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Original Article

Hybrid Renewable Energy System (HRES) Based Water Pumping System

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Abstract - *This paper illustrates the design and implementation of a hybrid renewable energy system (HRES) based water pumping system for household purposes. Two renewable energy sources have been utilised to formulate the system as a hybrid energy system: solar energy and wind energy. One wind turbine has been constructed to accomplish the project's central goal, which can be considered a vital project task. Moreover, one charge controller circuit is also designed, which is employed to charge up one 12-volt battery that is used to run one 8-watt DC motor. Additionally, one miniature-sized water pump is designed to finalize the project work. The application of this project is not area dependent, but the focus of the concerned project is household use only. The use of two different energy sources makes the project suitable for places where climate change is not stable. The prime goal of this project is to design a water pumping system that is both environmentally friendly and economically feasible. The expected outcome of the project indicates the factual choice of the idea that will be able to help on a small scale in this era of global warming.*

Keywords - *Global warming, Greenhouse gas (GHS), Hybrid Eenewable Energy System (HRES), Vertical Axis Wind Turbine (VAWT), The charge controller circuit.*

1. Introduction

The water pump is a mechanical device used to pump water from different water sources like ponds, wells and even underground for agricultural, industrial, household and factory use. Although Bangladesh is a developing country now and does not possess energy crises in urban areas, her rural areas receive only 30% of generated power, which is insufficient. Also, running water pumps using power from the power grid is quite expensive for people living in rural areas [1]. At the same time, human-induced global surface temperature increment, i.e. global warming, has become the major aspect of climate change which is responsible for extreme weather conditions like shifting wildlife habitats, melting glaciers, rising sea levels and so on. One of the prominent causes of this global warming is the release of greenhouse gases (GHG) which is the outcome of conventional power plants that use fossil fuels like coal, oil and gas. Coal-fired power plants emit a million tons of CO_2, and CO_2 is considered the main villain among greenhouse gases. It is found that although CO_2 concentration was significantly higher millions of years ago, it had remained fairly constant from the last ice age until the advent of the modem industrial age [2]. Global CO_2 emissions increased by 3% in 2011 compared to the previous year, reaching an all-time high of 34 billion tons which has projected warming of 0.2°C per decade for the next two decades [3]. Approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C [4].

Considering the above-mentioned side effects of GHG emissions, it is highly realized that GHG concentrations need to be stabilized. There are various ways to reduce GHG emissions while maintaining the same desired power services. Here comes the concept of clean or green energy sources. Green energy is produced in such a way as to have a less negative impact on nature compared to other energy sources like fossil fuels [5]. Renewable technologies are considered clean sources of energy, and optimal use of these resources decreases environmental impacts, produces minimum secondary waste and is sustainable based on the current and future economic and social needs [6]. Following all the analysis, by reducing the impact of GHG on global warming and increasing energy demand, a power generation project based on renewable technology is proposed, designed and implemented in this paper. To complete the project idea, a water pumping system is constructed and fed by two renewable energy sources, wind and solar. Since this project is being built using two renewable energy sources, this project can be categorized under a hybrid renewable energy system (HRES) based project [7]. Using PV cell active solar heating system is being followed in this paper rather than passive solar design, and one Savonius type VAWT is designed to complete the goal of the project [8][9].The categorization of this paper: Section II describes the historical background of the project idea, Section III depicts the methodological approach of the whole system, Section IV presents an implementation of the project, Section V holds the experimental result analysis, and Section VI concludes the paper.

2. Literature Review

In this era of increasing agricultural growth, insufficient power supply due to the depletion of fossil fuel resources hampers the optimized usage of clean water. Therefore, it is essential to have an alternative power source to make the best use of scarcely available water [24]. When two or more renewable energy systems work together as a team to produce electricity, the system is known as a hybrid renewable energy system (HRES) [11]. HRES can produce a little bit higher amount of energy than a single energy source. In fact, when a single renewable energy source is used, fossil fuel is needed for emergency/backup use. If the system stops working properly, fossil fuels will take their place and produce electricity which inverts the advantages of using renewable energy systems [12]. As a result, a hybrid renewable energy system can be a good solution to omit fossil fuels completely. Renewable energy can be subdivided into two categories: renewable energy power generation like photovoltaic (PV), biomass, wind and alternative energy generation, such as fuel cell microturbines and efficient and clean sources of energy [13].

