STUDIA UNIVERSITATIS BABEȘ-BOLYAI
Engineering 66(1) 2021 DOI:10.24193/subbeng.2021.1.5

The design and execution of a laboratory micro hydroelectric power plant

Elisabeta Spunei, Ionel Turcu, Alina Vişan*

Abstract. *The paper presents a laboratory micro hydroelectric power plant destined to applicative activities. The hydraulic turbine is a Pelton turbine, rebuilt by fast prototyping in Geomagic Design X and printed on a 3 D printer. The turbine casing and the afferent elements are made in-house. The hydrogenator is synchronous being an alternator from a Dacia vehicle. The hydrogenerator load is constituted by 3 groups of light bulbs. We analysed the working of the micro-hydroelectric power plant in idle run and for different loads. As a result of the analysis we found out that it stably works for different loads and by its open construction it is useful for developing students' ability to understand the phenomena. The installation designed and executed is useful for the engineering students as the pandemic forbids the thematical visits in hydro-energetic facilities.*

Keywords*: micro hydroelectric power plant, renewable energy, Pelton turbine, 3D printer*

1. The present stage related to the production of the electric power in hydro-energetic installations

The use of renewable sources of energy for the production of electric power contributes to the reduction of gas emissions with greenhouse effect. Thus, the European Union decided that in 2030 at least 32% of the raw final energy consumption should be ensured from renewable sources [1], hence the need to implement solutions for the production of electric energy from unpolluted sources.

An implemented solution is the use of water for the production of electric energy, micro-hydro energy being considered one of the most profitable energetic technologies [2]. Thus, more and more countries have built hydroelectric power plants or micro hydroelectric power plants which should ensure their power supply need.

On the international level, there are solutions which use drinking water, water used in irrigations and water used for the production of electricity [3-5]. For the production of electricity using micro-hydro energy, in Spain they proposed the use of water from all overflows [6], and in Belgium they intend to pump water which is 500 m deep in a deallocated mine [7].

When the turbine is placed directly on the supply pipe with water, the investment costs are very much reduced as compared to the classical variant of placing a turbine and the environment is not negatively influenced by this one [8].

In the case of locations with no national power supply network some solutions are implemented which consist of more than two combined systems of renewable energy (solar, wind, hydro-energetic) and a storage system. In some cases, these systems are completed and with diesel-generator able to supply energy in the situation in which the other systems are not working [9].

Where there is a power supply network for consumers, all the needs of electricity can be satisfied and the excess can be provided in the national network, the supply producers becoming consumers [10].

For an optimal working these systems need to be properly designed, depending on the functional objectively pursued (minimal total cost, maximum performance, minimal loss in the exploitation period, the static and dynamic performances) [11-13] thus it will work safely [14-17].

In the pandemic conditions, when the access to the hydro-power facilities is restricted, in order to provide students with an adequate understanding of a micro hydro power plant functioning, one was built in the laboratory. After the analysis of its operation, we remarked that they are working adequately, being able to ensure the need of energy for the configured consumers.

2. Design and achievement of the laboratory micro hydroelectric power plant

The block diagram of the main components which constitute the laboratory micro hydroelectric power plant are presented in figure 1. The electric generator is of the tree-phased synchronous type being in fact an alternator of a Dacia 1300 vehicle, having the following technical characteristics [18]:

- Working voltage U – 14 V;
- The maximal load current I_{max} – 30 A.

The maximal power P_{max} calculated results:

$$P = U \cdot I = 420 \text{ [W]} \tag{1}$$

The supply of the operating winding of the synchronous generator is achieved by an accumulator of 12V, 10A by means of the K1collector, the power provided being redressed by means of a diode block/circuit. The adjustment of the tension in the energizing circuit is achieved by a make-and-break relay and the electric values provided are monitored by a voltmeter and an ampermeter.

