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Design and development of hybrid energy generator (photovoltaics) with solar tracker

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Abstract. This paper is the outcome of a small scale hybrid energy generator (hydro and photovoltaic) project. It contains the photovoltaics part of the project. The demand of energy resources is increasing day by day. That is why people nowadays tend to move on and changes their energy usage from using fossil fuels to a cleaner and green energy like hydro energy, solar energy etc. Nevertheless, energy is hard to come by for people who live in remote areas and also campsites in the remote areas which need continuous energy sources to power the facilities. Thus, the purpose of this project is to design and develop a small scale hybrid energy generator to help people that are in need of power. This main objective of this project is to develop and analyze the effectiveness of solar trackers in order to increase the electricity generation from solar energy. Software like Solidworks and Arduino is used to sketch and construct the design and also to program the microcontroller respectively. Experimental results show the effectiveness of the designed solar tracker sytem.

1. Introduction

Global trends in energy supply and consumption are unsustainable. The major energy carriers, the fossil fuels, besides being depleted, it also causes severe damage to environment and health. Thus, finding a better energy resource nowadays is a very challenging task for mankind. The demand of energy resources is increasing rapidly since the industrial revolution. Fossil fuel energy resources like petroleum are finite and will be depleted sooner or later. The renewable energy like wave energy, wind energy, and solar energy have become the main energy resources to replace the fossil fuels. These renewable energies have been extensively explored and developed in order to fulfill the human needs.

Among the renewable energy sources in this world, solar energy is the most abundant and most reliable compared to others. This is because our Earth receives a very large amount of sunshine throughout the year. Solar energy system has widely been used in the tropical weather countries especially in the South Asian countries.

Taking into account, the difficulties of supplying electricity to the people living in the remote areas, this project aims to design and develop a small scale hybrid energy generator that basically made up of two environmental friendly energy sources which are solar energy and hydro energy. This paper will cover the solar energy component of the project.

The main objective of this paper is to show the effectiveness of the developed solar photovoltaic component for a small scale hybrid energy generator (hydro and photovoltaic) including the solar tracker system. For a photovoltaic hydro hybrid system, a low operating cost photovoltaic array and a hydro plant with a generator were used. The array usually provides 70 percent to 90 percent of the annual energy and the hydro plant with the generator provides the remainder.

Solar energy is a type of non-conventional energy. It is the energy emitted by the sun. The energy emitted by the sun is generated by nuclear fusion in the sun's core that converts approximately 650 000 000 tons of hydrogen to helium every second. The products of the fusion are mainly heat and electromagnetic radiation. The heat stays in the sun as it is essential in preserving the thermonuclear reaction. Whereas, the electromagnetic radiation including the visible light, ultra-violet radiation as well as infra-red light radiates out into space and propagates in all direction. Only a small fraction of the total radiation produced reaches the earth. To be exact, approximately two-thirds of this radiation is reflected back into space, but the remaining energy is greater than one hundred times the amount of power presently available on the Earth. Moan and Smith [1] state that "Most of the energy sources on the planet are indirectly derived from the Sun". It is estimated that approximately 170 000 terawatts (TW) of solar radiation is constantly impacting the surface of the Earth. Thus, the solar energy is considered as a renewable source of energy.

The two main components required to have a functional solar energy generator are collector and power pack as storage unit. The collector basically traps and collects the solar energy from the sun that falls on it and converts it to electricity, heat or even both. The storage unit is needed to store some of the energy generated in order to be used when needed such as in emergency or during night or during cloudy days. It also can hold the excess energy produced during where energy produces is in maximum productivity.

Photovoltaics (PVs) or solar panels are one of the ways of capturing solar energy. This is the systems that produce direct current electricity that were converted from the sun based on the principle of photovoltaic effect. When sunlight falls on certain metals, like silicon, the electrons get excited and escape from the metal, and then these are collected by another metal and passed through wires in a steady stream. Thus the electron flow set up constitutes the electric current [2]. Some materials, like selenium exhibit electric properties when exposed to light. Photovoltaic cells convert sunlight directly to electricity using solid–state, crystalline materials [3]. When these materials are crystallized with semiconducting elements like silicon, a PV cell is formed and electricity can be conducted. The basic unit of solar photovoltaic (SPV) is a solar cell which is a wafer of electron emitting metal.