Our project work is to interface solar and wind power in designing one HRES. The PV and the wind turbine technology are the most attractive technologies where wind and solar power work together for energy production [14]. It can be said that solar energy exhibits the highest global potential compared to other renewable sources like geothermal and biomass because geothermal energy is limited to specific locations, and there is an insufficient supply of biomass in nature [15]. However, the standalone solar panel and wind turbine installation, which is managed using a storage system, decreases the system's cost-effectiveness and bounds the benefits of using renewable energy [16]. The combination of solar power and wind power also increases the system's reliability because they function as a backup of one another. For example, if the weather is a little cloudy, there is no way to get a good amount of sunlight, so a wind turbine will do its job and produce electricity.

On the other hand, if one day the weather isn’t windy, but a good amount of sunlight is out, solar panels will do the whole job and generate a good amount of electricity. If both sources work collectively, power generation will be faster than the normal generation time. The application of PV-wind HRES can be multi-directional like- street lights, farms, buildings, ships etc. [17]. It was first seen used in streetlights. USA’s first-ever wind-solar hybrid power plant was in rural Minnesota. According to the report, the hybrid solar-wind power system could reach $1.47 billion by 2024. Some people use PV-wind hybrid systems to run the boat. Some Middle Eastern countries, like Egypt, Saudi Arabia, etc., use hybrid renewable systems in power stations. Saudi Arabia aims to develop the wind-solar hybrid system in the next 10 years. They want to produce 10% of their total power using the renewable system by 2023. Following the implementation of HRES-based power generating systems in various parts of the world, the idea of designing one wind-solar-based water pumping system for developing countries like Bangladesh came to the author’s mind, and this paper is a successful reflection of the idea.

3. Research Method

The prime objective of this project is to design a water pumping system which will feed with renewable energy sources (wind and solar). In order to accomplish the prime objective of the project, successful design and implementation of a wind turbine have been utilized, which can be considered a secondary objective of the project. The overall methodological approach of the respective project was a mixture of quantitative and qualitative approaches. Although it was impossible to undergo all the research methodologies, two of the very important parameters were accomplished. Firstly, people’s views and understanding of the research idea were evaluated through survey conduction.

Moreover, people were interviewed, and their opinions were gathered for the progression of the project work. Additionally, experiments were conducted under controlled variables and environments, and the desired output of the experiments represents the zenith success of the project work. Fig. 1 designates the flowchart of the complete methodological approach of the whole project work.

