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ORIGINAL ARTICLE

Experimental analysis of P.V panels, wind turbine, theoretical study of renewable energy hybrid system

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Abstract

Solar power is a demand of our planet in coming days due to the depletion of non-renewable sources of energy. The renewable sources of energy are responsible for 80% of world's power and we all are directly dependent on non-renewable source which will only last in coming decades. Due to increase in power demands new development in renewable sources of energy are going on due to which on commercial level solar cell achieved an efficiency of 15-20% and improving day by day. At a panel inclination of 22ºC, the effect of panel temperature and relative humidity on photovoltaic are studied. A precision digital hygrometer and thermometer, and a digital clamp meter were used in the process. Results obtained show that the effect of relative humidity on current, voltage, power of single and 10 panels combined together. The results also show that voltage and current remain fairly stable between 15% to 35% relative humidity. Panel's temperature also plays a significant role on performance after 55ºC, the voltage started dropping in both cases.
Output from the wind turbine has also been measured on a working condition day, and different readings has been recorded with an interval of 15 minutes at different wind speeds. It works by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied. The output energy comes directly depend on speed of wind and the blades swept area. Renewable Energy Hybrid System (REHS) is a system that utilizes two sources or more of renewable energy. As an advantage, it will produce continuous source of energy and utilizing one source in the absence of other source(s). The aim of this study is to enhance the energy output of renewable energy system which is the wind turbine by incorporating solar panels.

1. Introduction

This project is to emphasis on solar energy and wind energy. The aim of this project is to identify the performance of single P.V panel and 12 P.V panels attached in rectangular array (with series and parallel combination) under an environment conditions such as ambient temperature, relative humidity, wind speed and solar radiation during a span of 8 hours. A single wind turbine is also tested with different operating wind speed with time to understand the concept of wind power energy. Various important data has been observed and analyzed [1].
A combined system of two individual energy system consist is Renewable Energy Hybrid System (REHS). This system is providing continuous sources of energy at all times, if one is

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absent the other is working, in day time with proper sunlight both sources could be the source of working. The aim of this research is to enhance the energy output of renewable energy system which is the wind turbine by incorporating solar panels. Other objective is to investigate the effect of solar panels distribution on the total power output of the new created hybrid system by investigating two cases. First, by using single solar panel data are incorporated with the wind turbine. Second by using 12 P.V panel's results with wind turbine outputs, and compare the results.

The most commonly used wind turbine is horizontal axis wind turbine as shown in figure 1. Various key components such as blades, shaft and generator are mounted on the top of the tall tower (pole) and blades faced towards the direction of the wind. The shaft alignment is horizontal to the ground [2]. The moving wind strikes the blades of the turbine that are connected to a shaft causing rotation. The shaft has a gear connected at the end which turns a generator. The generator produces electricity and sends the electricity into the power grid.

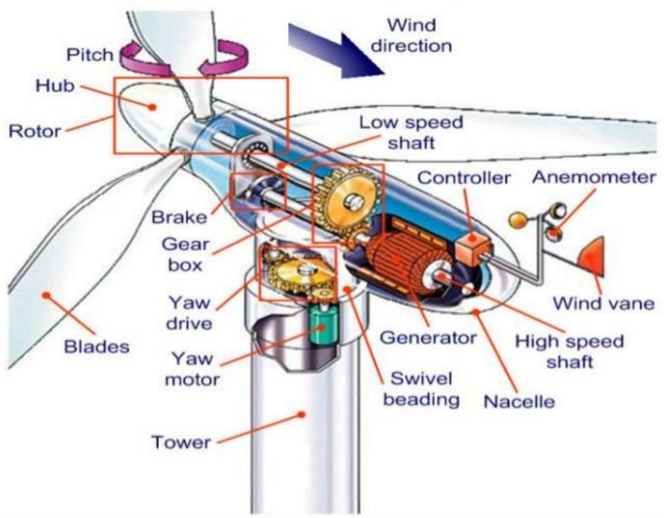


Figure 1: Horizontal wind turbine and its components

There are some additional elements incorporated to improve turbine efficiency. Inside the Nacelle an anemometer, wind vane and controller that read the speed and direction of the wind. As the wind changes direction, a motor (yaw motor) turns the nacelle so the blades are always facing the wind. The power source also comes with a safety feature. In case of extreme winds the turbine has a break that can slow the shaft speed. This is to inhibit any damage to the turbine in extreme conditions.