Solar photovoltaic system or solar array is an energy power system which is designed to supply usable solar power from sun by using photovoltaic cells. This system consists of several crucial components such as solar panels, solar inverter, charge controller, cables, battery bank, generator and other electrical accessories needed to set up this system. Solar panels is used to absorb and directly converting the sunlight into electricity while solar inverter will convert the electrical current from alternating current (AC) to direct current (DC).

The system's efficiency can be improved by integrating a solar tracking component with the system. The solar tracking is a system by which a solar panel is used to detect the source of sunlight in order to ensure that the photovoltaic solar panels receive a great amount of sunlight. In order to collect and convert the solar energy, photovoltaic solar panel is the best choice. Solar panel is basically a set of solar photovoltaic (PV) modules that connected electrically and built on an assisting mechanism. The solar panel contains PV cells that collect and convert the sunlight that enters the panel into electric current by means of PV effect. Since solar panel produces direct current, the current will be converted into alternating current by using the inverter. Furthermore, a typical PV system generally includes a solar panel, sometimes a battery and an inverter and/or solar tracker and some wiring.

Moreover, there are three essential materials that always used to make solar cell which are semiconductor compound, silicon and other conception (dye sensitized). The principle works of the solar modules based on the movement of the electrons in the N-type silicon and P-type silicon that will generate electricity [4].

Apparently, most of the photovoltaic cells on today's market operate at efficiency less than 15 percent approx. The photovoltaic cells production and its installation have increased throughout the globe. The available data shows an increase in areas of Far East and in Europe, although only a significant increase in North America and the rest of the world [5].

2. Solar tracker

In order to increase the solar yield and electricity generation, solar trackers and concentrators were usually used. This type of combination can increase the maximum input from the sunlight. Generally, the Photovoltaic system must be facing the sun throughout the daylight in order to collect the maximum sunlight as possible. Thus, a maximum power output can be harnessed from the Photovoltaic system. Besides, this combination also is the best possibility and can be practically used at small or at large scale Photovoltaic systems.

Recent development of solar panel which is known as concentrated solar power (CSR) is a technology of a solar tracking system which is focusing on a large area of sunlight. In this system, the actuator will rotate and move the solar panel to facing parallel to the sun in order to get the maximum sunlight. To do that, a proportional-integral-derivative (PID) controller is used to stabilize the actuator and to maximize the collection of sunlight. There are two types of trackers that are available in the market. One is standard photovoltaic (PV) and the other is concentrated photovoltaic (CPV) trackers. Their characteristics are different from each other and depend on specific conditions such as their actuation architecture, actuator type, their intended applications, number and orientation of the axes and also their vertical supports and foundation.

In terms of the mechanical design of the trackers, they are classified into two types which are single axis trackers and two axis trackers. In single axis trackers, the system has only one degree of freedom which is the rotation axis, whereas in two axis trackers, the system has two degree of freedom as shown in Fig. 1.

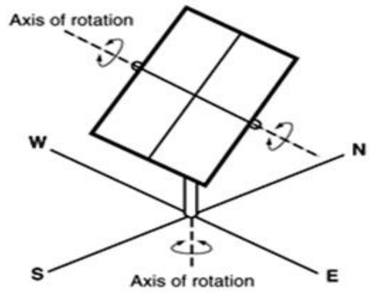

Figure 1. Two axis tracking system

In order to model the solar trackers, one may select from five types of single axis tracker and two types of two axis trackers. The single axis trackers are horizontal single axis trackers (HSAT), horizontal single axis tracker with tilted modules (HTSAT), tilted angle axis trackers (TSAT), vertical single axis trackers (VSAT), and polar aligned angle axis trackers (PSAT). Two common uses for two axis trackers are tip-tilt dual axis trackers (TTDAT) and azimuth-altitude dual axis trackers (AADAT). The actuator and sensor specifications are the most vital components for designing the tracker.

