DOI: https://doi.org/10.24425/amm.2024.151437

A. BOGORIN-PREDESCU[1], S. TITU[2,3], A.M. TITU[4,5*]

**DATA ACQUISITION SYSTEM FOR A HYDROELECTRIC TURBINE WITH DEFORMABLE BLADES**

The scientific paper proposes a remote data transmission and acquisition system, for the analysis of the electrical parameters of a portable hydroelectric turbine with deformable blades placed on the stream. The major objective proposed by the authors is to monitor the transformation of the kinetic energy of water into electricity. Due to the impossibility of directly measuring the turbine elements as a whole, remote data transmission was chosen. This information is collected from the generator of the hydroelectric turbine through transducer elements into digital signals, is encoded and transmitted wirelessly to the receiver located on the shore, decoded, and then processed in real time and displayed on the monitor screen of a computer system in order to make decisions when the situation requires it. Data transmission is carried out in both directions (half duplex) through an efficient request/response communication protocol. Considering that the turbine is located in a hard-to-reach place, on the river, it was imposed to supply with reserve electric energy, autonomous from batteries, for the electronic part that is responsible for acquiring data from the hydroelectric generator. In this way, the monitoring circuit works permanently regardless of the turbine's operating mode: normal or fault. The authors also present in detail the research methodology, the research results, the final conclusions resulting from the experimental data as well as the original contributions made through this applied research.

*Keywords:* Acquisition system; modeling and experimental optimization; SCADA; scientific research; communication protocols

## Introduction

Now, more than ever, there is a worldwide concern related to the need to develop renewable energy resources, paying great attention to environmental protection issues. Since the 90s, Rosu-Hamzescu was of the opinion that the development of renewable resources is necessary considering the gradual replacement of internal combustion vehicles with electric vehicles, and this action requires more energy in the electrical networks [1]. In practice, alternative energies are considered, the energies that come from sources that either regenerate themselves in a short time or are virtually inexhaustible sources. The idea of renewable energy consists in the forms of energy produced by the energetic transfer of energy resulting from natural renewable processes. The most widespread sources of renewable energy are solar energy, wind energy, geothermal energy and hydraulic energy (of running water) [2]. Hydraulic energy is the ability of the physical system represented by water to perform mechanical work through flow. Due to the water cycle in nature, this energy is considered renewable. An efficient solution for the conversion of electrical energy from hydraulic energy is the hydraulic wheel that is set in motion by the energy of flowing water. It lends itself to watercourses with low flows by exploiting the potential energy of the water using wheels on which buckets are mounted. The wheel is set in motion by the corresponding drop in the level difference between the points where the water is admitted and then discharged from the cups. The maximum efficiency of the drive wheel is 67%, but the cost of acquisition is low. The new modern direction of diversification of renewable resources is that of implementing a number of small units that supply electric power in the network.

Automation systems, more precisely SCADA (Supervisory Control and Data Acquisition) control and supervise the vital infrastructure for the proper functioning of our world such as transport systems, health systems, water, energy, economy, and security [3]. SCADA systems consists usually of four elements: Master Unit, Remote Unit, Communication mode and Software.

1 NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY POLITEHNICA BUCHAREST, 313 SPLAIUL INDEPENDENȚEI, BUCUREȘTI, ROMANIA, ADRIAN.BOGORIN@GMAIL.COM
2 IULIU HAȚIEGANU UNIVERSITY OF MEDICINE AND PHARMACY, 8 VICTOR BABES STREET, CLUJ NAPOCA, ROMANIA
3 THE ONCOLOGY INSTITUTE "PROF DR ION CHIRICUȚĂ" CLUJ NAPOCA, 34-36 REPUBLICII STREET, CLUJ-NAPOCA, ROMANIA
4 LUCIAN BLAGA UNIVERSITY OF SIBIU, 10 VICTORIEI STREET, SIBIU, ROMANIA
5 THE ACADEMY OF ROMANIAN SCIENTISTS, 3 ILFOV STREET, BUCHAREST, ROMANIA

* Corresponding author: mihail.titu@ulbsibiu.ro

The goal of this study is to describe the functionality of a hydroelectric turbine's remote data acquisition system (based on the SCADA concept).

The hydroelectric turbine is a working prototype for the "Portable Hydro-electrical Turbine with Deformable Paddles" patent [4].

## 1. Hydroelectric turbine with deformable blades

An application of SCADA consists in actual implementation of a remote supervision system of a portable hydraulic turbine, as shown in Fig. 1, which was designed and built at "Lucian Blaga" University from Sibiu (Romania), being appreciated by specialized official and wide public. SCADA (Supervisory Control and Data Acquisition) systems are needed to supervise multiple local power generation points.

The portable turbine with deformable pales takes over the kinetic energy of water flow and transforms it into mechanical energy by rotating axes which finally trigger the three-phase-current generator with permanent magnets [4]. The purpose of the data acquisition system is to remotely measure the electrical parameters of the turbine even in difficult conditions. Among the information collected are the voltage of the electric generator, the consumption current of the loads connected to the turbine, the rotation speed of the electric generator and environmental data such as temperature and humidity. Fig. 2 shows the block diagram of the data acquisition system of the hydro-electric turbine, which consists of the following components as SCADA:

– Remote Unit from Fig. 2a) b) c) and d),
– Master Unit from Fig. 2f) and g),
– Communication Mode between Remote Unit from Fig. 2d) and Master Unit from Fig. 2f),
– Software from Fig. 2g).

