Despite a sufficient energy supply, harvesting energy from rainfall is essential for intelligent water management. A significant part is still untapped or little exploited, which is the renewable energy produced from rainwater. This paper proposes a portable gutter of the rainwater energy harvesting system to provide electricity that may be sufficient for powering lights and charging cell phones in rainy locations with limited electricity. A prototype is designed and tested to determine the feasibility of rainwater as a source of renewable energy. The aim is to minimize and respectively suspend the use of fossil energy sources, as well as decrease the percentage of pollution as it is a cause of global warming. The system prototype consisted of a gutter assembly that collected and funneled water from the roof to a downspout. The turbine was connected through a gearbox to a DC motor serving as the generator. The device is optimal during high rainfall intensities that produce larger flow rates. A smart algorithm has been applied, which is salutary to keep the system working and has the ability to control the flow of collected rainfall water. Also, this system is useful to install and use in the rural area where the national grids are not common and the level of rainfall is high. The applied system utilized and installed in more than one hundred premises can produce more than 4 kWh for one rain. In some countries such as Malaysia, the average number of rainy days is 250 days a year, so the use of this system in 100 premises can help to provide 80 MWh to the national grid yearly. The system is characterized by simplicity of design and lack of complexity in addition to ease of installation and cheapness, which is the basis for the availability of this system for use by everyone

Keywords: renewable energy, roof gutter design, energy harvesting, rainfall water, booster circuit, controlled gate, gearbox, DC generator, rotated wheel, rural area

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DESIGN AND DEVELOPMENT OF A NEW PORTABLE ROOF GUTTER FOR ELECTRICITY PRODUCTION

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1. Introduction

Power demand witnessed a dramatic increase with the increasing population over the world in which the prediction of the electricity demand would increase as a percentage of 28 % until 2040 [1]. As known, electricity production stations work either by fuel, gas or other resources, so the use of these resources profusely leads to an increase in the percentage of pollution. Thus, the use of renewable energy becomes a crucial need to be applied to reduce the percentage of pollution as well as reduce the excessive use of natural resources for electricity production [2–5]. Countries began to find a reliable and applicable source of renewable energy. Iraq is one of these countries where some governmental sectors depend on renewable energy [6–8]. Based on information gathered from the ministry of science and technology in Iraq – Baghdad, some ministries departments depend on renewable energy in addition to national energy [9]. The use of a different source of renewable energy gained higher importance in Iraq since the Iraqi climate and environment are characterized by being sunny in addition to the presence of rain in the winter season based on the Iraqi Meteorological Organization and Seismology [10]. Despite the numerous attempts to obtain renewable energy from the sun, generating renewable energy from water is limited to the energy produced from dam water [11, 12]. It is necessary to take advantage of the waste water that comes from rainwater and to use this source effectively as a kind of renewable energy. Therefore, studies devoted to investigating renewable energy production gained significant importance over the world. Due to the increase in energy demand, a way is needed to reduce polluting emissions from traditional power stations.

2. Literature review and problem statement

The investigation of renewable energy produced from water is considered a pivotal factor for researchers nowadays. Since the exploiting of renewable energy from water intensified heavily on the energy of dam water [13]. As

well as successful trends have been recorded in terms of electricity production using the ocean waves with the utilizing of offshore hydropower as stated in [14]. In addition, utilizing the run of river hydropower in the river flow for electricity production has been investigated and practiced as mentioned in [15]. A significant part is still untapped or little exploited, which is the renewable energy produced from rainwater. Some trends have been recorded in utilizing rainfall water in the production of renewable energy over the world. According to statistical studies, the average rate of rainfall in Iraq is 192.03 mm/year for the last 38 years [16]. Some trends have been recorded in terms of using water for energy harvesting. As stated in [17], water droplets falling off on the hydrophobic polymer covered by a single electrode on its back side are used to produce energy, as shown in Fig. 1.

The limitation of this system has been figured out in which this system is unable to produce much power and develop the output power.

