59.865	1.038.380
Total annual savings and income		**€**	**86.278**				

Fig. 10. Financial analysis

Being a mountain area, logging is one of the economic activities in the area. There are sawmills and factories dealing with wood and using only some parts of the wood collected from the forest. Waste wood can be obtained from them and used for this biomass heating system, even at a very low price.

The amount of wood available can be increased if takes into account the planting of energy crops with short rotation time. If the type of the waste is unknown, it is assumed average heating value and moisture content of about 40%.

For the financial analysis (Fig. 10) and cost analysis (Fig. 11), we used the typical financial figures provided by the database software: an inflation rate of 2%, debt ratio of 80%, debt rate 8%, discount rate of 9% and a debt within 10 years. The heating is presumed to last 25 years.

RETScreen Cost Analysis - Heating project

Initial costs (credits)	Unit	Quantity	Unit cost		Amount		Relative costs
Feasibility study							
Feasibility study	cost	1	€	4.000	€	4.000	
Subtotal:					€	4.000	3,9%
Development							
Development	cost	1	€	4.000	€	4.000	
Subtotal:					€	4.000	3,9%
Engineering							
Engineering	cost	1	€	7.000	€	7.000	
Subtotal:					€	7.000	6,9%
Heating system							
Base load - Biomass system	kW	300,0	€	200	€	60.000	
Peak load - Boiler	kW	530,0			€	-	
Energy efficiency measures	project				€	-	
Appliances & equipment - credit	credit	126	€	100	€	(12.600)	
Spare parts	cost	100	€	250	€	25.000	
Subtotal:					€	72.400	71,1%
Balance of system & miscellaneous							
Spare parts	%				€	-	
Transportation	project	1	€	1.000	€	1.000	
Training & commissioning	p-d	20	€	60	€	1.200	
User-defined	cost	50	€	60	€	3.000	
Contingencies	%	10,0%	€	92.600	€	9.260	
Interest during construction	0,00%	6 month(s)	€	101.860	€	-	
Subtotal:					€	14.460	14,2%
Total initial costs					€	101.860	100,0%

Annual costs (credits)	Unit	Quantity	Unit cost		Amount	
O&M						
Parts & labour	project	100	€	20	€	2.000
User-defined	cost	1	€	1.600	€	1.600
Contingencies	%	10,0%	€	3.600	€	360
Subtotal:					€	3.960
Fuel cost - proposed case						
Natural gas	m³	21.668	€	0,340	€	7.367
Biomass	t	385	€	100,000	€	38.462
Subtotal:					€	45.829

Annual savings	Unit	Quantity	Unit cost		Amount	
Fuel cost - base case						
Natural gas	m³	246.509	€	0,350	€	86.278
Subtotal:					€	86.278

Periodic costs (credits)	Unit	Year	Unit cost		Amount	
User-defined	cost	7	€	3.000	€	3.000
					€	-
End of project life	cost				€	-

Fig. 11. Cost Analysis

The cost of energy is expected to grow at the same rate as inflation. The price of wood biomass is estimated at 100 euros/tone, but for large quantities and for a longer period, it can be negotiated. The cost of natural gas is calculated at 0.34 euro/m^3.

Another advantage of such a power system is the use of local labor, use of nearby resources, with benefits for the entire community.

Reduction of greenhouse gas emissions (Fig. 12), is also a strong point of this type of heating systems, with positive effects for the whole community. On globally is trying to reduce emissions of greenhouse gases, so that energy projects should take very much into account the emissions analysis. Intensive use of fossil fuels has affected the Earth's atmosphere, and the effects are beginning to see growing sharper.

RETScreen Emission Reduction Analysis - Heating project

☑ Emission Analysis

					Global warming potential of GHG		
○ Method 1							
◉ Method 2					25 tonnes CO2 = 1 tonne CH4		(IPCC 2007)
○ Method 3					298 tonnes CO2 = 1 tonne N2O		(IPCC 2007)

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Natural gas	100,0%	54,5	0,0040	0,0010	2.327	0,197	459,5

Proposed case system GHG summary (Heating project)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Natural gas	9,4%	54,5	0,0040	0,0010	205	0,197	40,4
Biomass	90,6%	0,0	0,0320	0,0040	1.971	0,007	14,1
Total	100,0%	5,1	0,0294	0,0037	2.175	0,025	54,5

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2		GHG emission reduction tCO2	GHG credits transaction fee %	GHG emission reduction tCO2
Heating project	459,5	54,5		405,0	0%	405,0
Net annual GHG emission reduction	405	tCO2	is equivalent to 74,2	Cars & light trucks not used		

Fig. 12. The emission reduction analysis

This analysis can be extended and applied to other buildings where teaching activity takes place. Also, the local authorities can benefit from this simulation and can perform similar simulations for the city education units or other public institutions or private. By accessing European funds or national funds having as the starting point this type of simulation can be performed on biomass energy systems or other types of renewable energy, thus lead to substantial savings but also at durable and sustainable development of these projects, the resource management and an increase in revenue.

5. CONCLUSIONS

Both in Romania as well as worldwide, it is necessary to develop full waste recovery technologies. Also, an effective analysis of land use and technologies for energy crops in order to not affect the adjacent ecosystems.

For the environmental impact assessment, studies and scenarios are required. Must be used the degraded lands where you can grow energy crops. Studies should include an assessment of the economic impact and the introduction of incentives for producers.

In conventional electricity generation the losses associated with the transmission and distribution of electricity are due to the distance from the power plant. Cogeneration and trigeneration units, reduce these losses, because they are located close to the consumers, thereby, increasing the distribution efficiency.

Considering the fact that cogeneration or trigeneration unit has a single fuel source and uses waste heat, occurs also a fuel efficiency. An important aspect is the reduction of greenhouse gas emissions, even when is using natural gas instead of coal.

For efficient use of biomass should be considered the availability of the resources, in order to determine access and resources seasonality. Geographical factors such as weather conditions, indicates the temperature and water availability in each area and if this area may be covered by biomass. Also, the profitability of biomass as an energy source will depend upon the market prices at any time.

Development and exploitation of forest biomass generates an environmental impact through a series of social and economic effects.[9] The introduction of a species in one location can affect the surrounding flora and fauna. Also, we should not forget some of the main objectives of renewable energy, reduce global warming and CO_2 emissions to the atmosphere by burning fossil fuels. Effect on soil nutrients is an important aspect, which may question the sustainability of this type of exploitation.[10]

A well-fitting legal framework to improve forest management, promoting bio-energy system and state of sustainability criteria and durability.

Biomass in the form of solid and gaseous fuels continue to be the primary source for heat produced from renewable sources. In Europe, biomass is being used even more in district heating systems. Another increasing trend is the use of biomethane, which is obtained by purification of biogas, which can be injected directly into the gas grid and used to produce electricity, heat and fuel.

Biomass present challenges are the development of biomass conversion technologies and research into the effects of these processes and reduce of production costs and an increase in efficiency.

REFERENCES

[1]. **Barbu I. C, Pop E., Leba M.** - *Microsisteme energetice durabile regenerative*, Editura Didactica şi Pedagogică, Bucureşti, 2009.

[2]. **Ciolea D.I., Dunca E.C.** - *Issues concerning the best available techniques for combustion of solid fuels*, Annals of the University of Petrosani, Mining Engineering, 11, 2010, ISSN 1454-9174.

[3]. **Crowley T. J.** - *Causes of Climate Change Over the Past 1000 Years*, Science 289 (5477), ISSN 00368075, 2000.

[4]. **Dinoiu A., Barbu C., Pop M.** - *Modelling and Simulation of Wind Turbines in Southern Carpathians*, Proceedings of 7th WSEAS International Conference on Renewable Energy Sources (RES '13), April 2013, Kuala Lumpur, Malaysia, ISSN 2227-4359.

[5]. **Dinoiu A.N., Pop E., Barbu I.C.** - *Modeling and simulation of a bioenergy system for Campus of the University of Petrosani*, SIMPRO 2014, Petroşani.

[6]. **Dunca E., Ciolea D.** - *Composting of the Green Waste Also its Use under the Ecological Reconstruction of Waste Dumps*, WSEAS International Conference Recent Advances in Energy, Environment and Geology NEGIC-14, Antalya, Turkey 2013, ISBN: 978-960-474-338-4.

[7]. **Falkowski P. et al.** - *The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System*, Science 290 (5490), 2000.

[8]. **M.D. Marcu, F.G. Popescu, L. Pana, I. Stepanescu, R. Slusariuc**, *Modeling and simulation of solar radiation.* 2014 3rd International Conference on Nanotechnology Technology and Advanced Materials (ICNTAM 2014), Dubai, UAE 1-2 October, 2014

[9]. **Zobaa A. F., Ramesh C. B.** - *Handbook of Renewable Energy Technology*, World Scientific Publishing Company, 2011.

[10]. www.biomassenergycentre.org.uk

[11]. www.discovery.org.in/PDF_Files/ds_20121203.pdf

[12]. www.retscreen.net

MECHANICAL HANDLER DRIVEN BY A WIN_PLC _7 PROGRAM

STELIAN VALENTIN CASAVELA[1], ANTONIO CASAVELA[2], CRISTOFOR CASAVELA[3]

Abstract: We used the STL,FBD, LAD as programming languages, in a WIN_PLC _7 (Siemens) programming environment for a simulation driving of a mechanical handler We completed the program much quicker with the so called sequencer wizard, offered by WIN_PLC_7 environment, which creates a basic framework for our PLC program. The sequences are generated in functions (FC or FB), edited in STL, FBD or LAD. So called flags or data bits, from a data block, are the addresses for steps. The flags are for FC and the data bits are for FB, with instance data blocks. An EMERGENCY-OFF switch or a CONTROL SYSTEM ON/ CONTROL SYSTEM OFF mechanism could have been used.

Keywords: sequencer, network, reset, table of conditions, symbol table, ControlSystem.

1. INTRODUCTION

1.1. The using of "sequencer"

As requirement, for to use a sequencer, after the installation of WIN_PLC _7 , we had to empty the project, i.e. no blocks in it. After that:

a) Open "Extras/Sequencer wizard /Settings" tab (see later the images). We may employ "flags" or "data blocks" as the memory for steps (step address). Then, if it is needed, it ticks the check box "Use emergency off switch". If required, it ticks the box "Use Control system ON/OFF'".

b) It ticks "Sequencer" tab and "New step" for obtaining steps for our driven mechanical handler. In the region of "Settings of the step", we define the title of network, comments about it and the "Conditions for the step": name.

c) It ticks "Symbols" tab and the button "Create symbol table". We are given all the addresses employed in the sequencer. We let unchanged the symbol names and we changed the comments about symbols.

d) It ticks "Create sequencer" tab and selects a representation (STL, FBD, LAD). The representation may be changed even in the block. It ticks "Create sequencer" to create the necessary blocks.

---

[1] *PhD lecturer, University of Petrosani*

[2] *Dr., Municipal Hospital of Timisoara*

[3] *Dr., Municipal Hospital of Timisoara*

What we are remain to done is to reset all variables, in the last step, and to assign the step addresses (flags or data bits) to the outputs.

1.2. Identification of the system which uses a mechanical handler. A mechanical handler arm has to transporte a box, by lifting it up, from left side, to right side. To begin the system cycle, let us start the "Control-IsOn" mechanism in the PLC program, by pushing the "ON" button. The led "Control is on" is turned on. The proper process is started when the "Start" button is pressed.
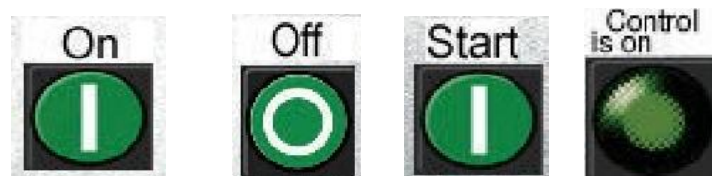
Fig.1. The control panel

The PLC programming is created for the next given technology scheme, using the sequencer wizard:

Fig. 2. The technology scheme

1. Tick Start , the mechanical handler is left-down.
2. Grip box;
3. Raise mechanical handler and box;
4. Move mechanical handler and box to right;
5. Lower the mechanical handler and box;
6. Open mechanical handler (the box is released down);
7. Raise up mechanical handler;
8. Bring mechanical handler to the left starting position. [5]

Going from this, we created the next assignment table:

Address	Assigned to
I0.0	Control system **ON** button (NO contact)
I0.1	Control system **OFF** button (NC contact)
I0.2	Start button (NO contact)
I0.6	Top stop position (S1)
I0.7	Bottom stop position (S2)
I1.0	Left stop position (S3)
I1.1	Right stop position (S4)
I1.2	Gripper open (S5)
I1.3	Gripper closed (S6)
Q4.0	Move gripper to the right
Q4.1	Move gripper to the left
Q4.2	Move gripper to the bottom
Q4.3	Move gripper to the top
Q4.4	Open gripper
Q4.5	Close gripper
Q4.6	"Control is on" lamp

NO means normally open and NC means normally closed.
The steps in the sequencer follows:

Step No.	Step description	Condition
Step 1	Gripper moving down	Start button: **A I 0.2**
Step 2	Close gripper	Gripper at bottom position: **A I 0.7**
Step 3	Gripper moving up	Gripper closed: **A I 1.3**
Step 4	Gripper moving right	Gripper at top position: **A I 0.6**
Step 5	Gripper moving down	Gripper at the right limit: **A I 1.1**
Step 6	Open gripper	Gripper at lower stop position: **A I 0.7**
Step 7	Gripper moving up	Gripper is open: **A I 1.2**
Step 8	Move gripper to the left home position	Gripper at top stop position: **A I 0.6**

Fig. 3. Table of conditions

Now, when all the required information have being purchased, those can inputted in the sequencer wizard for creating a new project (our case), or a new solution.