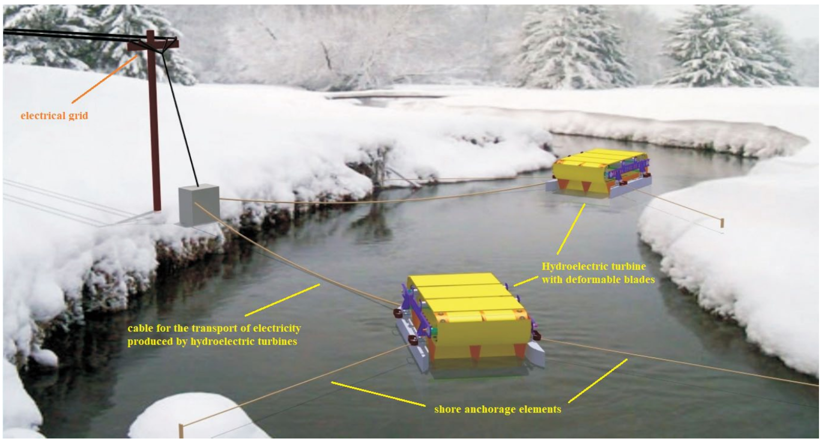


Fig. 1. Portable Hydro-electrical Turbine with deformable paddles

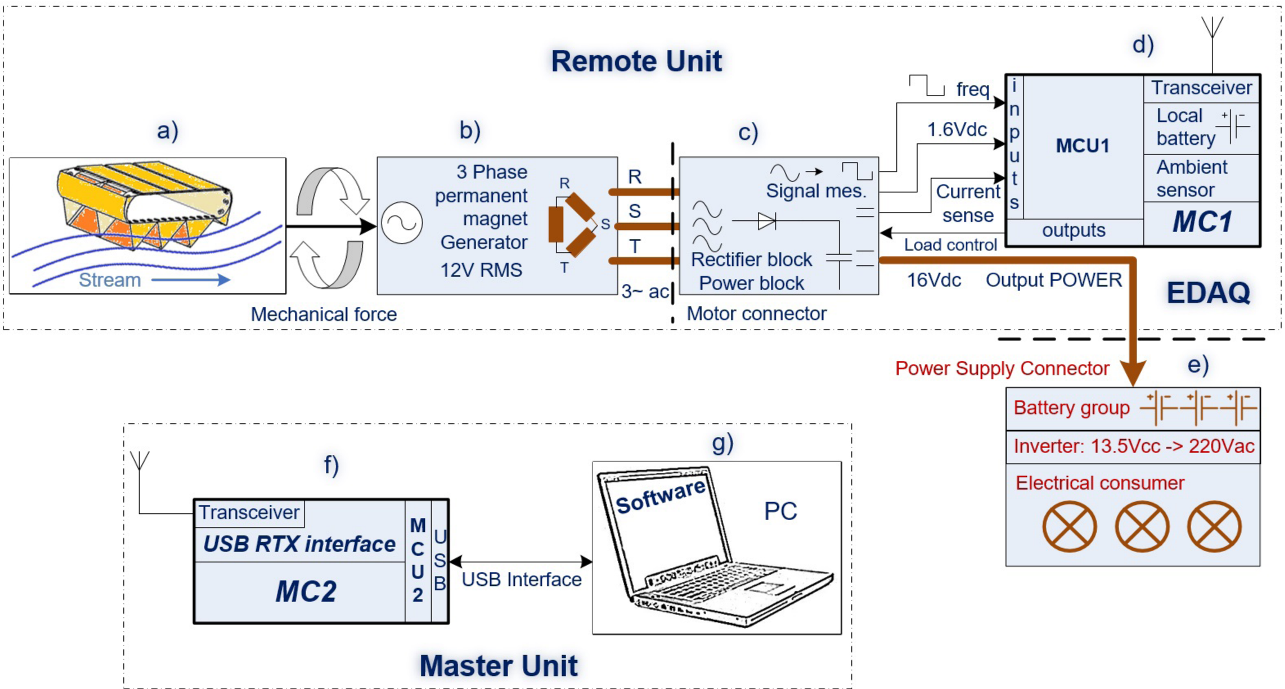


Fig. 2. Acquisition data system for a remote hydro-electrical turbine

The Remote Unit is located at the turbine, on the water of the mountain river and consists of the three-phase electric generator (Fig. 2b) of 12 V, the rectifier block (Fig. 2c) of the alternating three-phase voltage in direct voltage, the MC1 microcomputer (Fig. 2d) and the group of batteries that, together with the inverter from 13.5V to 220 V (Fig. 2e), provides constant power to the electrical consumers located on the shore. The Master Unit is located on the shore and consists of the PC computer (Fig. 2g) which initiates the control of the turbine through the MC2 microcomputer (Fig. 2f).

### 1.1. Remote Unit – Power and Rectifier Block

Remote Unit, from the hydro-electric turbine is located along the mountain river, and is made up of the following elements shown in Fig. 2:

- Mechanical element (a),
- 3 Phase Permanent Magnet Generator (b),
- Power and Rectifier Block (c),
- MC1 (microcomputer 1).

The mechanical elements transform the linear movement of the water into rotational movement that drives a synchronous three-phase electrical generator with permanent magnets. It provides 12 RMS alternating current with a maximum power of 500 W. The alternative electrical energy is then taken over by the rectifier block and is converted into direct current. Fig. 3 shows the Rectifier Block together with the Power Block.