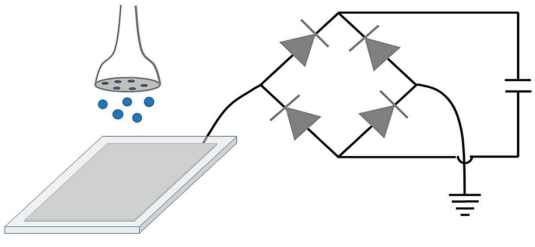


Fig. 1. Energy harvesting from water droplets

Using a structured design from the pipeline and piezoelectric generator as stated in [18] has facilitated the implementation of a system used for renewable energy production from water. Drawbacks have been highlighted in this system in which this system could not be implemented in all areas because it does not deal with the problem of intermittent rainfall.

Furthermore, an equivalent electromechanical scheme as mentioned in [19] for renewable energy harvesting from water contains two commercial transducers, which are lead zirconate titanate and polyvinylidene difluoride. It shows a limitation in energy production when high pressure is applied in which this system is unable to achieve the desired benefit in areas with heavy rain.

On the other hand, a system for energy harvesting practice has been developed in [20] by utilizing Platinum Alloy Tailored for energy harvesting from sun and rain. However, this system is unsuccessful to generate more energy from water in case of not sunny weather.

In spite of the above trends, a system [21] has been introduced for renewable energy production from rainfall in which the system overcomes the related drawbacks of the previous systems. It is designed from a channel used for water gathering from the roof and collected in a water pipe and connected through a gear with a DC generator.

It shows the ability to produce renewable energy from rainfall as represented in Fig. 2.

Regardless of the success in the design of renewable energy harvesting from rainfall water, limitations have been recorded. This system is unable to solve the problem of the lack of rainwater, the system is used for one stage only, the system can only be installed with a specific design of gutters and the system is unable to increase the level of produced energy.

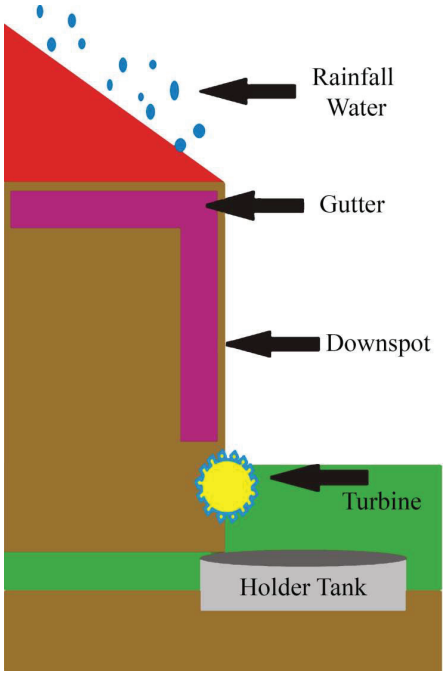


Fig. 2. Rainfall energy harvesting design

Notwithstanding the registered success of the above trends by utilizing rainfall water as a vital source of energy harvesting. It fails to solve the problem of developing such system for more energy harvesting, as well as the difficulties of solving the problem of scarcity of rainfall water in some areas. Moreover, the difficulty of implementation of the system in places where gutters have been installed.

3. The aim and objectives of the study

The aim of this study is to develop a system able to produce electricity from rainfall water using a gutter in any premises.

To achieve this aim, the following objectives are accomplished:

– to design a portable roof gutter able to solve the highlighted issues;

– to develop an algorithm to control the process of energy harvesting;

– to verify the desired output power using the roof gutter with and without the controlled gate.

4. Materials and methods

This section illustrates the scientific structure design of the proposed system used for renewable energy harvesting from rainfall water. It consists of three main parts: the mechanical part, represented by the design of the gutter and the design of mechanical water flow, the electronic part, represented by the DC generator, booster, water level sensor and gate controller and the overall algorithm to produce output power. The overall parts are represented in the block diagram shown in Fig. 3.

As represented in the above figure, the parts are connected and assembled together to collect rainfall water and control the process of energy production. This system is easy to install and use even with the installed gutters, and the

system can be used for more than one time for generating clean electrical energy.

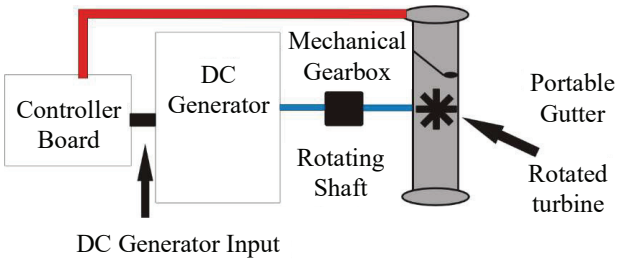


Fig. 3. Portable gutter block diagram

4. 1. Mechanical structure and calculations

This part exemplifies the mechanical structure of the roof gutter used for renewable energy harvesting. A combination of gutter tube, rotating turbine, rotating shaft and mechanical gearbox has been consummated together for the design of portable gutter used for energy harvesting.