2. THE SEQUENCER WIZARD USING

2.1. The Sequencer Wizard steps.

We select menu item Extras->Sequencer Wizard. We remove the tick mark from "Use emergency off switch" in the "Settings" tab, since the project needs not make use of an emergency off switch. We shall write the addresses for Control system ON/OFF and the figure looks like:
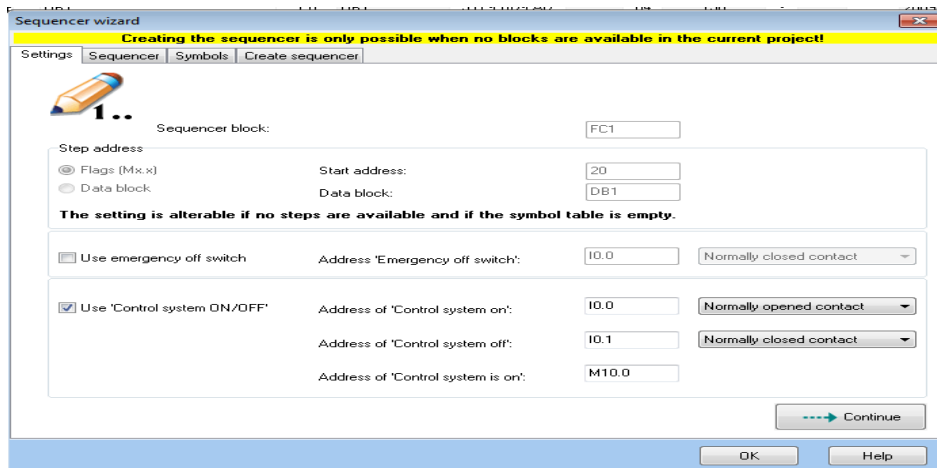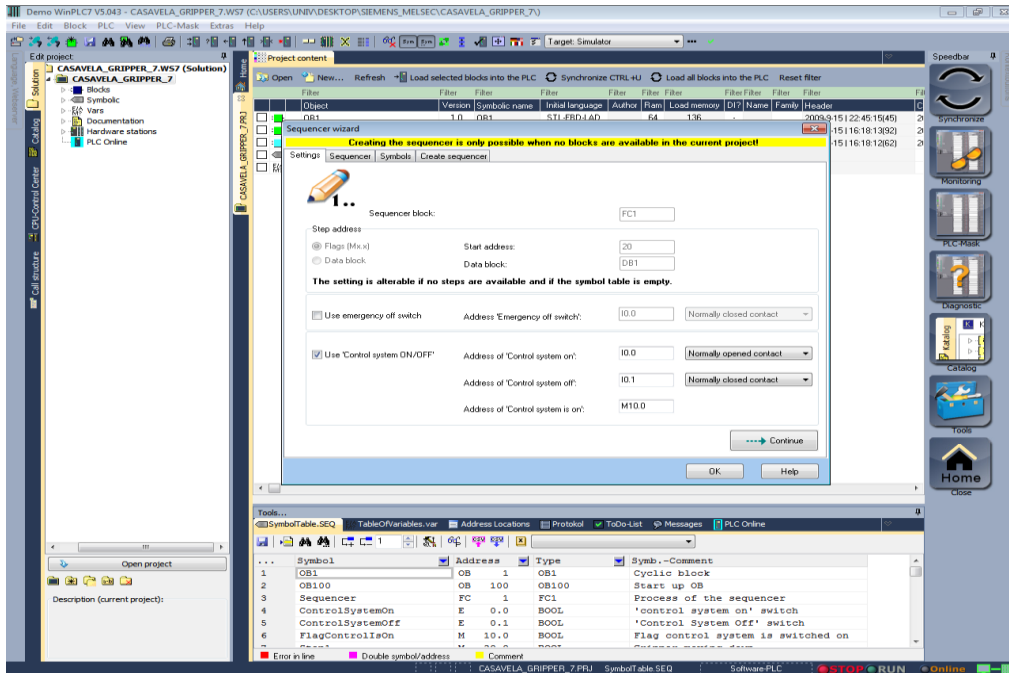
Fig. 4. Sequencer setting tab

We may tick the "Continue" button, or Sequencer tab, to pass to the next tab. An amount of 8 steps must be performed in the "Sequencer" tab employing button "New step". Then, in each step, we define the settings of the step. Each step must be related to a condition. The STL condition is taken from the "table of conditions"-fig 3, shown on the previous page. We can also write a significant text for the title of the network and the network comment.

Fig. 5. Step 1, 2 …7,8**.**

2.2. Create Symbol Table and Sequencer Project.

We now create symbols in the "Symbols" tab by ticking of the button "Create symbol table" or by modifying the required symbols, as well as the symbol comments.
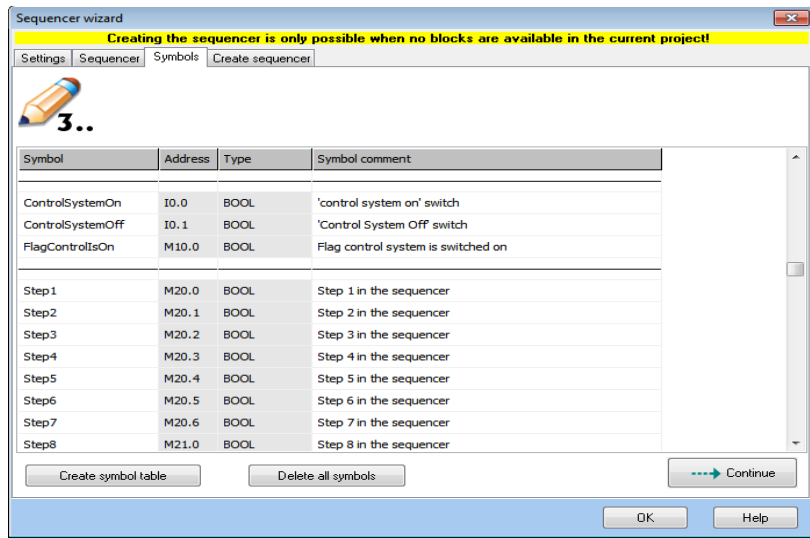
Fig.6. Symbols inputting

Now we can tick the type of representation used to create the program in the "Create sequencer" tab. Click the "Create sequencer" button for transferring blocks to the new project. The blocks are created in Project Content Window:
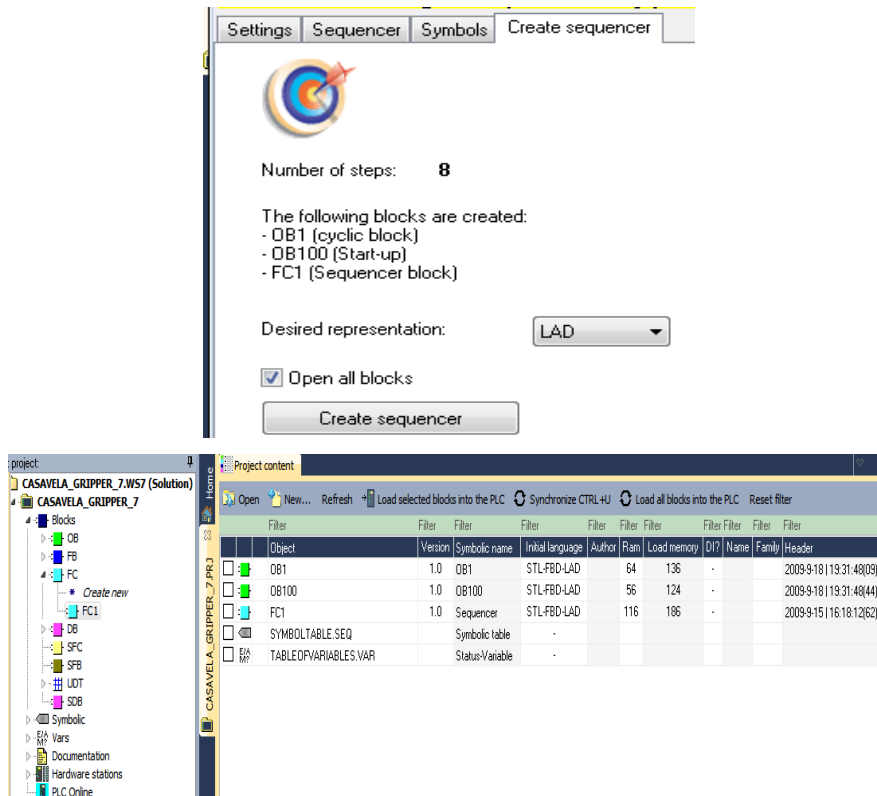
Fig. 7. Project creating

At last, the symbols for inputs must be added into the symbolic table:
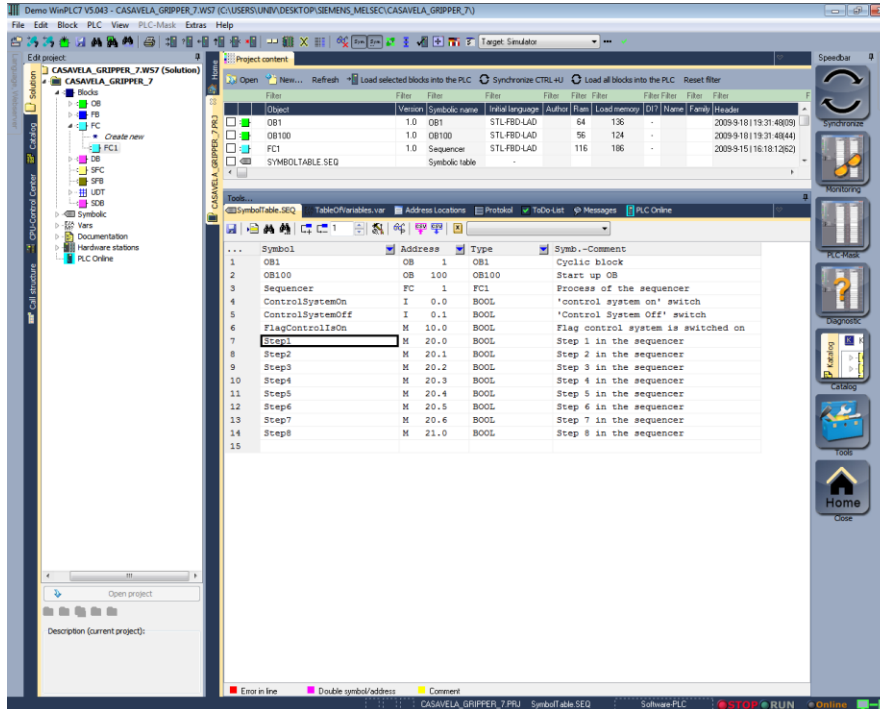
Fig. 8. Symbols for inputs

In "Network 1" of OB1 the "ControlSystem" is turned on and in "Network 2" a call is issued to block "FC1".
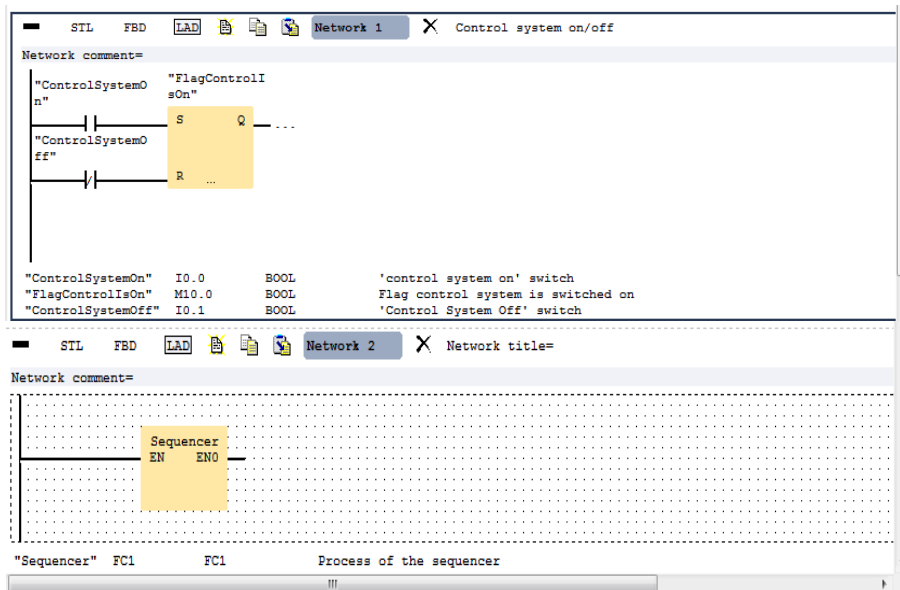
Fig. 9. Network 1 and Network 2