The rectifier bridge formed by diodes D19, D20, D21, D22, D23 and D4 convert the alternating current from the 3 phases R, S, T of the turbine generator into direct current. The two capacitors C1 and C2 filter the direct current from the rectifier bridge through the signals “*GENERATOR_U_POWER_1*” and “*GENERATOR_U_POWER_2*”, to the general supply for the electrical consumers. A part of this voltage (1/10) through the signal “*GENERATOR_U_POWER_1_10*” is collected through the resistive divider R2-R3 and is supplied to MC1 for monitoring the turbine output. Considering that the electric input signals in MC1 must not exceed 5 V, because those are applied directly to a microcontroller, they must be reduced using resistive dividers such as R2-R3. In order to measure the frequency from the electric generator of the turbine, it is necessary to collect the signal from one of the phases of the generator, then convert it from an alternating signal to a rectangular signal and limit its level to be applied to the input of MC1. The signal from the generator is taken from phase T, then it is applied to the parametric stabilizer formed by R4 and D4 and finally the rectangular signal “*GENERATOR_FREQ_RECTANGULAR*” is introduced into MC1. The BZX284C4V7 zener diode D4 stabilizes the voltage at 4.7 V ensuring the protection of the entrance to MC1.

For the ON/OFF control of electrical consumers, by the turbine, 2 separate power lines “*GENERATOR_U_POWER_1*” and “*GENERATOR_U_POWER_2*” were introduced, through which they can be controlled independently. The actuation elements for these 2 power lines are 2 PROFET BTS6143D integrated circuits from Infineon widely used in the Automotive industry.

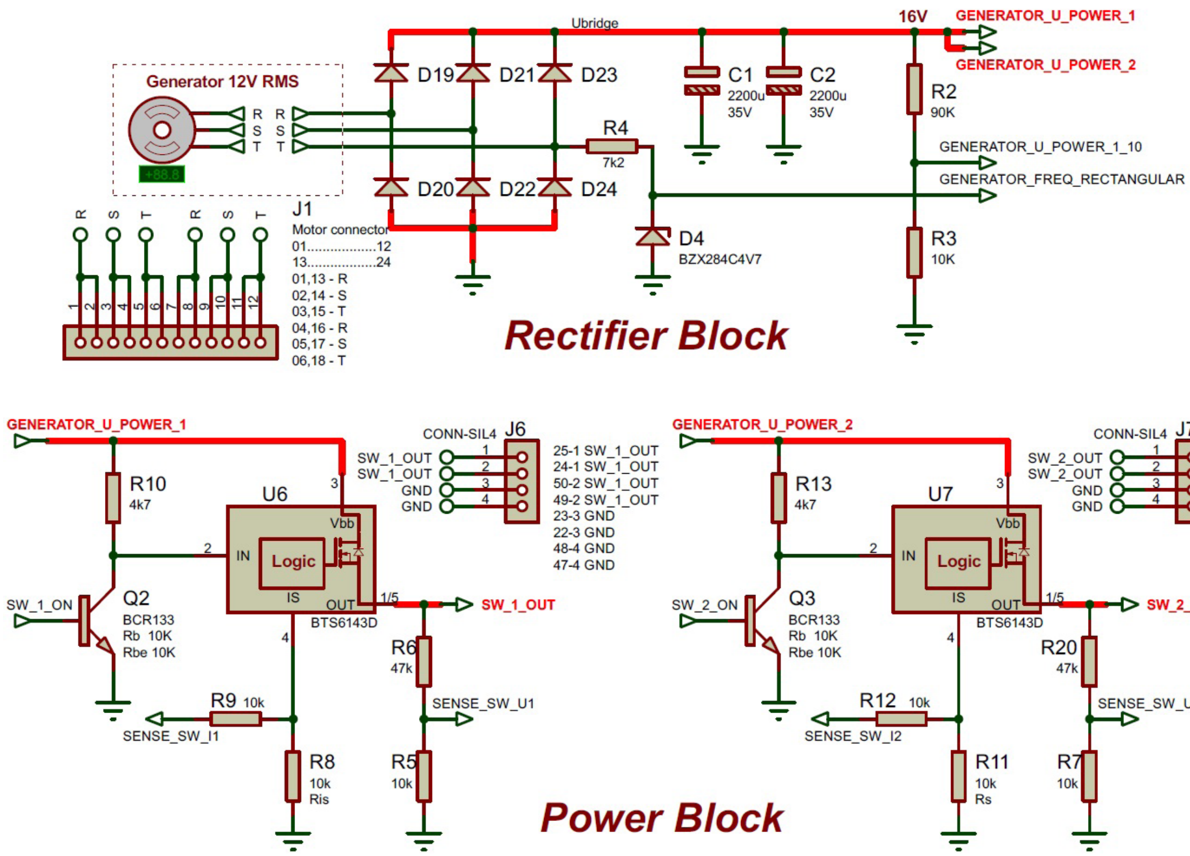


Fig. 3. Rectifier and Power Block

These are in fact smart switches and behave like an electronic relay. U6 and U7 from the Power Block shown in Fig. 3, are fed from the general lines "*GENERATOR_U_POWER_1*" and "*GENERATOR_U_POWER_2*" and their outputs "*SW_1_OUT*" and "*SW_2_OUT*" feed the final consumers that will be present on shore. The control inputs for these smart switches come from MC1 via the control signals "*SW_1_ON*" for U6 and "*SW_2_ON*" for U7. To activate the U7 smart switch, its input, pin 2, must be connected to ground. This is possible by saturating the Q3 transistor, by applying the 5 V signal to its base. In this way, U7 is open, and the "*GENERATOR_U_POWER_2*" signal from pin 3 is transferred to the output, pins 1/5 to "*SW_2_OUT*". To monitor the output voltage, the resistive divider R20-R7 applies a part of the "*SW_2_OUT*" signal via "*SENSE_SW_U2*" to the input of MC1. One of the performances of the BTS6143D smart switch, is to measure the load current through the Sense IS output on pin 4 [5]. A part of the voltage that reflects the consumption current is collected from IS through R12 and R11 and through the "*SENSE_SW_I2*" signal is applied to the input of MC1 to monitor the load current of U7.

