**BUCHAREST POLYTECHNIC NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY**
**FACULTY OF ELECTRICAL ENGINEERING**
**DOCTORAL SCHOOL OF ELECTRICAL ENGINEERING**

# ABSTRACT DOCTORAL THESIS

RESEARCH ON OPTIMIZING THE OPERATION OF A MICRO HYDROPOWER PLANT ON ISOLATED GRID

**Scientific supervisor:**
**Univ.Prof.Dr.Eng. Florin IONESCU**

**Doctoral student:**
**Eng. Dorian ANGHEL**

**BUCHAREST 2024**

## CONTENTS OF THE DOCTORAL THESIS

**THANKS**........................................................................................................2
**CONTENT**......................................................................................................3
**LIST OF NOTATIONS**..................................................................................7
**INTRODUCTION**..........................................................................................9
1. **The purpose of the doctoral thesis**.........................................................9
2. **The opportunity of the chosen theme**....................................................10
3. **Chapter organization of the work**..........................................................10
**CHAPTER 1**...................................................................................................11
**1.1 Current status**.........................................................................................11
1.1.1 Geographical setting.............................................................................11
**1.2 Presenting the existing wiring diagram and component parts**...............11
1.2.1 The generators.......................................................................................12
1.2.2 The autotransformer...............................................................................13
1.2.3 Capacitor bank.......................................................................................13
1.2.4 Existing voltage regulator......................................................................13
1.2.5. Deficiencies reported during the operation of the Ochiul Bei microhydropower plant..........................................................................................................14
**1.3. Establishing the optimal solution for the configuration of the microhydropower plant**..........................................................................................................15
1.3.1. Expertise of the technical condition of the microhydropower plant.....................15
**1.4. The schedule of works required to rehabilitate the microhydro aggregates in the Ochiul Bei trouts stream - Ocolul Silvic Sasca**..................................................16
**CONCLUSIONS**..............................................................................................17
**CHAPTER 2**...................................................................................................20
2. EXPERIMENTAL STAND FOR TESTING THE ASYNCHRONOUS GENERATOR OPERATING IN ISOLATED GRID............................................................................20
**2.1. Description of the experimental model of a hydrogen generator operating in isolated grid, without flow regulation**..........................................................20
**2.2. Electrical diagram of the experimental stand**..........................................22
2.2.1. Electrical diagram of the power supply installation MCC..................................24
**2.3. Determination of the operating characteristics of the asynchronous generator**...28
2.3.1. Operation of asynchronous generator in self-excited idle mode..........................29
2.3.2. Operation of asynchronous generator on load.....................................................31
2.3.3. Principle diagram of the control and voltage regulation installation at the generator
terminals..........................................................................................................33
**2.4. Experimental testing on the model**.........................................................34
2.4.1. Capacitor bank adjustable in steps...........................................................39
2.4.2. Acquisition system used............................................................................39
2.4.3. Experimental testing of the generator model at idle operation............................39
2.4.4. Experimental testing of the generator model at load operation............................42
2.4.5. Experimental testing of the generator model in unbalanced load operation.........43
**CONCLUSIONS**..............................................................................................46
**CHAPTER 3**...................................................................................................49
3. MATHEMATICAL MODELING OF THE ASYNCHRONOUS GENERATOR.............49
**3.1. Experimental attempts to determine the electrical parameters of the asynchronous generator**..........................................................................................49
3.1.1. Idle mode as an engine...............................................................................49
**3.2. Modeling the asynchronous generator**.....................................................50

**CONCLUSIONS**.....60
**CHAPTER 4**.....61
4. POWER AND CONTROL ELECTRICAL DIAGRAM OF THE MICRO HYDRO POWER PLANT.....61
**4.1. The asynchronous generator**.....62
**4.2. Capacitor bank**.....63
**4.3. Central power panel**.....65
**4.4. Supply voltage control and regulation board**.....67
4.4.1. Power supply.....70
4.4.2. Accumulators.....70
4.4.3. The network analyzer.....71
4.4.4. Voltage transducer module.....71
4.4.5. IGBT transistor control block.....72
4.4.6. IGBT block.....73
4.4.7. Ballast resistance.....74
**CONCLUSIONS**.....74
**CHAPTER 5**.....76
5. AUTOMATIC VOLTAGE AND FREQUENCY ADJUSTMENT.....76
**5.2. Programmable logic controller presentation**.....76
5.2.1. Power supply.....77
5.2.2. Digital inputs.....78
5.2.3. Analog inputs.....78
5.2.4. Transistor digital outputs.....80
5.2.5. Outputs with relay contact.....80
5.2.6. PWM outputs.....81
5.2.7. RS485 serial communication network.....82
5.2.8. Memory card.....82
5.2.9 Speed input.....82
5.2.10. Elaboration of schemes.....93
5.2.11. Practical realization of printed circuit board.....93
**5.3. Regulator power circuits**.....95
5.3.1. Ballast resistors circuit.....95
5.3.2. Adjustable capacitor bank circuit.....96
5.3.3. Surge suppression circuit.....97
**5.4. Generator frequency regulator**.....97
5.4.1. Control schemes.....98
**CONCLUSIONS**.....107
**CHAPTER 6**.....109
6. FINAL CONCLUSIONS.....109
**CHAPTER 7**.....112
7. PERSONAL CONTRIBUTIONS. FUTURE DIRECTIONS OF RESEARCH.....112
**7.1 Personal contributions**.....112
**7.2 Future research directions**.....114
7.2.1 Vanes and adjustable guide vanes automation.....114
7.2.2 Realization of a remote control and monitoring system.....118
ATTACHMENTS.....122
**Attachment 1**.....122
Details about the Ochiul Beiului hydro installation and location.....122
**Attachment 2**.....126

Mechanical deficiencies reported during the operation of the Ociul Bei microhydropower plant.........126
**Attachment 3**.........127
The technical condition of the micro power plant.........127
**Attachment 4**.........128
Works in order to rehabilitate the microhydro aggregates from the Ochiul Bei trouts........128
**Attachment 5**.........129
VPA 323 acquisition system.........129
**Attachment 6**.........130
Asynchronous machine operation.........130
**Attachment 7**.........141
Voltage monitoring relay type RNPP - 311M.........141
**Attachment 8**.........142
Ballast resistance.........142
**SELECTIVE BIBLIOGRAPHY**.........143

**Keywords:** micro-hydro power plant, isolated grid, asynchronous generator, experimental model of asynchronous motor-generator, capacitor bank, voltage regulator, frequency regulator, system of acquisition of electrical parameters, programmable automation, network analyzer, electrical panel, web server, gsm router.

## INTRODUCTION

Currently, hydropower plants produce 19% of the electricity consumed in the world [2].

In Romania, there is a great potential in the field of hydropower due to the abundant water falls, especially in the mountainous areas. It has been estimated that there are over 2000 locations in the Carpathian Mountains and the surrounding area, favorable for the development of microhydropower plants [3], [4].

The hydropower plants and most of the microhydropower plants built in Romania are connected to the National Energy System [5].

Our country has many small rural settlements that, due to isolation, lack electricity. In some of these settlements there are rivers that could be used for the production of electricity. Setting up a microhydro power plant in an isolated grid can generally be done with much lower costs than installing an electric line to transport energy from a long distance to a small settlement.

One of the advantages of using hydro energy in isolated grid is the fact that it does not require the storage of electrical energy, but it is produced at the level of the hydraulic energy of water in dams.

### 1. The purpose of the doctoral thesis

The purpose of the doctoral thesis is to study and find practical solutions to optimize the operation of a microhydropower plant in isolated grid.

The objectives are the following:

1. Realization of a more efficient voltage-frequency regulator, which maintains voltage and frequency within the limits imposed by the rules in force regarding electrical consumers.
2. Achieving better consumer protection in the event of a defect in the voltage generator-regulator assembly.
3. Generator overspeed protection when the load has disconnected.
4. Remote microhydropower plant process monitoring and control.
5. Realization of automation to track all installations in microhydropower plant starting with the valve, then the control device, the voltage and frequency regulators, so that it can be implemented in other similar micropower plants.
6. The practical realization of the automation as well as the implementation in the field, to be done like this so that costs are minimal without compromising quality.

### 2. The opportunity of the chosen theme

There are areas where, years ago, microhydropower plants were built, which are equipped with non-performing installations or which are only partially functional.

The thesis is opportune precisely for these isolated installations that need a re-technology of the electricity production process.

The solutions that will be presented in the thesis can also be used in projects newly made for microhydropower plants with isolated grid.

At the same time, the thesis proves its feasibility due to its low costs proposes in the realization of automation.

## SYNTHESIS OF THE CHAPTERS OF THE DOCTORAL THESIS

The doctoral thesis is structured in seven chapters, the first of which presents the current state of the microhydropower plant, at the beginning of the research, Chapter 2 presents the realization of a test stand of the asynchronous generator, Chapter 3 presents the simulation of the generator with the program Matlab, Chapter 4 presents the schematics of the power supply board and voltage and frequency control and regulation board, Chapter 5 presents the voltage regulator and frequency regulator, Chapter 6 where the conclusions are presented and Chapter 7 having the contributions personal research results.

## CHAPTER 1 - THE CURRENT STAGE

One of the isolated hydrotechnical installations in Caraş-Severin county is the microhydropower plant near the Ochiul Beiului trouts pond built in 1981. I chose this microhydropower plant to do research on the optimization operation and to find solutions to replace the old automation with a modern one.

The chosen location is in a tourist area in the Cheile Nerei - Beuşniţa National Park, on the border between the Anina Mountains and the Locvei Mountains, near the Beuşniţa waterfall and Ochiul Beiului Lake [10].

Over time, the electrical scheme of the microhydropower plant has undergone several changes. Since the commissioning (approx. 2001), changes were made in 2008.

The electrical diagram used between 2008-2018 is shown in figure 1.

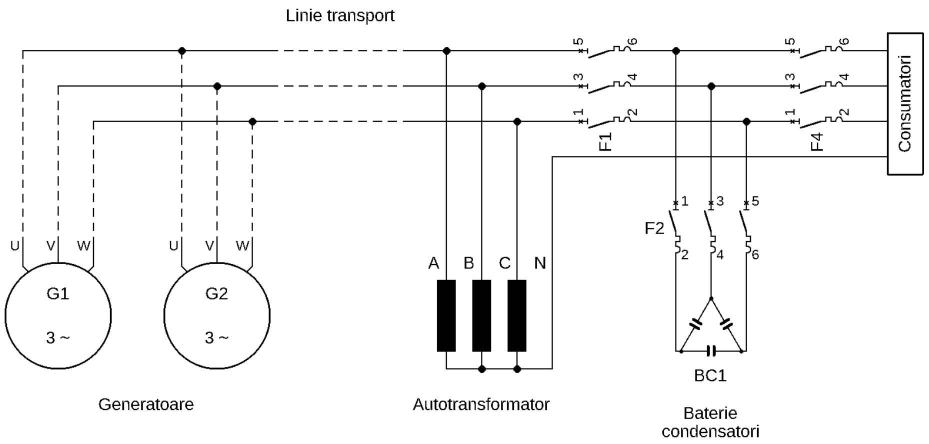


*Fig. 1. Wiring diagram used between 2008 - 2018*

Next, the main elements of the microhydropower plant scheme and the changes that have taken place over the years are presented.

1. The generators

Between the years 2001-2007 a 15 kW asynchronous motor was used as a generator and then until the year 2008 an 11 kW asynchronous motor was used both with star connection.

The generators did not have the original winding, but were rewound.

During this time frame (years 2001-2007) only turbine number 1 was used.

In 2008, an 11 kW asynchronous motor was mounted on each turbine, in a delta connection. These generators could not be star connected as required because they would have produced a phase voltage of 400V and the line voltage would have reached 660 V.

Existing generators cannot ensure the null of the installation, necessary for consumers.

2. The autotransformer

An autotransformer was connected in the scheme in 2008 in order to be able to create a null of the utility plant and thus make it possible to connect consumers that are single-phase.

This null-getting solution was intended as a stop-gap solution intended to be used only temporarily, but it worked for about 10 years.

3. Capacitor bank

The capacitor bank was mounted in a separate panel and consists of three groups of mixed capacitors, in series to increase the value of the working voltage and in parallel to obtain a higher capacity. The groups of capacitors are finally connected in delta.

The capacitor bank had a capacity of 3 x 90 μF - 3 x 100 μF.

4. The existing voltage regulator

In 2001, a three-phase voltage regulator was made for this microhydropower plant using a project designed by Jan Portegijs and presented on his website [2].

The generator is started by opening the valve that lets water enter the turbine and thus the generator rotates. When the speed of the turbine-driven asynchronous motor becomes higher than the synchronism speed, it enters generator mode due to the capacitor bank that is connected in parallel with the stator winding of the motor. In this moment the regulator is powered and goes into operation. The regulator works on the principle of introducing a resistive load into the circuit, when there is no consumption, to decrease the voltage and frequency.

At each start-up, the regulator discharges the active power on the ballast resistors, and then when the voltage and frequency are within the nominal parameters, it engages contactor C1 and through it the consumers. Also, this contactor interrupts the supply to consumers if the voltage and frequency limits imposed for consumers are exceeded.

The resistors are grouped two on each phase so that there are two stages of ballast. Each resistor has a power of 2 kW, so a total power of 12 kW can be controlled with this regulator.

This regulator worked for 7 years.

After the installation of the autotransformer (year 2008), the regulator worked one more time short period of time after which it was stopped and switched to operation without a regulator like this how to use the generator 18 years ago.

The technical expertise we carried out at the microhydropower plant led to the following conclusions:

- A large part of the sub-assemblies of the microhydro aggregates in the plant have a grade due to wear and tear, requiring reconditioning or in some cases replacing them with new ones.

We have drawn up a program of works considering the reconditioning of the following subassemblies: hydraulic turbine stators, hydraulic turbine rotors, asynchronous generator stators, mechanical couplings with bolts and elastic rings.

At the same time, it was necessary to replace some elements where the degree of wear exceeded the maximum limit: radial and axial bearings of the rotors and the sealing semi-rings in the hydraulic turbines. At hydrounit no. 1, it was necessary to replace the main axis of the turbine rotor, as the bearing levels were far below the values allowed in the standards.

The sealing elements of the turbine bearings wear out in a very short time, which leads to premature wear of the bearings.

In the framework of the thesis, a modern sealing system was designed and practically realized that ensures the protection of the bearings, greatly increasing their service life. In the old configuration the seal between the turbine body and the lower bearing housing was made of a rubber bearing. This rubber bearing was cast directly onto the lower bearing housing, was about 200 mm long and I suspect was turned to size. This bearing has not been reconditioned since commissioning, which has caused it to be worn such that it no longer fulfills its sealing role. Not having the technology to thunder a layer of rubber and to bring it back to the original dimensions, I made a seal with semi-rings. For this, only the turning of the turbine body was needed to reach the height of the half ring.