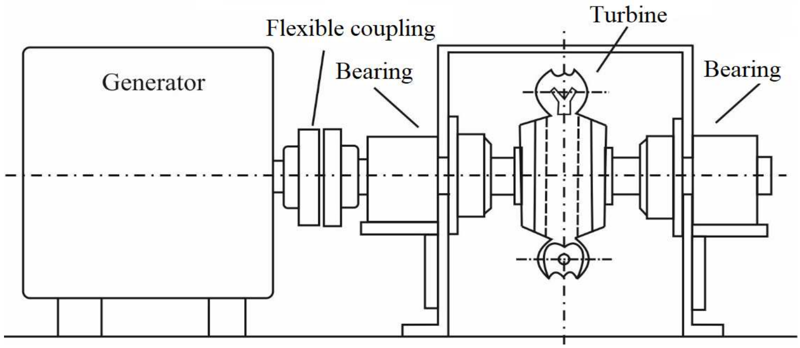

Figure 1. The main components of the laboratory micro hydroelectric power plant.

The supply of the operating winding of the synchronous generator is achieved by an accumulator of 12V, 10A by means of the K1collector, the power provided being redressed by means of a diode block/circuit. The adjustment of the tension in the energizing circuit is achieved by a make-and-break relay and the electric values provided are monitored by a voltmeter and an amperemeter.

The connection between the electric generator and the hydraulic turbine is achieved by an elastic hitch.

The hydraulic turbine is made of:

- casing made of transparent polycarbonate;
- the rotor of Pelton turbine rebuilt by fast prototyping in Geomagic Design X and built with the help of a 3D printer made of PLA (polylactic acide) using the technology FDM (fused deposition modeling) [19, 20];
- the metallic shaft supported on 2 roller bearings (radial-axial bearing) on which the rotor of Pelton turbine is imbedded. At the exit from the casing the shaft has sealing semerings on both sides;
- injector designed in the Autodesk Inventor software and placed on the turbine casing which by means of a screw on the thread end offers the possibility to modify the injector position concerning the water flow control;
- the drainage coupling placed in the turbine casing used for the evacuation of the turbined water.

Figure 2 shows a Pelton turbine bucket, Figure 3 presents a Pelton turbine, both of them rebuilt in Geomagic Design X, and Figure 4 shows an image from the process of 3D printing of the Pelton turbine.

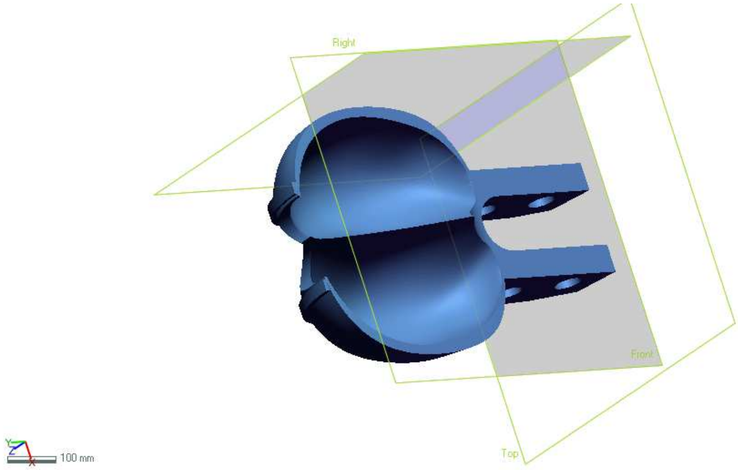

Figure 2. Pelton turbine bucket.