### 1.2. Remote Unit – Micro Computer 1

The electrical circuit diagram for MC1 (Microcomputer 1) is shown in Fig. 4.

The main elements of MC1 are:

– U1 – MCU 1 (MicroController Unit 1) type PIC18F2550,
– U2 – temperature and humidity sensor SHT10,
– U3 – HM-TRS868 wireless transceiver,
– U4 – RS232 driver of the MAX3232 type,
– U5 – the 5V voltage regulator NCV4264.

The PIC18F2550 is an 8-bit microcontroller based on a modified Harvard RISC architecture and is part of the PIC18F2455/2550/4455/4550 family [6]. The role of MCU1 is to collect the turbine information (inputs in MC1), such as the voltages from the turbine output, the current charged by the turbine to the electric consumers, the frequency of the electric generator, and the environmental data represented by the temperature and humidity in MC1. The output elements of MC1 are the control of the 2 smart switches for activating/deactivating the electrical loads from the shore. MCU1 is controlled by wireless radio transmission from the shore, by the MC2 system.

All signals input elements in MC1 for measuring voltages are connected to MCU1 (PIC18F2550) on the ADC (Analog to Digital Converter) ports marked with "AN" in MCU1 as follows: "GENERATOR_U_POWER_1_10" to AN0 (MCU1 pin 3), "SENSE_SW_U1" to AN8 (MCU1 pin 23), "SENSE_SW_U2" to AN9 (MCU1 pin 24), "SENSE_SW_I1" to AN2 (MCU1 pin 4), "SENSE_SW_I2" to AN3 (MCU1 pin 3) and "ADC_VBATT_U" to AN0 (MCU1 pin 2). The Frequency measurement is performed on input RA4 through pin 6 from the MCU1 on the corresponding signal "*GENERATOR_FREQ_RECTANGULAR*". The control of the 2 smart switches is done through the digital ports related to the command signals: "*SW_1_ON*" to RC0 (MCU1 pin 11), "*SW_2_ON*" to RC1 (MCU1 pin 12). MC1 has a 3.6 V back-up battery that is charged from the generator. The integrated circuit U2 is a temperature and humidity sensor type