94

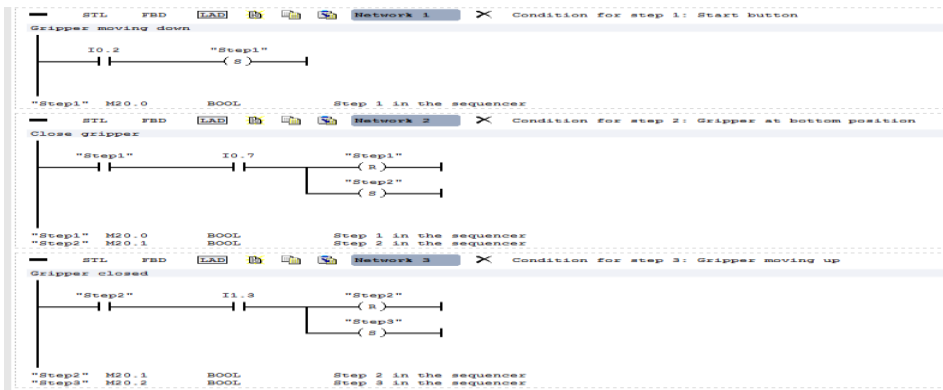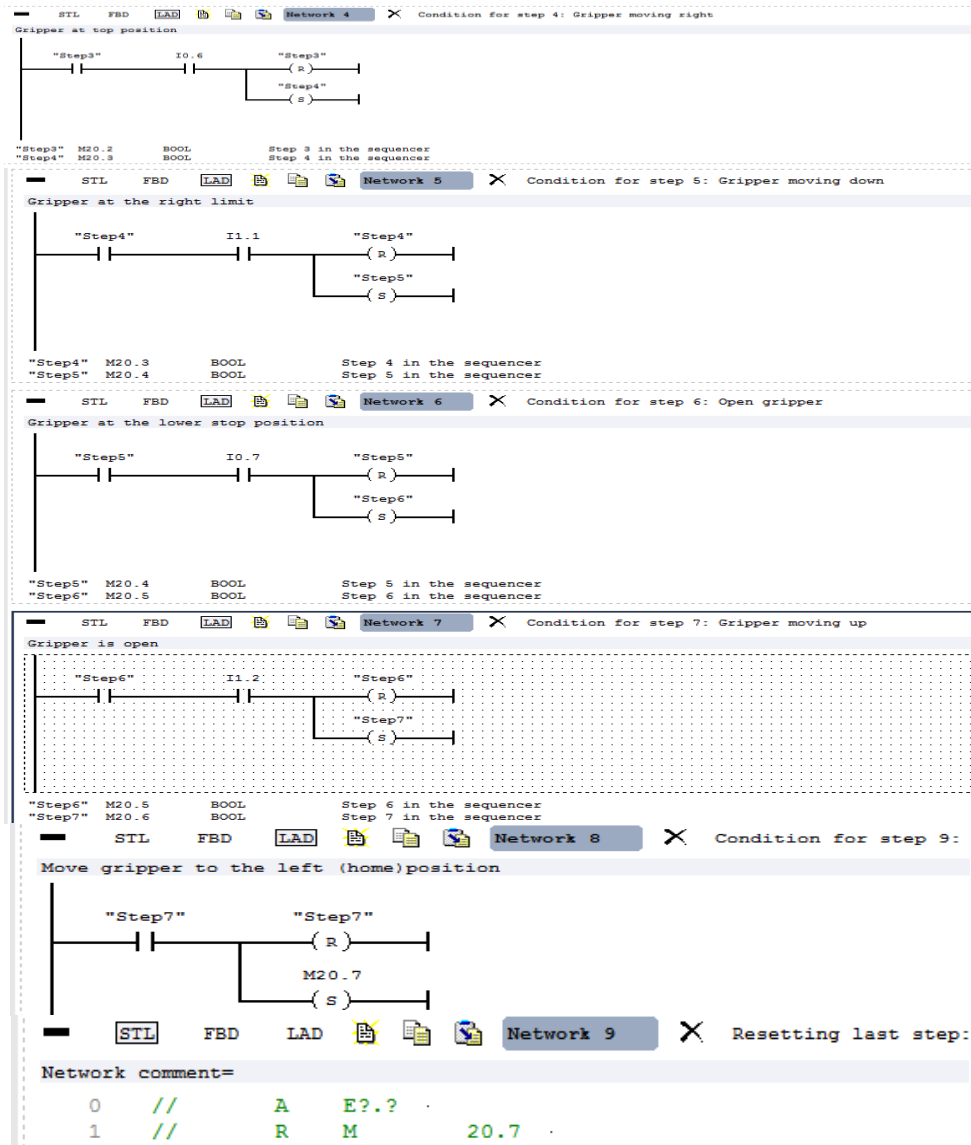The program is reset in the restart of object OB100:
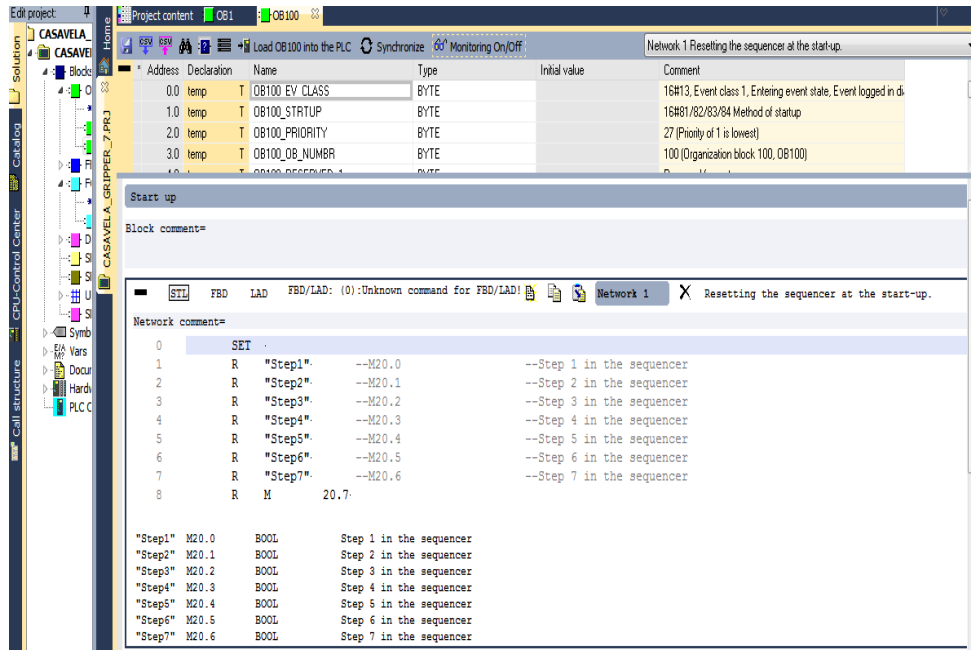
Fig.10. Object OB100 of program

2.3. Creating of the own Program

In the Sequencer Project, only Network 9 and Network 11 were changed and all the other networks are used directly in how they were designed by the sequencer. The actual sequencer is contained in Network 1…8 of FC1.
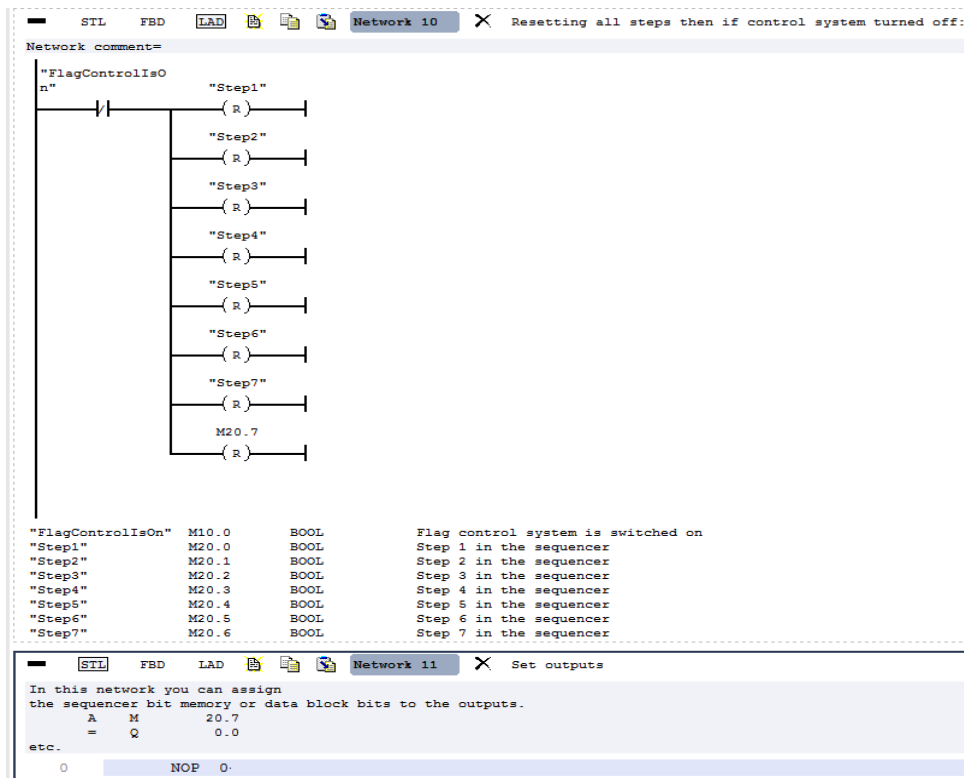
Fig. 11. Function FC1 of the Project

REFERENCES

[1]. Pătrăşcoiu N., Barbu I.C., *Processing the data acquired from potentially explosive atmosphere*, Annals of University of Petrosani, Electrical Engineering, Vol. 15, pag.47-52, Petroşani, 2013, ISSN 1454-8518, Ed. Universitas.

[2]. Pătrăşcoiu N., Tomuş A.M., *Angular speed measurement using fpga technology*, Annals of University of Petrosani, Electrical Engineering, Vol. 13, pag.71-76, Petroşani, 2011, ISSN 1454-8518, Ed. Universitas.

[3]. Samoila B. L., Popescu F. G., Slusariuc R., *Virtual instruments used in direct current circuits learning process.* Annals of University of Petrosani, Electrical Engineering, Vol. 15, pag.47-52, Petroşani, 2013, ISSN 1454-8518, Ed. Universitas.

[4]. Samoila B. L., Marcu M. D., Popescu F. G., *Equipment Designed to Control a Heating Hybrid System with Solid Fuel Boiler and Solar Panels*, Proceedings of the 7th International Conference on Renewable Energy Sources (RES '13), Proceedings of the 1st International Conference on Environmental Informatics (ENINF '13) Kuala Lumpur, Malaysia April 2-4, 2013, pag. 106-111, ISSN: 2227-4359, ISBN: 978-1-61804-175-3.

[5]. Marcu M., Popescu F., Slusariuc I.R., "*Performance improvement of ac electric drives using field oriented control and digital speed transducers*", SIMPRO, Petroşani, 2011

[6]. http://www.scribd.com/doc/209692479/Manual-Winplc7

[7]. http://biblioteca.regielive.ro/cursuri/electrotehnica/programarea-controlerelor-germane-vipa-si-simatic-189737.html

[8]. www.vipa.com/

AN OVERVIEW ON ELECTRONIC THERMOSTATS

GABRIEL N. POPA[1], IOSIF POPA[2], CORINA M. DINIŞ[3], ANGELA IAGĂR[4]

Abstract: The paper presents four application types, made with electronics components and with PLC, that perform the function of thermostat. The first two applications were made with electronic components, integrated circuits, and thermistors. The last applications were made with CPU 224 PLC, extension modules EM 231 RTD, EM 235, Pt 100 thermo-resistance, and operator interface TD 200 (Siemens). It can view on the operator interface TD 200: current temperature, maximum temperature and minimum temperature that exceeded the setting values of temperature. The article presents, also, a comparative analysis between the two PLC programs.

Key words: sensor, temperature, measure, text display, PLC.

1. INTRODUCTION

Temperature measurements are based on different physical effects caused by temperature variation. The most important of these are: expansion of solids, liquids or gases, the change in electrical resistance, electromagnetic force at the junction of two metals, the intensity of the emitted radiation, change in resonant frequency of a crystal, etc. The usual temperature range can be considered between 0 ... 20000 K, in general, or 0 ... 5000 K in most industrial, scientific, etc. This is an extremely broad range that can't be covered by any type of the known temperature sensors. Other important parameters are: measurement accuracy, size, sensitivity, stability, response time.

Process control must be carried out with the help of electronic devices that provide stability, accuracy and decreases the length of the transient processes [1,4,6,8].

As a result of the rapid development of technology, many of the problems have been solved through the use of PLCs, and possibly through the use of a PC for supervision. By using PLCs shrinks the number of connections between devices (displays, motors, sensors, switches, valves, etc.) and there is the possibility of using communication tools, thus ensuring a high level of service and high flexibility in controlling processes [7-9,14]. In automated systems, PLCs represent the main part of the management and control of the process. Through the execution of a program stored

---

[1] Ph.D., Assoc. Professor Eng., Politehnica University Timişoara

[2] Ph.D., Assoc. Professor Eng., Politehnica University Timişoara

[3] Ph.D.,Lecturer Eng., Politehnica University Timişoara

[4] Ph.D.,Lecturer Eng.,Politehnica University Timişoara

in the program memory, PLCs monitors the status of the process by the signals received from the input devices. By building the program, PLCs determines actions on output devices. In the case of more complex processes it is possible to connect several PLCs from a PC [5,15].

Automatic management of industrial processes can be done with general purpose PLCs type, and, also, with specialized PLCs type. Examples of specialized PLCs for industrial processes may be: automation equipment for boilers and heating installations in buildings, control and signal equipment for the detection and alarm, fire detection, driving pumping stations and water supply of communities, etc. The operative part orders send command to the system and to the operative information about evolution is collected under orders sent [2,3].