3. Design and experiment

The system is equipped with sensors and actuator which are used for the solar tracking purposes. The data collected by the sensor will be transmitted to the microcontroller and the actuator will move based on the data from the microcontroller. The amount of energy that has been collected will be received by microcontroller, and the information will be displayed at the LCD screen. The information will help us to choose the perfect spot in order to get the maximum energy input. The sunlight energy collected will be compared between the light-dependent resistors (LDR) and the Arduino microcontroller will interpret which one received the highest amount of sunlight and sends response to the servo motor to face the solar panel towards the direction with highest amount of sunlight. The flow chart of solar tracker's activity is shown in Fig. 2.

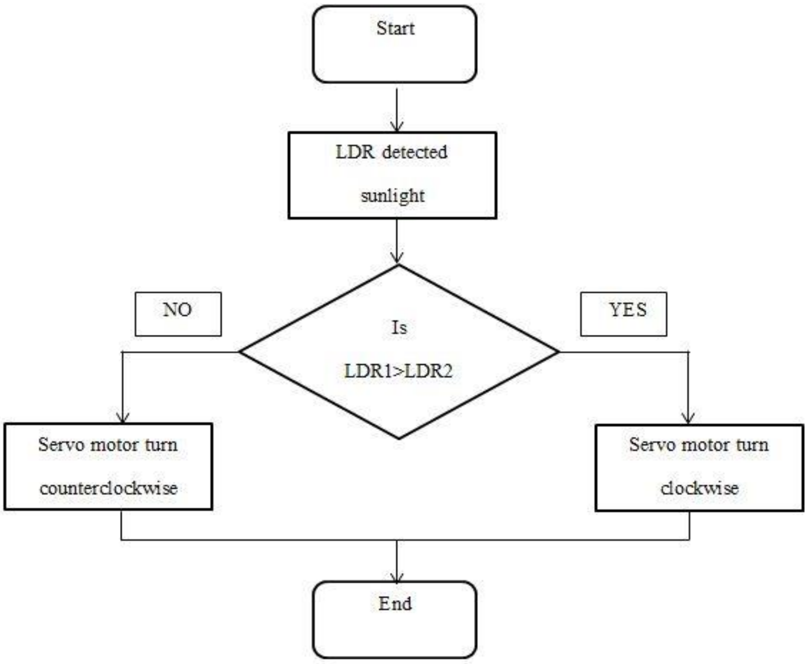

Figure 2. Solar tracker's flowchart

Monocrystalline solar panel is used in this project which can produce 50 Watts and the voltage is 12 volts. Digital servo motor was used as an actuator for the solar tracker system. It was selected since it is of light weight and high torque. The function of the servo (like angle of rotation and speed) can be controlled by Arduino programming.

Light dependent resistor (LDR) or simply a photoresistor is basically a light controlled resistor. This resistor operates as when the light intensity increases, the resistor value decreases which makes it suitable to be used as the sensor for the solar tracking system. Two sets of LDR were used in this system, which sense and receive the intensity of the sunlight. The data from the sensors are then compared between them and the microcontroller will choose the LDR which receives the highest sunlight intensity. Hence, the servo will rotate according to the data from the microcontroller, which eventually make the solar panel facing towards the highest light intensity in order to maximize the energy collected by solar panel.

In order to program the servo motor, a micro controller is needed and the suitable microcontroller used is Arduino UNO. The specification of the microcontroller is given in Table 1. Arduino is basically a microcontroller which manipulates the data whether in analog form or digital form. This open-source physical computing has a simple microcontroller board and a development environment for writing the codes of the system.

Table 1. Arduino specification

Specification	Details
Microcontroller	ATmega 328
Operating voltage	5 V
Input voltage (recommended)	7 – 12 V
Input voltage (limit)	6 – 20 V
Digital I/O pins	14 (6 pin for PWM output)
Analog pin	6
Direct current per I/O pin	40 mA
Flash memory	32 kB (ATmega 328), 0.5 kB used by boot loader
SRAM	2 kB (ATmega 328)
EEPROM	1 kB (ATmega 328)
Clock speed	16 MHz

Generally, it is used to form an interactive object, collecting inputs from sensors, actuators actuating and output is displayed. The voltage sensor circuit can be used to measure the voltage output of the solar panel, hydro generator and also power of the battery. The digital pin from the Arduino UNO will be connected in between the resistor 100k and 20k.