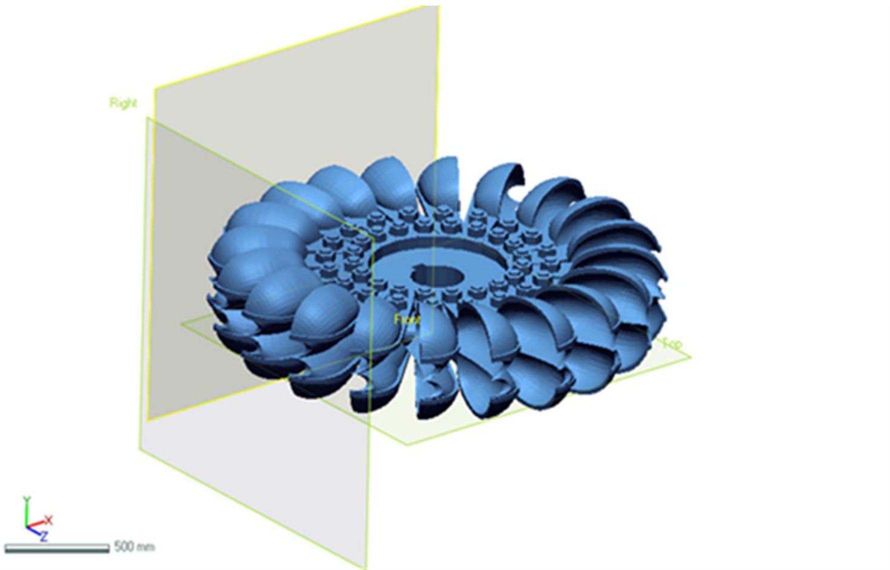

Figure 3. Pelton turbine.

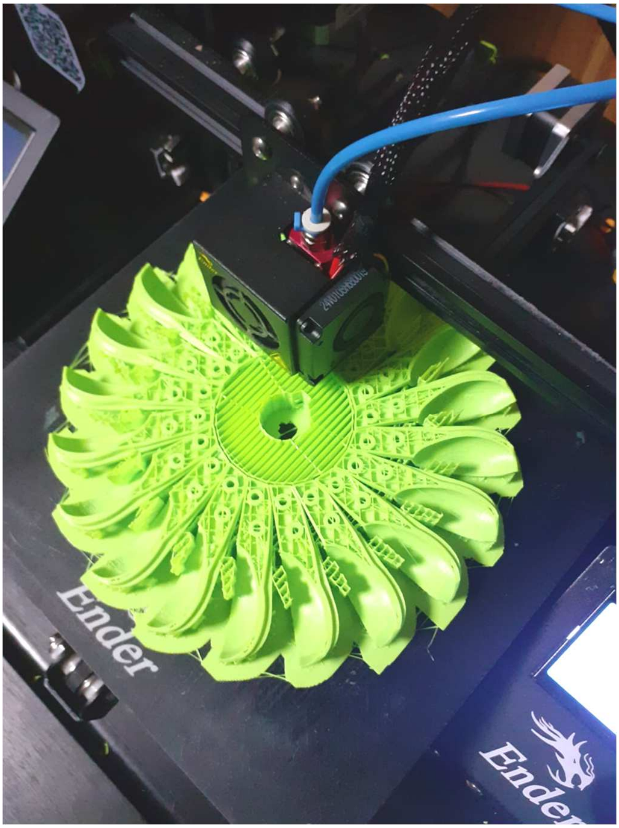

Figure 4. The Pelton turbine during the printing process.

The water supply for the laboratory micro hydroelectric power plant was achieved from the city network which has a pressure of 4 bars and 12 light bulbs, 35W were the consumers. In order to vary the load, these were connected in 3 turns, with 4 bulbs in a turn, the total power being:

$$P_r = P_{bulb} \cdot no_{bulb/row} = 140 \ [\mathrm{W}] \tag{2}$$

The supply diagram of the excitation winding of the synchronous generator and the supply of consumers is presented in figure 5 and in figure 6 there is an image with micro hydroelectric power plant achieved and mounted in the laboratory.