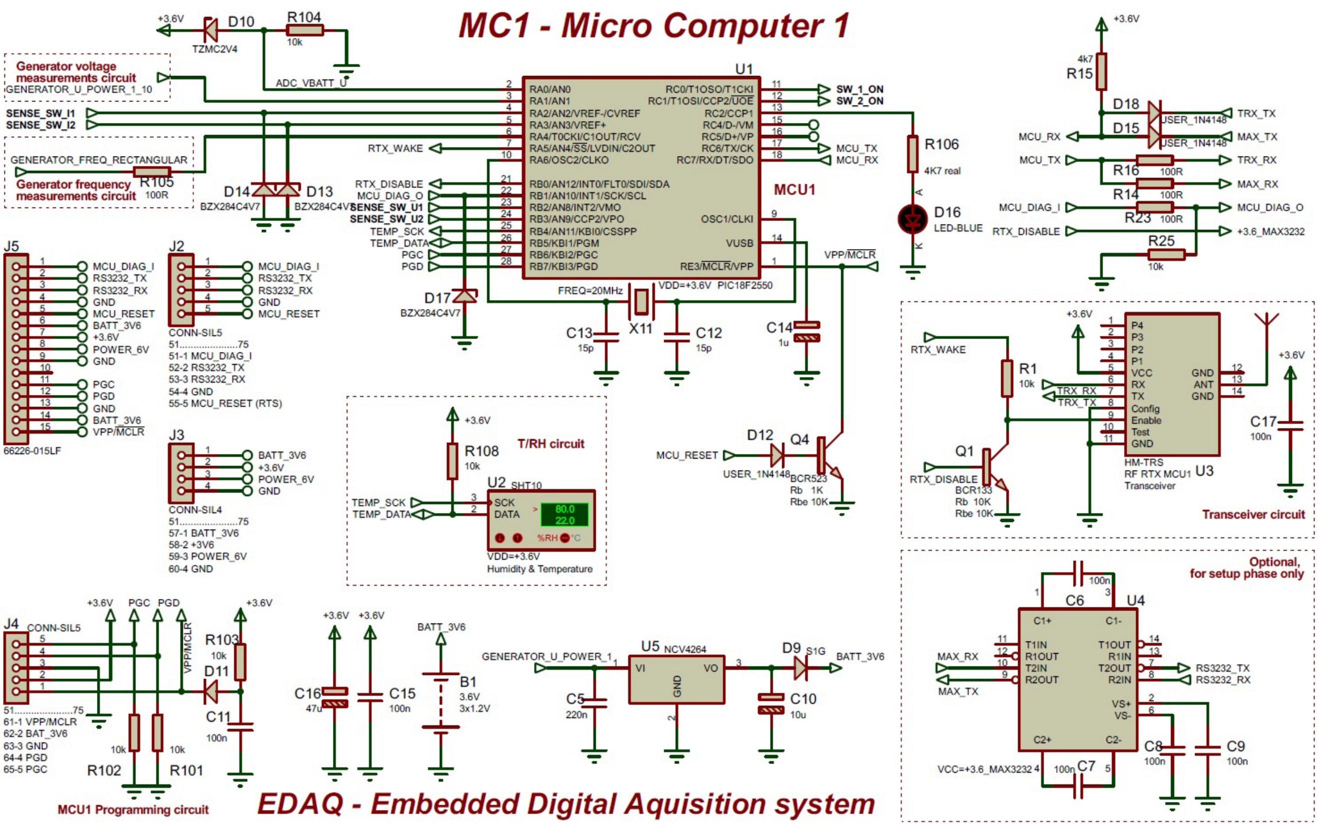


Fig. 4. Micro Computer 1

SHT10 from Sensirion. It measures temperature between –40°C and 100°C with an accuracy of ±0.5°C and relative humidity from 0 to 100% with an accuracy of ±4.5% [7]. It is controlled by MCU1 on the I2C communication bus on ports RB4 and RB5. U2 is located directly on the motherboard of MC1, and its role is to monitor the ambient conditions from the electronic part of the turbine. In this way, it is known if the electronic part has been flooded with water from the river. The communication between MC1 and MC2 is carried out by wireless transmission using the U3 module, which is an HM-TRS868 transceiver produced by Hope Microelectronics. HM-TRS series transparent wireless data link module dedicated for application that needs wireless data transmission. It can be used for high data rate and longer transmission distance under 100 meters with 868MHz frequency. The communication protocol is self-controlled and the major benefit is the transparences for the user interfaces [8].

The plastic housing was sealed to prevent river water from flooding the electronic components.

## 2. Master Unit

The Master Unit is located on the shore, operated manually by an operator or works automatically. The Master Unit consists of a computer (Fig. 2g) and a MC2 (Microcomputer 2 from Fig. 2f) connected to the computer's USB port. The Software on the computer monitors and controls the hydroelectric turbine through commands sent to MC2 via USB, which in turn sends the commands to MC1 wirelessly.

### 2.1. Microcomputer 1

The communication path between the surveillance computer and the remote unit consists of a USB to RTX interface. The HM-TRS interface transceiver is based on serial UART. The USB RTX module is actually a USB interface to HM-TRS transceiver. It acts as a communication relay, transferring data from the USB bus to the MC1 module via wireless radio waves. The circuit diagram is presented in Fig. 5.

The MCU2 microcontroller is also of the PIC18F2550 type, as in the case of the MCU1 microcontroller. The PIC18F2550 connects with the computer USB port through the D– pin 15 and D+ pin 16. The HM-TRS transceiver from the MC2 is connected to U1 (MCU2) via the UART serial lines.

While the maximum supply voltage of the HM-TRS is 3.6 V, the power supply had to be changed from 5 V, from USB, to 3.3 V. The Transceiver is powered by the voltage regulator U2, LM1117-MP3 which supplies the output voltage with 3.3V.

### 2.2. Communication Protocol

Fig. 6 shows the communication flow between the PC and the turbine. The communication protocol is request response type.

It is always the PC that initiates the data transfer. For example, for reading an electrical parameter, the computer (Fig. 6g) sends a request to the MC2 (Fig. 6f). It receives the request, decodes it, and forwards the request to the turbine via the wire-