In the paper are presented four applications made with electronic components, integrated circuits and PLC for the temperature measurement and adjustment of low temperature industrial furnaces. The first application uses NTC thermistor to measure the temperature, operational amplifiers, trigger Schmitt circuits and relays at the output of the thermostat. The third application, uses CPU 224 PLC [12], extension module EM 231 RTD (specialized for thermo-resistance connection) [14], TD 200 operator interface [13] and thermo-resistance Pt 100 [17]. The last application, use the extension module EM 235 (with four analogue inputs and one analogue output, 12 bit conversion); it is use in applications only one input and one analogue output [14]. The analogue output is used to inject a constant current (regardless of the temperature) through Pt 100. Due to the change in temperature will change the voltage on Pt 100 that will be measured with the analogue input module. For the last application, the program is complicated because it converts the measured voltage on the temperature displayed into TD 200 operator interface.

2. ELECTRONICS THERMOSTAT

Thermistors are temperature-sensitive semiconductor device whose resistance varies greatly with temperature. Most types of thermistors have a negative temperature coefficient (NTC type). Thermistors are manufactured from mixtures of oxides of nickel, manganese, cobalt, iron, magnesium, titanium and other metals, sintered at temperatures above 1000 °C. If R_0 is resistance of the thermistor to a certain initial temperature T_0 (273.15 K), the R_T is resistance of the thermistor at unknown temperature T [K] can be compute with the relation [9]:

$$R_T = R_0 \cdot e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$ (1)

where B [K] is a constant of thermistor that depends on the material of the thermistor material. Thermistors are useful in the -70 to +200 °C, and the time constant is between a few tenths of seconds to a few seconds. Compared to thermo-resistances (RTD) have the following advantages:
- 10 times higher sensitivity;
- high initial resistance, resistance giver error connecting wires are smaller and ensures easy adaptation of impedance circuit;
- small size.

Thermo-resistances (RTDs) are based on variations in electrical resistivity depending on temperature of metals. Platinum, nickel, copper, and tungsten are now widely used for making RTDs. Other metals such as iridium, rhodium, silver, iron, and tantalum are used in special applications. RTDs can be used to measure the temperature between -180 ... 1000 °C, with an accuracy typically 0.1 ... 1 °C, but can be reaches, for special RTDs up to 0.002 °C. Their response time is relatively short. The dependency between resistance and temperature is given by:

$$R_T = R_0 \cdot \left[1 + a \cdot (t - t_0) + b \cdot (t - t_0)^2 \right] \qquad (2)$$

where R_t [Ω] is resistance of RTD at temperature t [°C], R_0 [Ω] is resistance of RTD at temperature $t_0 = 0$ °C, and a [1/°C] and b [1/(°C)^2] are coefficients of material.

Electronic thermostats have great applicability they can successfully replace conventional electric thermostats. Some examples of using electronic thermostats are:
  - Apartment boilers where the thermostat serves to maintain the temperature of the room to a set value;
- Protection of a power semiconductor element (transistor, thyristor, triac), the thermostat can control pulses interrupt the power element if its radiator temperature increases accidentally;
- Protection of intelligent integrated circuits (IC), where the thermostat is integrated into the same capsule that protects the circuit.

Basically, an electronic thermostat consists of the following functional blocks: sensors, amplifying stage and output stage.

For thermostat from Fig.1, as a temperature sensor, a NTC thermistor may be used, or one or more diodes connected in parallel. The use of a diode as a temperature sensor, is based on the fact that the voltage across it increases or decreases depending on the temperature.

Amplification stage can be achieved with operational amplifiers (eg. βA 741, LM 324 N), or transistors connected in various ways (eg. Darlington, common-emitter, differential connections). The output stage is adopted according to the terms and conditions that will be used thermostat, for example:
- The thermostat must be disconnected from the mains electric motor when its cage temperature increases can use a relay output stage;
- If the thermostat is used to maintain constant temperature of a radiator, the output stage can use a medium power transistor, which which will connect a fan.

In Fig.1 is represented an electronic thermostat consists of:
- NTC thermistor (approx. 700 Ω at 20 °C);
- Gain stage made with βA 741 operational amplifier and trigger Schmitt circuit made with bipolar transistors T_1 and T_2;
- Output stage composed of: DZ Zener diode, T_3 transistor, 1N4001 diode and relay.

The non-inverting input (3) of the circuit is determined βA 741 some potential using trimmer resistance, which together with and form a resistive divider (R_1, R_2, R_3) of fact to be determined tempera-ture range at which the thermostat will work.
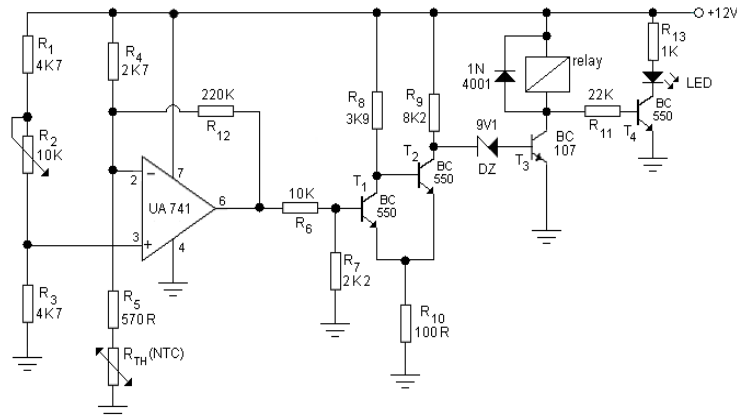
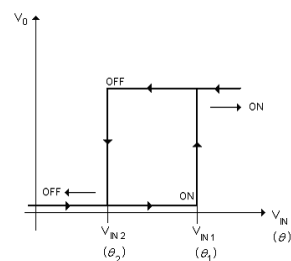**Fig. 1.** Thermostat made with operational amplifier and transistors
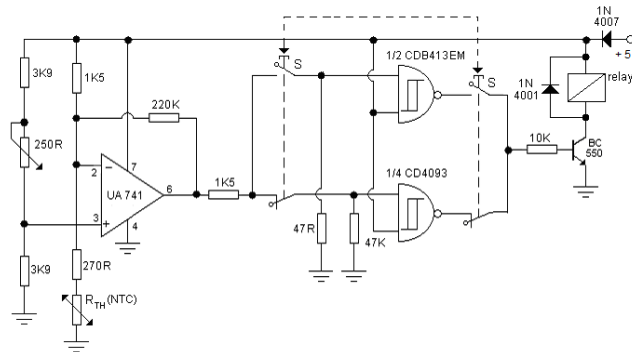

Fig. 2. Experimentaly thermostat from fig.1

Thermistor (R_{TH}) set at a point on the inverting input voltage (2). The thermistor is connected into a voltage divider (R_4, R_5, R_{TH}). The voltage difference between the two inputs is amplified by the operational amplifier βA741. The gain value is given by the reaction resistance value. The scheme has a negative feedback loop. The amplified voltage difference is applied through a resistive divider (R_6 and R_7 made with trigger Schmitt circuit. The trigger Schmitt circuit transform the slow variation of the signal strength of the base of the transistor, a sudden change (trigger circuit, has a transfer function with hysteresis) to ensure firm engagement of the relay. If the voltage of the transistor base reaches a certain values V_{IN1} which is the upper limit of the curve hysteresis (ON state), and returns to its original state when the voltage of its base touching the lower value V_{IN2} (OFF state) (Fig.3). In Fig.2 is presented the practical thermostat from Fig.1.

In Fig.4 presents an electronic thermostat with trigger – Schmitt circuit conducted with logic gates TTL NAND (CDB 413 EM) or CMOS NAND (CD 4093). The operating principle is the same with thermostat from Fig.1, except that tilt thresholds of one the two NAND gates are established from 47 Ω or 47 kΩ (from S). The switch S switches from one NAND gate to another, so the two gates can't drive simultaneously. In Fig.5 is the practical thermostat from Fig.4.
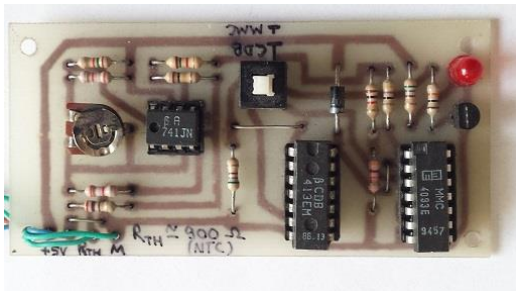

Fig. 3. The transfer characteristic of the trigger – Schmitt circuit

Fig. 4. Thermostat made with operational amplifier and logic gates

Fig. 5. Experimentaly thermostat from fig.4

3. SIMATIC CPU 224 SIEMENS

PLCs are simple microcomputers that are built specifically to deal with issues of combinational and sequential programs. They are used to replace the combinational and sequential automation made with contacts and relays. In a general form PLC can be considered as a piece of equipment that allows the logical linkages between a large number of inputs and outputs, without additional interfacing devices. [5,7,8,12].

These systems offer fewer characteristics than process PCs, but can be used by less qualified staff due to application-oriented languages. Carrying out a program on such a system is synchronous. PLCs are built specifically to operate in industrial environments, with the necessary protections against environmental pollution from industry and having interfaces adapted for transducers and actuators elements most commonly used in the industry. For more advanced applications, there is currently high performance PLCs which approaches the complexity of computers. The PLCs work with words of 8, 16 and 32 bit and may perform floating point arithmetic operations. PLC types available on the market are spread, and their characteristics are different from one manufacturer to another.

The S7-200 PLCs (Siemens) is intended for low-complexity applications and includes several types of central units (Table 1). For a schedule of this series are required, in addition to functionality, a PC computer, programming Step 7 MicroWIN and a communication cable between the PC and PLC (PPI port serial port on computer - PC/PPI). Siemens manufactures and a new series of automatic small S7-22x, equipped with communication facilities on the network embedded in the central unit [12].

Table 1 **The main characteristics of CPU 224 [11]**

Communication port type	RS 485
For use with	SIMATIC S7-200 Series
Input type	Analogue, Digital
Manufacturer series	SIMATIC S7-200
Maximum baud rate	187.5 kbit/s
Battery backup	Yes
Maximum inputs/outputs	203 (168 Digital, 35 Analogue)
Maximum Operating Temperature	+45°C
Minimum operating temperature	0°C
Mounting type	Rack
Number of communication ports	1
Number of I/O	24
Number of inputs	14
Number of outputs	10
Output current	750 mA
Output type	Analogue, Digital, Transistor
Programming interface	Computer, SIMATIC PG/PC
Programming language used	STL, LAD, FBD
Scan time	0.22 μs
Total memory available	12 kB (Program Memory), 8 kB (Data Memory)
Voltage supply	20.4 → 28.8 V D.C.
Width	120.5mm
Depth	62mm
Length	80mm

An S7-200 PLC consists of a CPU module, alone or with multiple extensions. CPU module is composed of a central unit, power supply and input/output in a compact structure. CPU module has a number of status LEDs (SF/DIAG, RUN, STOP) and visualization of the status of inputs and outputs.

Step 7 MicroWIN is a software package for programming and configuring PLCs Siemens S7-200 series. This software package allows set parameters for hardware debugging, editing, and uploading in PLCs programs developed.

Languages supported by Step 7 MicroWIN are:
• STL, which is a text language consisting of usual instructions list;
• LAD, which is a semi-graphic language, consisting of objects, which is achieved through interconnection circuits, called networks, which are similar to those made with contacts and relays;
• FBD, is a semi-graphic language, consisting of objects, which is achieved through interconnection circuits called networks, which are similar to those made with integrated circuits.

In principle, for any industrial application where is used PLC using the following sequence of command diagram [11]:
a. Process must be selected to be controlled. The system automatically can be a machine or a process. Process control is constantly supervised by input devices (sensors) that transmit signals to the programmable machine. When running the machine scheme, PLC transmits signals to output devices (elements) that determine the operating mode of the process. In order to understand the functioning of the program it is necessary to construct flowcharts.

b. It must set the devices that connect to the entry and exit of programmable machine. Input may be connected to different switches, sensors, etc. It can connect the output coils, valves, electromagnetic valves, micro-motors, relays, signal optical instruments and/or acoustic, LEDs, etc.

c. Implementation of the program with specific PLC instructions according to the flowchart. The program must be stored in the PLC programmable memory. After the implementation of the program, it is necessary to detect program errors. Also, through the program shall be provided for all possible situations that may arise in the process. Before setting off for the first time, the facility must be checked once all input and output if are connected to the correct inputs and outputs programmable machine. After connection of the power supply voltage, the process begins to be controlled by the PLC.
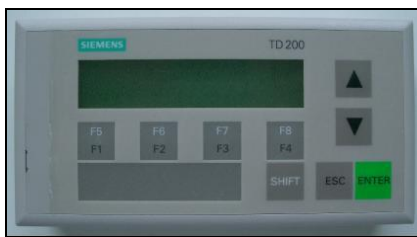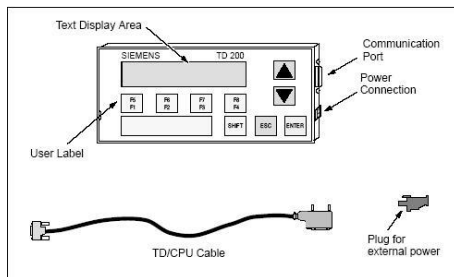

Fig. 6. Text display TD200 Siemens

4. OPERATOR INTERFACE TD200 SIEMENS

TD200 (Text Display) is an operator interface with text display (Fig.6) designed specifically for the family S7-200 PLCs.

Communication is done through the serial port by using the PPI Protocol. The unit (Fig.7) is powered either from the mains to 24 V from PLC (via special cable TD/CPU) or from a separate voltage source (i.e. 230 V, 50 Hz) [13]. The most important functions of the TD 200 are:

Fig. 7. Operator interface TD200 components

• Display of read messages from AP S7-200;
• Adjusting the variables in the process;
• Possibility to control the process from the buttons F1-F8;
• Ability to force/release values in input/output registers;
• Possibility to set clock and date for S7-200 units that have built-in clock function;
• Provides menus and messages in six languages.

