



ISSN: 2350-0328

**International Journal of Advanced Research in Science,
Engineering and Technology**

Vol. 7, Issue 5, May 2020

Monitoring and Controlling the Supply Energy to the Load in the Micro Hydropower System

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ABSTRACT: The hydropower is widely used to generate the electricity by building the dams which is very expensive and need a lot of time. For that, researchers have been working to exploit the hydropower energy in the other ways by using the micro hydropower system like run of river system and the gravitation water vortex power plant systems. The aim of this study is to design a graphical user interface by MATLAB for monitoring and controlling the generated power from water turbines and the consumed energy by the load. That leads to determine the critical states which the system could not provide the load with the necessary energy. In addition, it attempts to make the necessary adjustments to the overall system to meet the needs of the load. This process is achieved by Arduino which receives the signals from sensors and give the read value to MATLAB. By this way, it can be drawn the required figures, monitor and compare the generated and consumed power.

KEY WORDS: Arduino, control, GUI, Hydropower, MATLAB, monitoring, Run of River.

I. INTRODUCTION

Hydropower is a good source of power because of many reasons. Firstly, it is a relatively cheap compared with some other power sources. In addition to it is a reliable source, because it is available throughout the year. Not only that but also this type of power is sustainable, and renewable energy that does not deplete natural sources nor produces toxic emissions and waste. Actually, hydropower is the least expensive and most efficient system for producing electricity, and its price is competitive compared with traditional power sources such as gas, fossil fuels, and biomass. Most produced hydroelectric energy today is being produced by hydroelectric dams that generate electricity when they convert the potential energy of falling water from reservoirs which are made by human. These reservoir-fed systems damage the ecosystem and local environment, hence there is opposition towards their construction and utilization. Run of the river (RoR) hydroelectric stations are an alternative method to large-scale stations as they do not require a huge reservoir capacity, so that the flowing water from upstream must be utilized for generation the power at that moment or must be allowed to avoid the Run of the river station. This reason is a key that told us why such RoR systems are as green power or environmentally friendly [1], [2], [5].

In recent years many researchers have been working on this subject. For example, Yan-pin (2010) tried to solve some problems that exist in the monitoring systems of small hydropower plants, the authors suggest some appropriate structure of monitoring system for small hydropower plants and the authors consider that it has benefits for the automation system conversion of small hydropower plants [2]. Liu, Zou, and Zhou (2011) suggested a condition monitoring system for hydro turbines that depend on LabVIEW. The suggested system is constructed and carried out with the configuration and function modules. The application gives results that have proved that as this system can help to get the hydraulic turbine's state. In addition to it is promising to be a technical reference that can support the engineers which work in this field [3]. Yildiz (2015) introduced a numerical model, called HYdroPower or HYPER, which simulates the power generation of a Run of River (RoR) system in response to a historical record of discharge values every day, and design process variables. HYPER is designed by MATLAB which provide a graphical user interface (GUI) which clarifies the numerical simulation and the results [4]. Krasteva, Bachvarov, and Boneva (2011) presented the distributed system which contains three microcontrollers. This system aims to control and monitor the waterwheel of a small hydroelectric power plant. A software is improved, realizing "PEAK POWER TRACKING"

method for automatic control. Each 10 seconds, the measured data are sent as reports to the centre computer (centre station) by GPRS/ Internet. The utilized communication protocols are ZigBee; GPRS; TCP/IP; SMS; USB [5]. Malik, at all (2018) studied the wind turbine which had been implemented in the ducting system. The aim is analysing the power generation and the system quality. They develop power monitoring system for monitoring the performance of the system by depending on three parameters setting that are current, temperature and air velocity. The importance of this system come from avoiding failure and studying the trend of produced electricity via wind turbine [6].

In this study, the generated power from hydropower system, consumed power by load and the state of battery charge will be monitored for trying to control and supply the required power to the system and exploit the surplus energy in supplying extra loads or for charging the batteries. This is executed by GUI in MATLAB which takes its data from sensors that are connected with Arduino.

In the next section, there are information about the system structure of micro hydropower systems and how to get these values by Arduino and the studied parameters of the studied system are discussed in the third section. In the fourth section, it will be mentioned how to show that parameters in GUI that will be designed by MATLAB. The last section will be discussed the results and conclusion.