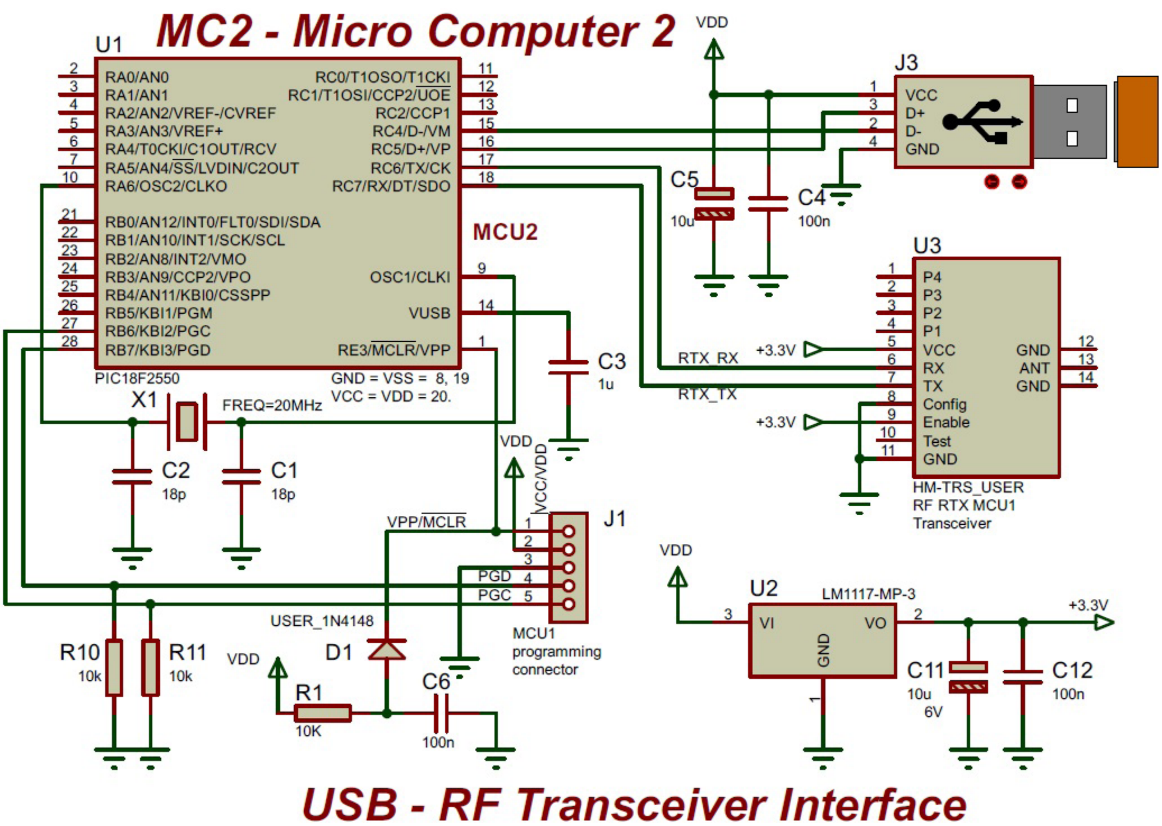


Fig. 5. Micro Computer 2

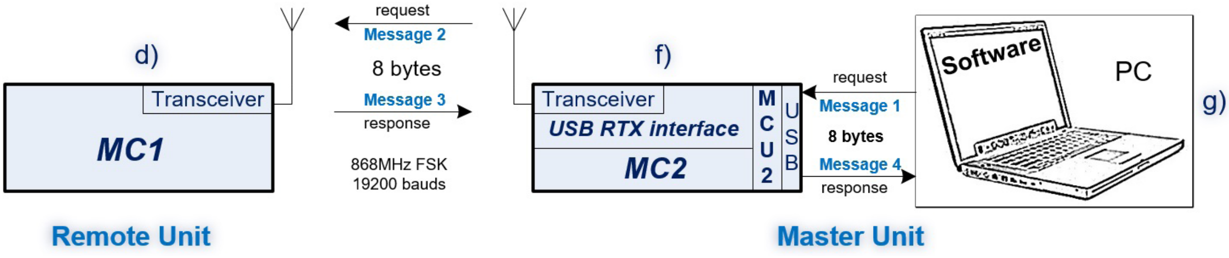


Fig. 6. Communication flow

less UART transceiver. MC1 receives the request, decodes the information, and transmits back to MC2 the requested data. MC2 receives the response from MC1 and further forwards the response requested by the PC to the PC. The length of the data packets between PC and MC1 is 8 bytes, and between MC1 and MC2 (inter-microcontroller) is also 8 bytes. Fig. 7 describes an example for reading the voltage and current from smart switch 1 inside the Power Block and the frequency from the turbine by the PC through command 0×68.

The PC sends the request contained in message 1 (*0x3B 0x68 0x00 0x00 0x00 0x00 0x00 0x00*) to the MC2 via the USB port. MC2 receives the request, decodes the request, and forwards message 2 (*0x31 0x68 0x00 0x00 0x00 0x00 0x00 0x00*) to the wireless transceiver. MC1 receives message 2, decodes it, processes it and then returns the measured values in message 3. On message 3, the voltage value is positioned in byte 2 (*V1M*) and 3 (*V1L*), the current value is in byte 4 (*I1M*) and 5 (*I1L*) and the frequency is present on byte 6 (*FM*) and 7 (*FL*). MC1 trans-