- The operating mode of the turbines, in the initial version, was not the optimal one, according to the operation diagram, the maximum opening of the steering device not being correlated with the optimal water flow regime through the turbine rotor. In order to establish the optimal regime, a load test program was established at different openings to establish the optimal opening of the steering apparatus.

- The capacitor bank used for the self-excitation of asynchronous generators is not performing well, with a very short lifespan, requiring its replacement with a more performing one.

- The connection diagram of the stator windings being in a triangle, does not allow the supply of single-phase consumers, and it is necessary to introduce an adaptation transformer to ensure the neutral for single-phase consumers. It is required to rewind the asynchronous generators in star connection with the accessible neutral, thus eliminating the adaptation transformer from the scheme.

- In the old electricity supply scheme, the generators were connected through a single cable that was manually connected to the terminals of the generator to be used.

It is necessary to connect both generators to the general supply panel, switching the supply to the backup generator from a switch.

- In the old scheme, the electrical switchboard for supplying consumers was located in the area of the Forestry Canton, at the entrance to trouts, so the connection of the generators was ensured by a very long cable.

Placing the electrical panel very far from the generator presented many disadvantages, among which we mention:

- To supply electricity to the consumers, two people were needed: one to connect the cable to the generator to be used and then to manually open the water valve through which the turbine is started in idle mode at nominal speed, and two people will manually connect the switch that feeds the consumers' circuit. It is necessary to design and build a new electrical supply panel located inside the plant to ensure the automatic connection of the switch when the voltage and frequency at the generator terminals reach the nominal values without the need for the intervention of the staff from trouts.

- Since at the entrance to the hydraulic turbines there are no suitable grills to prevent the entry of woody materials into the turbine, there have been numerous failures at the level of the steering apparatus as well as at the turbine rotor, thus leading to significant energy losses and additional expenses. In order to eliminate such shortcomings, it is necessary to create a grill that ensures the safe operation of the hydraulic turbines.

- The scheme of the electrical installation for supplying electricity to the consumers in that location does not ensure the monitoring of the main electrical parameters phase and line voltage, phase currents, active and reactive power absorbed by each phase, voltage frequency at the generator terminals. It is thus necessary to create a modern system for monitoring these parameters, with local and remote visualization of them.

- The voltage and frequency regulation system at the existing synchronous generator terminals did not ensure safe operation of electrical consumers, with frequent burning of equipment due to overvoltages occurring in the system or overheating of household consumers due to large frequency deviations.

An automatic system is required to ensure protection against overvoltage and overload of consumers.

A separate frequency regulation system independent from the voltage regulation system is also required.

## CHAPTER 2 - EXPERIMENTAL STAND FOR TESTING THE ASYNCHRONOUS GENERATOR OPERATING IN ISOLATED MODE

In the microhydropower plant, it was not possible to test the equipment made during the research, like that we built a stand in the Equipment Testing laboratory within the U.B.B. Resita.

The experimental stand was made practically in order to verify the adjustment performances of the two regulators made in the framework of the doctoral thesis: the RAV speed regulator and the RAT voltage regulator, through which to ensure a supply of electricity to useful consumers within the nominal parameters of frequency and voltage.

The principle diagram of the experimental stand is given in figure 2.

For this purpose, the voltage regulation at the generator terminals is carried out by means of a battery of adjustable capacitors that fulfills the role of RAT. The voltage information is taken directly from the terminals of the GA generator.

The GA asynchronous generator is driven at rated speed by means of the DC motor, MCC. The operation of the generator is conditioned by the existence of a capacitor bank C, connected in parallel with the asynchronous machine, which ensures the magnetizing current of the asynchronous generator [23].

The induction generator (GA) is driven by means of a direct current motor fed from a DCREG fully controlled three-phase rectifier system.

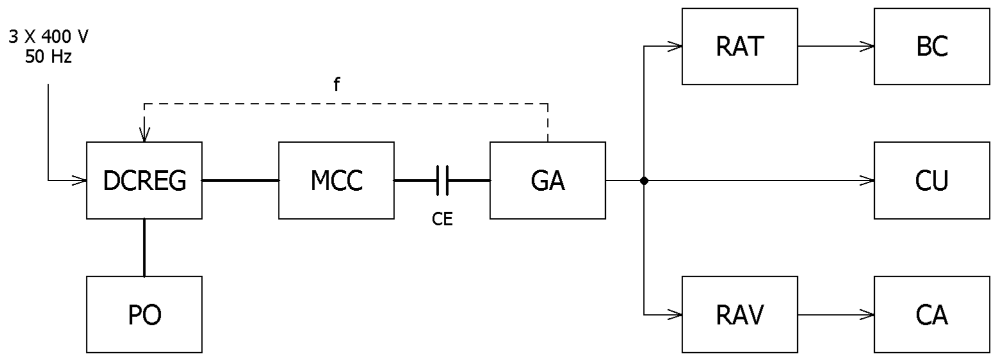


*Fig. 2. Principle diagram of the experimental stand*

In figure 2, the notations are as follows:

DCREG - controlled three-phase rectifier;
PO - DCREG operator panel;
MCC - direct current motor;
CE - elastic coupling;
GA - asynchronous generator;
RAT - automatic voltage regulation;
RAV - automatic speed adjustment (frequency);
BC - adjustable capacitor bank;
CU - useful consumers;
CA - additional consumers (ballast resistors);
f- generator frequency.

A 2.2 kW three-phase asynchronous generator model (figure 3 left) was used, which is coupled with a 2.5 kW direct current electric motor (figure 3 right), which replaces the turbine.

Figure 4 shows the control part of the DC motor. On the right side we have the DCREG type three-phase rectifier, and on the lower left side are the command confirmation lamps and the manual control buttons.

Starting from the left side, the lamps have the following functions: presence of voltage, enable, DCREG OK, start DCREG, decrease speed, increase speed and current loop.

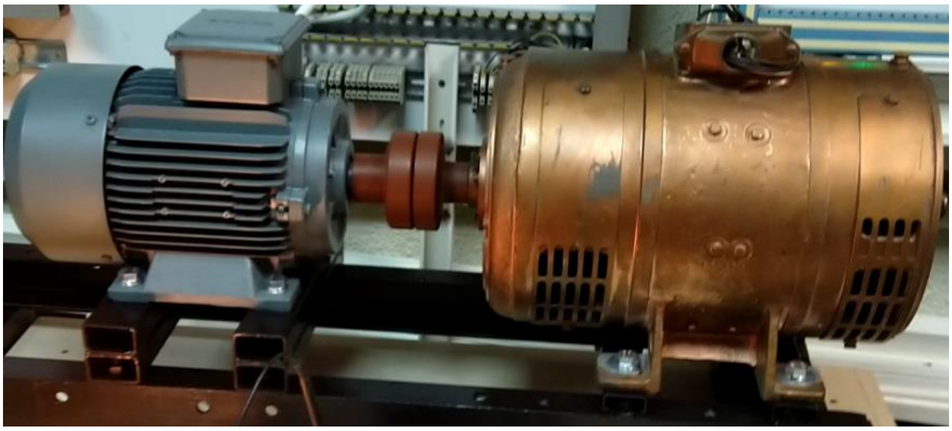

*Fig. 3. The microhydroaggregate experimental model*

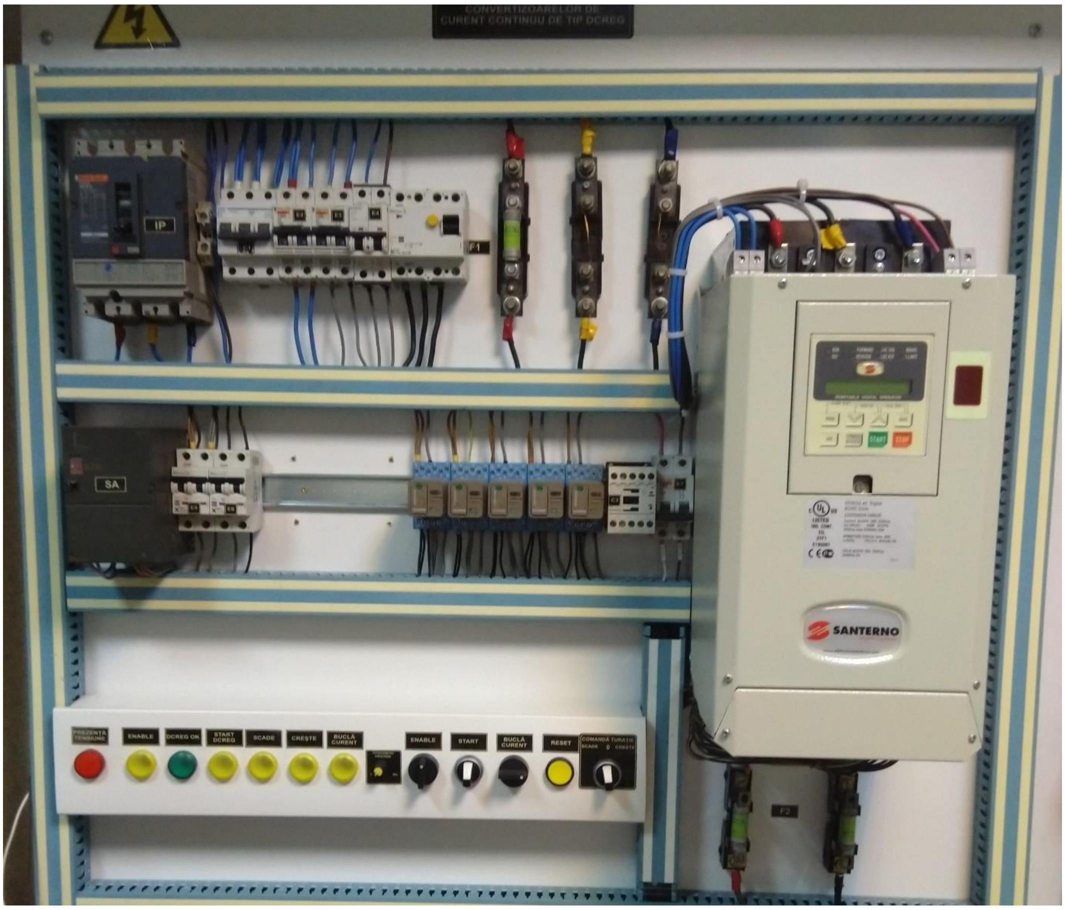


*Fig. 4. The experimental model of the MCC control part*

In the center of the control panel there is a potentiometer with which the speed of the direct current motor can be adjusted, being connected to an analog input of the DCREG type rectifier.

On the right side are the control buttons having the function, starting from the left side, enable, start, current loop, reset, speed command decrease-0-increase.

Current loop refers to the fact that the rectifier activates an internal regulator depending on the output current.

Figure 5 shows the control part of the asynchronous generator (GA). In the upper part of the painting, I made an aluminum construction like a ladder, divided into 3 sharp rectangles, for the 3 phases and inside which I mounted 4 bulbs of different powers.

The bulbs are of the type used in halogen reflectors, which can have powers between 50 400 W. These bulbs are used as useful consumers. They are inserted or removed from the circuit with the help of fuses F6 F15 according to the diagram in figure 6, so that we can simulate different values of the useful power generated.

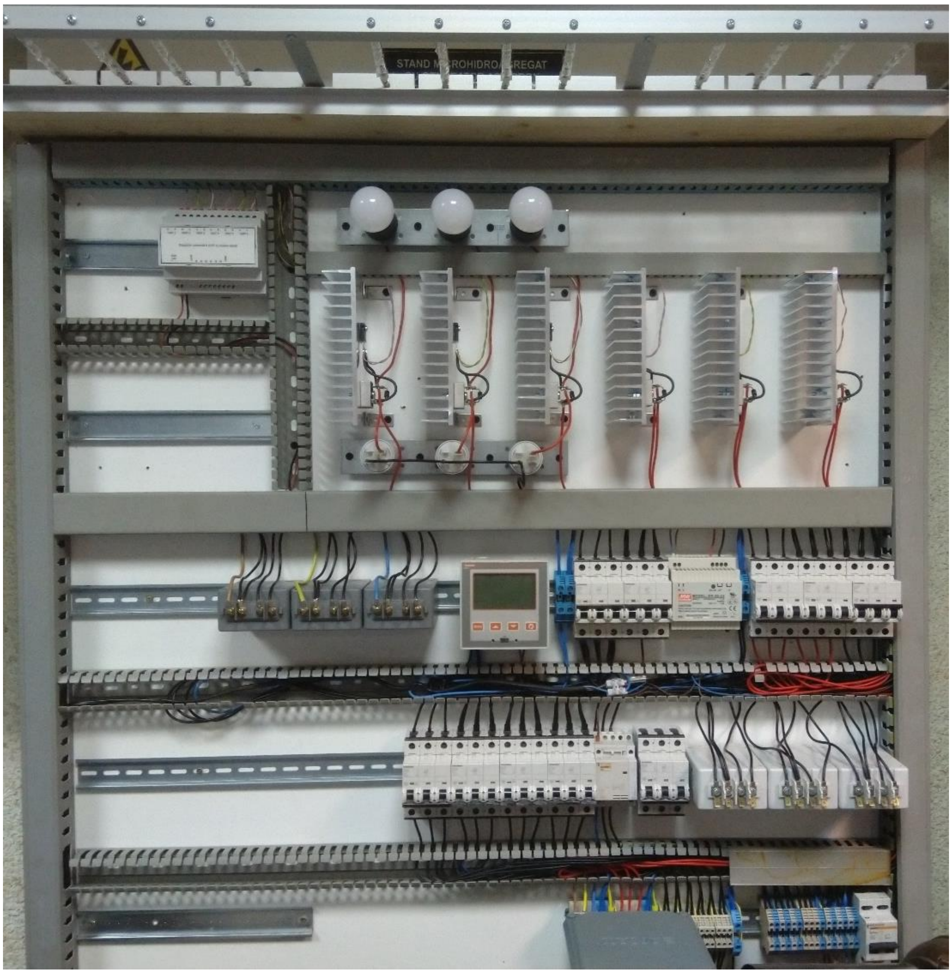

*Fig. 5. The experimental model of the GA control part*

Table 1 presents the results of the asynchronous generator testing analyzing the following parameters: speed, frequency, line voltage, phase voltages, phase currents and generated power, for different powers starting from idling to the maximum power of the generator [76] . In the first column of the table I indicated the power of useful consumers.

In the same column, for the first experimental tests, a fixed three-phase capacitor bank of 3 x 12 µF was used, and next the value of the additional battery that was inserted into the circuit to increase the self-excitation of the generator and implicitly the voltage at the terminals is indicated.

In the last row of the table, I also presented an experimental test without consumers but with the maximum capacity of the capacitor bank, which caused the voltage to rise above the allowed limits. This situation could only occur if the regulator failed.