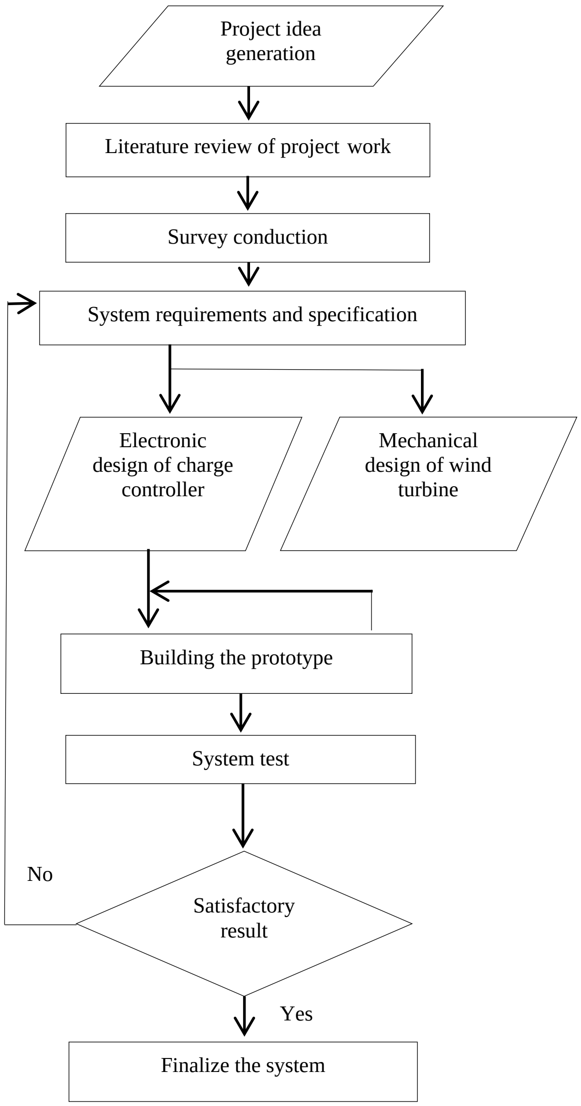


Fig. 1 Flow chart of the methodological approach of the project

3.1. Survey Research

Survey research is the "Collection of information from a sample of individuals through their responses to questions" [18]. Survey research can be continued as a quantitative strategy, qualitative strategy or a mixture of both [25]. For this project work, a quantitative survey strategy has been followed. The survey is being conducted to detect the societal and environmental impact of the project. For each section of the survey, one questionnaire was made, including 10 questions and a minimum of 200 people from Bangladesh were targeted for the process. The key objective of the survey is to localize the acceptance of the project work among people of a developing country like Bangladesh as well as to focus on the people's view towards the environmental impact of the project work. The response to the survey work was a kind of positive. More than 90% of people found the project an efficient one to fight against global warming. Besides that, people voted the project as a perfect project considering cost and implementation in the socio-economic scenario of Bangladesh. The survey outcome was taken as support to proceed with the experimental setup of the project.

3.2. Experimental Design

Fig. 2 illustrates the flow chart of the experimental design of the project work. In this project, one Vertical Axis Wind Turbine (VAWT) is designed to be integrated with one 8Watt solar panel to charge a 12volt DC battery. To regulate the battery voltage, one charge controller circuit is designed to regulate the voltage level of the battery. Finally, the charged-up battery will be utilized to run a water pump which is also designed in a miniature form.

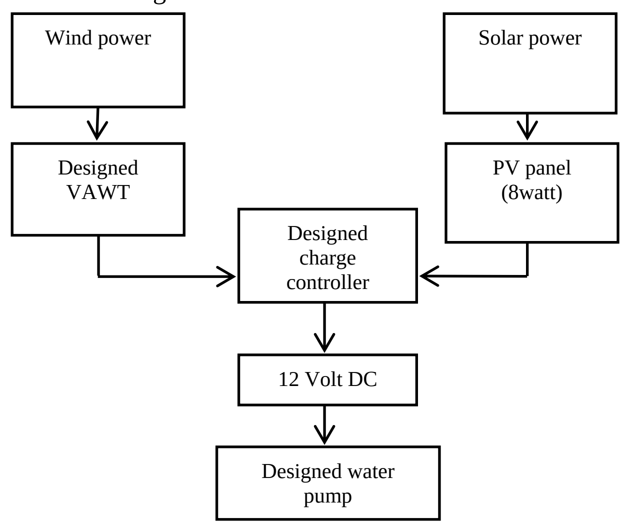


Fig. 2 Flowchart of the experimental design of the project

4. Equipment Familiarization

The overall system contains different functional units combined together that interact with each other to provide the total functionality of a water pumping system. The leading components of the system are- (i) One designed VAWT, (ii) One purchased 8watt PV panel, (iii) a Designed charge controller circuit, (iv) a 12volt DC battery and (v) a Designed prototype of the water pumping system.

4.1. Designed VAWT

Wind turbines can be classified depending on size, dimensions, blade numbers, angle of attack and geographical condition (airflow) surrounding the turbine [16]. Wind turbines can be classified into two main categories depending on the orientation of the blades: (i) Vertical axis wind turbine, VAWT and (ii) Horizontal axis wind turbine, HAWT. VAWTs commonly function nearer to the ground and have the benefit of enabling the placement of heavy equipment, such as the gearbox and generator, close to the ground level [9]. VAWTs possess few advantages over HAWT. They can be packed closer together in wind farms, allowing more in a given space. They are quiet, Omnidirectional, producing lower forces on the support structure. They do not require as much wind to generate power, thus allowing them to be closer to the ground where wind speed is lower. They are easily maintained by being closer to the ground and can be installed on chimneys and similar tall structures [20]. In a VAWT, the rotational axis is perpendicular to the wind direction. Since it is a vertical axis machine, it is very simple in construction and operation. Besides simplicity, the structure is robust and has strong starting torque [21]. Now, there are two core kinds of VAWT exist: (i) Savonius type VAWT and (ii) Darrieus type VAWT [9]. Savonius wind turbine works like a water wheel using drag force, and Darrieus wind turbine uses blades like HAWT. Savonius type wind turbine is designed considering material availability and structure flexibility in our project work.