4. 1. 1. Design of gutter tube

A plastic tube has been designed using 3D Max software and printed using a 3D printer with the specifications of 110 cm height, 20 mm thickness and 10.16 cm diameter. The dimensions of the designed gutter are compatible with the gutter's dimensions used in different premises for draining the rainfall water as represented in Fig. 4.

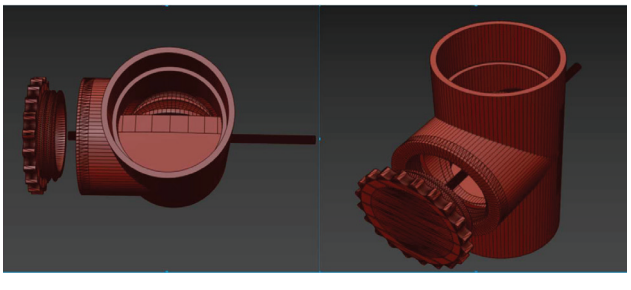


Fig. 4. Proposed gutter

The two ends of the tube gutter are circular and have a diameter of 12 cm, which is bigger than the diameter of any tube gutter for the handiness of utilizing with any installed gutter. The tube gutter contains the rotating turbine connected through a rotating shaft and mechanical gearbox to a DC generator.

4. 1. 2. Design of rotating turbine

The design of the rotating gutter is illustrated in the block diagram where the structure of the rotating tube is represented as a spherical turbine in which the division of the spherical turbine into slides affects the rotation significantly [22, 23].

The rotating spherical turbine has been designed once with 8 blades with the angle between two blades of 45 degrees and 16 blades with the angle between two blades of 22.5 degrees. Two experiments have been conducted to select the appropriate rotating turbine whether it has 8 blades or 16 blades depending on the number of turns. Also, the diameter of the spherical turbine of 4 mm has been designed, which is smaller than the diameter of the tube to ensure that water falls on the surface of the blades as represented in Fig. 5.

a

b

Fig. 5. Rotating turbine: *a* — rotating turbine with eight blades; *b* — rotating turbine with sixteen blades

Also, there is an axial hole in the center of the ball with a diameter of 10 mm fixed with a stainless steel blade that serves as the axis of rotation of the rotating shaft coupled with a mechanical gearbox in order to increase the rotating speed.

4. 1. 3. Setting of the rotating shaft&mechanical gearbox

This part is responsible for converting the rotating turbine spinning into the DC generator through a rotator shaft and mechanical gearbox in which the rotator shaft is mounted directly with the rotator turbine from one side. On the other side, the rotating shaft is connected to the mechanical gearbox. The mechanical gearbox has been installed, which is designed with the specifications of 200 mm and the number of teeth of 24 with a converting ratio of 1:2, in which the rotating speed has doubled as practiced in [24, 25].

4. 2. Electronic component and calculations

This is the second important part of the proposed system in which the responsibility of energy harvesting and electricity production rests upon this part. Two sub-parts are represented by the DC generator and controller board utilized to control the rainfall water flow based on the input signal from a level sensor.