After testing the generator on the experimental stand, the following results emerge conclusions:

Since the use of a hydraulic turbine to drive the asynchronous generator in the experimental stand presents many disadvantages, the hydraulic turbine was replaced by a separate excitation direct current motor of close to that of the turbine. This was possible because the torque equations for the separately excited DC motor are similar to those of the axial turbine;

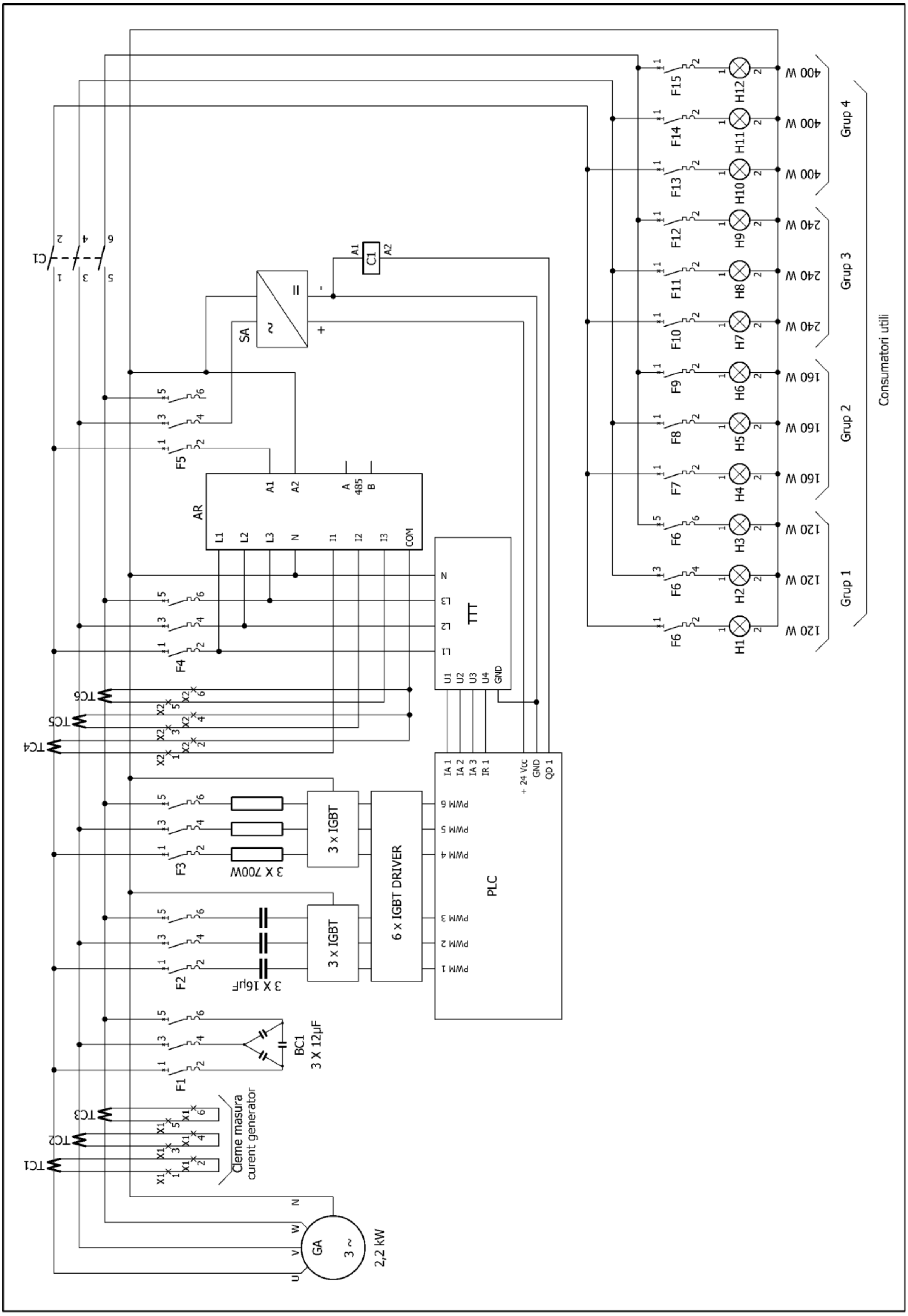


Fig. 6. Scheme of the experimental model of the generator part

- for driving the direct current motor, an ac/dc converter was used, having embedded in it two rectifier bridges, one fully controlled for powering the stator winding and one semi-controlled for powering the excitation windings of the direct current motor.

Tabel 1. Rezultate măsuratori parametri electrici la diferite puteri produse

| | Turație | Frec venţă | U linie | UR | US | UT | IR | IS | IT | P |
|---|---|---|---|---|---|---|---|---|---|---|
| | [rpm] | [Hz] | [V] | [V] | [V] | [V] | [A] | [A] | [A] | [W] |
| Gol | 1506,44 | 50,13 | 410,35 | 236,60 | 235,87 | 238,04 | 0,009 | 0,020 | 0,002 | 3 |
| 360 | 1511,35 | 50,02 | 397,58 | 229,48 | 228,34 | 230,79 | 0,556 | 0,561 | 0,548 | 382 |
| 480 | 1514,60 | 50,03 | 392,99 | 226,78 | 225,94 | 227,96 | 0,739 | 0,735 | 0,734 | 501 |
| 720 | 1519,41 | 50,00 | 381,86 | 220,56 | 219,64 | 221,55 | 1,063 | 1,067 | 1,070 | 706 |
| 840 | 1522,60 | 50,00 | 374,57 | 216,15 | 215,39 | 217,17 | 1,261 | 1,252 | 1,250 | 814 |
| 840 + 1 μF | 1522,68 | 50,00 | 396,80 | 228,96 | 228,20 | 230,12 | 1,298 | 1,291 | 1,288 | 888 |
| 720 + 1 μF | 1519,63 | 50,00 | 402,34 | 232,19 | 231,26 | 233,42 | 1,097 | 1,100 | 1,104 | 767 |
| 1080 + 1 μF | 1528,96 | 50,02 | 385,33 | 222,48 | 221,50 | 223,43 | 1,612 | 1,617 | 1,619 | 1078 |
| 1200 + 1 μF | 1531,18 | 50,00 | 378,19 | 218,26 | 217,43 | 219,35 | 1,765 | 1,757 | 1,740 | 1149 |
| 1200 + 2 μF | 1530,84 | 50,00 | 397,95 | 229,54 | 228,84 | 230,90 | 1,809 | 1,808 | 1,790 | 1242 |
| 1560 + 2 μF | 1540,36 | 50,00 | 376,24 | 217,33 | 216,02 | 218,30 | 2,293 | 2,289 | 2,266 | 1487 |
| 1560 + 3 μF | 1540,14 | 50,00 | 396,27 | 228,66 | 227,81 | 229,90 | 2,362 | 2,363 | 2,333 | 1615 |
| 1680+ 3 μF | 1543,60 | 50,00 | 389,05 | 224,34 | 223,74 | 225,76 | 2,525 | 2,515 | 2,504 | 1694 |
| 1680 + 4 μF | 1543,22 | 50,00 | 405,87 | 234,08 | 233,37 | 235,53 | 2,584 | 2,578 | 2,556 | 1808 |
| 1920 + 4 μF | 1549,42 | 50,00 | 393,13 | 227,06 | 225,88 | 227,99 | 2,881 | 2,877 | 2,868 | 1958 |
| 1920 + 5 μF | 1549,65 | 50,00 | 407,79 | 235,41 | 234,18 | 236,72 | 2,937 | 2,940 | 2,924 | 2072 |
| 2040 + 5 μF | 1553,37 | 50,00 | 400,88 | 231,35 | 230,36 | 232,63 | 3,126 | 3,123 | 3,096 | 2163 |
| Gol + 5 μF | 1504,16 | 50,00 | 460,81 | 264,41 | 264,72 | 269,03 | - | - | - | - |

In this way, there is the possibility of simulating all the operating regimes characteristic of hydraulic turbines, with the online monitoring of the electrical and mechanical parameters, which characterize the operation of the direct current motor, respectively the operation of a turbine both in idle mode and in variable load mode at different RPM values.

Since the hydraulic turbines in the Ochiul Bei plant do not have their own turbine water flow regulation system, thus there is a danger of a dangerous over-speeding of the turbine-generator assembly, the stand allows the simulation of this regime, with online monitoring of the engine speed and emergency shutdown in case the speed exceeds a certain imposed value. The emergency shutdown also occurs when the electrical parameters exceed the maximum or minimum values imposed.

A special performance of the proposed scheme is the fact that the voltage regulation at the terminals of the asynchronous generator is carried out by means of a battery of capacitors with continuously variable capacity whose scheme is presented in chapter 5.

Through the control and adjustment scheme proposed in this chapter, the possibility of an automatic adjustment of the voltage frequency at the generator terminals is created, through a continuous variation of the currents in the three-phase ballast consumer.

The main advantage of this system is the fact that the current regulation is done separately on each phase, thus eliminating the possibility of phase imbalances in the three-phase consumer supply system.

In order to eliminate the intervention of trouts staff, in the process of supplying voltage to consumers, the scheme made in this chapter ensures the automatic connection of contactor Cl through which the electricity supply of trouts and the cabins is carried out.

In conclusion, it follows that the voltage regulation and speed regulation equipment from the scheme of the experimental model will also be used in the scheme of the electricity supply installation in Ochiul Bei Păstravăria.

The main advantage is the fact that these equipments have been tested on the experimental stand.

## CHAPTER 3 - MODELING OF THE ASYNCHRONOUS GENERATOR

To model the asynchronous generator with short-circuited rotor, a component from the library of the Matlab program - Simulink figure 7 [34], [36] is used.

This component constitutes a model of an asynchronous machine, which can be used either in motor mode or in generator mode, the switching being performed by changing the sign of the input variable Tm [90] [93]. This variable Tm represents the mechanical torque.

The mathematical model of the asynchronous machine is made up of several distinct functional blocks according to figure 8, namely: the power block, the electrical model of the machine, the mechanical model of the machine, the measuring block of the quantities that characterize this model.

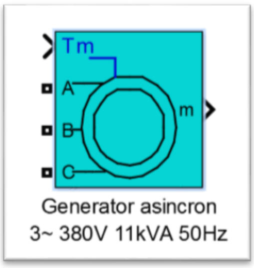


*Fig.7. Asynchronous machine model - Simulink* [34], [36]

The electrical model of the asynchronous machine is made of several functional blocks (figure 9) that use the transformation model of the three-phase system to a two-axis d, q system using Park and Clarke's transforms [36], [37].

The scheme of the mechanical model of the asynchronous machine is shown in figure 10.

Figure 11 shows the mechanical and electrical quantities that must be taken and used in the simulation.

It should be noted that most quantities are expressed in relative units, in the "per unit" (pu) system. This system is widely used in the power system industry to express the values of voltages, currents, powers and impedances of various energy equipment. mainly used for transformers and alternating current machines For a given quantity (voltage, current, power, impedance, torque, etc.), the relative value is the value relative to a basic quantity [35], [36], [37] , [38].

The value in p.u. = value expressed in SI units / base value [39].

The specific sizes of the machine we will model are entered into the program in the parameters window. These parameters are: rated power, line voltage, frequency, stator resistance, loss inductance, rotor resistance, rotor loss inductance relative to the stator, magnetizing (mutual) inductance, mechanical inertia coefficient, friction coefficient, number of pole pairs.

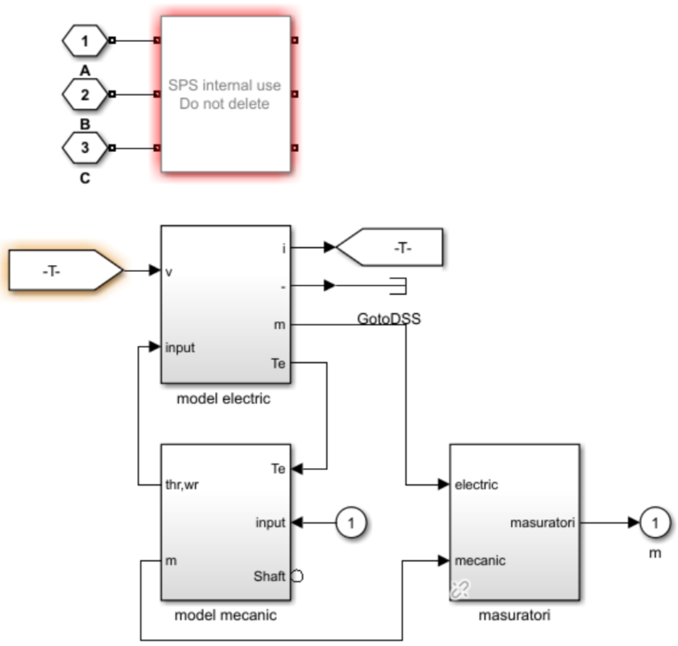


*Fig. 8. Block diagram of the asynchronous machine model* [33], [36]

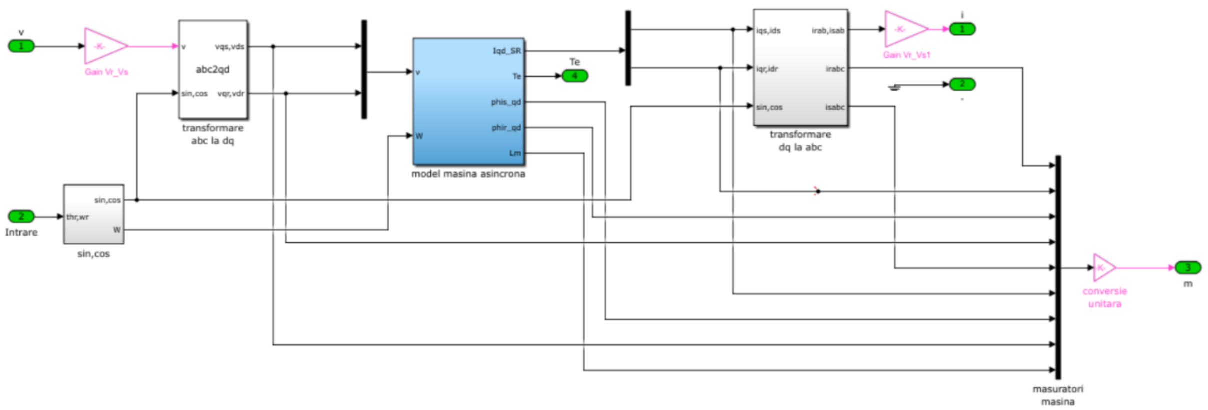


*Fig. 9. Diagram of the electrical model of the asynchronous machine* [32], [33]