The foremost component of the whole project is a VAWT designed with very common, available and cheap materials that make the project cost-effective and easy to implement. Since the project idea has planned considering the terrain and environment of south Asian countries, especially Bangladesh, and it has been found that the airflow and weather condition of this kind of topology best support the VAWT, so the design of VAWT has been chosen over Horizontal Axis Wind Turbine (HAWT). Figure 3 demonstrates the design prototype of VAWT. The construction of the VAWT for this project work is easy to implement because the materials needed for VAWT are market available. The turbine blades are made up of Polyvinyl Chloride (PVC) pipes. Firstly, 8 pieces of 30.48cm PVC pipes were taken and cut vertically into two pieces and were given the shape of the turbine bades. Besides that, two-cycle rims were taken, and all 8 turbine blades were attached to the rim with the help of 16 steel anglers. Additionally, a smooth roping system coupled with one DC motor and a gearbox was coupled with the turbine. Finally, the whole rim structure was connected with a Galvanized Iron (GI) pipe to form the holder of the turbine.

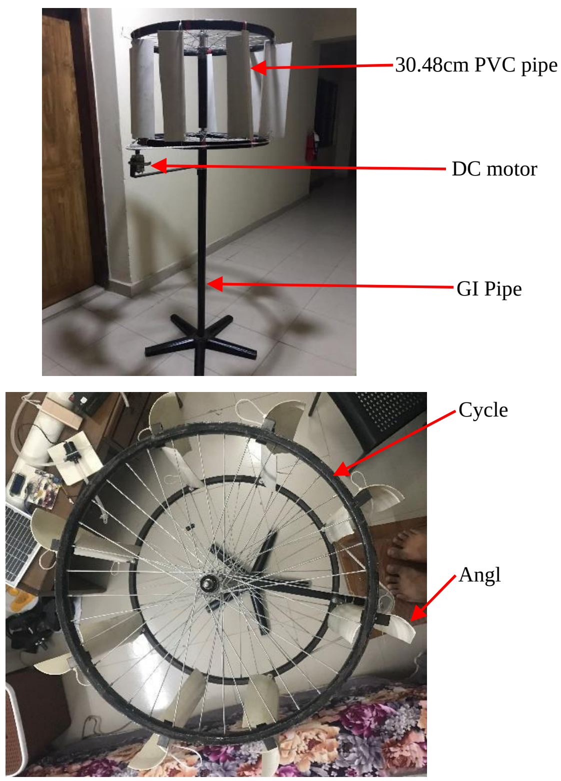
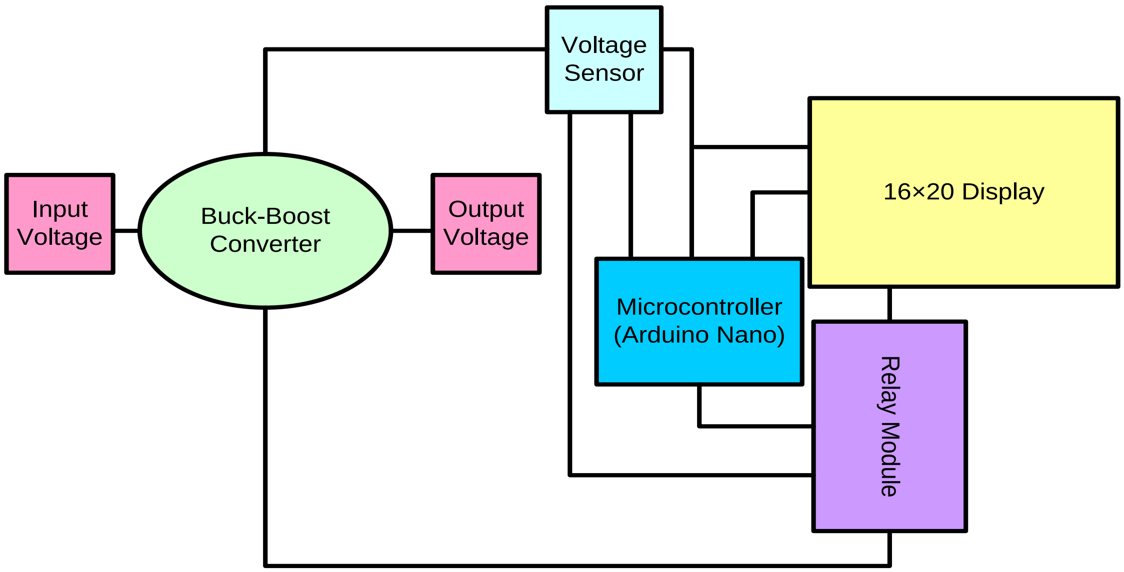