II. SYSTEM ARCHITECTURE

There are many components, which are used in this study. Figure 1 illustrates the main parts. Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on computer, used to write and upload computer code to the physical board. It does not need a separate a programmer in order to load new code onto the board - simply a USB cable can be used. It provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package. This search uses the Arduino for reading the analog values from the sensors and sending these values to MATLAB to show them on the Graphical User Interface (GUI) and process them to resend some commands to Arduino for controlling the run of river system.

The second part is the current sensors which are used to get the values of the generated power by the turbine and consumed power which is required from the load. The designed system supposes that there are four types of the power levels which can deal with it. These levels are 1.5 kW, 3 kW, 10 kW and more than 10 kW. For that, it is used four different types of current sensors which are 10 A, 20 A, 40 A and 200 A. The output of these current sensors is between 0-5 V, because the analog inputs of the Arduino can deal with just range of these values. The system needs two current sensors, one for measuring the current which is generated from turbine and the other one for measuring the current which is consumed by the load. Table 1 illustrates the types of suggested current sensors.

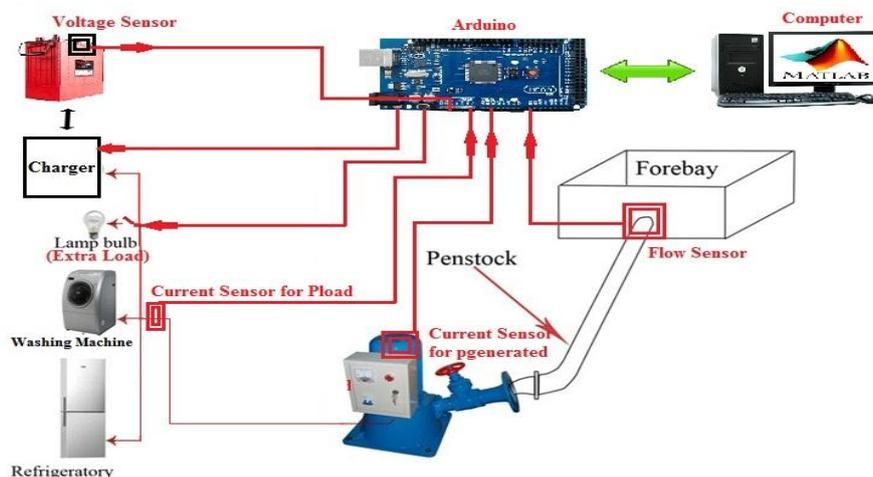


Fig.1. The studied system

Table 1. Types of suggested current sensors.

Name of Sensor	Range (A)	Sensitivity (mV/A)	Output Voltage
ACS723LLCTR-10AU-T	10	400	0-5 V
ACS723LLCTR-20AU-T	20	200	0-5 V
ACS723LLCTR-40AU-T	40	100	0-5 V
ACS758ECB-200U-PSF-T	200	20	0-5 V

The other type of sensor is the flow measurement sensor which converts the flow of water through penstock to analog values which can be read by the Arduino. According to these values the Arduino can calculate the generated power by using the equation of power max of the hydro system, then it compares this value with the value which can be got it by the current sensor of generated power.

In addition to the voltage of battery can be read by Arduino by using voltage divider to convert the high voltage of battery from 13 V to appropriate voltage which can be read by Arduino. Figure 2 illustrates the sensors which were suggested with this system.

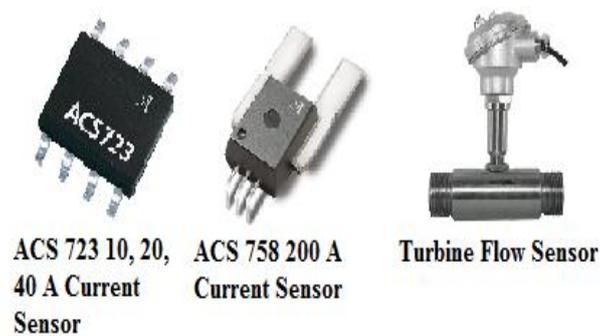


Fig.2. The suggested sensors of the studied system

III. THE STUDIED AND MONITORED PARAMETERS

There are many parameters that will be studied for monitoring the studied system to control it and providing the required power to the load and exploiting the extra power in the best way.