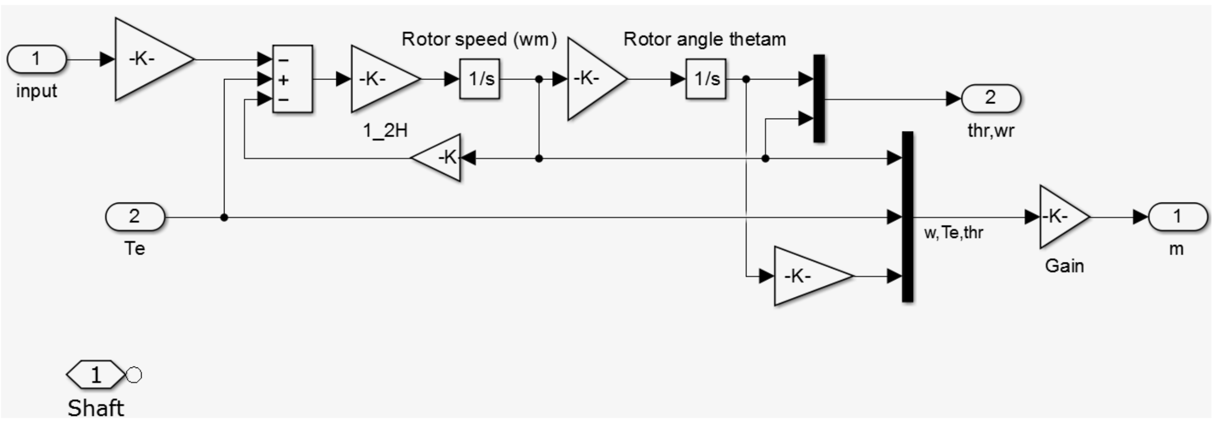


*Fig. 10. Scheme of the mechanical model of the asynchronous machine* [32], [33]

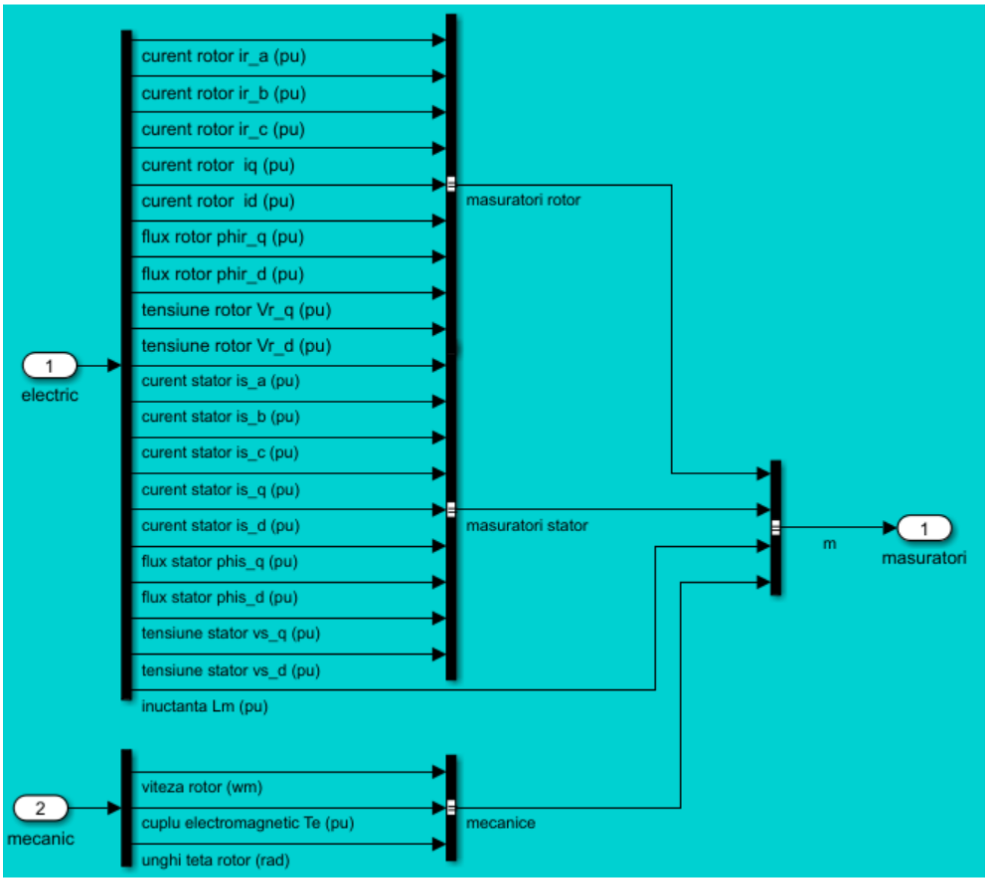


*Fig. 11. Accessible parameters of the chosen model* [32], [34]

Figure 12 shows the model used for the simulation.

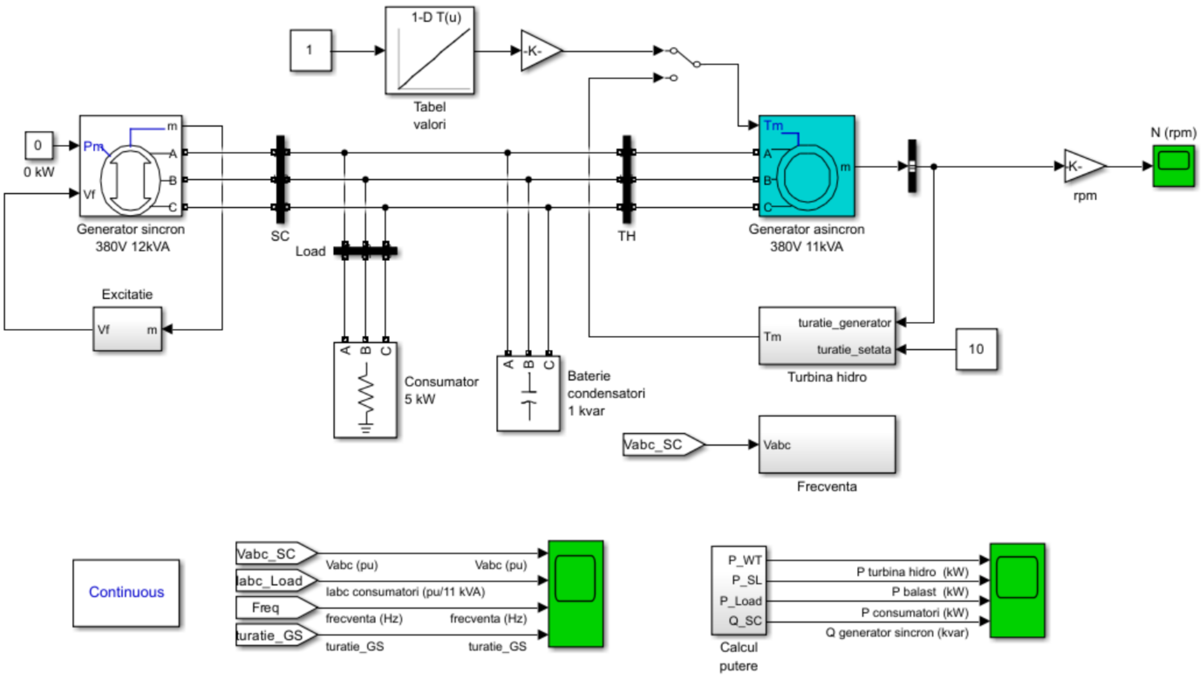


*Fig. 12. The proposed model for simulation*

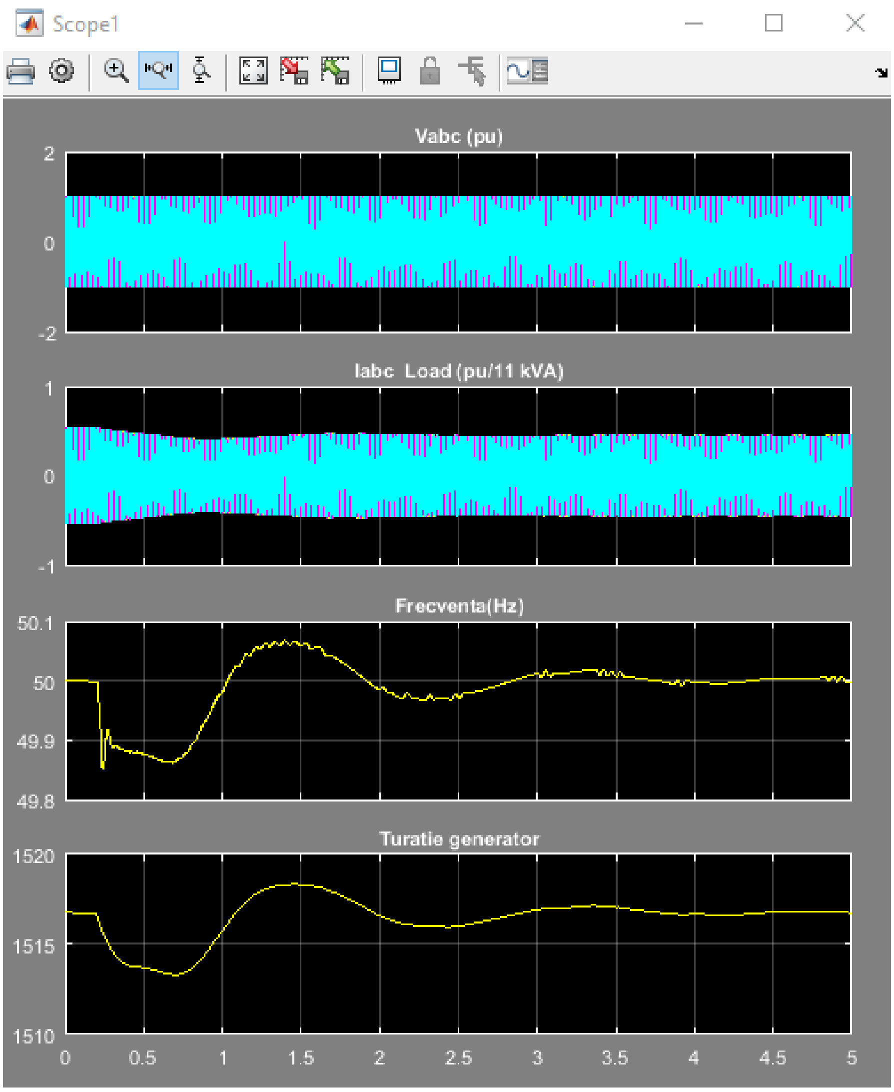


*Fig. 13. Graph line voltage, load current, frequency and speed*

Following the simulation, some characteristics were drawn which are presented in figures 13 and 14. According to the curves in figure 14, it can be seen that when the active load varies, the reactive power produced by the synchronous generator also changes according to those presented in the previous subsection [42], [ 43], [44].

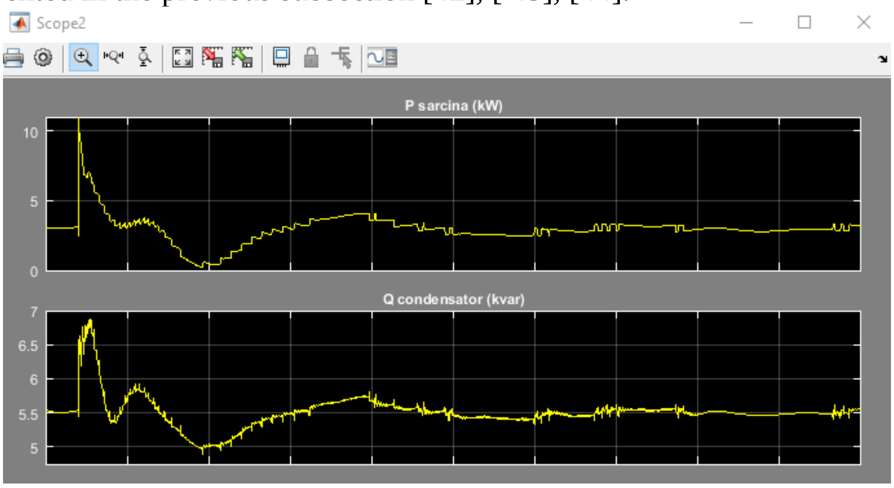


*Fig. 14. Graph load power and reactive power produced*

Through this simulation I tried to create a power shock by suddenly changing the power of the useful consumers in the direction of its increase and then its decrease. Through simulation, I wanted to test the response time of the developed automation system to these shocks.

Based on the graphs in figures 13-14, it can be seen that the regulator behaves well, managing to bring the voltage and frequency back to the optimal values. Mathematical modeling is based on the equations of voltages, currents and magnetic fluxes, which describe the operation of the asynchronous generator in different operating regimes.

To establish the mathematical model of the synchronous generator, it is necessary to experimentally determine the impedances that define its equivalent scheme: the stator impedance, the rotor impedance reduced to the stator as well as the magnetization impedance.

In this chapter these impedances were determined for the asynchronous machine used to operate as an asynchronous generator in the experimental model provided in chapter 2.

The tests carried out on the experimental model of asynchronous generator have shown the following:

For an asynchronous generator, which is to operate in isolated mode, there is a minimum speed at which its stable operation is possible under no-load conditions at the nominal voltage.

The maximum speed of an asynchronous generator operating in isolated mode is limited by the maximum value allowed for the voltage at the generator terminals.

- The stability of the operation of a self-excited asynchronous generator in isolated mode, in certain speed and voltage limits is conditioned by the value of the capacity of the capacitor bank connected to the generator terminals, requiring that it fall within certain limits. These values were determined for the experimental model and were implemented in the Ociul Bei microplant.

## CHAPTER 4 - ELECTRICAL DIAGRAM FOR POWER AND CONTROL OF THE MICRO HYDRO POWER PLANT

### Central power panel

The central power switchboard ensures the connection of the asynchronous generators to the consumer use circuit in Pastrăvărie and Ocolul Silvic. Figure 15 shows the power supply board, and figure 16 shows the diagram of the board.

The asynchronous generators Gl and G2 are connected to the supply board TA by means of automatic switches, which in turn are connected to the two inputs of the three-phase switch S1.

The consumers are fed through the switch and contactor C1. The contacts of the contactor Cl can be short-circuited by means of the switch F3, which is provided with overload or short-circuit protection at the terminals.

The switch F3 allows the manual connection of consumers in conditions where contactor Cl is disconnected. The F4 switch allows the visible separation of the consumer use circuit, in the conditions where central revision works or at the consumers are carried out.

The connection of capacitor banks in the generator circuit takes place by means of switches FB1, FB2 [78].

The connection of contactor Cl occurs automatically when the voltage in the circuit supply, at the exit from the switch reaches the nominal voltage and frequency parameters.

The connection of the contactor can take place through the relay RT1 which monitors the value of the phase and line voltages and gives the command to close the contactor when the voltage value falls within the limits (0.9-1.1)Un.