TD200 interface works as master when it is connected to one or more automated S7-200. TD200 is also designed to operate together with other devices in the network master. TD200 is a small, compact, providing all the necessary elements for the creation of the PLC S7-200 CPU (Fig.7).

TD200 is a display device used for alpha-numeric display of messages validated by the PLC S7-200 CPU. TD200 interface programming is not necessary. The only operating parameters stored in the memory are the interface address TD200, S7-200 CPU address, baud rate and location configuration block (called TD200 Block). This block is stored in the memory variable (V) functionality. The interface configuration parameters as language, TD200 discount rate, message and the validation

of the message bits are stored in the block TD200. On start-up, it reads the configuration block TD200 and verifies the accuracy of all parameters. If everything is alright, start checking TD200 validation of bits messages to determine what message is necessary to display.

In the last dialog box will use the "Finish" button to validate and save the block parameters and close the configuration tool. To begin configuring it will press the button "Next". The program Step 7 Micro/WIN is equipped with a "special feature" (wizard) to ease the Bloc's TD200 configuration and messages in the data memory of the PLC S7-200. The selection options and creating messages, wizard automatically writes TD200 block with parameters and text messages in TD200 window Data blocks. This block of data (Data Block) and block containing TD200 can now be downloaded (downloaded) in memory of the machine. This section contains the procedure for creating a template. It will use the following guidelines to create a block TD200 and two messages. The first message will contain the text and data. The second message will require acknowledgement (acknowledge) operator. To select the Setup function of the interface it will select Tools TD200 > Wizard. To navigate forward or backward, use the buttons "Next" and "Previous". In the last dialog box will use the "Finish" button to validate and save the block parameters and close the configuration tool.

5. APPLICATIONS WITH PLC FOR MEASURING AND ADJUSTING TEMPERATURE

**Fig. 8.** The laboratory equipment used in experiments
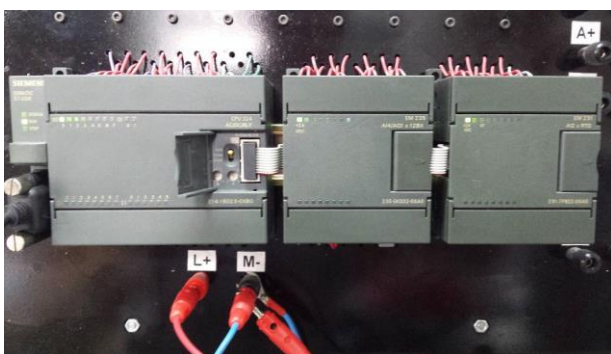
Fig. 9. CPU 224 PLC and EM 235 and EM 231 RTD extension modules

In this chapter are presented two applications that perform the function of thermostat for electric or gas industrial furnaces.

Applications were made with PLC Siemens CPU 224, extension module EM 231 RTD (can connect two RTDs of various types configurable from switches) and EM 235 (4 analogue inputs and one analogue output, voltage or current, configurable from switches) [14], TD 200 operator interface [13]. Temperature measurement in both situations is made with Pt 100 thermo-resistance (100 Ω at 0°C) [17].

To check the operation of the programs have set the temperature lower limit value at 22°C, and for the upper limit at 25°C.
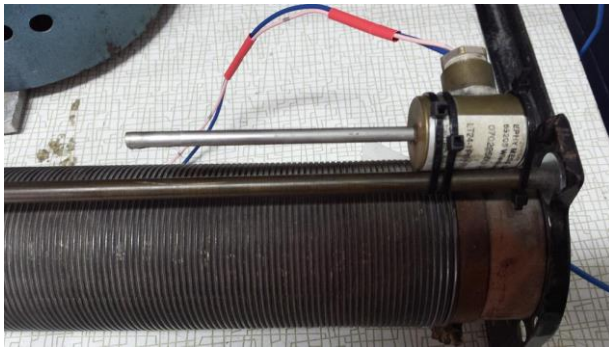
Fig. 10. Pt 100 thermo-resistance used in experiments (connected on a power resistor)

While the Pt 100 temperature measured is between 22 and 25 °C, it displays the message 1. If the temperature is higher than the upper limit, in addition to the message 1 a message 2 is displayed. If the temperature is less than the lower limit, in addition to the message 1 a message is displayed 3.

5.1. Measuring and adjusting the temperature with Pt100 and EM 231 RTD module

The operation of this application is the thermostat switch to the temperature thresholds, with the values imposed by the program. The temperature and the maximum and minimum values are displayed on the operator interface TD 200 (Siemens). A digital output using the output Q0.0 that is 1 logical when the temperature is lower than the lower value, or 0 logic when the temperature exceeds the upper assessment threshold. Output Q0.0 (electric contact), connects with the coil of a contactor or electro-valve for command of a three-phase power resistors (which produces heat) or a servo-valve for the gas supply to a gas oven (Fig. 11). This application requires the following equipment:
- CPU 224 (Siemens);
- EM 231 2xAI RTD (Siemens);
- operator interface TD-200 (Siemens);
- thermo-resistance Pt 100;
- a power autotransformer, a contactor K that supply the power resistance R.
The switches of EM 231 RTD were achieved the following configuration (at the 8 switches) for Pt 100:
SW1 SW2 SW3 SW4 SW5 SW6 SW7 SW8
 0   0   0   0   0   0   0   1
SW1-SW5 configures the type of thermo-resistance;
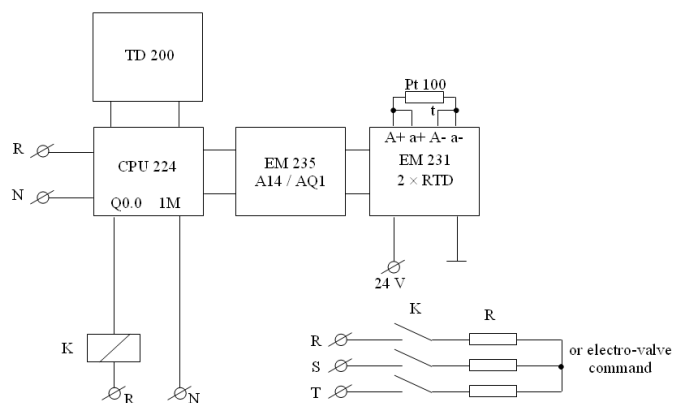SW6 - 0 to measure the positive temperatures, 1 to measure negative temperatures;
SW7 - 0 degrees Celsius, 1 degree Fahrenheit;
SW8 - 1 for thermo-resistances with 2 or 4 wire, 0 for thermo-resistance with three conductors.
In this application, Pt 100 thermo-resistance connects to EM 231 RTD:
- -a Pt100 connector at A- and a-;
- +a Pt100 connector at A+ and a+ (Fig.12).

Fig. 11. Connection scheme of CPU 224 PLC, TD 200,
EM 231 RTD and power resistance R

Fig. 12. Connect the conductors to the
first application (with EM 231 RTD module)

EM 231 RTD feeds from CPU 224 supply. CPU 224 connects to power supply single phase, 230V, 50 Hz, CPU 224 has an internal switched mode power supply 24V. Is connected, also, an analogue module 235 EM (four analogue inputs and one analogue output) with 12-bit conversion. This module cannot be used at the first application. Because the application uses the first entry of the module EM 231 RTD, and before this module is connected the module EM 235 (with four analogue inputs), AIW8 input is used for temperature measurement.

TD-200 operator interface displays (Fig.13) the current value of the temperature measured (1 message), overcoming the higher set value (message 2) and minimum value set (3 message). The program was developed in STL, but can be viewed, also, on LAD or FBD. AIW8 is the number 1 input of EM231 analogue module, and EM 235 module is connected before EM 231 RTD (which has inputs AIW0, AIW2, AIW4, AIW6).

Program listing for application 1
Network 1 Setting the limits of the operating temperature of the regulator
```
LD    Prima_scanare        // In the first cycle of operation
                           // SM0.1=1
MOVD  +0, VD260            // To delete the values in VW260 and
                  //VW262
MOVW  +0, VW200            // Deleting the memory where it will be
                  // introduced AIW8 entry
MOVW  +250, VW260          // The upper limit setting of regulator
                           // = 25°C; temp. value x 10
MOVW  +220, VW262          // The lower limit setting of regulator
                           // = 22°C; temp. value x 10
```
Network 2 Calculating and validating the message 1
```
LD    Tot_timpul_1         // SM 0.0 is logical 1 and determine
                            // program execution
```

```
MOVW   AIW8, VW200        // The size of the analogue displacement
                          //measured (temperature) at the AIW8 in memory of VW200.
MOVW   VW200, VW116       // Transfer result at VW116 (which is in
                          //connection with operator interf. TD 200) for displaying information.
S      V12.7, 1           // Message 1 validation to display
                          // TD 200.
```
Network 3 If the temperature exceeds the maximum value, it validates the message and exit Q 0.0 are reset.
```
LDW>=  VW200, VW260       //If the temperature is > = than the
                          //stored maximum temperature, VW260
= V 12.6                       //it validates the message 2 and will be
                               //displayed on the TD //200.
R    Q0.0, 1                  // Q0.0=0 output (reset)
MOVW   VW260, VW136       // Transfer the result to memory
                            //VW136 (who is in touch with TD 200
                            //operator panel) to display message 2.
```
Network 4 If the temperature falls below the minimum value, it validates the message 3 and exit Q 0.0 sets.
```
LDW<=  VW200, VW262            //If the temperature is the
                              //minimum temperature than < = stored in VW262,
=V12.5                        //validating message 3 and will be displayed on the TD 200.
 S    Q0.0, 1             // Q0.0=1 output (set)
MOVW   VW262, VW156      // Transfer the result to memory
                        //VW156 (who is in touch with TD 200 operator panel) to display the
                //message 3.
```
Network 5 End of programme
```
MEND                     //  End of programme.
```
Data Block for TD 200 configuration
```
// data block DB1 (V memory):
//
// The parameters block for TD200 for writing messages measured
//temperature values and to overcome the upper and lower limits.
// Configuration is done with specialized for TD 200Wizard
//in the STEP 7 Microwin
VB0    'TD'        // Operator panel identification TD 200
VB2    16#10       // English setting and up-dating fast
VB3    16#00       // Setting 20 characters; Button up V3.2;
                   // Button down V3.3
VB4    3           // Setting the number of messages: 3
VB5    0           // Setting the buttons and their association with
                   //memoirs M 0.0-M 0.7
VW6    100         // Setting memory addresses starting with VW100
VW8    12          // Setting addresses for validation bits VW12 messages
// Message 1
// Validation bit message 1 V12.7
VB100  'Temperatura = '
VB114  16#00       // No editing, no confirmation and no password;
VB115  16#31       // Word without a sign; a digit to the right of the
         //decimal place;
VW116  16#0000    // Moving the date to be displayed.
VB118  'ßC'        // Message 1 ends.
// Message 2
// Validation bit message 2 V12.6
VB120  'Temperatura > '
VB134  16#00       // No editing, no confirmation and no password;
VB135  16#31       // Word without a sign; a digit to the right of the
         //decimal place;
VW136  16#0000    // Moving the date to be displayed.
VB138  'ßC'        // Message 2 ends.
// Message 3
// Validation bit message 3 V12.5
VB140  'Temperatura < '
VB154  16#00       // No editing, no confirmation and no password;
VB155  16#31       // Word without a sign; a digit to the right of the
         //decimal place;
VW156  16#0000    // Moving the date to be displayed.
VB158  'ßC'        // Message 3 ends.
//end configuration block TD 200.
```

Fig. 13. Displaying the messages on the operator interface TD 200

5.2. Measuring and adjusting the temperature with Pt100 and EM 235 module (4 analogue inputs and 1 analogue output) with 12-bit conversion

The operation of this application is the thermostat switch to the temperature thresholds, with the values imposed by the program. The temperature and the maximum and minimum value of the temperature are displayed on the operator interface TD 200 (Siemens). A digital output is using Q0.0 that is 1 logical when the temperature is lower than the lower value, or 0 logic when the temperature is higher than the upper threshold (Fig. 14).
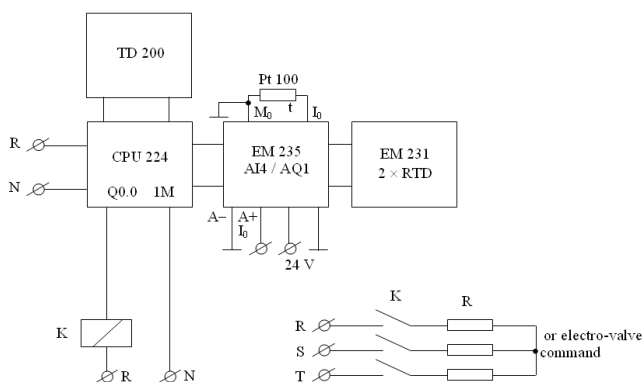

Fig. 14. Connection scheme of CPU 224 PLC, TD 200, EM 235 and power resistance R

This application requires the following equipment:
- CPU 224 (Siemens);
- EM 235 (4xAI, 1xAQ, Siemens);
- operator interface TD-200 (Siemens);
- thermo-resistance Pt 100;
- a power autotransformer, a contactor K that supply the power resistance R.