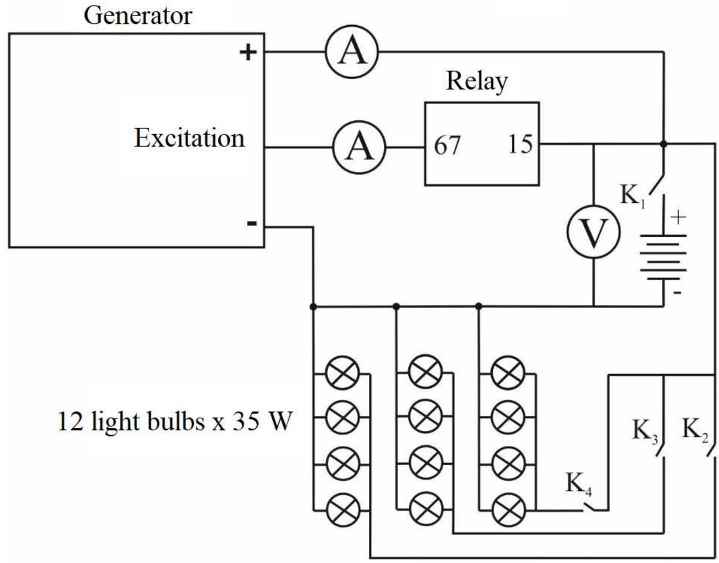

Figure 5. Supply electric diagram for the excitation winding of the generator and consumers.

Figure 6. The laboratory micro hydroelectric power plant.

3. Analysis of the laboratory micro hydroelectric power plant operation

The analysis of the operation was achieved in 2 stages: at the assembly place where the water supply of the turbine was doing at the pressure of 2 bars and in the laboratory where the pressure of water at the entrance of the turbine was of 3,5 bars.

In the first stage the excitation power was adjusted by the regulating relay around 1,5 A. For the revolution of the generator there were 840 rot/min, the power provided was 14,5 V. At the coupling of the load the power of the load had the values in table 1.

Table 1. The values of the load current

Load power [W]	Load current [A]
140	10
280	13,5
420	17

After mounting the micro hydropower plant in the laboratory the speed was measured in idle operation, the mode of the speed variation being presented in figure 7. The maximum speed for the idle operation of the micro hydropower plant was 1112,2 rot/min, this being reached in 1,3 seconds.

We did some analysis referring to the operation of the micro hydropower plant with 1/3, 2/3 in load and nominal load.

For the analysis of the operation with 1/3 load, we connected a row of bulbs and we observed the fact that the value of the current in the circuit of the consumer is 13,7 A, and the voltage supplied was 11,5 V, the current measured in the excitation circuit being 2,62 A. The mode of the speed variation at operation with 1/3 of load is presented in figure 8 where we observe that the maximal speed is 877 rpm and it is reached in 0,82 seconds.

For the analysis of the operation with 2/3 load two rows of bulbs were connected. In this situation the current in the consumer circuit is 14 A and the voltage supplied is 11,2 V. The variation mode of the speed at operation with 2/3 load is presented in figure 9 where we observe that the maximal speed is 768,6 rpm and it is reached in 0,49 seconds.

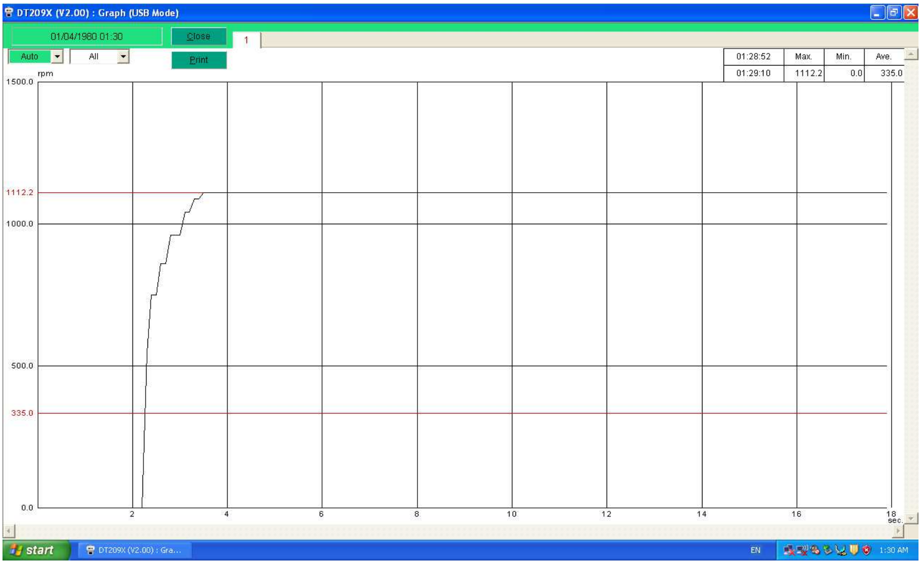

Figure 7. The mode of the speed variation at the start of the micro hydropower plant in idle operation.