The C1 contactor connection command can also be given through the programmable automaton mounted in the TCR control and adjustment cabinet.

*Fig. 15. Microhydropower power supply panel*

For overvoltage protection of asynchronous generators and consumers introduces into the circuit a voltage monitoring relay RT2 of the same type as relay RT1.

The relay monitors the line and phase voltages, and when a voltage exceeds a prescribed maximum value, the relay will command the closing of contactor C2 which will connect. the ATR autotransformer that supplies a three-phase resistance Rp, thus creating additional loading of the generator that will limit the voltage at the terminals below the prescribed maximum value.

To monitor the line current in the consumer supply circuit, TC current measuring transformers were introduced, having a nominal current of 25 A in the primary and 5 A in the secondary (transformation ratio 5). The secondary currents of the measuring transformers are connected to the current circuit of the AR network analyzer mounted in the TCR control and adjustment cabinet. The voltage circuit of the AR analyzer is connected directly to the supply voltage via the three-phase fuse FU in the supply panel. In this way, all electrical parameters in the power supply circuit can be displayed on the analyzer display: currents and voltages f phase respectively line, active and reactive power, total active and reactive energy.

Figure 15 on the left shows a view of the interior of the central power supply panel.

Three voltmeters and a frequency meter were mounted on the front panel of the power supply cabinet, through which the voltages on the three phases and the frequency of the power supply voltage can be visualized, figure 15 right.

The lighting circuit is also connected to the central supply panel, respectively the circuit of sockets in the central, by means of the switch F7. Figure 16 shows the diagram of the TCA central supply panel.

The three-phase voltage relays RT1, RT2 are of the RNP-311M type [51] [52] [53]. This relay monitors the following network parameters: minimum voltage, maximum voltage, correct phase sequence, phase asymmetry.

**Supply voltage control and regulation panel**

The control and regulation panel (figure 17) ensures the automatic power regulation, with the maintenance of the nominal load of the generator by means of the RP power regulator.

- automatic voltage and frequency regulation of the asynchronous generator by means of the RU voltage regulator
- order to connect or disconnect consumers from the voltage
- power provided by the asynchronous generator through the programmable automaton AP.
- monitoring the electrical parameters in the utility circuit by means of the AR network analyzer.

Figure 19 shows the diagram of the voltage regulator board, and in figure 18, the cabinet door can be seen on the left and the counter panel with the component parts on the right.

The following components were used to make the voltage regulator: 24V DC power supply SA, 12V batteries, AR network analyzer, voltage transducer module (M7), programmable controller (PLC), IGBT grid control modules (M1... M6), IGBT groups + rectifier bridge + RC circuit (Q1...Q6).

The electricity supply scheme, carried out in the framework of this doctoral thesis, eliminates all the shortcomings reported during the technical expertise carried out, which were presented in chapter 2. In conclusion, I mention some of the solved problems:

- the capacitors previously used for the self-excitation of asynchronous generators, were not performing well, having a very short lifetime, thus generating repeated failures with the generators being taken out of operation. In the framework of the thesis, a new battery was created, consisting of high-performance three-phase capacitors with a much longer life span.
- the power supply panel made ensures the permanent connection of the asynchronous generators in the power plant and the selection of the microhydro aggregate to be used is done by means of a switch mounted on the front panel of the power supply panel.
- the electrical scheme made ensures, by means of a specialized network analyzer, the online monitoring of the electrical parameters in the consumer supply circuit: the phase and line voltages, the current on each phase, the active power on each phase and total, the reactive power on each phase and total, power factor per phase, voltage frequency at the generator terminals.
- the designed control and adjustment scheme allows the automatic switching of the contactor in the consumer supply circuit, when the frequency and voltage at the generator terminals reach the nominal values.
- the power supply panel made ensures the permanent connection of the asynchronous generators in the power plant and the selection of the microhydro aggregate to be used is done by means of a switch mounted on the front panel of the power supply panel.
- the electrical diagram ensures, by means of a specialized network analyzer, the online monitoring of the electrical parameters in the consumer supply circuit: the phase and line voltages, the current on each phase, the active power on each phase and total, the reactive power on each phase and total, power factor per phase, voltage frequency at the generator terminals.
- the designed control and adjustment scheme allows the automatic switching of the contactor in the consumer supply circuit, when the frequency and voltage at the generator terminals reach the nominal values.
- the old scheme required the presence of two people to supply the consumers: one to make the manual connection of the generator and then turn on the turbine, and the second person to manually connect the switch in the electrical switchboard for supplying the consumers located at the entrance to trout.

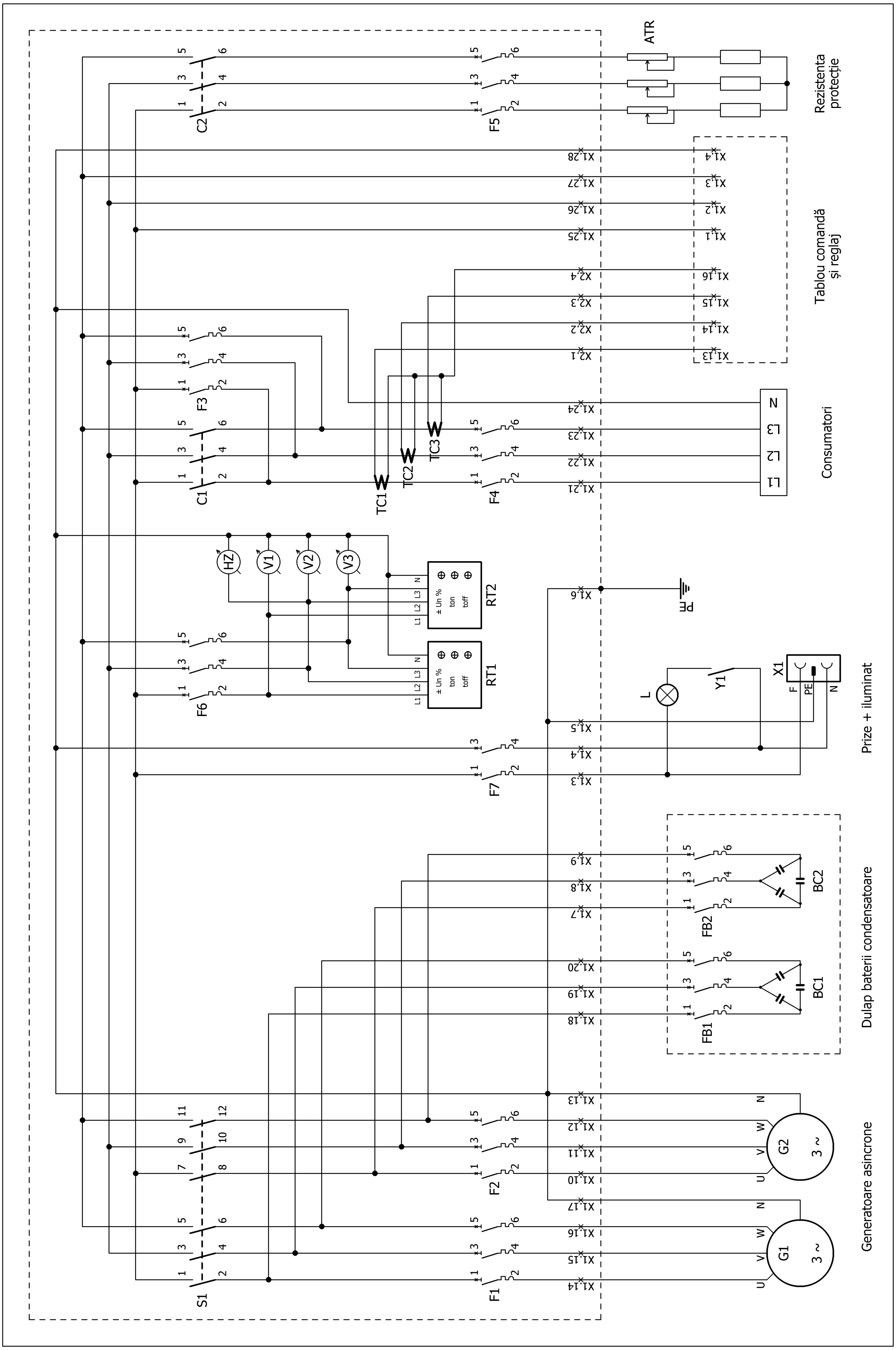


*Fig. 16. Scheme of the central power supply board*

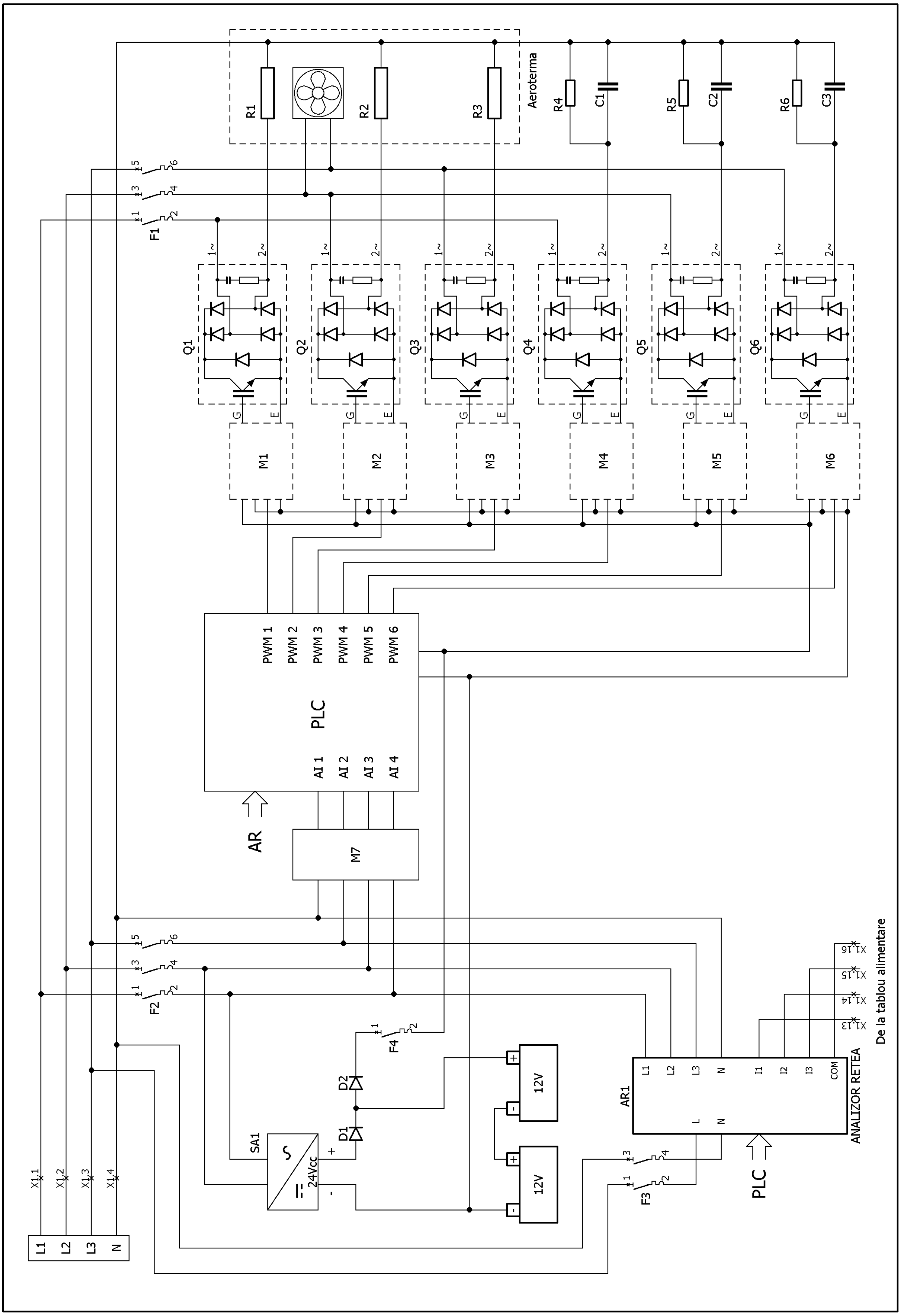


*Fig. 17. Regulator board diagram*

*Fig. 18. Control panel and voltage adjustment*

- the voltage regulation scheme allows maintaining the voltage balance on the phases, under the conditions of asymmetrical loads caused by single-phase household consumers. The voltage balancing on the phases is carried out according to the currents on each phase, by connecting or disconnecting single-phase ballast consumers at the generator terminals. In the old installation, the voltage adjustment was made according to the average value of the currents on the three phases by connecting or disconnecting three-phase ballast resistance stages there being no possibility of balancing the phase voltage.
- Since the water reserve in the dam does not allow the parallel operation of those two generators, the automation scheme made allows the use of a single generator to supply the consumers, the other generator being in warm reserve.

## CHAPTER 5 - AUTOMATIC VOLTAGE AND FREQUENCY ADJUSTMENT

**Automatically programmable presentation**

In 2014, I made a small programmable automaton as a dissertation topic at the completion of my master's studies. I thought that this automatic would be able to fulfill the function of voltage regulator.

The programmable automaton (figure 19) has the following characteristics:

- supply voltage 24V direct current;
- 8 digital inputs with positive or negative logic;
- 8 analog voltage inputs 0-30V that can also be used as digital inputs with positive logic;
- a fast count input;
- 8 digital outputs with transistor, positive logic;
- 8 relay outputs;
- 8 PWM outputs;
- an RS485 serial communication network;
- it is made in a 35mm DIN rail mount case;
- each digital input and output is equipped with an LED to indicate the status;
- it has three bicolor LEDs that indicate the source status (ok - green or defective - red), the module status (ok or defective), the operating status (in function green, in stop - red or in function with disabled outputs orange)

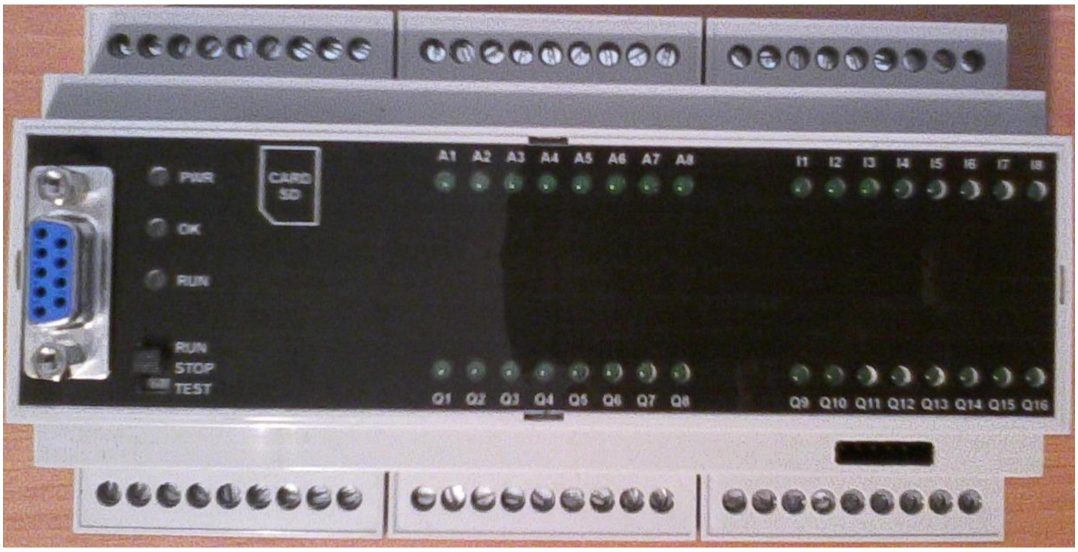


*Fig. 19 Programmable automation*

*Power supply*

A source built around the circuit is used as a power source for the automaton integrated MC34063. This circuit is a DC/DC voltage converter [75].