A. Generated Power of Run of River System

Run of River systems generate the power which can be calculated by two ways. One of these ways depend on the potential energy that is existed in the stored water, by the other words, the conserved power in the head of water. The second way exploits the kinetic energy which is produced by flowing water.

- **Potential energy method:**

Potential energy per unit volume is:

$$PE = \rho gh \tag{1}$$

where ρ is the density of the water (10^3 kg/m^3), h is a head of the water (m) and g is the gravitational constant (9.81m/s^2).

The power max of the hydro system (in kW) is given by:

$$P_{max} = \eta \rho ghQ \tag{2}$$

where Q is the volume of water flowing per second (the flow rate in m^3/s) and η is the efficiency of the turbine. When the flow of water is $1 \text{ m}^3/\text{s}$ from a head of 1 m, the produced power is 9.81 kW, if the efficiency of an energy conversion is considered 100% or the generated power is just over 9 kW when a turbine efficiency is between 90% and 95%. This formula generally applies to static hydro, by using stored water. If this equation is intended to use with

dynamic or kinetic systems, some alertness is needed to be found for the calculation of the values because they influence the generated power.

- **Kinetic energy method:**

The turbine transforms the flowing water kinetic energy into the rotational energy of the turbine which is connected with the generator. For that, the produced energy depends on the quantity of water that crosses through the turbine and the square of water flow velocity.

The maximum generated power from a turbine, which is utilized in a kinetic ROR projects, is proportional to the kinetic energy of the water flowing through the turbine. The maximum output power, when the efficiency η of the turbine is taken in consideration, is given by:

$$P_{\max} = \frac{1}{2} \eta \rho Q v^2 \quad (3)$$

Where v is the velocity of the water flow, ρ is the density of water (10^3 kg/m^3) and Q is the volume of water flowing through the turbine per second which is given by $Q = vA$, where A is the swept area of the turbine blades. Thus, that can give the next equation:

$$P_{\max} = \frac{1}{2} \eta \rho A v^3 \quad (4)$$

The 4th relationship is appeared that the power output is proportional to the cube of the velocity of the water. If it is returned to Eq. (2) and utilize the Bernoulli equation:

$$v = \sqrt{2gh} \text{ or } v^2 = 2gh \quad (5)$$

We can get the following equation:

$$h = \frac{v^2}{2g} \quad (6)$$

Substituting for h in Eq. (4) produces:

$$P_{\max} = \frac{1}{2} \eta \rho v^2 Q \quad (7)$$

Consequently, $Q = vA$ so $P_{\max} = \frac{1}{2} \eta \rho A v^3$, which is the same result as in Eq.(4) The result is that if the head or pressure drop is known but the velocity is not known, the Eq.(2) can be utilized and if the velocity is known with the neglected head and Eq.(4) can be used. Thus, the generated power will be 0.5 kW or slightly less taking in the consideration the inefficacies in the system by one cubic meter of water flowing at one metre per second through a turbine which its efficiency is 100% [7]. Here, it is depended on the potential energy method for calculating the generated power (p). Not only that but also it is used current sensors, which will be studied in the next sections. In addition, the seeking to find the generated power ($P_{\text{generated}}$) which is generated by hydro turbines at the output of these turbines and the power (P_{load}) which is required by the load.

B. The State of Charge of Battery

Lead acid batteries consist of cells. Each cell gives approximately 2 V, so the six individual cells can construct a 12 V battery. A fully charged 2 V cell has approximately a voltage of 2.15 V, but a fully discharged 2 V cell has a voltage of 1.9 V. The difference is only 0.25 V on each cell from fully charged to fully discharge. For that, a 12 V battery will give a measurement about 12.9 V if it's fully charged and about approximately 11.4 volts if it is fully discharged. That means that the full range of charge on a 12 V battery is a total of 1.5 V. The calculation of how much charge the battery has left, it can be calculated a percentage of charge remaining that is directly proportional to the battery voltage. For example, if the battery voltage is 12.15 V, and 11.4 V representing no charge or 0% charge available, the subtraction 11.4 V from the read voltage, $12.15 - 11.4 = 0.75 \text{ V}$, there are only 1.5 V above 11.4 V that represents the full range of charge. It can be divided the difference that it is just calculated by 1.5 V to get the percentage of charge remaining, $0.75 \text{ V} / 1.5 \text{ V} = 0.5$ or when expressed as a percentage, multiply by 100 and get 50%.The formula which is applicable to 12 V Batteries:



$$\text{SOC} = ((\text{Measured Battery Voltage} - 11.4 \text{ V}) / 1.5 \text{ V}) \times 100\% \quad (8)$$

Eq. (8) represent battery State of Charge (SOC) calculation which was used in the current work [8].

There are other parameters, which are studied and monitored by the sensors to control the Run of River systems and achieve the required process in the best way. These parameters were discussed in the previous section when the sensors are studied, whereas the sensors read the values of these parameters.

IV. APPLICATION AND RESULTS

There are many ways to achieve the software part and writing the program. Some of searcher prefer to write the program in two parts one on the MATLAB and the other one by the Arduino environment programmer. Here, it is depended to write the program completely in MATLAB and the function of Arduino is just to use its inputs for reading the values from sensors and outputs for implementation the commands which will come from MATLAB.

The MATLAB is used to design Graphical User Interface (GUI) of the run of river system which is used to monitor the generated and consumed power, flow of water with the generated power and the state of charge of battery. Figure 3 illustrates the designed GUI for the run of river system. Firstly, the connection between MATLAB and Arduino can be established after selecting the number of port and push the “connect” button after that it can be pushed the “start” button. If the number of ports is wrong, the warning message will appear. Secondly, the part one consists of three popupmenu for selecting the type of hydro turbines according to generated power and the sensors that are required with it. In the parameters part, where H is the head of the river that is measured where the turbine will be put, Q is flow of the river which is measured by the sensor flow, e efficiency of the turbine that will be gotten from the turbine guide, P is the max power which is calculated according to H, Q and e, Pgenerated is the generated power which is generated by the turbines and it is gotten by the current sensor, Pload is the consumed power by the load it is gotten by the current sensor, Pextra gives the extra generated power according to equation that is (Pgenerated-Pconsumed), Battery is the voltage of the battery and SOC is state of charge which is gotten by the potentiometer. The “disconnect” push button is for disconnecting the connection between MATLAB and Arduino. The “clear” push button is for erasing figures and resetting the GUI and “exit” push button is for closing the GUI. In the control panel part, there are three radio buttons for pausing, continuing and stopping the system. In addition, there is a camera part for monitoring the system. Finally, there are three graphical results, first one is at the top left side of the screen for drawing the relationship between the generated and consumed power. That can help for monitoring the power in the studied system. The second one is at the up-right side of the screen for drawing the relationship between flow of river and the generated power. That can help to define the amount of the power during the seasons according to the flow of river. The last one gives the information about the voltage of the battery.

After getting the values from the sensors, the control process is achieved by comparison the eventual values of generated power (Pgenerated), consumed power (Pload), and the state of charge (SOC) in three main states. In this study, the used prototype depends on the potentiometers that give the same voltage of used sensors outputs. Figure 4 illustrates the flow chart of the control process. After running the Arduino and starting the program on MATLAB and establishing the connection between them, the Arduino check the values which are coming from sensors to compare them and give the suitable command. Firstly, if the generated power is enough just for feeding the load, generated power equal to load power, all the generated power will be given to the load. But if the generated power is not equal to the load power, there are two probabilities. The first one is, if the generated power is more than the need of the load power, the voltage of battery is checked. If the charge of battery is more than or equal 90%, the extra power is used to feed the extra load. The second one is, if the generated power less than the needed power of the load. Here, if the charge of battery is between 60% and 100%, the generated power is used to charge the battery and at same time the load is fed from the battery. One the other hand, if the charge of battery is less than 60%, the generated power is used to charge the battery and run the generator to feed the load. The checking operation continues in a cycle during the real time. Table 2 illustrates the studied states.