Fig. 15. Connect wires for the second application

On the panoply of experimentations are three connected modules: a PLC CPU224, an analogue extension module EM 235 and another extension module EM 231 2xRTD; last module in this application shall not be used. CPU 224 is fed from single-phase mains voltage (230V,

110

50Hz). The PLC has an internal voltage source with a value of 24 V DC. From this source is feeding EM 235 module. Output Q0.0 (contact form), connects with the coil of a contactor or electro-valve for command of a three-phase power resistors (which produces heat) or a servo-valve for the gas supply to a gas-fired furnace. EM 235 is powered from + 24 V and the mass of the internal source of CPU 224 (Fig.15).

In this application, it can use the analogue output in the form of the current (maximum 20 mA, between M0 and I0 terminals) from which connects Pt 100 thermo-resistance (100 Ω at 0 °C). Pt 100 is injected into a constant current of 12.5 mA. With a 12.5 mA current injected into the Pt 100 is obtained 5 mV/°C (Fig.16). If the Pt 100 change with temperature (increases with increasing temperature), the voltage on the Pt 100 also increases. By measuring the voltage on Pt 100, using AIW0 input of EM 235 module, it can measure temperature with Pt 100. Modification of Pt 100 resistance is about 0.4 Ω/°C.

Measurement range of Pt100 is usually between -60 and 400 °C. Resistant Pt 100 connects between M0 and I0 (exit 235 EM module). The ends of thermo-resistance connect to the first input (AIW0) EM 235 analogue module. His Pt 100 connecting at the entrance of EM 235 is between A- (ground) and A +. AIW0 input is the number 1

Fig. 16. Aspects at the experience of the last application

input from EM 235 module which is used in the application. Module EM 235 entries set the micro-switches to measure single-polar voltages (10 V). At switches EM 235 has achieved the following configuration (at the 6 switches):

SW1 SW2 SW3 SW4 SW5 SW6
  0   1   0   0   0   1

TD-200 operator interface displays the current value of the temperature measured (1 message), exceeding the higher set value (message 2) and exceeding the minimum value set (3 message).

The program was developed in STL, but can be viewed and the LAD or FBD (Siemens).

Program listing for application 2
Network 1 Setting the limits of the operating temperature of the regulator
LD   Prima_scanare
// In the first cycle of operation   // SM0.1=1
MOVD +0, VD260   // To delete the values in VW260 and
MOVW +0, VW200   // Deleting the memory where it will be introduced AIW8 entry
MOVW +250, VW260   // The upper limit setting of regulator = 25°C; temp. value x 10
MOVW +220, VW262   // The lower limit setting of regulator = 22°C; temp. value x 10
        Network 2 Calculating and validating the message 1
LD   Tot_timpul_1   // The bit SM0.0 is 1 logic and determine program execution
MOVW AIW0, VW200 // Moving the value of the input AIW0 in the VW200.
-I   VW252, VW200   // Substracting value for 0° C (offset) VW200-VW252.
DIV   VW250, VD198   // The result of VD198 is divided in VW250 (for 1° C)

```
MUL   +10, VD196          // The remainder is multiplied by 10.
DIV   VW250, VD196        // Dividing the remaining value from  VD196 to VW250 (1° C)
MOVW   VW198, VW160       // The movement amount with a decimal  place to the left
MOVW   +0, VW198          // Deleting content from VW198.
MUL   +10, VD198          // Multiplying the temperature measured     with 10
+I   VW160, VW200         // Result decimal place value roundup
MOVW   VW200, VW116       // Transfer result in VW116 (which is in /connection with operator panel TD 200)
S    V12.7, 1             // Message 1 validation
                         // for TD 200 display.
       Network 3 If the temperature exceeds the maximum value, it validates the message and exit Q 0.0 are reset.
LDW>=  VW200, VW260          //If the temperature is > = than the
                         //stored maximum temperature, VW260
= V 12.6                    //it validates the message 2 and will be displayed
                         //on the TD 200.
R    Q0.0, 1             // Q0.0=0 output (reset)
MOVW   VW260, VW136   // Transfer the result to memory
                         //VW136 (who is in touch with TD 200
                         //operator panel) to display message 2.
       Network 4 If the temperature falls below the minimum value, it validates the message 3 and exit Q 0.0 sets.
LDW<=  VW200, VW262  //If the temperature is the
                         //minimum temperature than < = stored in VW262
=V12.5                   //validating message 3 and will be displayed on the TD 200.
 S    Q0.0, 1           // Q0.0=1 output (set)
MOVW   VW262, VW156   // Transfer the result to memory
                         //VW156 (who is in touch with TD 200 operator panel) to
                         //display the //message 3.
      Network 5 End of programme
MEND                    //  End of programme.
```

The data blocks to set up TD 200 is the same way as the application 2. In the last application, the experiments connected the mili-ammeter (12.5 mA) to be able to measure the constant, regardless of the temperature, by Pt 100 thermo-resistance. Constant current is generated by extension module EM 235 (12.5 mA) (Fig. 16).

6. ISSUES REGARDING THE USE OF PLCS

The most significant disadvantages of classical control systems (with electronic components and integrated circuits) are:
- high working time for connections between electrical devices;
- the difficulty of replacement parts;
- difficulty in determining of faults;
- the need for the use of a qualified staff with practical experience;
- the emergence cannot be determined the time of elimination of the defect; usually this time is high, the process must be stopped.

With the invention of PLCs, changed the way in which the command installations; occur a number of advantages.

The advantages of using PLC in command installations are:
- compared to classical control systems (with relays) number of conductors needed to greatly reduce the connections (generally 80%);
- power consumption is much lower due to the fact that a PLC uses less electricity than a group of relays that performs an equivalent function;
- fast determination and remedy the issues in the system;

- rapid adaptation to different applications with command systems with PLC by modifying the program running in the PLC (no change of conductors for connections, being only necessary to adapt certain devices for input and output);
- the total size is reduced compared to conventional equivalent facilities;
- installations with PLCs are cheaper compared to the classics, especially in the case of installations with a large number of input devices and output;
- safety in operation is greater in the case of orders made with PLCs.

7. CONCLUSIONS

Electronic thermostats are widely used in industry. The classical electronic thermostats with electronic components and integrated circuit have the disadvantages to precisely control of temperature.

PLCs are used increasingly more often in the industry. An application of those is temperature control of industrial furnaces (e.g. for drying of painted components) with electrically or gas heated. The applications are based on operation of thermostat with switch to two limits for temperature (limits can be changed into the program). The current temperature and the maximum value or the minimum values are displayed on the operator interface. The values shown are displayed with one decimal place.

REFERENCES

[1]. Andrei D., Georgescu I., Guran M., *Automatizări în industria minieră*, Editura Tehnică, Bucureşti 1977.

[2]. Badea I. and other, *Protectia prin relee şi automatizarea sistemelor electrice*, Editura Tehnică, Bucureşti, 1973.

[3]. Groza V.R., *Analiza şi sinteza dispozitivelor numerice*, Universitatea "Politehnica" Timişoara, 1995.

[4]. Poanta Aron, Pătrăşcoiu Nicolae, *Circuite şi echipamente electronice utilizate în industria minieră*, Editura Didactică şi Pedagogică, Bucureşti, 1997.

[5]. Pop E., Leba M.C., *Microcontrollere şi automate programabile*, Editura Didactică şi Pedagogică R.A., Bucureşti, 2003.

[6]. Popa G.N., Popa I., *Instalaţii electrice*, Editura Mirton, Timişoara, 2005.

[7]. Popa G.N., Popa I., Deaconu S., ***Automate programabile în aplicaţii*, Editura Mirton, Timişoara, 2006.**

[8]. Popa G.N., Popa I., Diniş C.M., Iagăr A., *Measuring and Adjusting the Temperature with CPU 224 PLC and TD 200 Operator Interface Siemens*, Proceedings of the 6th International Multidisciplinary Scientific Symposium Universitaria SIMPRO, 10-11 October 2014, Petroşani, România, pp. 275-282.

[9]. Popa I., Popa G.N., *Dispozitive electronice cu structură cablată şi programată de protecţie a motoarelor asincrone trifazate de joasă tensiune*, Editura Mirton, Timişoara 2000.

[10]. Toma L., *Sisteme de achiziţie şi prelucrare numerică a semnalelor*, Editura de Vest, Timişoara, 1997.

[11]. Voloşencu C., *Standardizare şi metodologii de proiectare în automatizări industriale*, Editura Matrix Rom, Bucureşti, 1998.

[12]. ***, *Siemens S7-200 Programable Logic Controller. User Manual*, Siemens, 2003.

[13]. ***, *Siemens TD 200 Operator Interface. User Manual*, Siemens, 2005.

[14]. http://www.automation.siemens.com/

[15]. http://www.control.com/

[16]. http://www.directindustry.com/

[17].http://www.ziehl.de/ziehl/englisch/temperature_monitoring/5pt100sensoren_e.pdf

FUNCTION BLOCK DIAGRAM (FBD) PROGRAM FOR A MIXTURE PROCESS

**STELIAN VALENTIN CASAVELA[1], ANTONIO CASAVELA[2], CRISTOFOR CASAVELA[3]**

Abstract: Two liquid substances (liquid A and liquid B) are mingled together in a tank by an agitator. The resulted substance is drained from the mixer through a drain valve. The process is divided into functional areas and individual tasks. The area for ingredients A and B is followed by the mixing tank area and the drain area. Programming the FBs (function blocks) for the motors and valves from any areas and the interconnecting of these is our program.

Key words: logic blocks, symbolic addresses, feed pump, sensor, valve, function block, network, input, output.

1. The process areas and logic blocks

(See figure 1) The basic steps used for to project a blending process are the next:
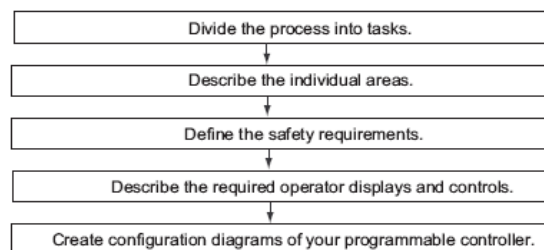
Dividing in tasks and areas, safety requirements and describing them. From the four distinct areas (seen above), the areas for the A and B ingredients employ the similar equipments.

The pumps are turn off if the "Tank empty" signal is received from the tank level sensor. The level switches in the tank, interlock the feed motors and the agitator motors. Every device can be turns on or off by the human operator from the console (see figure 2). This console contains indicators for the status of the blending process.

---

[1] *PhD Lecturer, University of Petrosani*

[2] *Dr., Municipal Hospital of Timisoara*
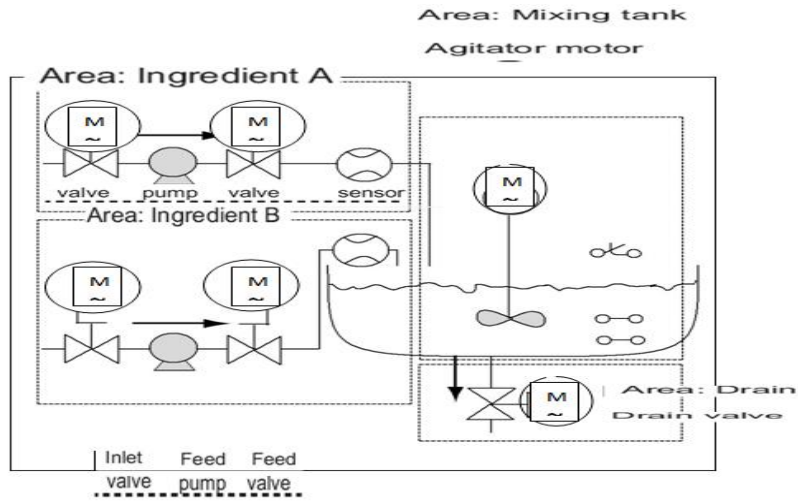
[3] *Dr., Municipal Hospital of Timisoara*
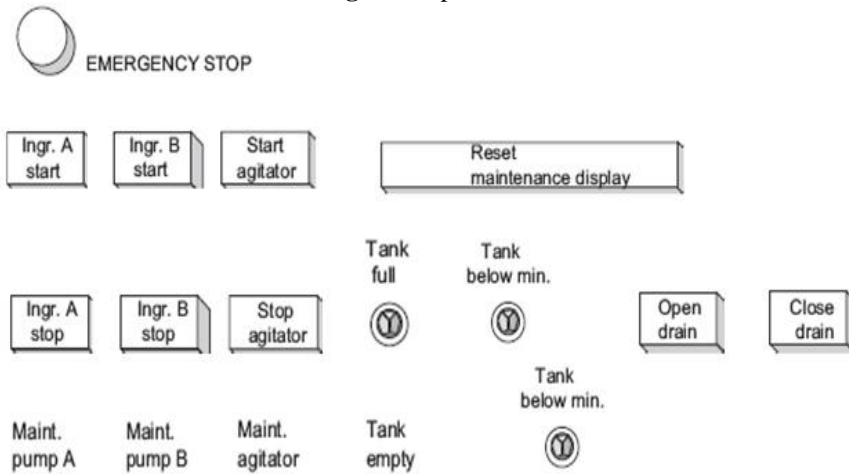
Fig.1. The process areas

Fig 2. Displays and Controls

The maintenance is for the display, after a certain number of starts. to reset the corresponding counters to 0.