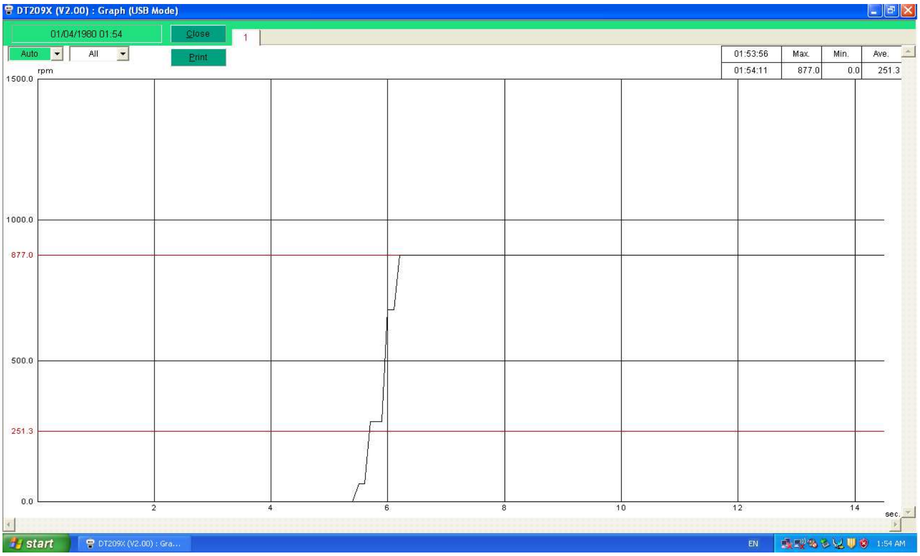

Figure 8. The mode of the speed variation at the start of micro hydroelectric power plant and operation in 1/3 load.

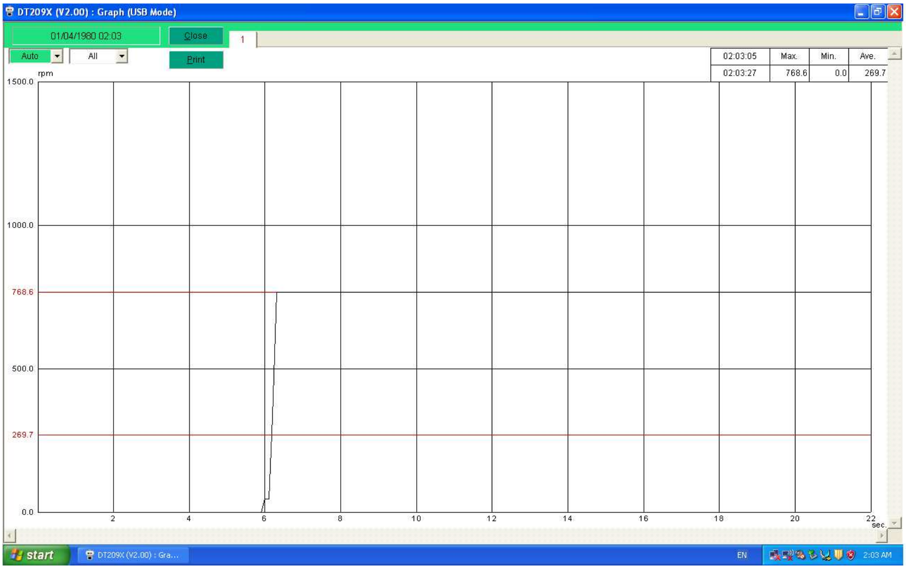

Figure 9. The variation mode of speed at the start of micro hydroelectric power plant and operation with 2/3 load.