The source of the automaton is made according to the diagram in figure 20, a configuration that provides a voltage of 5V at the output which is then stabilized with a 5V/3.3V regulator.

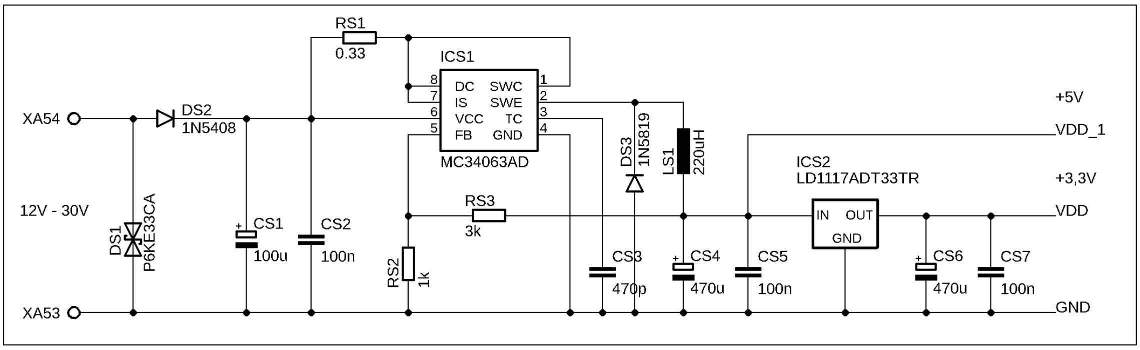


*Fig. 20 Power source*

*Digital inputs*

For the digital inputs we used a scheme with optical isolation, in which the signal of input is completely isolated from the signal that reaches the microcontroller with the help of a optocoupler (figure 21). The chosen optocoupler has an alternating current input that makes ca the input signal can be used regardless of polarity. The isolation of the input from the output se achieves up to a voltage of 5kV for the chosen optocoupler. The stars of the digital inputs are displayed by LEDs, arranged on the face of the machine and marked with 11-18.

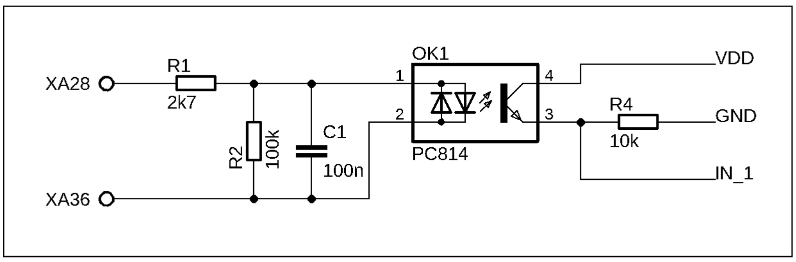


*Fig. 21 Digital input*

*Analog inputs*

The scheme chosen for the analog inputs is made with a voltage divider. The diodes are used as protection against overvoltages that could occur at the analog input of the microcontroller (figure 22).

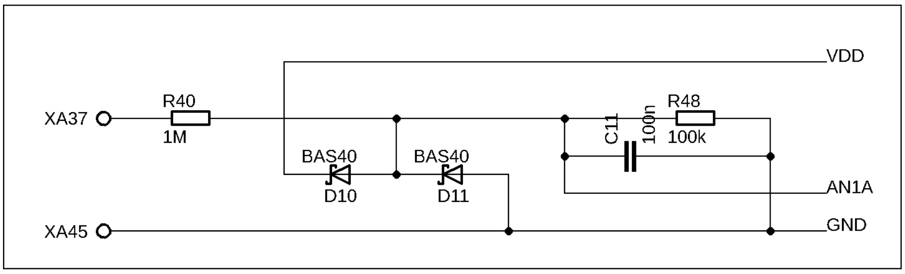


*Fig. 22 Analog input*

The analog input can measure a voltage between 0 and 30.8V with an accuracy of 15.04mV (+7.52mV). Figure 23 shows the binary value from the output of the analog-digital converter depending on the input voltage [66].

Each analog input can be converted very simply into a digital input. Cal voltage threshold for digital input I chose the value of 9V to be able to use the input at 12V and 24V.

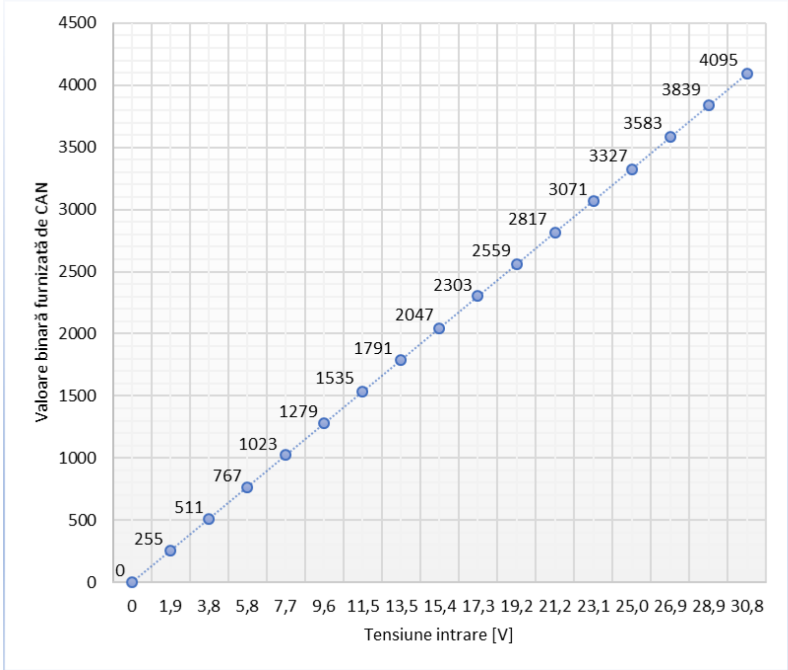


*Fig. 23 CAN input voltage-output value characteristic*

*Digital output with transistor*

Digital relays with transistors are made using the UDN2982 integrated circuit figure 24.

The circuit contains 8 outputs with transistors, which can control relays, coils, motors, actuators or lamps. All outputs are protected with diodes to be used in inductive circuits. The states of the outputs are displayed by LEDs, arranged on the face of the automaton and noted with Q1-Q8.

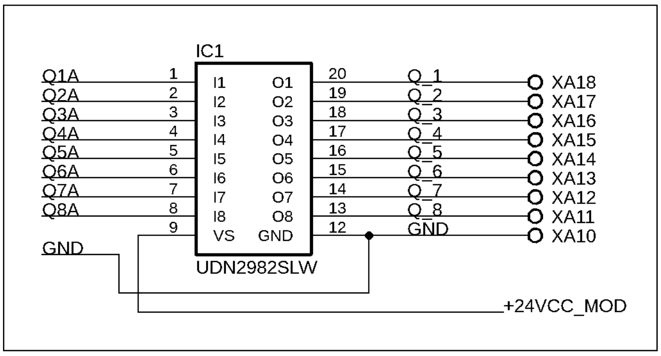


*Fig. 24 Transistors output*

*Relay contact output*

Relay contact output are used to control circuits that are powered at high voltages and that need isolation from the assembly components. The relays are of the miniature type, with the coil powered at 24V direct current, their contact withstands up to a voltage of 250Vac and a current of 3A.

Each relay has a normally open contact.

The relay control circuit is made with the ULN2803 integrated circuit, it can control 8 relays with output transistors (figure 25).

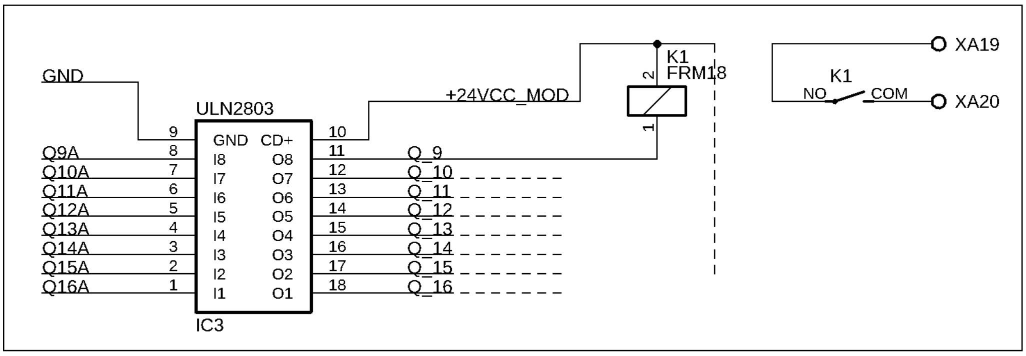


*Fig. 25 Relay output*

The states of the outputs are displayed by LEDs, arranged on the face of the automaton and marked with Q9-Q16.

*PWM outputs*

Command PWM pulse-width modulation-represents the duration modulation a pulses.

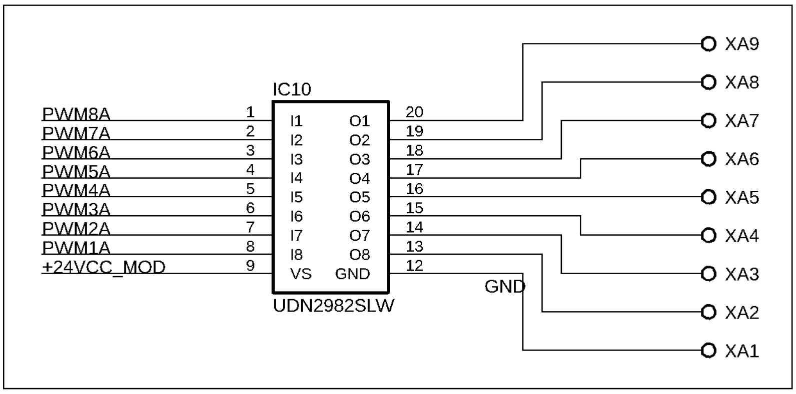


*Fig. 26 Ieșiri PWM*

The automaton has 8 pwm outputs as seen in figure 26. the sockets are of the cu type empty collector and become positive when activated by the microcontroller outputs. All the sparks are protected with diodes so they can be used in inductive circuits.

The output current on each channel is a maximum of 60 mA per channel in order not to exceed the total current.

*RS485 serial communication network*

The RS485 serial communication network (figure 27) is divided into two, one part connects the server and the automaton, the second is connected to the network analyzer, from which the automaton reads the values measured by them [73].

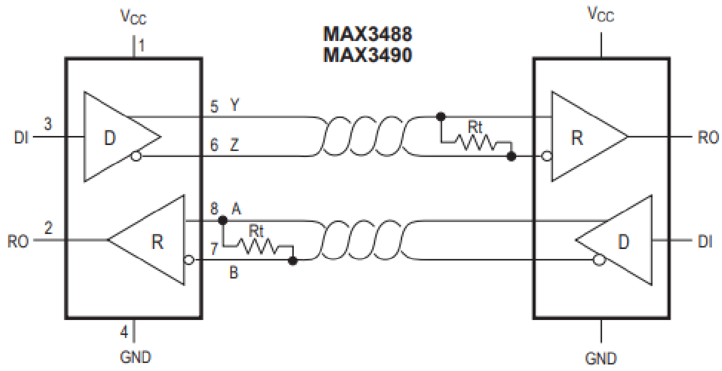


*Fig. 27 Rețea de comunicație 485* [67]

*Memory card*

The programmable automaton also includes a memory card that can be used to record data. For example, electrical parameters can be recorded at a certain time interval, in order to use them later when building a graph over a period of time. In Figure 28 shows the part of the schematic that contains the memory card.

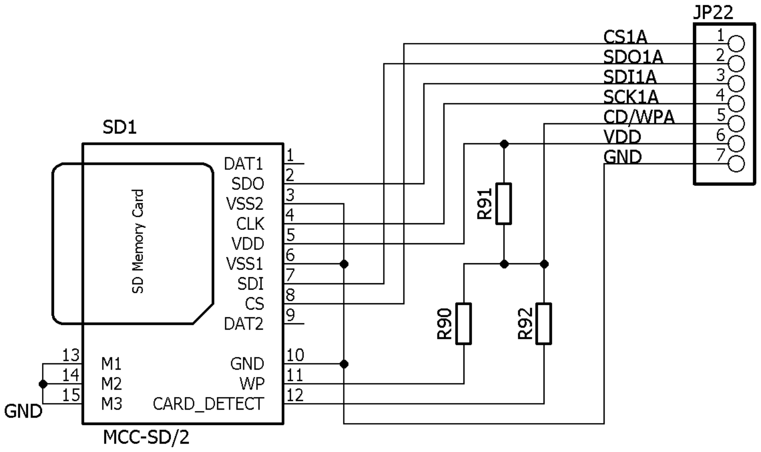


*Fig. 28 Memory card*

*Speed Input*

The automaton also has a separate high processing speed input that is used by usually for speed or frequency measurement. The schematic of this entry is given in figure 29.

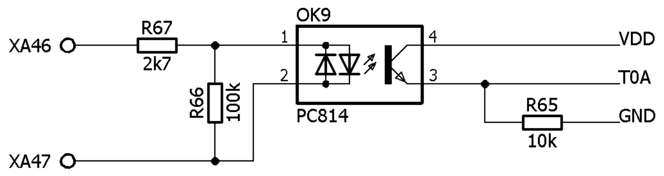


*Fig. 29. Speed input*

**Generator frequency regulator**

The frequency regulator was built in a box with a panel mount to mount it on the door of the regulator panel.

I chose to make the frequency regulator separate from the voltage regulator, in order not to overload the microcontroller in the regulator (PLC).

Figure 30 shows the block diagram of the frequency regulator.