Configuration Diagram. Input / Output diagram for our motors. (see figure 3).
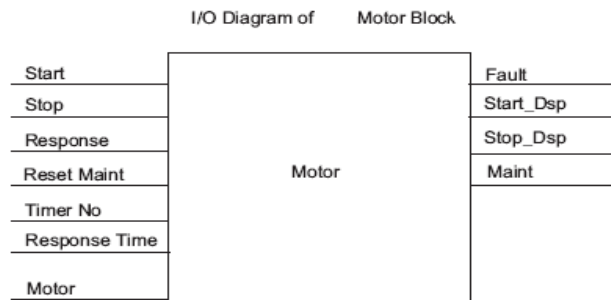

Fig 3. I/O diagram for motors

Each valve is controlled by its own "valve block" that is the same for all valves used. The logic block has two inputs: one to open the valve and one to close the valve. It also has two outputs: one to indicate that the valve is open and the other to indicate that it is closed. The block has an in/out to activate the valve. It is used to control the valve but at the same time is also edited and modified in the program for the "valve block." [4]
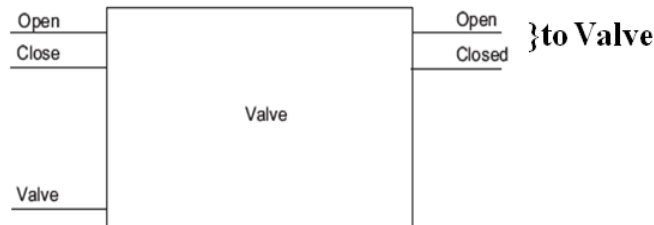
Fig.4. To valve block

CPU and Interfaces. The diagram of configuration contains: type of Central Processor Unit, modules of Input /Output , their configuring.
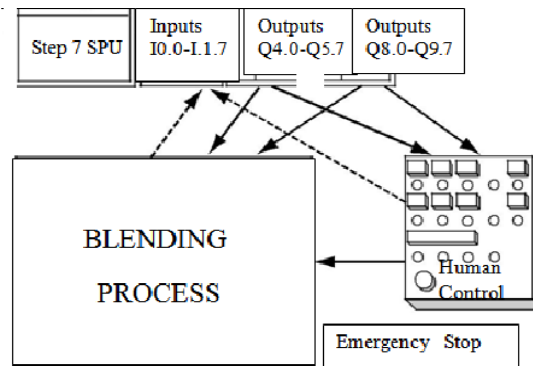

Fig. 5. Blending Control

The Central Processor Unit runs two principal programs: the operating system and the user program. Any Central Processor Unit has an **operating system**, which organizes all its functions and sequences, but without to be for a dedicated task of a process. That is, some of its tasks are: -to handle restart (warm and hot), -to update the image table of the inputs and to offer the image table of the outputs, belonging to the process, -to call the user program, -to acquire information about interrupts and to handle interrupts, - to recognize and to handle errors, -to manage the CPU memory, -to communicate with the keyboard, the mouse, the network etc.

The User Program will be created on PC and it will download to CPU. That program will comprise the functions for to control the process. Some goals of the user program are: - to specify the conditions for a warm start and hot restart on the Central Processor Unit (beside others, to initialize the signals with a certain value), - to process data (to handle binary signals from inputs and to generate others for to be outputted, idem for analog signals), - to handle interrupts and to react to perturbations in the normal program cycle. [3]

Mixing area: The agitator motor must be turned off when the level sensor returns the signal "level below minimum" or the drain valve is open. The agitator motor signals after reaching its rated speed. If no signal appears within 10 seconds after starting, the motor must be stopped.

Drain area:- A solenoid valve prevents drainage of the tank. This solenoid valve is handled by the operator' hand, but must be closed by the "tank empty" signal

Operator Station. It is equipped with the following: switches for stages of the process, "reset maintenance display" switch, for to reset the counters for the maintenance interval to 0, LEDs. for status of the process, the emergency stop switch.

Blocks in the User Program. (see Figure 6). OB1 has the main program, from OB1 are called FB1 and FC1 and are transferred to them the control parameters. FB1 controls all two pumps and the agitator motor the requirements being identical. DBs 1, 2, 3 are associated with FB1. FC1: The feed valves with only the function "open and close" are programmed.
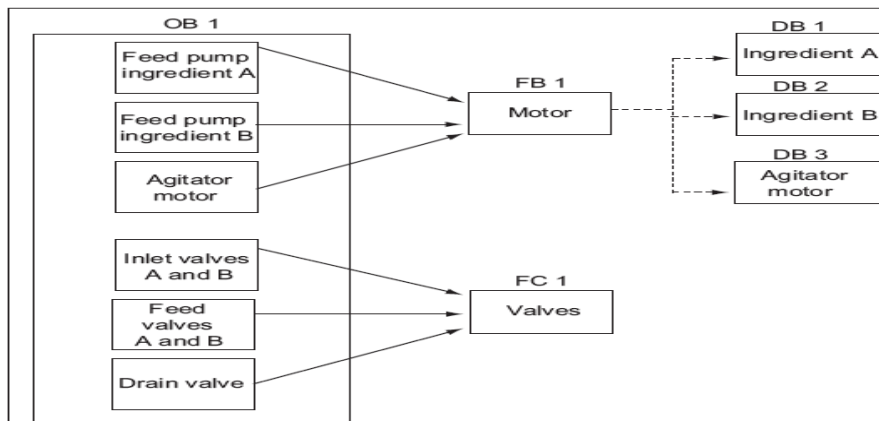

Fig. 6. Logic blocks and hierarchy of their Calls

2. **Designing of the function control blocs (FB1 and FC1)**

The symbol table (see Figure 7) contains the symbolic names and the absolute addresses of elements.

| ...	Symbol	Address		Type	Symb.–Comment
10	Feed_pump_A_maint	Q	4.6	BOOL	Lamp for "feed pump A maintenance"
11	Feed_pump_B_start	I	0.3	BOOL	Starts the feed pump for ingredient B
12	Feed_pump_B_stop	I	0.4	BOOL	Stops the feed pump for ingredient B
13	Flow_B	I	0.5	BOOL	Ingredient B flowing
14	Inlet_valve_B	Q	5.0	BOOL	Activates the inlet valve for ingredi
15	Feed_valve_B	Q	5.1	BOOL	Activates the feed valve for ingredie
16	Feed_pump_B_on	Q	5.2	BOOL	Lamp for "feed pump ingredient B runn
17	Feed_pump_B_off	Q	5.3	BOOL	Lamp for "feed pump ingredient B not
18	Feed_pump_B	Q	5.4	BOOL	Activates the feed pump for ingredien
19	Feed_pump_B_fault	Q	5.5	BOOL	Lamp for "feed pump B fault"
20	Feed_pump_B_maint	Q	5.6	BOOL	Lamp for "feed pump B maintenance"
21	Agitator_running	I	1.0	BOOL	Response signal of the agitator motor
22	Agitator_start	I	1.1	BOOL	Agitator start button
23	Agitator_stop	I	1.2	BOOL	Agitator stop button
24	Agitator	Q	8.0	BOOL	Activates the agitator
25	Agitator_on	Q	8.1	BOOL	Lamp for "agitator running"
26	Agitator_off	Q	8.2	BOOL	Lamp for "agitator not running"
27	Agitator_fault	Q	8.3	BOOL	Lamp for "agitator motor fault"
28	Agitator_maint	Q	8.4	BOOL	Lamp for "agitator motor maintenance"
29					
30	Tank_below_max	I	1.3	BOOL	the Level of the Tank//Sensor "mixing
31	Tank_above_min	I	1.4	BOOL	Sensor "mixing tank above minimum lev
32	Tank_not_empty	I	1.5	BOOL	Sensor "mixing tank not empty"
33	Tank_max_disp	Q	9.0	BOOL	Lamp for "mixing tank full"
34	Tank_min_disp	Q	9.1	BOOL	Lamp for "mixing tank below minimum l
35	Tank_empty_disp	Q	9.2	BOOL	Lamp for "mixing tank empty"
36	Drain_open	I	0.6	BOOL	Drain Valve//Button for opening the d
37	Drain_closed	I	0.7	BOOL	Button for closing the drain valve
38	Drain	Q	9.5	BOOL	Activates the drain valve
39	Drain_open_disp	Q	9.6	BOOL	Lamp for "drain valve open"
40	Drain_closed_disp	Q	9.7	BOOL	Lamp for "drain valve closed"
41	EMER_STOP_off	I	1.6	BOOL	Other//EMERGENCY STOP switch
42	Reset_maint	I	1.7	BOOL	Reset switch for the maintenance lamp
43	Motor_block	FB	1	FB1	FB for controlling pumps and motor
44	Valve_block	FC	1	FC1	FC for controlling the valves
45	DB_feed_pump_A	DB	1	FB1	Instance DB for controlling feed pump
46	DB_feed_pump_B	DB	2	FB1	Instance DB for controlling feed pump
47	DB_agitator	DB	3	DB3	Instance DB for controlling the agita

Fig.7. Symbol address table

Designing of the FB as FB1 for the Motor. It contains the logical functions:
- start and a stop input,
-interlocks ("Motor_enable," "Valve_enable") which status is saved in the temporary local data (L stack) of OB, and is logically combined with the start and stop inputs when the FB1 for the motor is processed.
-Feedback from the devices. Otherwise, an error or fault would occur. The FB1 function then stops the motor.
-The moment and the length of the response or error/fault cycle has to be specified
-With the start button pressed and the motor validated, the motor switches itself on and runs until the command of stop button
-When the motor is switched on, a timer counter starts. If the feed back signal from the process is not arrived in duration, settled in timer, the motor stops.
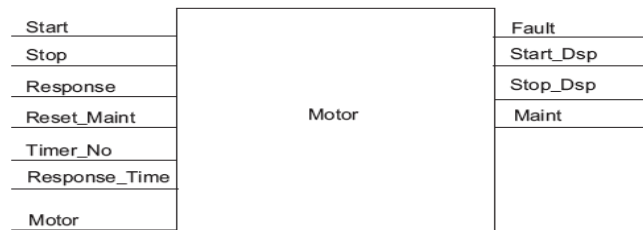
**Fig 8.** The inputs and outputs of the FB1

119

The general parameter names for the inputs and outputs have to be used, because there is a multiple instance FB1 for the motor (both pumps and motor). The Declaring Variables Table of the FB1 follows (see Figure 9).

Fig.9. Variables Table of FB1

OB1 shall call FB1, but specifying an instance DB, with different values for the above input, output, in/out, and static variables. L (local variables) are stored in. stack, temporarily.

Program of the FB1 function, used for Motor. FB1 is called by OB1 and must be created before the block OB1, containing its call. FB1 is written in STL, LAD and FBD languages (see Figure 10).
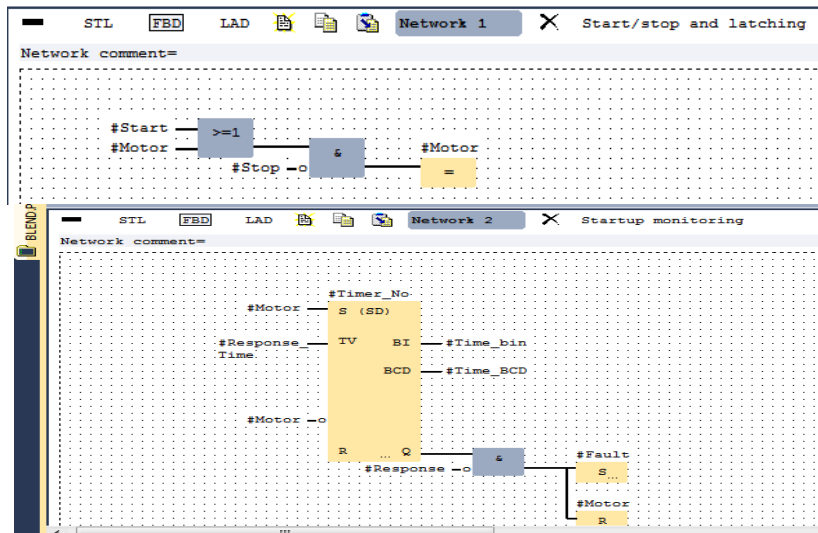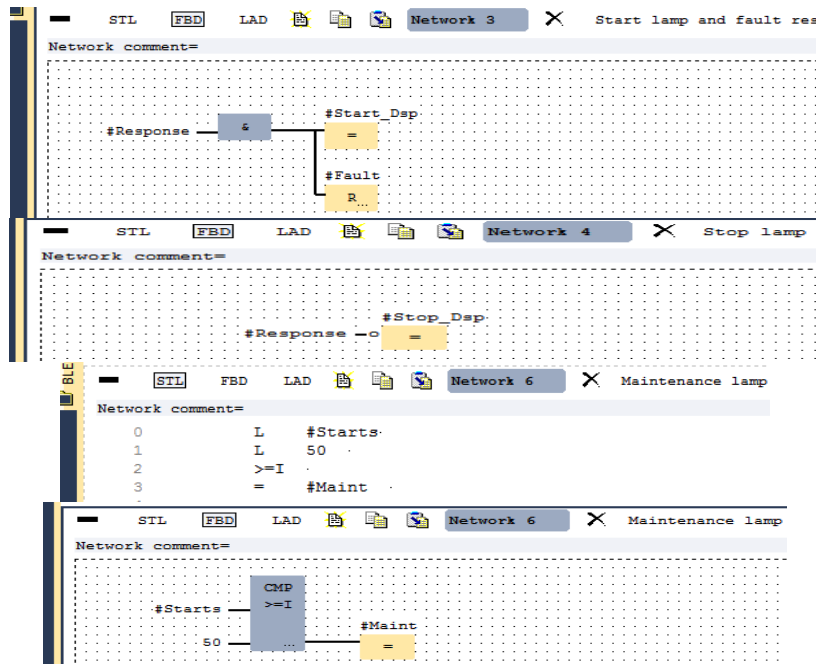
Fig.10. Program of the FB1

Now, we design three data blocks DB1, DB2, DB3, assigned to FB1, one after another, with the menu: "New Data Block"/ "Data block referencing a function block." /"Reference" and select "FB1.