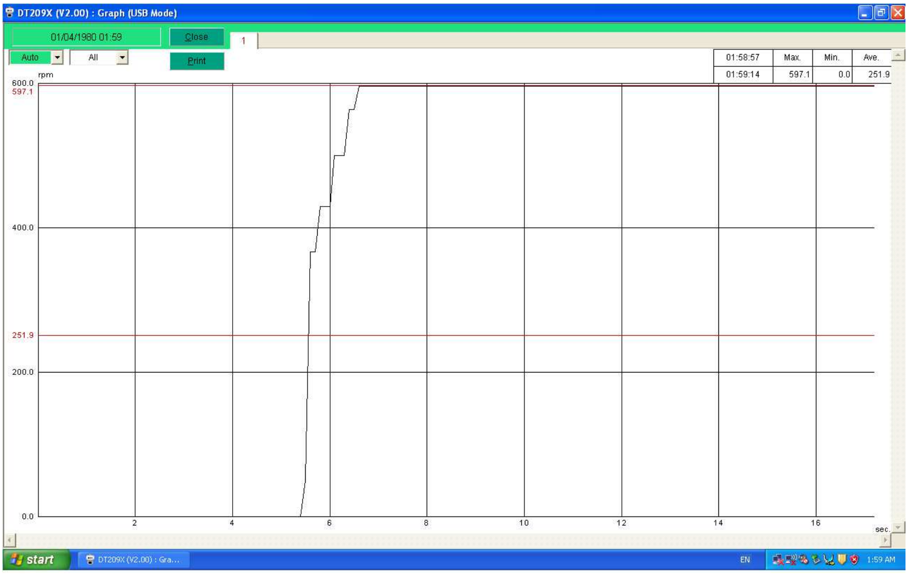

Figure 10. The variation of the number of revolutions at the start of the micro hydroelectric power plant and its operation at nominal load.

For the analysis of operation at nominal load all the bulbs in the circuit were connected in the consumer circuit being 17,9 A and the tension supplied is 10,2 V. The mode of speed variation at start and operation in nominal load is presented in figure 10 where we observe that the maximal speed is 597,1 rpm and this is reached in 1,18 seconds.

4. Conclusion

The providers of turbines or hydraulic micro-turbines have a catalogue with models experimentally tested, which have been initially designed based on the measurements achieved on industrial turbines.

Generating the geometry of the Pelton rotor by fast prototyping in Geomagic Design X offers the possibility of reducing the design time as compared to the classical variant and brings the following advantages: fast achievement of components, very high precision, low-cost price.

After analysing the functioning micro hydroelectric power plant designed and executed in the laboratory we found out that it stably functions being able to provide the necessary electricity for consumers.

References

[1] Share of energy consumption from renewable sources in Europe, https://www.eea.europa.eu/data-and-maps/indicators/renewable-gross-final-energy-consumption-5/
(downloaded at September 3rd, 2021).

[2] Manzano-Agugliaro F., Taher M., Zapata-Sierra A., Juaidi A., Montoya F.G. An overview of research and energy evolution for small hydropower in Europe, *Renewable & sustainable energy reviews*, 75, 2017, pp. 476-489.

[3] Mitrovic D., Chacon M.C., Garcia A.M., Morillo J.G., Diaz J.A.R., Ramos H.M., Adeyeye K., Carravetta A., McNabola A., Multi-Country Scale Assessment of Available Energy Recovery Potential Using Micro-Hydropower in Drinking, Pressurised Irrigation and Wastewater Networks, Covering Part of the EU, *Water*, 13, 2021, Article number: 899.

[4] Ali A., Baig F.S., Memon A.H., Designing Hydel Power Generation Capacity using a Mini/Micro Hydro Power Plant at Left Bank Outfall Drain Drainage System, near Goth Ahori, Jhuddo, Sindh, *Mehran university research journal of engineering and technology*, 39, 2020, pp. 554-563.

[5] Kamran M., Asghar R., Mudassar M., Abid M.I., Designing and economic aspects of run-of-canal based micro-hydro system on Balloki-Sulaimanki Link Canal-I for remote villages in Punjab, Pakistan, *Renewable energy*, 141, 2019, pp. 76-87.