Liquid-crystal display (LCD) is a display panel which uses the light modulating properties of liquid crystal. Generally, it is used to display fixed images or arbitrary images just like one in the computer display. It is made up of a series of segments filled with liquid crystals and arrayed in front of backlight so that images will produce in monochrome or colour. The LCD is used in this project to show the data of the microcontroller and the voltage data from the solar panel and generator.

An inverter is used to convert the DC current produced by the solar panel to AC current. Battery selection for the power pack is chosen based on the storage capacity and also the voltage it can supply. The suitable battery that was chosen is lithium-ion battery for its high life cycle and affordability. The battery can store about 2500 mAh and the voltage is 3.7 volt. Thus, the system needs a total of 4 batteries 2 for generator and 2 for solar. Since battery's voltage is 3.7 volt, a voltage regulator (7805) is needed for 5 volt voltage output. In addition, a diode also is needed so that the solar panel and hydro generator are supplying voltage to the battery and not the other way.

4. Results and discussions

The charge controller box is needed in order to monitor and control the rate of charge of the battery. The controller will control the battery voltage by comparing the battery voltage and the battery voltage whether the system should continue charging the battery or not.

The experiment was conducted on the rooftop of Block E2, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM). The experiment was done from 7 am to 7 pm. The intensity of sunlight also was measured using the solarimeter. The result of the output voltage and current was recorded separately for the system with the aid of solar tracker and without the aid of solar tracker in Table 2 and Table 3 respectively.

Table 2. Output voltage and current collected by solar panel using solar tracker

Time	Sunlight intensity (W/m^2)	Voltage (V)	Current (A)	Power (W)
7 am	357	10.01	0.12	1.20
8 am	415	10.12	0.18	1.82
9 am	624	11.23	0.23	2.58
10 am	760	11.56	0.28	3.24

11 am	872	12.50	0.34	4.25
12 noon	940	12.53	0.35	4.39
1 pm	1022	12.59	0.41	5.16
2 pm	976	12.56	0.39	4.90
3 pm	805	12.53	0.35	4.39
4 pm	788	12.23	0.33	4.04
5 pm	612	11.98	0.30	3.59
6 pm	550	11.65	0.24	2.80
7 pm	414	11.01	0.22	2.42

Table 3. Output voltage and current collected by solar panel without using solar tracker

Time	Sunlight intensity (W/m^2)	Voltage (V)	Current (A)	Power (W)
7 am	342	9.78	0.11	1.08
8 am	476	10.22	0.15	1.53
9 am	543	11.11	0.21	2.33
10 am	643	11.54	0.27	3.12
11 am	840	12.35	0.30	3.71
12 noon	915	12.43	0.33	4.10
1 pm	972	12.47	0.35	4.36
2 pm	892	12.12	0.30	3.63
3 pm	765	11.97	0.30	3.60
4 pm	700	11.12	0.26	2.89
5 pm	634	11.00	0.23	2.53
6 pm	556	10.57	0.19	2.01
7 pm	441	9.23	0.13	1.20

Both results show the same trend even though different sunlight intensity was received during the experiment. The system with the aid of solar tracker shows more voltage and power produced than the system without the aid of the solar tracker. This shows that the solar tracker system eventually helped the solar panel to harvest more sunlight and produce more output voltage and power. Figs. 3 and 4 show the graphs of the voltage versus time for the system with the aid of solar tracker and without the aid of the solar tracker respectively. Both of the graphs show the same trend of increase of the output voltage as the time approaching the midday.