Fig. 3 Design prototype of VAWT

4.2. Designed Charge Controller Circuit

Besides VWAT, another inevitable component of this project work is the charge controller circuit which acts like a voltage controller that maintains the healthy battery life by preventing the battery from overcharging. MPPT (maximum power point tracking) charge controller circuits were used for this project. Maximum power point tracking with pulse width modulation (PWM) makes the charge controller more reliable and efficient by controlling the charging current depending on the battery's voltage level [22]. Considering the compact size and good functionality, Arduino NANO has been chosen for the design rather than Arduino UNO. Moreover, two displays (I /p, O/p) for voltage, a 16×2 display, voltage sensor, relay switch, and buck-boost converter are being used for the circuit's functionality. Figure 4 (a,b) illustrates the charge controller circuit's circuit diagram and hardware design.



(a)

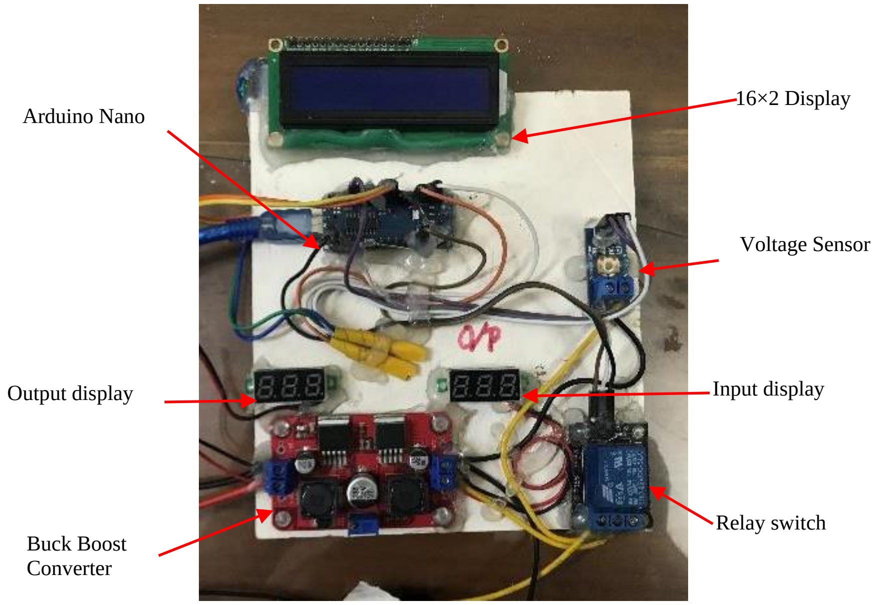


Fig. 4 Design prototype of the charge controller circuit

4.3. Prototype of Water Pumping System

The water pump is a mechanical device for pumping water from underground [23]. A prototype model of a water pump is designed in this project work. Figure 5 illustrates the water pumping system, designed in miniature form to complete the project work. The rating of this pump is approximately 12volt and 0.67 Amps. Other than mentioned designed equipment, one 12volt DC battery and one 8Watt solar panel are being purchased to complete the project work.

(a)

(b)

Fig. 5 Design prototype of the water pumping system

5. Experimental Setup and Working Principle of the System

This project work specifically aims at designing one architype of HRES (wind and solar power) based water pumping system for household uses, focusing on the rural area setups of developing countries like Bangladesh in order to reduce the pressure on the national grid. To accomplish the project's goal, one VAWT will intake wind power, and one solar panel will be procured to utilize Sun energy to generate sufficient power to run the water pump. The combined power is stored in a 12V DC battery whose voltage is controlled by a charge controller circuit. Finally, the stored energy is utilized to run the water pump. The overall working principle of the project is very easy to understand, but the successful application of the project work is of great use. Since this project targets prototype design, the whole model is made in miniature form, but the model functions successfully, as shown in Figure 6.