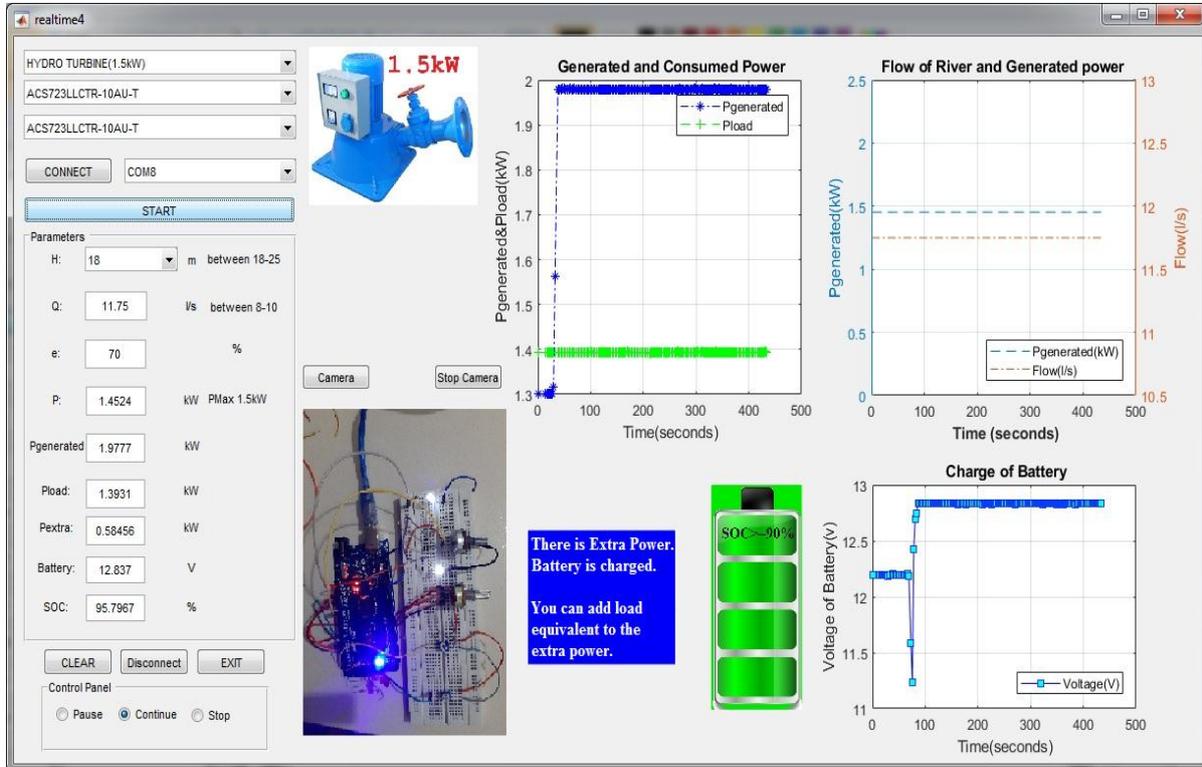


Fig.3. The designed GUI

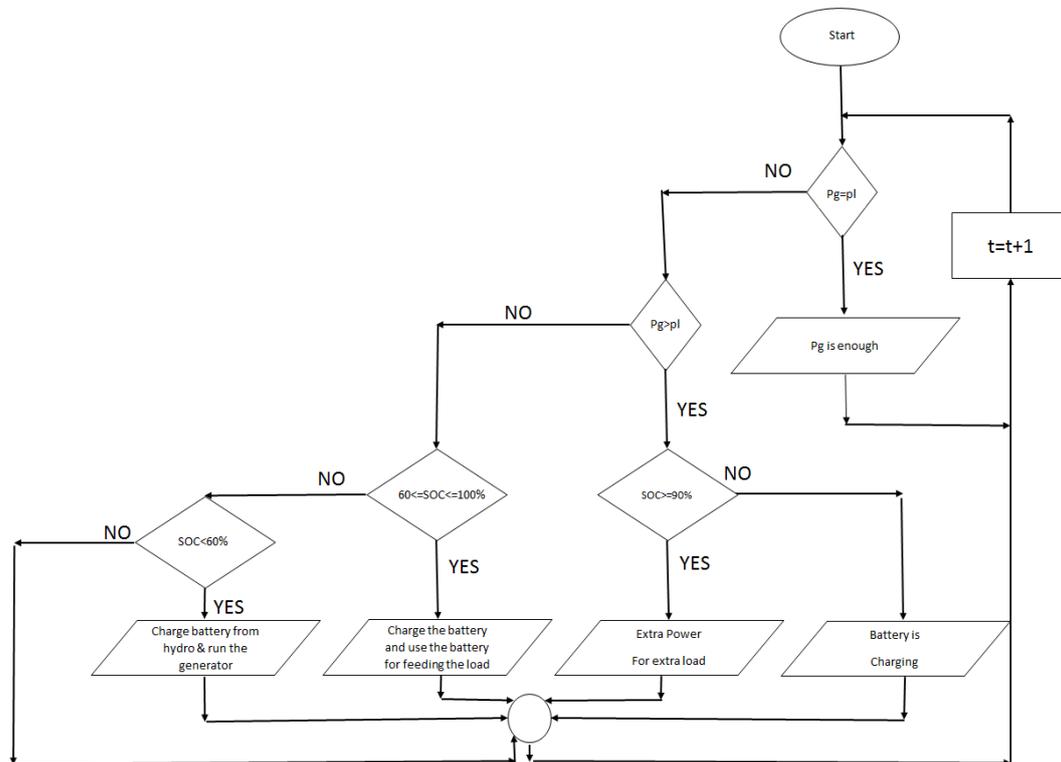


Fig.4. The flow chart of the control process

Table 2. The studied states.

The state	SOC (%)	The action
$P_{generate}=P_{load}$	Not Matter	The generated power is enough for load without extra power.
$P_{generated}>P_{load}$	$SOC \geq 90$	There is extra power, it can be given to load that is equivalent to the extra power.
$P_{generated}>P_{load}$	$SOC < 90$	There is extra power for charging the battery.
$P_{generated}<P_{load}$	$60 \leq SOC \leq 100$	Charge the battery and feed load from battery.
$P_{generated}<P_{load}$	$SOC < 60$	Critical state, charge the battery from hydropower and run the generator for feeding the load.

The hardware part of our system was tested by using Arduino and collection of potentiometers which can give variable values like the mentioned sensors in the hardware part like it is presented in Figure 5.

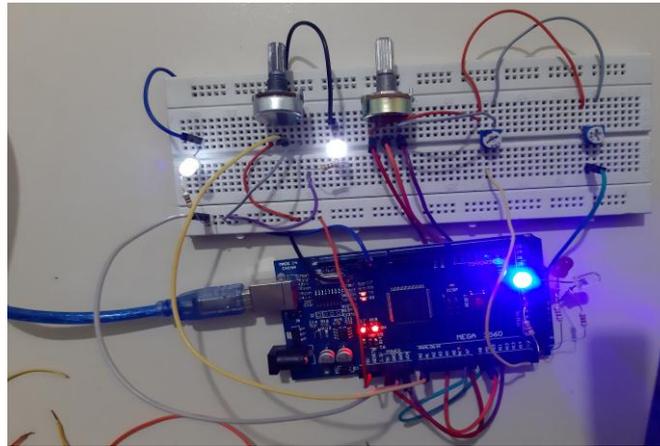


Fig.5. Arduino and potentiometers of the tested system.

V. CONCLUSION

In this study, it was discussed three states of the generated and consumed power with the existence of batteries where the state of charge (SOC) of these batteries was taken in the consideration. All the mentioned processes were processed by collection of hardware and software components. The hardware components were presented by the Arduino which was reading the analog values from sensors and sending them to software components which was presented by MATLAB. In MATLAB, the Graphical User Interface (GUI) was designed for monitoring the different values which are received from Arduino and were processed in MATLAB to take a new decision that resend to Arduino as a command for achieving specifics functions. According to primary results, the studied system proved its effectiveness in processing the different states to feed the load with the required power and exploit the generated power in the best way. This study can be expanded to include more complicated system with a greater number of sensors with advanced GUI that give the possibility to control the system by the internet and design an Android application for more easily usage.

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ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 5 , May 2020

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