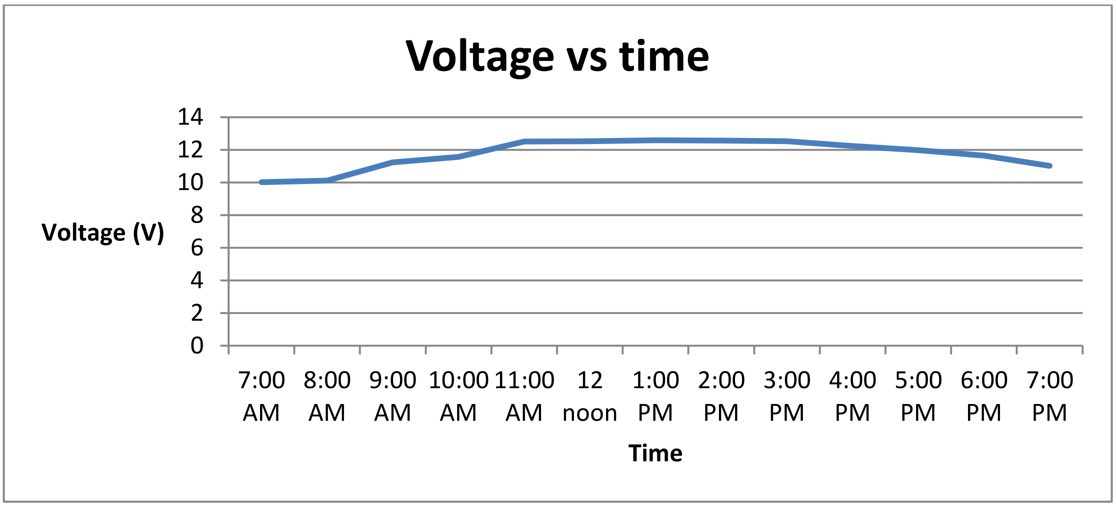

Figure 3. Voltage versus time for the system with the aid of solar tracker

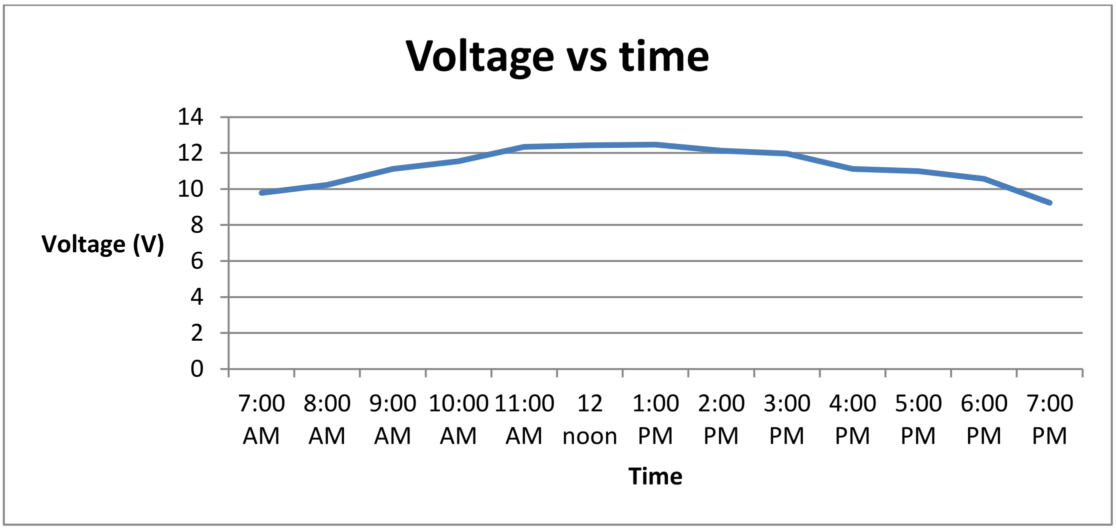

Figure 4. Voltage versus time for the system without the aid of solar tracker

Fig. 3 shows the voltage output for the system with the aid of solar tracker and Fig. 4 shows the same for the system without the aid of solar tracker. It is clear from the figures that the voltage output in Fig. 3 is much higher than that of Fig. 4. First visible changes in the graphs start from the third hour of the experimentation. It was observed that the voltage output continues to increase steadily for the system with the aid of solar tracker afterwards which is not the case for the system without the aid of solar tracker. Even though both graphs show the same trend, but we can see the difference at the end hours of the experiment. Graph in Fig. 3, has almost steady trend at the end hours of the experiment. This shows that the solar tracker system helps solar panel to maximize the process of harvesting the solar energy.

4. Conclusion

The following conclusions can be drawn from the present study:

1. The sunlight intensity affects the voltage output of the solar panel.
2. Maximum voltage output of 12.59 V was successfully collected by the solar panel with the help of solar tracker.
3. Solar tracker system was successfully integrated with the solar panel to maximize the power output from the solar panel system.

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