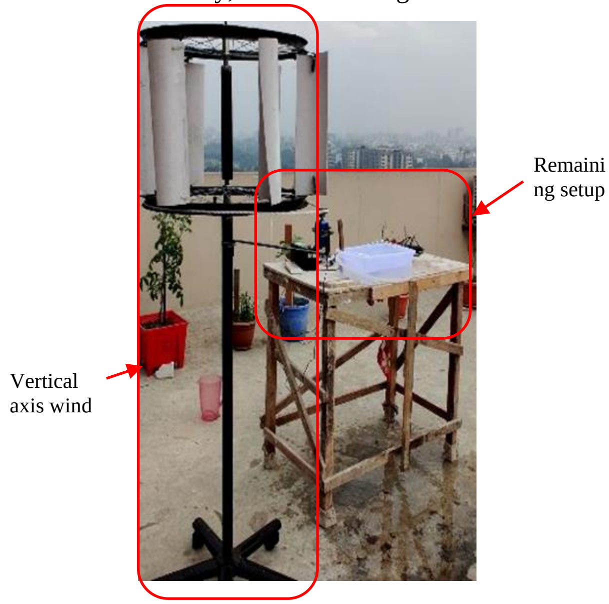


Fig. 6 Design prototype of the whole project

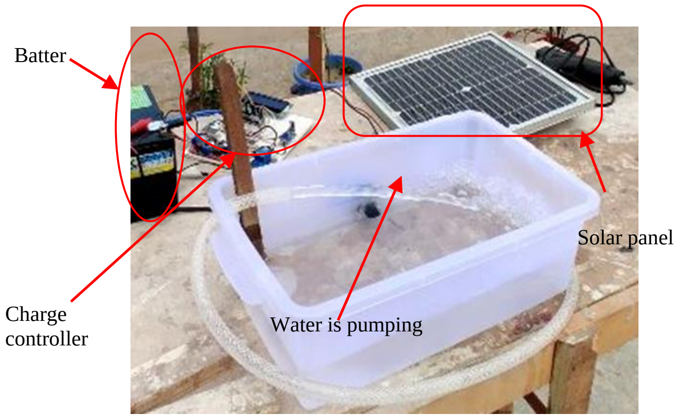


Fig. 7 Running condition of the project

6. Results and Discussion

6.1. Outcome of VAWT

Initially, the VAWT is being designed without the gearbox, and the output power received from the turbine is in the milliwatt range. But as long as the gearbox is attached to the turbine, a sufficient amount of power is generated from the VAWT to run the prototype. In this prototype, during performance analysis of the turbine alone, artificial speed is generated using a table fan and supplied to the turbine. Table 1 and Table 2 represent the output of the wind turbine.

Table 1. The output of a wind turbine without a gear system

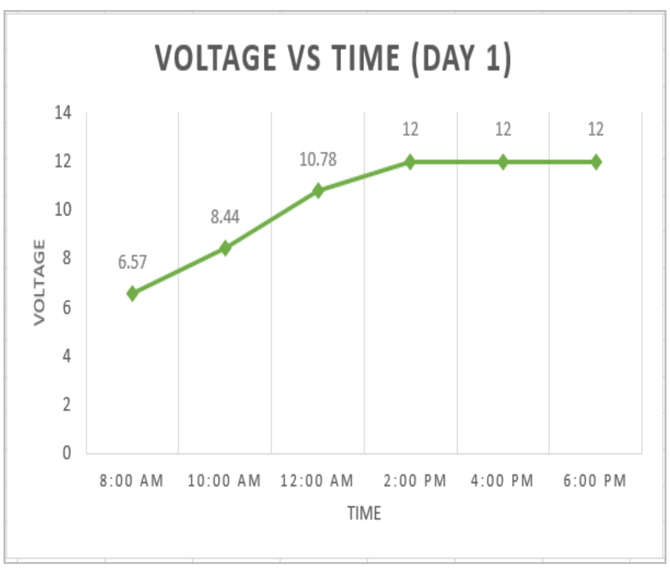
Input rpm (wind given to the turbine)	Received rpm (wind power received by the turbine)	Output Voltage(V)	Output Current (amp.)	Power (watt)
6675	303	1.09	0.11	0.1199
6955	364	1.15	0.14	0.021
7556	388	1.23	0.18	0.0414
7740	423	1.38	0.29	0.1102
8009	475	1.65	0.44	0.286