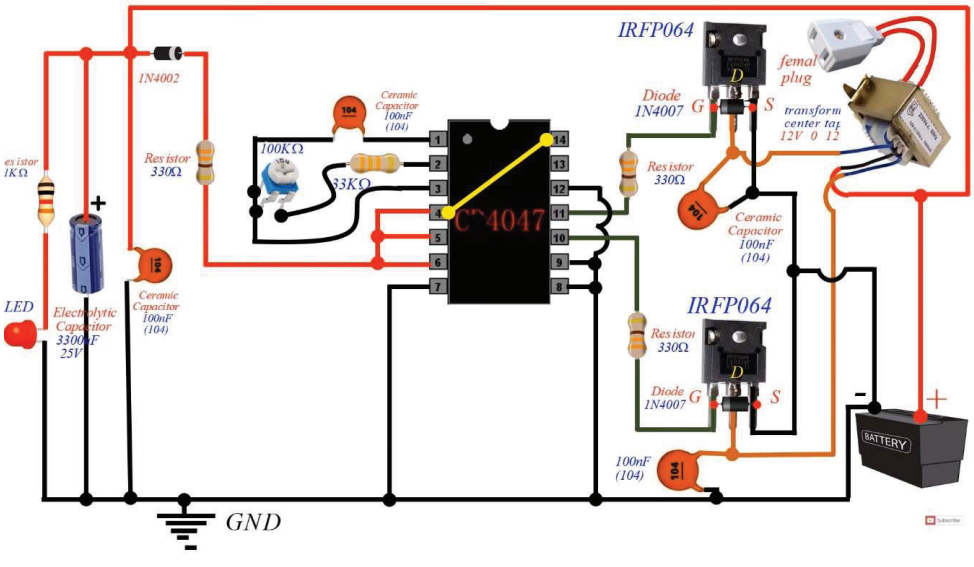
4. 2. 1. DC generator selection

A DC generator has been coupled with the mechanical gearbox for energy production based on the rotation of the rotating turbine due to rainfall water flow. The specifications of the utilized DC generator are explained as shown in Fig. 6.

A storage battery has been used and a convertor circuit has been utilized for electricity production since the convertor circuit has been designed as illustrated in Fig. 7.

The invertor circuit and storage battery have been used and connected to the DC generator and connected in the portable gutter for electricity production as the calculation of output power will be highlighted in the following section.

Fig. 6. 250 W DC generator



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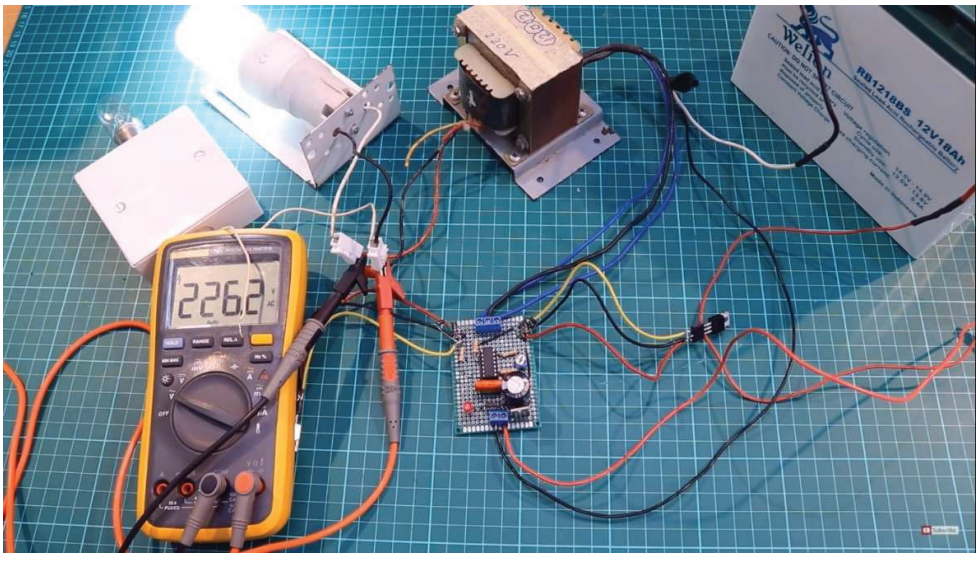


b

Fig. 7. Invertor circuit: *a* — invertor circuit diagram; *b* — practical invertor circuit [26]

4. 2. 2. Controller sub-part

This part is in charge of controlling the amount of rainfall water falling on the rotated turbine. It controls the shut-off gate based on the signal from the level sensor for determining the amount of falling rainfall water, collected inside the gutter as represented in the diagram shown in Fig. 8.

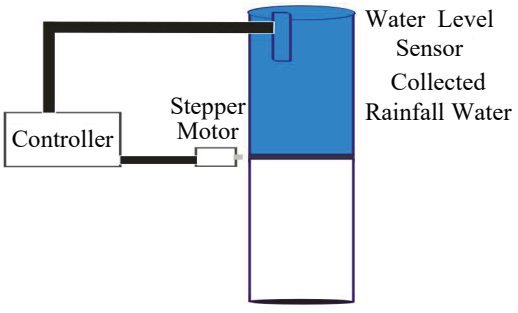


Fig. 8. Shut-off gate control

Signals are gathered from the level sensor (Conductive point level detection liquipoint FTW31) in which the amount of collected water in the gutter is indicated. After reaching the required level (level which has been calculated practically and analyzed scientifically) of 1.5 meters of collected rainfall water into a nominal point, the controller and the shut-off gate are activated. The collected rainfall water works on rotating the rotated turbine for electricity production.