I built the regulator using:

- a transformer (TR) that steps down the voltage from the generator terminals to the value required for the input of the frequency converter (CDF);

- a voltage regulator block (RT);

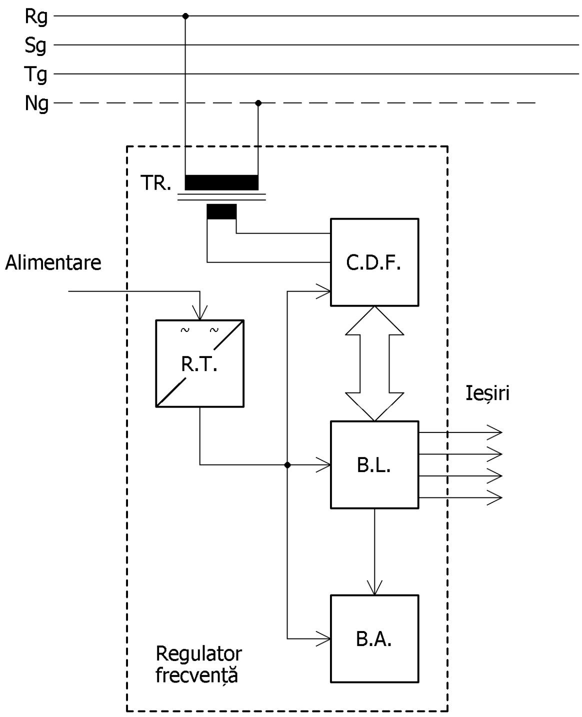


*Fig. 30 Frequency regulator block diagram*

- a digital frequency converter block (CDF) that takes the frequency information from a transformer winding; a logic block (BL) that digitally takes the result of the conversion, processes it and sends it commands to outputs;

- a display block (BA), which displays the value of the frequency by lighting one LED next to the frequency written on the panel and a 2x16 character LCD display (figure 31). When the asynchronous generator begins to produce voltage at the terminals, it is taken by the transformer and sent to the digital frequency converter, which measures the frequency and transmits the information to the logic block. The logic block sends the information in digital form the display block, made of 23 colored LEDs from which the corresponding one will light up frequency marked on the panel.

Also in the logical block are set the limits in which the frequency is considered accepted (49-51Hz) as well as the thresholds for which the frequency must be corrected [74].

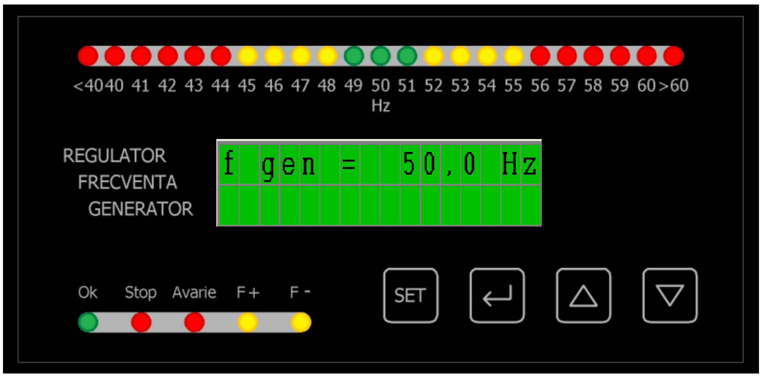


Fig. 31 Regulator front panel

The frequency regulator will send pulses of constant duration to one of the two outputs f- if the frequency is to decrease or f+ if the frequency is to increase. After sending the pulse, the reaction of the generator is waited for a while, after which the next pulse is sent and the cycle is repeated until the frequency reaches a value close to 50 Hz. The further the generator frequency is from the set value, the shorter the pause time between two pulses so that the system can bring the frequency to equilibrium more quickly.

Conclusions

- The voltage and frequency adjustment is carried out by two adjustment systems, one, separate from the frequency, by connecting or disconnecting some ballast resistors at the generator terminals, and another voltage adjustment by adjusting the connected capacitor battery capacity in parallel with the use circuit. In the old regulation scheme, there was only one frequency voltage regulator which, under the conditions of constant capacity of the capacitor bank, ensures a frequency regulation by connecting and disconnecting three-phase resistance stages in the consumer supply circuit. This type of regulator does not ensure a proper regulation of the voltage at the consumer terminals.

- The advantage of the system realized within the thesis is therefore very great, ensuring a safe supply, at the nominal parameters, of the consumers in the respective location.

- The speed regulation system through the ballast resistors is very reliable, due to their over-dimensioning and forced cooling. The old system used natural air-cooled ballast resistors, undersized for continuous operation, which led to their frequent burning.

- The electronic voltage and frequency regulators are numerical, which gives them a high degree of reliability and safety in operation. The regulator existing in the power plant was of analog type, containing a very large variety of electronic components, some unreliable, so the frequency of defects was very high, leading to frequent breakdowns in the consumers' electricity supply system.

- The completed automation installation ensures online monitoring of the maximum voltage values at the generator terminals. When these values exceed a limit imposed, by means of an electronic voltage relay, the additional load command of the generator is given by connecting to its terminals an additional resistance on each phase, so that the voltage and frequency fall below the imposed limit. This eliminates the possibility of over-revving or over-exciting the generator in the event of deficiencies in the operation of automatic speed and voltage regulators.

- The automation installation made allows the remote monitoring of the electrical parameters that characterize the operation of the microhydrogenerators in the respective plant, a fact that allows a safe operation of the respective objective.

- As a perspective, using the valve and the director device, controlled electrically, the water entering the turbine can be quickly stopped, ensuring the protection of the generator against over-revving, and the remote control of the start and stop of the hydrogen generators can be achieved.

The electrically controlled steering device makes it possible to reduce or increase the power of the generator (to a small extent), a very important problem during the dry months when the water flow drops a lot.

The use of batteries to power the control system makes it possible to remotely start and monitor the system even when it is off.

## CHAPTER 6 - FINAL CONCLUSIONS

The research carried out in this work was subordinated to the main objective, namely the modernization of a microhydropower plant equipped with two microhydro aggregates with vertical Kaplan turbines and asynchronous generators, operating in isolated mode, located in a tourist area of the Cheile Nerei Beusniţa National Park, in the immediate vicinity of of Ochiul Beiului trouts and Ociul Bei Forest canton.

In order to establish the works required for the modernization of this micro-hydro power plant, the first stage was the expertise of the technical condition of the micro-hydro aggregates and the related electrical installations in the respective location.

In this way, the main shortcomings related to the montage concept were highlighted and operation of these equipments.

A number of mechanical and electrical deficiencies were found.

An under-dimensioning of the metal supports on which the microhydrogenerators are fixed was found, their mechanical rigidity being far below the minimum admissible value, a fact that led to additional mechanical vibrations during the transient start-up and stop-off processes as well as in the stabilized mode of operation of the equipment respectively.

Operation with vibrations led to frequent breakdowns of microhydro units, with all the consequences that followed from this fact. Solutions were imposed to increase the mechanical rigidity of the respective supports in view reducing the mechanical vibrations of the fixed parts and stabilizing the dynamics of the rotating assembly.

The stable operation without vibrations leads to the increase of the operating time of the microhydrogenerators thus ensuring an uninterrupted supply of electricity to the consumers.

By placing the battery of capacitors in the power plant and by rewinding the asynchronous generators in a star connection, we obtained an increase in active power, thus a higher efficiency operation on the microhydrogenerators.

Taking into account the existing situation in 2018, it was necessary to design and build high-performance regulation equipment, which would ensure a safe supply of consumers in terms of the voltage level and frequency of the supply voltage.

Currently, following the commissioning of the adjustment equipment that we designed and realized in the framework of the thesis, the following can be observed:

The voltage values on the three phases are equal, thus ensuring a supply in safety conditions at constant voltage within ±10% of the nominal voltage 230 V, of single-phase consumers, connected to the three-phase system of the microhydropower plant. The regulation of the supply voltage is carried out by a continuous regulation of the current of magnetization.

Under conditions in which the power absorbed by useful consumers is reduced, the useful power at the generator terminals remains constant, through a continuous variation of the active power absorbed by ballast consumers, thus keeping the value of the frequency of the supply voltage constant.

Operation in overvoltage conditions leads to the automatic connection of a three-phase consumer that reduces the voltage level below the maximum admissible value, thus contributing to the protection of consumers and asynchronous generators,

Operation under voltage conditions below the minimum value leads to disconnection automatic switching of an additional three-phase consumer (ballast), so that the voltage returns to the imposed limits.

In order to protect against overcurrent, the values of the currents on the three phases are monitored online, ensuring that they fall within the imposed limits.

When a limit value is exceeded on a phase, an optical signal is given, and when a maximum admissible value is exceeded, the contactor is automatically disconnected from the consumers' supply circuit.

One of the shortcomings reported in the old electrical installation for supplying consumers was the lack of information regarding the level of the main electrical parameters of the circuit.

The installation made in the framework of the doctoral thesis ensures the online monitoring of all electrical parameters, at the terminals of asynchronous generators: the active powers per phase and the total active power, the reactive power per phase and the total reactive power, the current per phases, the phase and line voltages, the power on each phase, frequency of supply voltage

The values of these electrical parameters can be accessed and displayed on the display of the acquisition system on the front panel of the cabinet.

An important advantage of the automation scheme realized in the doctoral thesis is the fact that it allows remote monitoring of all electrical parameters, a fact that creates the conditions for a safe operation of the microhydropower plant.

# CHAPTER 7 - PERSONAL CONTRIBUTIONS. FUTURE DIRECTIONS OF RESEARCH

## 7.1 Personal contributions

Taking into account the proposed objectives, during the individual scientific research program, bibliographic titles including books, articles on websites and scientific papers were studied, of which bibliographic references indirectly belong to the author.

The following are the main personal contributions resulting from the research carried out in the field addressed in this paper as well as from the technical expertise regarding the technical condition of the operating performance of the existing electrical and mechanical equipment in the Ochiul Bei microhydropower plant:

1. Highlighting the main deficiencies that characterize the operation of the electrical and mechanical equipment in the Ochiul Bei microhydropower plant, the most important of which are:

- the mechanical instability of the fixing supports of the microhydro aggregates, which led to high vibration operation of turbines and synchronous generators in all regimes of exploitation;
- premature wear of radial and axial bearings due to ineffective sealing solutions, during operation with high water flows of hydraulic turbines;
- the existence of accentuated imbalances in the supply voltages of single-phase consumers, determined by the non-performing regulation of the existing frequency and voltage regulation system at the terminals of asynchronous generators;
- the use of an adaptation transformer, to ensure the null of the supply network of single-phase consumers, in the conditions where the stator windings of of the asynchronous generators were in delta connection at Un 400 V, a fact that led to the decrease of the efficiency of the asynchronous generators;

- the use of non-performing capacitor batteries, which led to repeated breakdowns with the unavailability of the consumers' power supply system for longer periods of time;

- there was no equipment to measure electrical parameters from the electricity supply network of the consumers in trouts and the Ocolului Silvic cabins, so there was no information on the level of phase voltages and the active powers absorbed by the respective consumers;

- starting the hydro aggregates and connecting the consumers took place manually, the presence of two people being required, one in the microhydro power plant for the manual opening of the hydraulic veins and another at the connection and supply panel of the consumers, which was at the entrance to Pastrăvărie, without communication between the two people;

- the capacitor bank was placed at a great distance from the asynchronous generators, which led to a current overload of the power cable, respectively to voltage drops and additional losses in the respective cable;

- the electrical supply installation was not equipped with overvoltage and overcurrent protection devices, a fact that led to repeated burning of light bulbs and some electrical household equipment in the circuits used by consumers;

- the capacitor banks used were not correctly dimensioned, not taking into account the magnetization characteristics of each asynchronous generator, so that it was not possible to operate at the nominal voltage and frequency parameters of the respective generators.

- the regulation scheme used had in mind the constant maintenance of the voltage frequency at the terminals of the asynchronous generator by connecting or disconnecting in steps some ballast power consumers in steps close to that of the useful consumers without thus achieving a voltage adjustment depending on the level of charging the generators.

2. The development of effective solutions to eliminate the identified deficiencies and mentioned in point 1, which refer to:

- stiffening of the assembly of the fixing supports of the microhydro aggregates;

- sealing the bearings fixed on the hydraulic turbine rotor;

- recalculation of the winding scheme for rewinding the stators of asynchronous generators in star connection, with the accessible zero in order to eliminate the transformer adaptation;

- recalculating the capacity of the capacitor banks in order to operate the generators at the nominal frequency and voltage parameters (50 Hz, 400 V);

- relocating the capacitor banks in close proximity to the generators in order to reduce voltage and power losses on the connection cable.

3. The design and practical implementation of a high-performance system for automatic regulation of the voltage frequency at the generator terminals.

The scheme designed and realized within the thesis, allows an automatic adjustment of the frequency, through a continuous variation of the power absorbed by the ballast consumers, so that the total power charged by the asynchronous generator remains at the value corresponding to the operating point in the load at the nominal frequency of 50 Hz.

4. Realization of an automatic adjustment scheme of the phase voltages of the asynchronous generators, in order to ensure a symmetrical three-phase system of supply voltages for single-phase consumers.

The voltage regulator previously existing in the plant had as reference voltage the average value of the phase voltages so that it was impossible to balance the phase voltages in order to obtain a symmetrical three-phase system of voltages.

The new adjustment variant uses the phase voltages as a reference, thus keeping these voltages constant through an automatic adjustment of the load level with ballast load on each phase.

5. Automatic regulation of the voltage during load operation of the generators through a continuous variation of the capacity of a capacitor bank. For this purpose, an additional battery is connected to the terminals of the asynchronous generators of capacitors whose capacity is continuously variable, depending on the voltage level at the load operation of the respective generators.

6. Drawing up an efficient scheme for monitoring the electrical operating parameters of microhydro units with the possibility of viewing them remotely.

At the end of the research, thanks to the developments developed through the doctoral thesis, the microhydro power plant is in perfect working order, with energy debited over 20 MWh/year, it works in continuous mode, it supplies Păstrăvăria, the forester's canton, a small terrace (where they sell trouts dishes) and two villas of Ocolului Silvic.

Its cost is competitive because it uses an asynchronous generator, which is much cheaper than a synchronous generator, with which other existing microhydropower plants are equipped.

**Future research directions**

I believe that the further development of the microhydropower plant could take place in three directions:

- automation of the valves and the steering apparatus
- creating a monitoring and remote control system
- making a multifunctional regulator

**Automation of vanes and steering vanes**

It is necessary to purchase 2 electrically actuated valves as well as one direct current electric motor, with reducer, for each steering device. All these elements must work at the supply voltage of 24 V direct current, so that they can be operated from batteries [79].

**Realization of a remote control and monitoring system**

To achieve the remote control of the microhydropower plant presented in the paper, the following components will be used:

- a PLC;
- a web server;
- a router with a GSM card.

The PLC supervises the automation by taking information from network analyzers and from the other elements (sensors, contacts, buttons) which it processes and transmits to the server [80].