Table 2. The output of wind turbine with gear system

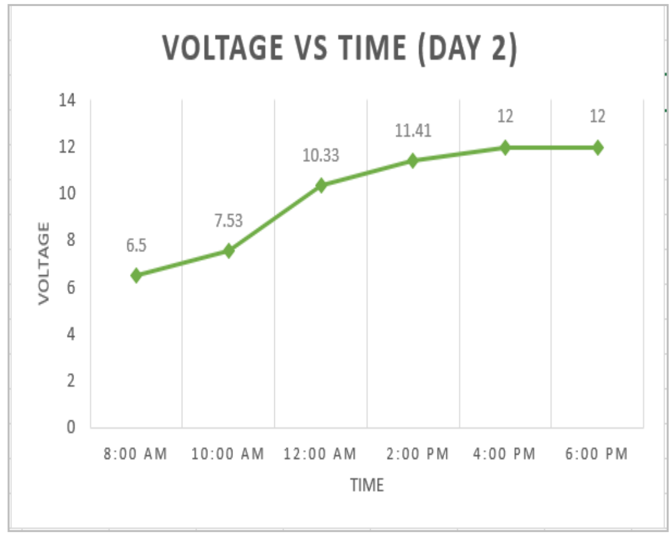
Input rpm (wind given to the turbine)	Received rpm (wind power received by the turbine)	Output Voltage(V)	Output Current (amp.)	Power (watt)
6217	345	1.21	0.75	0.91
6842	392	1.29	0.95	1.23
7780	425	1.33	1.01	1.34
8010	501	1.58	1.09	1.72
8559	565	1.73	1.17	2.02

6.2. Analysis of Battery Charging Time

After implementing the whole project, the charging time of the battery was documented using single and multiple sources. All the data were collected for two days within the same period (9.00 a.m. - 6 p.m.). Firstly, the battery was



(a)



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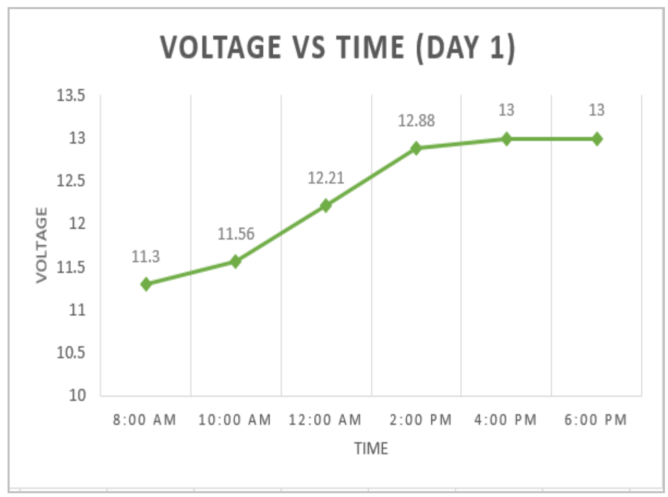
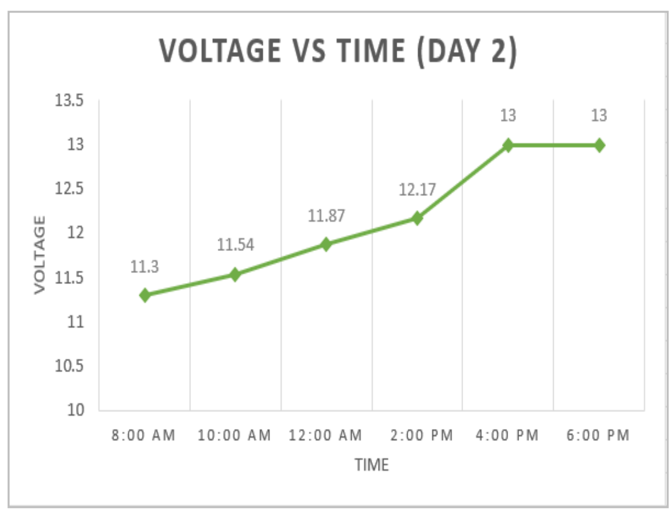
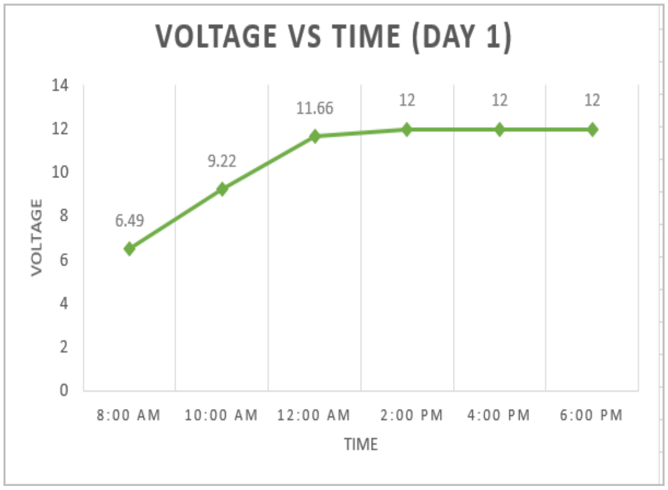