4. 3. Practical developed algorithm for electricity production

The current study depends mainly on energy produced using a portable gutter in which a source of green energy has been produced via the current system. An algorithm has been developed based on the parameter of the system in which it controls the required amount of rainfall water used to round the rotated turbine for electricity production.

The overall processes of the proposed roof gutter for energy harvesting have been summarized as follows:

– the system has been installed in the gutter of any premises in which the new design is handy for installation in any gutter;

– in the rain season, the proposed system has been activated, which aims to collect the rainfall water from the roof and compile it in the proposed system until reaching the nominated value of collected water;

– the controller has endorsed the signal gathered from the Conductive point level detection liquipoint FTW31 sen-

sor, as the amount of collected water reaches the nominated value, the shut-off gate has been activated and the rotated turbine has been rounded due to the outpouring of collected water;

– the DC generator has been rounded and electricity has been generated as the rounding of the rotated turbine to produce DC voltage;

– as the level of collected water decreased, the controller has controlled the shut-off gate to close based on the endorsed signal from the level sensor.

The process of energy production using the proposed system has been repeated based on the collected rainfall water. Fig. 9 presents the overall algorithm, which has been applied in the current study.

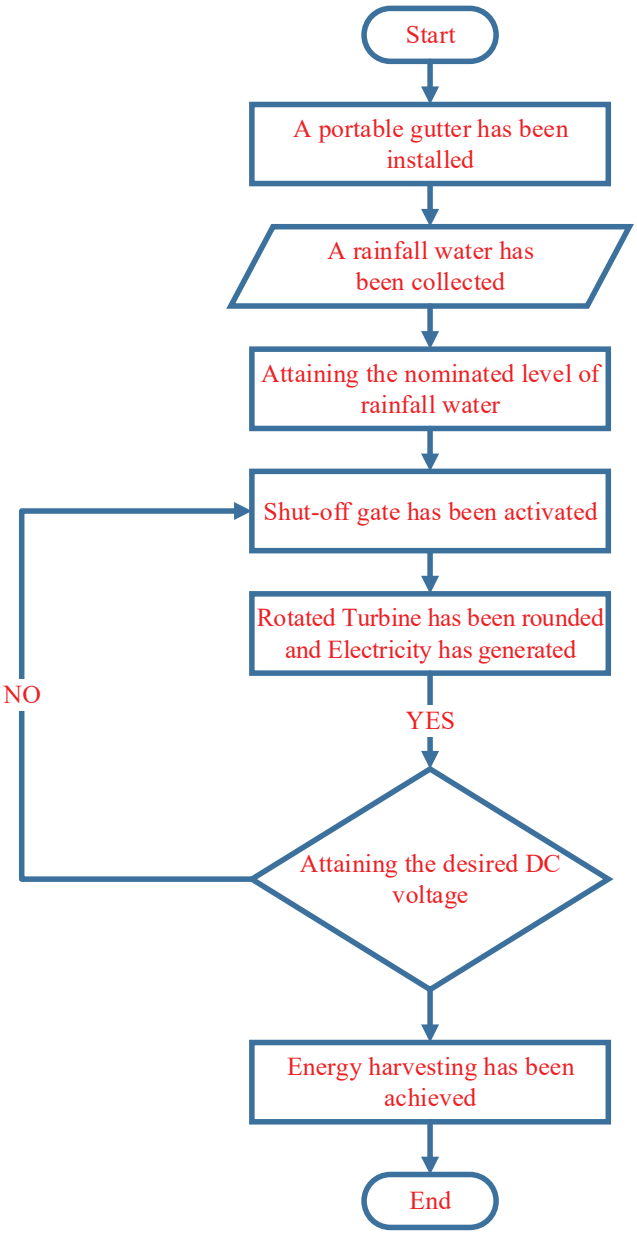


Fig. 9. Algorithm of electricity production via the proposed system

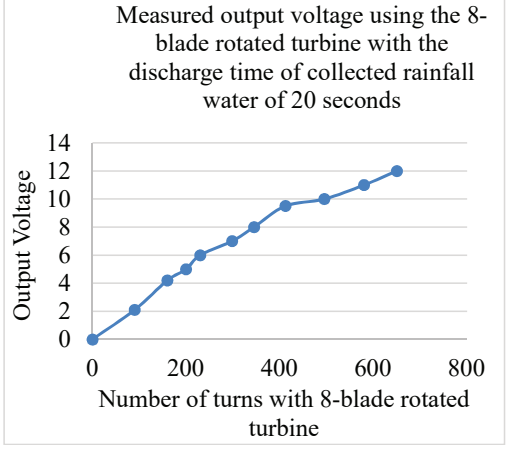
This system gained a high significance in the area with high rates of rainfall as the amount of rain varies from one area to another as stated in [27]. In addition, there is the benefit of utilizing such system in the countryside area where the national electricity is not available. The proposed system has been practiced in the premises of the University of Baghdad-Khwarizmi College of Engineering – Iraq and the premises of the authors' house.

5. Results

The system has been installed and electricity has been produced using the proposed system in which it is considered renewable energy. The electric component has been selected and assembled with the proposed design of the gutter when it rains, the rotated turbine has been rounded and the DC generator has started electricity production. The results have been divided into three parts as follows.