The web server is a module that takes the information from the PLC and translates it into web pages that can be accessed by one or more users.

The GSM router is that device which, being connected to a 3G / 4G mobile phone network, brings the Internet in two ways: through the plugs on the device or through radio waves, creating a wireless network. In the location of the microhydropower plant, the GSM signal is quite weak, so I attached 2 antennas with longer cables to the router, but I still haven't created a very secure internet network. I will do a test with other GSM antennas with higher gain and put them at a higher height [77].

To view the parameters of the microhydropower plant, it is necessary to have a device that has an application for opening internet pages (PC, laptop, tablet, mobile phone) and to know the IP of the server. This IP is usually dynamic, but there are ways to pass it to a DNS server where it can be retrieved.

Knowing the IP we can access the first page of the web server, that of registration, where a username and password are required.

After registration on the server, the following page will open where the automation is presented and where the operating parameters of the microhydropower plant can be viewed.

From here it is possible to order the microhydro power plant to start and stop automatically from a distance and view some parameters read from the network analyzer [81].

An hour counter can also be implemented to monitor the number of operating hours of each generator, respectively of each capacitor bank. Through this monitoring, a schedule is obtained for the maintenance of the generators and when the capacitor banks need to be changed.

**Realization of a multifunctional regulator**

During the testing on the laboratory model of the regulator, I came to the conclusion that I could build a faster and more compact regulator model.

I imagine the new regulator as having the following technical data: an input for generator frequency; 3 inputs for generator voltages; 3 inputs for consumer currents; a pwm output for adjustable capacitor bank; 3 pwm outputs for ballast resistors; a relay contact for voltages and frequency ok; a display and some keys for settings.

The chosen microcontroller has a 16-bit analog converter and 16-bit pwm outputs, thus greatly increasing the accuracy of the regulator.

By using this multiprocessor system we will get faster tracking of each phase voltage and frequency. Each microcontroller will run its program in parallel and independently of the others. If we want to change certain settings they will change simultaneously in regulators of the same type.

I believe that this type of multifunctional regulator will effectively monitor the parameters of the three-phase system and act quickly to adjust them.

## SELECTIVE BIBLIOGRAPHY

[2]. Roman Baican, REVISTA BAABEL, 02.12.2021, ISSN 2734-4967, ISSN-L 2734-4967, https://baabel.ro/2021/12/energia-apei-ii-centrale-hidroelectrice/
[3]. Ana Ionica, POTENȚIALUL DE ENERGIE REGENERABILĂ DIN ROMÂNIA, 30.01.2018, https://smartcityblog.ro/potentialul-de-energie-regenerabila-din-romania/
[4]. Paul Gheorghinescu, Alexandru Gheorghinesscu, Istoria hidroenergeticii romanesti vol.I (1884-1970). De la microcentrala castelului Peles la marea centrala Portile de Fier, Editura Noua Curtea de Arges, 2021
[5]. Basarab Guzun, George Darie, Stelian Al. Gal, Dan Olovinaru - Centrale stații și rețele electrice, Editura Academiei Române 2005
[10]. Parcul Național Cheile Nerei – Beușnița, Județul Caraș-Severin - Wikipedia https://ro.wikipedia.org/wiki/Parcul_Na%C8%9Bional_Cheile_Nerei_-_Beu%C8%99ni%C8%9Ba
[23]. Mina Emil Roșu, Cristian Nichita - optimizarea energetică a sistemelor de conversie electromecanică, Editura Tehnică București 1999.
[26]. A. T. Golovanov, T. P. Barabaș, The functioning of induction generator in self-excitation operation, Electricestrov Nr. 3 1950.
[32]. A. Câmpeanu, Dinamical models for the saturated induction machine, Revue Roum SCI Techn_Electrotech et Energ 46.1 2001 pp 89-99
[33]. A. Câmpeanu, I. Cantel, I. Vlad, S. Enache Modelarea și simularea mașinilor electrice de curent alternativ. Complemente. Editura academiei române București 2020
[34]. A. A. Ivanov, A. Câmpeanu, Matlab, Simulink Library for AC drivers simulation, Simulation 98 University of York, UK 1998.
[35]. A. Câmpeanu, A. Ionescu, I. Vlad, S. Enache, Prediction trugh simulation of the optimal behavoir of the induction machine process, SPEEDAM 2008, Ischia(Italy) 11-13 June PP. 1136-1140
[36]. A. Câmpeanu, I. Cantel, I. Vlad, S. Enache, Modelarea și simularea mașinilor electrice de curent alternativ. Complemente. Editura academiei române București 2012
[37]. A. Câmpeanu, M. Enache, T. Câmpeanu, Equivalent Circuits Models of Induc'ion Machines - A Rewiev, Cluj Napoca,Acta Electrotehnica Volume 44 Number 3 2004 pp 11-17
[38]. N. Budișan, A. Stern, A. Spilco, Characteristics of the autonomus self-ecited asynchronus generator with voltage stabilization by rotation speed at hydroplants, Sympozium Ecological small Hydropower Social and Economic Impact, 5-7 October 1993 Hidrotim SA Timișoara.
[39]. M. Opaschi, Proiectarea hidrogeneratoarelor și a motoarelor sincrone, vol. 2, Editura Mirtom Timișoara.
[40]. A. Câmpeanu, M. Rădulescu, Influence of Cross-Saturation for Modeling and simulation of the Dinamic Process in the induction Motor, Eurocon 2007, pp 1830-1833.
[41]. Florin Ionescu, Dan Floricău, Smaranda Nițu, Dan Fodor, Mina Emil Roșu, Remus Teodorescu, Ion Bivol, Dimitrie Alexa, Mihai Lucanu, Adrian Maxim, Dorin Octavian Neacșu, Adriana Păstrăvanu, Nicolae Lucanu, Etienne Milent - Electronică de putere Modelare și Simulare, Editura tehnică, București 1997
[42]. Ghiță Constantin - Elemente fundamentale de mașini electrice, Editura Printech, București 2002
[43]. Matlab https://www.mathworks.com/help/sps/powersys/ref/per-unit-and-international-systems-of-units.html;jsessionid=956af0f8b69426675dc8de3cde6b 2024
[44]. T. Dordea, R. Munteanu, A. Cmpeanu, Mathematical Models of A.C. Machines. Cutical Analysis Theorie, Proceedings of ASTR, Cluj Napoca 2009.

[51]. Releu supraveghere tensiune RNP-311M https://www.tme.eu/ro/details/rnpp-311m/relee-de-supraveghere/novatek-electro/ 2024
[52]. Imagine releu supraveghere tensiune https://www.tme.eu/ro/details/rnpp-311m/relee-de-supraveghere/novatek-electro/ 2024
[53]. Documentatie Releu supraveghere tensiune RNP-311M https://www.tme.eu/Document/f4aed7ef29ac0f89a1702883ec09f728/RNPP-311M_EN.pdf 2024
[66]. *L. Toma*, Sisteme de achiziție și prelucrare numerică a semnalelor, Editura de vest Timişoara 1997.
[67]. Analog device MAX 3485 https://www.analog.com/media/cn/technical-documentation/data-sheets/1079.pdf
[73]. ***Anghel Dorian****; Ionescu Florin; Marius Florian Predus*, The testing stand of the ferrite core transformers, 2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE) https://ieeexplore.ieee.org/document/7905061 (WoS, IEEE Xplore)
[74]. *Spunei Elisabeta*, *Piroi Ion*, ***Anghel Dorian***, *Piroi Florina*, The square root method for terminal voltage adjustment in a self-excited synchronous generator, 2017 5th International Symposium on Electrical and Electronics Engineering (ISEEE) https://ieeexplore.ieee.org/document/8170633 (WoS, IEEE Xplore)
[75]. *Ion-Cornel Mituletu*, ***Dorian Anghel***, *Loredana Ardeljan*, *Mihael Magda*, DC-DC Buck Converter Based on Arduino Uno Sliding Mode Controller, 2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE) https://ieeexplore.ieee.org/document/9425185 (WoS, IEEE Xplore)
[76]. *E Răduca, C Haţiegan, M Molnar,* ***D Anghel***, *MD Stroia*, *G Liuba*, Testing of electrical parameters at direct start-up of a synchronous motor of 4650 kW/6 kV, Journal of Physics: Conference Series vol. 1426 nr 1 Editor IOP Publishing https://iopscience.iop.org/article/10.1088/1742-6596/1426/1/012048 (WoS)
[77]. *Deian Dorel Ardeljan, Ion-Cornel Mituletu,* ***Dorian Anghel***, 3D Printer Fire Detection System with GSM Transmission, 2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE) https://ieeexplore.ieee.org/document/9425246 (WoS, IEEE Xplore)
[78]. *Marius Florian Predus, Florin Ionescu,* ***Dorian Anghel***, Insulating oil quality diagnosis in exploitation, 2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE) https://ieeexplore.ieee.org/document/7905066 (WoS, IEEE Xplore)
[79]. *Ion-Cornel Mituletu*, ***Dorian Anghel***, Automatic Control of a Dual-SMA Actuator System, ANALELE UNIVERSITĂŢII "EFTIMIE MURGU" REŞIŢA ANUL XXIII, NR. 1, 2016, ISSN 1453 – 7397 http://vechi.uem.ro/CS_LIR_PDV/fileadmin/lucrari/Mituletu%20Cornel%20-%20ID%2021.pdf (EBSCO, Index Copernicus)
[80]. *Mihaela Dorica Stroia*, ***Dorian Anghel****, Dănuţ-Eugeniu Moşteanu, Cornel Haţiegan*, Comunication interface prototype used for data transmission at electric systems, SCIENDO, International conference KNOWLEDGE-BASED ORGANIZATION, Volume 25: Issue 3, 2019 https://sciendo.com/article/10.2478/kbo-2019-0119 (EBSCO, Ulrich's)
[81]. ***D Anghel****, MD Stroia, C Haţiegan, AC Timofte*, ANDROID APPLICATION FOR DIGITIZING CONTRAVENTION DOCUMENTS, Annals of 'Constantin Brancusi' University of Targu-Jiu. Engineering Series/Analele Universităţii Constantin Brâncuşi din Târgu-Jiu. Seria Inginerie, 2023 https://www.utgjiu.ro/rev_ing/pdf/2023-2/04_d%20anghel_android%20application%20for%20digitizing%20contravention%20documents.pdf (EBSCO, DOAJ)
[82]. *Luis Miguel Esquivel-Sancho; Roberto Pereira-Arroyo; Mauricio Muñoz-Arias*, Voltage Regulation for a Self-Excited Induction Generator, 2021 60th IEEE Conference on Decision and Control (CDC), 14-17 December 2021, Austin, TX, USA
[83]. *Ashish Sharma; Deepa Kumari; Rinku Sharma*, Expansion of Isolated Generator System with Self Excited Induction Generator, 2021 First International Conference on Advances in Computing and Future Communication Technologies (ICACFCT), 16-17 December 2021, Meerut, India.

[84]. *Claudinilson Alves Luczkiewicz, Edson Da Costa Bortoni*, Voltage and Frequency Control in Isolated Generation Using Binary Logic, 2022 International Conference on Electrical, Computer and Energy Technologies (ICECET), 20-22 July 2022, Prague, Czech Republic
[85] I.P. Shorstkin; M.G. Kiselev; *K.V. Krukov; N.S. Rodkin*, Frequency and voltage stabilization of induction generator based on STATCOM, 2024 6th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE), 29 February 2024 - 02 March 2024, Moscow, Russian Federation.
[86]. *Xin Ding; Wei Lin; Jian Xu; Yuanzhang Sun; Liangzhong Yao; Beilin Mao*, Coordinated frequency control for isolated power systems with high penetration of DFIG-based wind power, CSEE Journal of Power and Energy Systems ( Early Access ), DOI: 10.17775/CSEEJPES.2021.08320, Pag. 1-15, 06 May 2022
[87]. *Venu Yarlagadda; Garikapati Annapurna Karthika; M. Nagajyothi; J. Bhavani*, DSTATCOM based Closed Loop Controlled Wind Power Plant with Self Excited Induction Generator for Controlling Terminal Voltage against Load Disturbances, 2022 IEEE Fourth International Conference on Advances in Electronics, Computers and Communications (ICAECC), 10-11 January 2022, Bengaluru, India.
[88]. *Pradeep Singh; Krishan Arora; Umesh C. Rathore*, Performance Evaluation of a Grid Connected Variable Speed 3-Φ Doubly Fed Induction Generator in Wind Energy Conversion System Using Battery Energy Storage System, 2022 10th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), 13-14 October 2022, Noida, India.
[89]. *Shalvi Tyagi; Bhim Singh*, Seamless Connection of Wind and Small Hydro Based Energy Conversion System With Storage, 2022 IEEE 2nd International Conference on Sustainable Energy and Future Electric Transportation (SeFeT), 04-06 August 2022, Hyderabad, India.
[90]. *Haitao Li; Xuehu Peng; Yaolin Lou; Lili Chen*, Analytic Calculation for Stator Frequency of Self-Excited Induction Generators With Routh Criterion, 2022 4th International Conference on Intelligent Control, Measurement and Signal Processing (ICMSP), 08-10 July 2022, Hangzhou, China.
[91]. *Saira Tariq; Faisal Khan; Zain Ul Abideen; Umair Ali*, Self-Excited Induction Generator with Electronic Load Controller installed in Naran, Pakistan, 2022 International Conference on Technology and Policy in Energy and Electric Power (ICT-PEP), 18-20 October 2022, Jakarta, Indonesia.
[92]. *Kesari Hanumanthu, Natarajan Kumaresan*, A Novel Control Scheme for Induction Generator Based Stand-alone Micro Hydro Power Plants, Aug 2023 Distributed Generation and Alternative Energy Journal 38(6):1791-1814, DOI: 10.13052/dgaej2156-3306.3864
[93]. *Agus Hermanto , Diki I. Permana, Dani Rusirawan , Tito Shantika*, Investigation of Very Low Micro-Hydro Turbine: Design, Simulation and Prototype Experimental, International Journal of Heat and Technology Vol. 41, No. 2, April, 2023, pp. 332-340.
[94]. *Chandra BUANA*, Performance Analysis of Micro Hydro Power Plants Using a Pelton Turbine with Two Nozzle Variations, July 2023PRZEGLĄD ELEKTROTECHNICZNY 1(7):86-90, DOI: 10.15199/48.2023.07.16.
[95]. *Remon Lapisa1, Arwizet1, Krismadinata2, Prima Yane Putri3, Junil Adri1, Firman Omni S1, Doni Saputra1 dan Aldi Alfarizi1*, Cross-Flow Turbine Design of Micro hydro Power Generator for Rural Energy-Independent Area, MOTIVECTION : Journal of Mechanical, Electrical and Industrial Engineering, Volume : 5, Number : 2, 2023.