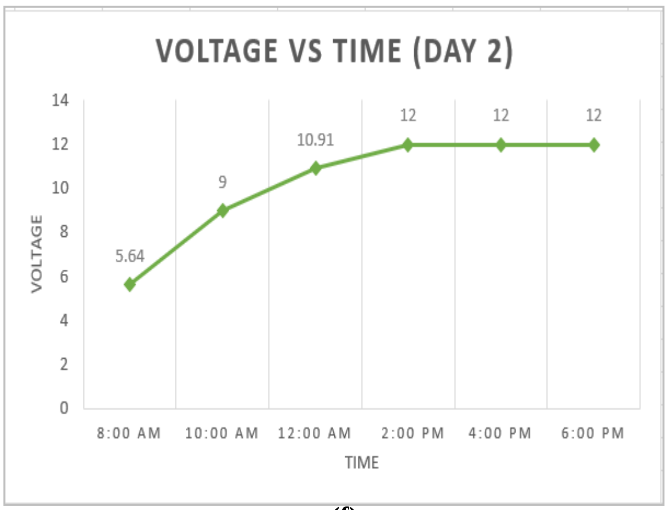
(c)



(d)



(e)



(f)

Fig. 8 Battery charging time (a, b) using the solar panel only and the battery was deeply discharged, (c, d) using the solar panel only and the battery was moderately discharged, (e, f) using both solar panel and VAWT

being discharged deeply to approximately 6 Volt, so the average time for charging the battery was about 9 hours. But the charging time was reduced to approximately 5 hours when the battery was discharged to a safe voltage level. Figure 8(a-f) illustrates the battery charging time for all possible days and sources. It can be seen from the experimental waveshapes that when both solar panels and VAWT are connected as the source, then the battery is being charged at an increasing rate.

6.3. Final Output of the Project

With the fully charged battery (12Volt) project was run. At the motor terminal, received voltage and current were found at 11Volt and 0.6Amp, respectively, i.e. the motor consumed 6.6Watt power. Since only one motor was used for the water pump prototype and due to the power rating limitation of the motor, it was not possible to run the motor for more than 30mins. Otherwise motor was facing serious overheating conditions. As because the pump was run for 30 mins, so within this time-

The energy consumed by the motor was-

$$=6.6\times(30\times60) \text{ joules}$$

$$=11.88 \text{ kjoules}$$

It has been found that the motor was able to pump around 35litres of water in 30 minutes, which means the water pumping rate of the motor is= 350/30 = 11.67 liters/min

7. Limitations of the Project Work

A design prototype has been implemented based on the proposed idea of HRES-based water pumping system construction. Due to limited time and resources, real-life implementation was not possible. So, project finance cannot be presented that would reflect any idea regarding the system's cost-effectiveness if it had been installed in practical life. Besides that, the project outcome is somewhat dependent on weather conditions, for example, wind flow and sunlight. So, extreme weather conditions can hamper the functionality of the project sometime.

8. Novelty of the Project Work

As far as the authors are aware, the project work is within the journal's scope and meets the journal's novelty standard. This research uses an innovative methodology to represent renewable energy sources' significance in power generation.

9. Conclusion

This paper successfully implements the design of a hybrid renewable energy system-based water pumping system that can be utilized in household works. Additionally, this work illustrates the importance of renewable energy systems in this age of global warming. Moreover, this paper demonstrates the worth of the proposed idea for the rural people in developing countries as there is still a scarcity of power supply in rural life. Renewable energy sources, solar and wind energy, have been used. Full analysis and design of vertical axis wind turbine (VAWT) has been presented. Eventually, experimental results have been presented to validate the presented concept.

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