5. 1. System parameter results (rotated turbine selection)

The elementary experiment at the system construction shows that the use of a spherical structure with eight plates presents an increasing in terms of spherical spinning with the number of turns in which the elementary experiment shows that the use of 8 blades produces a higher output power compared to using a rotated turbine with sixteen blades as represented in Fig. 10.



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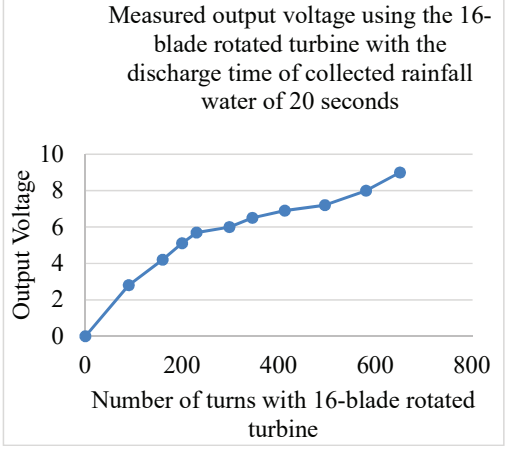

b

Fig. 10. Extracted output voltage: *a* – using 8-blade rotated turbine; *b* – using 16-blade rotated turbine

As appeared and illustrated in Fig. 10, there is a variation in terms of output power with respect to the use of rotated turbine with 8 blades under the same conditions. It shows that under the same conditions, the use of rotated turbine with 8 blades produces more output voltage for the same amount of collected rainfall water.

5. 2. Gathered output power

Experiments have been practiced with different gutter distances to determine the appropriate DC generator based on the rotated wheel speed (RPM) as presented in Table 1, which shows rotated wheel speed with reference to the gutter distance.

Table 1

Rotated wheel speed vs. gutter distance

Gutter Distance (Meter)	Amount of Collected Water (Litter)	Rotated Wheel Speed (RPM)
1.5	12	735
3.0	24	1,320

According to the obtained results for the rotated wheel speed, a 12-volt 250 W DC generator has been selected for electricity production.

Secondly, the system testing has been commenced after checking the parameters of the whole system and testing the efficiency of each part. The overall system is represented as shown in Fig. 11.

The obtained results in terms of output power for different gutter distances are illustrated in Fig. 12.

Despite the increasing in terms of output power production with respect to the gutter length, the gutter system with a length of 1.5 meters has been selected to practice the overall output power due to its handiness of using. As measured practically in some countries over the world, the required rated time for collecting the rainfall water is two minutes as stated in [28, 29], as the required time to discharge the collecting rainfall water is twenty seconds using the proposed system. The gathered output power has been calculated as follows:

0.15 kW with a 1.5-meter gutter distance

The required time for collecting rainfall water in rainy weather is 2 minutes..... (calculated practically)

The discharge time of the collected rainfall water in the gutter distance with the length of 1.5 meters is 20 seconds..... (calculated practically).