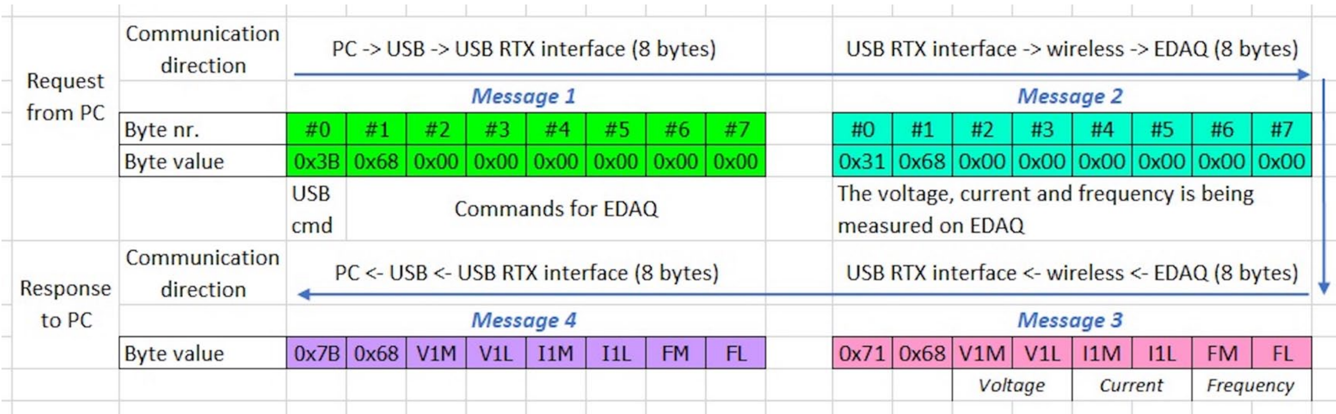


Fig. 7. Communication protocol

TABLE 1

Communication protocol message frame format

| Type | Message description | Message name | Direction | Command frame | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | #0 | #1 | #2 | #3 | #4 | #5 | #6 | #7 |
| **Based commands** | Switch load ON/OFF | MCU1_WR_OUT_LOAD | PC->MC1 | 1A | 02 | 02 | **0N** | **0L** | 00 | 00 | 00 |
| | | | PC<- MC1 | 5A | 02 | 02 | **0N** | **0L** | 00 | 00 | 00 |
| | Read analog value from MC1 | MCU1 RD Analog | PC-> MC1 | 1B | 05 | **CH** | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 5B | 05 | **CH** | **MB** | **LB** | 00 | 00 | 00 |
| | Read temperature from generator housing | MCU1_RD_I2C_Temp | PC-> MC1 | 3B | 07 | **01** | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 07 | **01** | **MB** | **LB** | 00 | 00 | 00 |
| | Read humidity from generator housing | MCU1_RD_I2C_Humidity | PC-> MC1 | 3B | 07 | **02** | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 07 | **02** | **MB** | **LB** | 00 | 00 | 00 |
| | Read indirect frequency from the generator | RD TIMER X indirect values | PC-> MC1 | 3B | 13 | **0T** | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 13 | **0T** | **MB** | **LB** | 00 | 00 | 00 |
| **Custom commands** | Read OUT1 parameters and generator frequency | Read OUT1 voltage, current, generator frequency | PC-> MC1 | 3B | 68 | 00 | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 68 | **V1M** | **V1L** | **I1M** | **I1L** | **FM** | **FL** |
| | Read OUT1 parameters and generator frequency | Read OUT2 voltage, current, generator frequency | PC-> MC1 | 3B | 69 | 00 | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 69 | **V2M** | **V2L** | **I2M** | **I2L** | **FM** | **FL** |
| | Read Battery level and ambient information | Read Battery level, Temperature, Humidity | PC-> MC1 | 3B | 6A | 00 | 00 | 00 | 00 | 00 | 00 |
| | | | PC<- MC1 | 7B | 6A | **VbM** | **VbL** | **TM** | **TL** | **HM** | **HL** |

mits to MC2 the newly formed message 3 through the wireless transceiver, and MC2 receives it, decodes it and transmits the new message 4 to the PC. The PC receives message 4, analyzes the response for the initial request (message 1) and displays the information on the graphic interface on the screen. The commands supported by the communication protocol for acquiring data from the turbine are presented in TABLE 1.

These are divided into based commands and custom commands. Based commands read each electrical parameter separately, while custom commands read together 3 electrical parameters.

### 2.3. Software

The PC software is a component part of the Master Unit, located on shore. Its purpose is to monitor and supervise the Remote Unit. The communication protocol is implemented at the application level and is based on the request-response approach. When data acquisitions are requested from the turbine, during transmission, the Software from the PC sends requests to the turbine (Fig. 7, message 1), at regular intervals of 500 milliseconds. At the reception, the software constantly monitors the response from the turbine (Fig. 7, message 4). Fig. 8 shows the GUI (Guide User Interface) of the PC software.

All the information collected from the turbine is recorded locally on the hard disk of the computer system for later analysis when needed.

### 3. Measurement result

The prototype that implements hydroelectric turbine with deformable blades was tested only once on the water of the mountain river from Gura Raului in Sibiu county, Romania. For electrical tests, a projector with LEDs of 20W connected to smart switch 1 and the voltage and current on the load were measured through it.

The results obtained after the measurements are presented in Fig. 9.

As a result of the field measurements, 2945 samples were recorded for the voltage (“SENSE_SW_U1”) and the current (“SENSE_SW_I1”) generated by the turbine at intervals of 500 milliseconds each, that is 88.35 minutes of operation. From the total voltage graph marked in green in Fig. 9a consisting of 2945 points, it can be seen that the step on the X axis is 46 samples. For a better visual analysis of the green voltage graph, the range of samples between positions 139 and 185 was taken and then displayed on the graph on Top marked with gray color (zoom in). In this way, the evolution of the voltage generated by the turbine can be more easily analyzed. The voltage on the gray graph was recorded in a period of 23 seconds. It can be seen that the voltage evolution is quite stable over time. Anyway, even if there are voltage variations, they can be removed with the battery and shore inverter in Fig. 2e. The graph from Fig. 9b shows the evolution of the current consumed by the LED projector. It can be easily observed that the variation compared to the voltage graph is directly proportional because the value of the load is the same, it does not change.