Designing of the function control FC1 for valves. The FC1 for the inlet and feed valves and for the drain valve needs - an input for opening and an input for closing valves.

-interlocks, which state saved in the (L-local) stack of OB1 ("Valve_enable"), is logically combined with the inputs for opening and closing when the FC for the valves is processed.

The call instruction for the FB delivers input parameters. The FC returns output parameters.

Variables of the FC for the Valves are transferred to the FC, created below.

Fig.11. Declaring the Variables of the function FC

The called block FC1 valves is created before the calling block OB1.

Fig.12. Programming the FC

Designing of the OB1 (object 1)

OB1 is the most important structure of program, containing the parameters which to be transferred to FB1 and FC1: - inputs ("Start") and ("Stop") for the FB1 of the motor, also for the response ("Response"), and for resetting the maintenance display ("Reset_Maint"). The FB1 for the motors and the FC for valves are present in every cycle of the PLC, because they are called in OB1.

The FB1 being processed, the inputs Timer_No and Response_Time inform the function of whom timer is used and which time must be measured. The FC for the valves and the FB for the motors are processed in every program cycle of the programmable controller because they are called in OB1. The different instance DBs (1,2,3) of the FB1 for the motor are used to handle the control over the pumps and the agitator motor. In the variable declaration table for OB1 (see Figure 13 below), the first 20 bytes contain the start information of OB1 and must not be modified.

Fig.13. The variable declaration table for OB1

Designing of the Program for OB1. The blocks FB1(with different instance DBs) and FC1 are called many times in OB1.
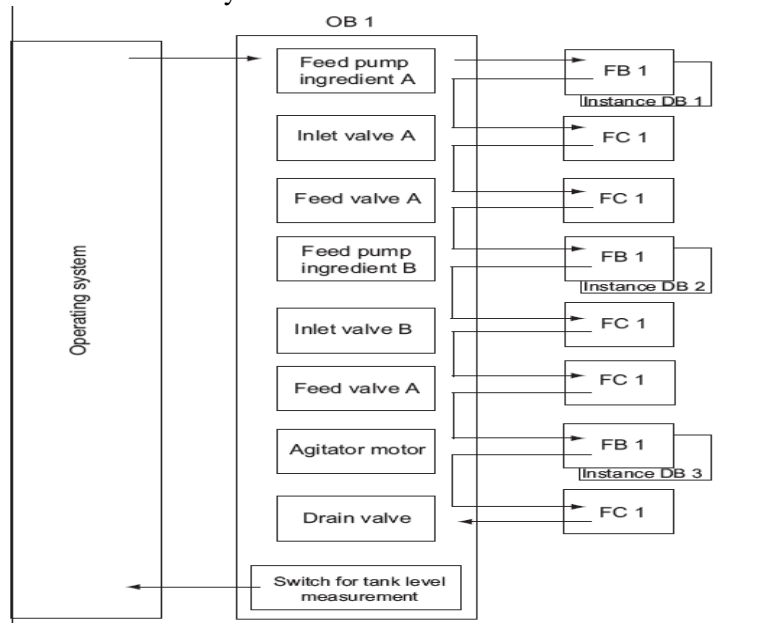
Fig.14. Diagram of the program

BLEND.PRJ

STL | FBD | LAD | Network 1 | ✕ Interlocks for feed pump A

Network comment=

```
                    #Enable_mo
                    tor
        "EMER_STOP      =
        _off"
```

STL FBD LAD FBD/LAD (16):A local data assignment have a wrong address! Network 2 ✕ Calling FB Motor for ingredient A

Network comment=

```
0       A    "Feed_pump_A_start"                    --I0.0        --Feed Pump, Agitator Motor, and Inlet Val
1       A    #Enable_motor
2       =    #Start_fullfilled
3       A(
4       O    "Feed_pump_A_stop"                     --I0.1        --Stops the feed pump for ingredient A
5       ON   #Enable_motor
6       )
7       =    #Stop_fullfilled
8       CALL "Motor_block","DB_feed_pump_A"          --FB1         --FB for controlling pumps and motor
9            Start:=#Start_Fullfilled
10           Stop:=#Stop_Fullfilled
11           Response:="Reset_maint"                 --I1.7        --Reset switch for the maintenance lamps c
12           Start_Dsp:="Feed_pump_A_on"             --Q4.2        --Lamp for "feed pump ingredient A running
13           Stop_Dsp:="Feed_pump_A_off"             --Q4.3        --Lamp for "feed pump ingredient A not ru
14           Maint:="Feed_pump_A"                    --Q4.4        --Activates the feed pump for ingredient
15           Motor:="Feed_pump_A"                    --Q4.4        --Activates the feed pump for ingredient A
```

STL FBD LAD Network 3 ✕ Delaying the valve enable ingredient A

etwork comment=

```
0       A    "Feed_pump_A" --Q4.4        --Activates the feed pump for ingredient A
1       L    S5T#1S
2       SD   T     13
3       AN   "Feed_pump_A" --Q4.4        --Activates the feed pump for ingredient A
4       R    T     13
5       A    T     13
6       =    #Enable_valve
```

STL FBD LAD Network 4 ✕ Inlet valve control for ingredient A

etwork comment=

```
0       AN   "Flow_A"              --I0.2        --Ingredient A flowing
1       AN   "Feed_pump_A"         --Q4.4        --Activates the feed pump for ingredient A
2       =    #Close_Valve_Fullfilled
3       CALL "Valve_block"         --FC1         --FC for controlling the valves
4            Open:=#Enable_Valve
5       Close  :=#Close_Valve_Fulfille
6            Dsp_Open:=#Inlet_valve_A_open
7            Dsp_Closed:=#Inlet_valve_A_closed
8            Valve:="Inlet_valve_A"    --Q4.0        --Activates the inlet valve for ingredient A
```

STL FBD LAD Network 5 ✕ Feed valve control for ingredient A

etwork comment=

```
0       AN   "Flow_A"                      --I0.2        --Ingredient A flowing
1       AN   "Feed_pump_A"                 --Q4.4        --Activates the feed pump for ingredient A
2       =    #Close_Valve_Fullfilled
3       CALL     FC1
4       Open :=#Enable_valve
5       Close:=#Close_Valve_Fullfilled
6       Dsp_Open :=#Feed_valve_A_open
7       Dsp_Closed:=#Feed_valve_A_closed
8       Valve :="Feed_valve_A"            --Q4.1        --Activates the feed valve for ingredient A
```

```
—    STL    FBD    LAD   📄  📑  📋   Network 6    ✗   Interlocks for feed pump B

Network comment=
.................................................................
.................................................................
.........................┌─────┬──┐..............................
..........."EMER_STOP────┤  &  │..│..............................
..........._off".........│     │..│..............................
.........................│     │..│..............................
..........."Tank_belo────┤     │..│·#Enable_mo··.................
.....w_max".............│     │..│·tor·..........................
.........................│     │..│.......┌──────┐...............
............"Drain"─o────┤     │..└───────┤  =   │...............
.........................└─────┴──┘.......└──────┘...............
.................................................................
```

```
STL   FBD   LAD   FBD/LAD (20):A local data assignment have a wrong address! 📄 📑 📋  Network 7   ✗  Calling FB Motor for ingredient B

work comment=

0       A     "Feed_pump_B_start"·         --I0.3              --Starts the feed pump for ingredient B
1       A     #Enable_motor·
2       =     #Start_fullfilled·
3       A(·
4       O     "Feed_pump_B_stop"·          --I0.4              --Stops the feed pump for ingredient B
5       ON    #Enable_motor·
6       )·
7       =     #Stop_fullfilled·
8       CALL  "Motor_block","DB_feed_pump_B"· --FB1             --FB for controlling pumps and motor
9             Start:=#Start_Fullfilled·
10            Stop:=#Stop_fullfilled·
11            Response::=Flow_B"·            --I0.5              --Ingredient B flowing
12            Reset_Maint::=Reset_maint"·    --I1.7              --Reset switch for the maintenance lamps on all motors
13            Timer_No::=14·
14            Reponse_Time:=S5T#75·
15            Fault:="Feed_pump_B_fault"·    --Q5.5              --Lamp for "feed pump B fault"
16            Start_Dsp:="Feed_pump_B_on"·   --Q5.2              --Lamp for "feed pump ingredient B running"
17            Stop_Dsp:="Feed_pump_B_off"·   --Q5.3              --Lamp for "feed pump ingredient B not running"
18            Maint:="Feed_pump_B_maint"·    --Q5.6              --Lamp for "feed pump B maintenance"
19            Motor:="Feed_pump_B"·          --Q5.4              --Activates the feed pump for ingredient B
```

```
STL   FBD   LAD   Line 1: The Timer/Counter is not complete! 📄 📑 📋  Network 8   ✗  Delaying the valve enable ingredient B

work comment=

0       A     "Feed_pump_B"·   --Q5.4           --Activates the feed pump for ingredient B
1       L     S5T#1S·
2       SD    T      15·
3       AN    "Feed_pump_B"·   --Q5.4           --Activates the feed pump for ingredient B
4       R     T      15·
5       A     T      15·
6       =     #Enable_valve·
```

```
STL   FBD   LAD  📄 📑 📋  Network 9   ✗  Inlet valve control for ingredient B

twork comment=

0       AN    "Flow_B"·                                          --I0.5          --
1       AN    "Feed_pump_B"·                                     --Q5.4          --
2       =     #Close_Valve_Fullfilled·
3       CALL    "Valve_block"          ·
4       Open :=#Enable_valve ·
5       Close := #Close_Valve_Fullfilled ·
6       Dsp_Open   :=#Inlet_valve_B_open·
7       Dsp_Closed :=#Inlet_valve_B_closed ·
8       Valve:="Inlet_valve_B"·                                  --Q5.0          --
```

```
STL   FBD   LAD  📄 📑 📋  Network 10   ✗  Feed valve control for ingredient B

twork comment=

0       AN    "Flow_B"·                         --I0.5           --Ingredient B flowing
1       AN    "Feed_pump_B"·                     --Q5.4           --Activates the feed pump for ingredie
2       =     #Close_Valve_Fullfilled·
3       CALL    "Valve_block"          ·
4       Open  :=#Enable_valve ·
5       Close  :=#Close_Valve_Fullfilled ·
6       Dsp_Open:= #Feed_valve_B_open  ·
7       Dsp_Closed:=#Feed_Valve_B_Closed·
8       Valve:="Feed_valve_B"·                   --Q5.1           --Activates the feed valve for ingredi
```

```
    ■      STL    FBD    LAD   📄 📑 📜   Network 11    X   Interlocks for agitator

    Network comment=


        "EMER_STOP        &
        _off"

        "Tank_abov                  #Enable_mo
        e_min"                      tor

            "Drain" -o                  =


STL   FBD   LAD  📄 📑 📜  Network 12   X  Calling FB Motor for agitator

twork comment=

0       A    "Agitator_start"             --I1.1          --Agitator start button
1       A    #Enable_motor
2       =    #Start_fullfilled
3       A(
4       O    "Agitator_stop"              --I1.2          --Agitator stop button
5       ON   #Enable_motor
6       )
7       =    #Stop_fullfilled
8       CALL   "Motor_block", "DB_Agitator"
9       Start:=#Stop_fullfilled
10      Stop :=#Stop_fullfilled
11      Response := "Agitator_running"
12      Reset_Maint :="Reset_maint"       --I1.7          --Reset switch for the maintenance lamps
13      Timer_No   :=T 16
14      Reponse_Time  :=S5T#10S
15      Fault  :="Agitator_fault"         --Q8.3          --Lamp for "agitator motor fault"
16      Start_Dsp :="Agitator_on"         --Q8.1          --Lamp for "agitator running"
17      Maint :="Agitator_maint"          --Q8.4          --Lamp for "agitator motor maintenance"
18      Motor  :="Agitator"               --Q8.0          --Activates the agitator


    ■    STL    FBD    LAD  📄 📑 📜   Network 13   X   Interlocks for drain valve


    etwork comment=
    ---------------------------------------------------------------


        "EMER_STOP        &
        _off"

        "Tank_not                   #Enable_va
        empty"                      lve

        "Agitator" -o                   =
```

126

Fig.15. Program for OB1

REFERENCES

[1]. Logix5000 Controllers Function Block Diagram - Rockwell. Literature .rockwellautomation.com /.../1756-pm.

[2]. Statement List (STL) for S7-300 and S7-400 Programming.. *.iat.fs.cvut.cz/109 /files/S7/S7-SW2.pdf*

[3] Marcu M.D., Uţu I., Popescu F.G. *Program de simulare pentru funcţionarea variatoarelor statice.* Revista Minelor Nr. 5 / 2007, pag.31-33.

[4] B. L. Samoila, F. G. Popescu, R. Slusariuc, *Virtual instruments used in direct current circuits learning process.* Annals of University of Petrosani, Electrical Engineering, Vol. 15, pag.47-52, Petroşani, 2013, ISSN 1454-8518, Ed. Universitas, EBSCO.

[5]. https://moodle.dce.fel.cvut.cz/file.php/17/Manualy/**FBD**v54_e.pdf. Function Block Diagram (**FBD**) S7-300 and S7-400 **Programming**

[6]. Brawn Mixer - *Fluid Mixing Solutions* www.brawn**mixer**.com/

[7]. VisiMix – Mixing Simulation for Chemical Engineers . www.visimix.com/

[8]. Perry's Chemical Engineers' Handbook, Eighth Edition accessengineeringlibrary .com/.../perrys-chemic.

INDEX OF AUTHORS