The obtained output power for one discharge process of collected rainfall water is calculated practically and is 0.15 kW as shown in Fig. 12.

The produced output power for one hour is calculated as follows:

One hour=60 minutes

The time of collecting rainfall water and discharge is=2 minutes+20 secs=2.2.

The total output power for one hour of raining

60/2.2*0.15 kW= 4 kWh.

The required power to turn ten lights for one hour is 1 kWh as stated in [30] when the extra produced power can be kept in a storage battery in order to support the national grid or use it in case of scarcity of rain.

Fig. 11. Proposed gutter system for electricity production

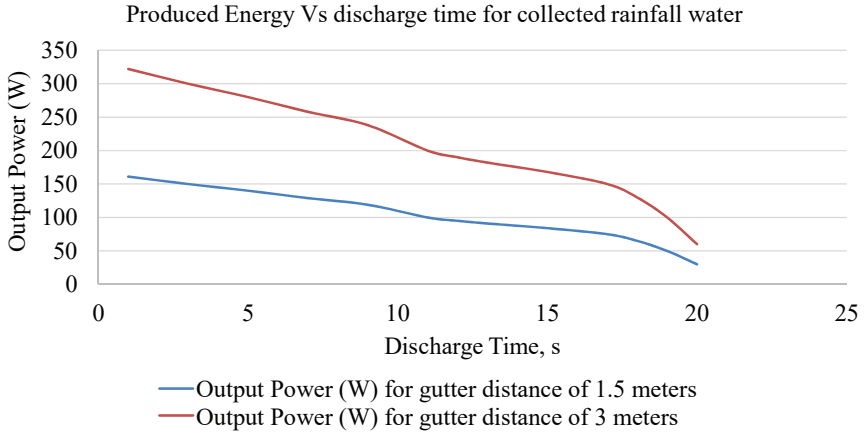

Fig. 12. Energy produced vs. gutter distance

5. 3. Output power verification results

This system introduces the handiness in terms of using it for multistage design with different gutter lengths. The application of the proposed system in a multilevel building with a gutter distance of 1.5 meters and re-installing it two times in a building, the gathered output per one hour is 8 kWh of green energy as represented in Fig. 13.

When it rains, whether the amount of rain is small or large, the rainfall water is collected inside the roof gutter.

In case of using the gutter without the gate, the water simply falls on the turbine and produces low power as it depends on the abundance of rainfall water. With the controlled gate, even if the amount of water is small, the rainfall water is collected and flows to generate power.

Thus, a comparison has been conducted in terms of output power two times and under the same conditions once by utilizing the proposed gutter with applying the controlled gate and utilizing the same gutter without the controlled gate in which the output has been varied and practiced as represented and shown in Fig. 14.

As shown above, there is a variation in terms of produced output power when using the roof gutter with and without the controlled gate. Since the controlled gate helps to collect the rainfall water into a nominated level, after that the controller

releases the collected water, the rotated turbine rotates and energy is produced, which has been proven practically.