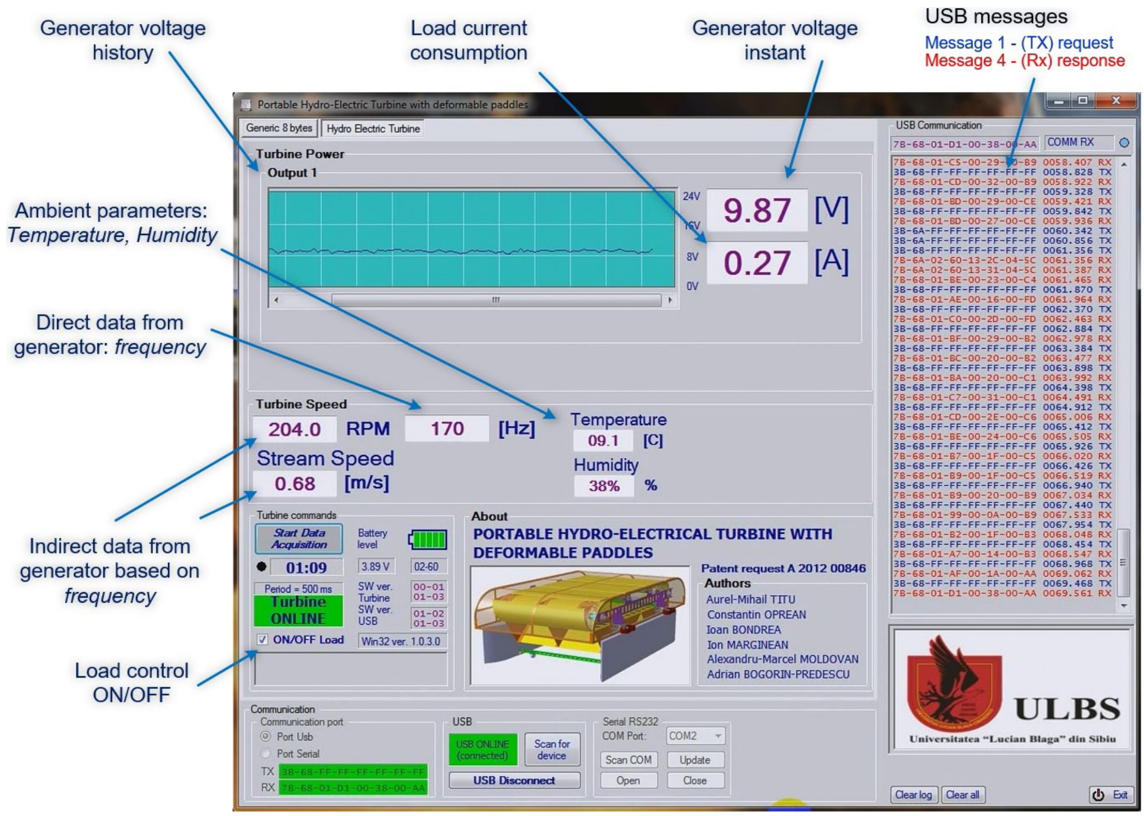


Fig. 8. MC2 Printed Circuit Board


Fig. 9. Experimental data

The graph in Fig. 9c shows the variation curve of temperature and humidity inside MC1. Compared to voltage and current, which were acquired at a cyclic interval of 0.5 seconds, the ambient data is read cyclically at an interval of 10 seconds. After the turbine was launched into the water, in the interval 1-105, the temperature is approximately constant between 25°C and 30°C. Considering that the power consumed by the LED projector is relatively small, it takes a while until the power consumption of the load is reflected in the power dissipated on the electronic components in MC1. Then after more time of operation, the electronic components release heat and heats the air inside MC1 starting from moment 105. Then starting from moment 353, the temperature of MC1 drops because the casing is cooled by the river water.

It is crucial to remember that low-cost remote data collecting devices have raised questions in the hydroelectric and wind energy sectors. As an illustration, Casallas J. S.and authors, created an instrument for gathering data that makes use of a wind turbine. The velocity of the wind and turbine tilt are recorded by this method using electrical sensors. The electrical signals from the sensors are obtained by a minicomputer outfitted with an ESP32 microcontroller, and they are subsequently transmitted to an external computer [9].

## 4. Conclusions

The acquisition data system acts like SCADA concept. Based on the information given by the GUI, the human operator can control the electrical consumer state acting like human-machine interface. All the data collected are enough to determine operating Turbine state. Experiments have shown that using remote data transmission and processing computer can be strictly determinate, digitally and easily seen, the best position of the location on the river hydroelectric generator to achieve maximum efficiency of conversion of kinetic energy of water into electricity. The acquisition data system for this remote hydro-electrical turbine signals, indicates the functionality, and emergency cases which can damage the hydro-electrical turbine: signals the increasing water level above the flood; occurrences of frost, if is not removed from the water; obstacles mechanical logs; bottles.

The advantage of this acquisition data systems are: remote monitoring, do not have to enter the water; eliminate the need for human presence at the site guarding.

## REFERENCES

[1] I. Roşu-Hamzescu, Criză energetică sau criză de tehnologii? Editura Scrisul Românesc, Craiova (1984).

[2] M. Iovescu, A. Buglea, G. Balan, S. Kisapati, M. Lukovics, Studiu privind eficienta utilizarii solutiilor de energie alternativa (2017).

[3] A. Tidrea, A. Korodi, I. Silea, Elliptic Curve Cryptography Considerations for Securing Automation and SCADA Systems (2023).

[4] A.M. Ţîţu, C. Oprean, I. Bondrea, I. Mărginean, A.M. Moldovan, A. Bogorin-Predescu, Portable Hydro-electrical Turbine with deformable paddles, Patent number 128224, Romania (2018).

[5] Infineon, PROFET™: Smart High-Side Switches, Infineon Technologies AG (2014).

[6] PIC18F2455/2550/4455/4550 Data sheet, Microchip, 2355 West Chandler Blvd., Chandler, AZ 85224-6199 (2009).

[7] Sensirion, Datasheet SHT1x (SHT10, SHT11, SHT15) Humidity and Temperature Sensor IC, SENSIRION AG Laubisruetistr. 50 CH-8712 Staefa ZH Switzerland, (2011).

[8] HM-TRS Data sheet, HOPE MICROELECTRONICS CO.,LTD Add:4/F, Block B3, East Industrial Area, Huaqiaocheng, Shenzhen, Guangdong, China, (2006).

[9] J.S. Casallas, H.G. Parra-Peñuela, E.E. Gaona, Wireless Real-Time Data Acquisition System for Aerodynamic Characterization of a Wind Turbine. In Ingeniería **28**, Issue Suppl, p. 18860. Universidad Distrital Francisco Jose de Caldas (2023).