[6] Garcia A.M., Diaz J.A.R., Morillo J.G., McNabola A., Energy Recovery Potential in Industrial and Municipal Wastewater Networks Using Micro-Hydropower in Spain, *Water,* 13, 2021, Article number: 691.
[7] Morabito A., Spriet J., Vagnoni E., Hendrick P., Underground Pumped Storage Hydropower Case Studies in Belgium: Perspectives and Challenges, *Energies*, 13, 2020, article number: 4000.
[8] Berrada A., Bouhssine Z., Arechkik A., Optimisation and economic modeling of micro hydropower plant integrated in water distribution system, *Journal of cleaner production*, 232, 2019, pp. 877-887.
[9] Muh E., Tabet F., Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons, *Renewable energy*, 135, 2019, pp. 41-54.
[10] Syahputra R., Soesanti I., Planning of Hybrid Micro-Hydro and Solar Photovoltaic Systems for Rural Areas of Central Java, Indonesia, *Journal of electrical and computer engineering,* 2020, vol. 2020, article number: 5972342.
[11] Spunei E., Piroi I., Piroi F, Optimizing Structural Dimensions and Costs of a Synchronous Generator Depending on the Current Blanket, *Analele Universității Eftimie Murgu, Fascicula de Inginerie,* 19(1), 2012, pp. 303-310.
[12] Spunei E., Piroi I., *The importance of choosing the value of current density in the stator windings on the cost and efficiency of the synchronous generator*, 7th International Conference and Exposition on Electrical and Power Engineering, EPE 2012, IEEE Catalog number CFP1247S-DVD, 25-27 Oct., Iaşi, 2012.
[13] Spunei E., Piroi I., Comparative Analysis Between Stationary and Dynamic Parameters of a Synchronous Generator, with the Main Variable of the Air Gap Magnetic Induction, 11th International Conference on Applied and Theoretical Electricity (ICATE), Oct. 25-27, 2012, Craiova, *Analele Universității din Craiova, Seria Inginerie Electrică*, 36(36), Editura Universitaria, 2012, pp. 386-389.
[14] Espinoza O., Tiwary A., Assessment of autonomous renewable energy system operability under extreme events and disasters, *Sustainable energy technologies and assessments*, 44, 2021, article number: 100995.
[15] Delgado J., Ferreira J.P., Covas D.I.C., Avellan F., Variable speed operation of centrifugal pumps running as turbines. Experimental investigation, *Renewable energy*, 142, 2019, pp. 437-450.
[16] Arani H.A., Fathi M., Raisee M., Nourbakhsh S.A., The effect of tongue geometry on pump performance in reverse mode: An experimental study, *Renewable energy*, 141, 2019, pp. 717-727.
[17] Morabito A., Hendrick P., Pump as turbine applied to micro energy storage and smart water grids: A case study, *Applied energy*, 241, 2019, pp. 567-579.
[18] Tocaiuc G., *Echipamentul electric al automobilelor*, Editura Tehnică București, 1982.

[19] Nedelcu D., Cojocaru V., Ghican A., Periș-Bendu F., Avasiloaie R., Considerations Regarding the Use of Polymers for the Rapid Prototyping of the Hydraulic Turbine Runners Designed for Experimental Research on the Model, *Materiale Plastice*, 52(4), 2015, pp. 475-479.
[20] Nedelcu D., Pop F., Cojocaru V., Hopota A., Prototiparea rapidă a unui rotor Pelton, *Știința și Inginerie*, 2012, pp. 335-342.

Addresses:

- Lect. Dr. Eng. Elisabeta Spunei, Babeș-Bolyai University, Faculty of Engineering, 1-4, Traian Vuia Square, 320085, Reşiţa, Romania
  elisabeta.spunei@ubbcluj.ro
- Eng. Ionel Turcu, Babeș-Bolyai University, Faculty of Engineering, 1-4, Traian Vuia Square, 320085, Reşiţa, Romania
  ionel.turcu@stud.ubbcluj.ro
- Lect. Dr. Alina-Dana Vișan, Babeș-Bolyai University, Faculty of Letters, Horea Street, Cluj-Napoca, Romania
  alina.visan@ubbcluj.ro
  (*corresponding author*)