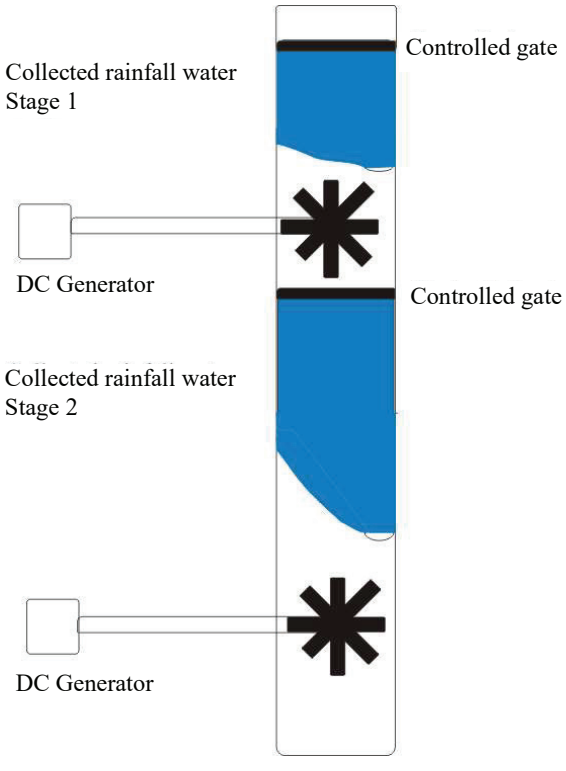

Fig. 13. Multistage roof gutter design for energy harvesting

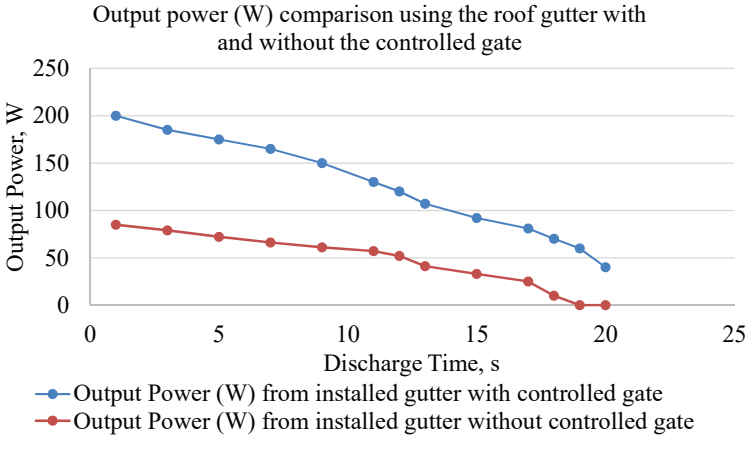

Fig. 14. Energy harvesting using roof gutter with and without the controlled gate

6. Discussion of experimental results

First of all, a portable roof gutter, which has been designed and utilized for electricity production introduces the ability to produce electricity from clean sources. As the system provides the handiness of utilizing in any existing roof gutter of any premises. As well as, the handiness of installing the proposed system in any roof gutter, the proposed system provides the ability to re-use and reinstall the system many times for output energy maximization.

Moreover, the proposed system introduces the predisposition to assemble and disassemble the system for cleaning, replacing parts and developing the entire design.

Section 6. 1 introduces a comparison of output voltage with respect to the number of turns by using a rotated turbine once with 8 blades and 16 blades. It has been proven practically that the use of 8-blade rotated turbine produces more output voltage as the reason beyond this is related to the increase in surface area. An experiment is needed to conduct in the future related to using a rotated turbine with 4 blades and its effect with increasing the rotated turbine.

Producing the output power calculated when utilizing the system for one hour, the produced output power reaches around 4 kWh. If the applied system is utilized and installed in more than one hundred premises, it can produce more than 4 kWh for one rain. In some countries such as Malaysia, the average number of rainy days is 250 days a year, so using this system in 100 premises can help to provide 80 MWh to the national grid yearly. In addition to the system benefit in electricity production, the use of such system is considered a good factor to decrease the percentage of pollution.

Another benefit is characterized by the use of a controlled gate, which can easily solve the issue of the scarcity of rainfall water.

On the other hand, the system is characterized by simplicity of design and lack of complexity in addition to ease of installation and cheapness, which is the basis for the availability of this system for use by everyone.

Despite the handiness of the proposed system in design, cost and installation, as well as the use of the proposed system in electricity production, this system introduces a disadvantage of being unable to produce electricity unless there is rainfall water, so in the area with less percentage of rainfall as well in the summer season, this system is considered useless and cannot produce electricity.

7. Conclusions

1. The portable roof gutter design shows the handiness of installation in any premises since the structure is applicable with any design. The system is portable, which means it can be assembled and disassembled easily. As the cleaning process is considered a challenge for gutters, this system helps the cleaning process of gutters from the stuck dirt.

2. The application of the proposed algorithm shows a high significance in terms of controlling the collected rainfall water in order to use it for rounding the rotated wheel, compound into a generator. It is important to control and collect the rainfall water in order to make the system able to round the rotated wheel into a specific round, which makes the DC generator to round and produce electricity.

3. Output energy has been produced since the system (portable gutter) has been assembled as well as rainfall water has been collected. The practical calculation of the output power has proven the significance of this system in which it can work smoothly and generate a sufficient output power for different appliances. It shows the importance in terms of using the proposed system in many premises in one area as it can provide the national grid with the energy, which is able to switch the lights of these premises. This will lead to a decrease in the demand for electricity from its sources and reduction in the percentage of pollution.

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