A photovoltaic (PV) system is a system composed of one or more solar panels combined with an inverter, other electrical and mechanical hardware that use energy from the sun to generate electricity. Some common types of system explained by [3]. Our analysis and study based on, the research carried by other peoples in the past in same areas, and some of the research noted based on: related to environmental effects on solar panel its performance, working principle of wind turbine its energy generation and renewable energy hybrid system that utilizes two or more source of renewable energy. S. Mekhilef , R. Saidur , M. Kamalisarvestani (2012) study effect of dust, humidity and air velocity on efficiency of photovoltaic cells, and found humidity and air velocity affecting the performance. The environmental and economical merits of converting solar energy into electricity via photovoltaic cells have caused an ever increasing interest among developed and developing countries [4]. Ligavo Margdaline Musanga, Wafula Henry Barasa and Mageto Maxwell [2018] this study established the effect of solar irradiance and temperature on the performance of monocrystalline module in Kakamega. The performance of this module was evaluated in terms of its response variables (V_{oc}, I_{sc}, FF,η, V_{mp} , I_{mp}, and P_{max}) as a function of solar irradiance and module surface temperature [5]. Sujit Kumar Jha [2013], presented global solar radiation data for ten cities in Oman. Due to limited fossil resources and environmental problems associated with them, the need for other sustainable energy supply options that use renewable energies. [6]. Joseph Amajama, Julie C. Ogbulezie, A. Akonjom, Victor C. Onuabuchi [2016] study impact of wind on the output of P.V panel and solar illuminance/intensity [7]. Armstrong O. Njok and Julie C. Ogbulezie the effect of temperature and relative humidity on photovoltaics close to river in Calabar. This research shows that the effect of relative humidity on current, power and efficiency are observed to be the same. The research also confirms that the ambient temperature has little or no direct effect on the module temperature [8].

E. B. Ettah, P.O Ushie, J. N Obiefuna, N. C. Nwachukwu [2015] study of the effects of relative humidity on solar electricity generations carried out in Uyo and Port –Harcourt cities. Their results were compared to ascertain which city generates more solar electricity in relation to relative humidity of the city by high relative humidity is experienced in the morning and evening hours while low relative humidity is experienced in the noon hours, because temperature is directly proportional to relative humidity [9]. Mohamed Elnaggar, Ezzaldeen Edwan and Matthias Ritter studied [2017] a feasibility study of the wind energy potential in Gaza, which suffers from a severe shortage of energy supplies The results also depict the great potential of wind energy to complement other renewable resources such as solar energy [10]. Asis Sarkar, Dhiren Kumar Behera [2012] investigate Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied [11].

F. Wanga, L. Baia, J. Fletcherb, J. Whitefordc, D. Cullenc [2007] design of a small wind generator for domestic use. This suggests that first the developed computer model was robust and could be used later for design purposes. Second the methodology developed here could be validated in a future study for a new rotor blade system to function well within the scoop [12]. Ehab Hussein Bani-Hani [2018]: Renewable Energy Hybrid System (REHS) is a system that utilizes two sources or more of renewable energy is studied. The advantage of maximizing the power output and keep a continuous source of power supply were proved [13]. Ashish S. Ingole, Prof. Bhushan S. Rakhonde [2015]: Hybrid Power Generation System Using Wind Energy and Solar Energy Hybrid power generation system is good and effective solution for power generation than conventional energy resources. It has greater efficiency [14].

2. Methods

When light hits the material, it can be transmitted, reflected or absorbed by most of the photon energy to heat energy. Photon gives energy to electron based on the principle of "conservation of energy and momentum". The free or generated electron moves across the crystal; this phenomenon is called photovoltaic effect. Semiconductors materials have an energy band gap between the conduction band and the valence band. Energy of the valance band in which the electron is bound to host atoms. In conduction band electrons get free and not to bound in host atom. At absolute zero temperature, no electrons are at conduction band that leads to no conductivity, but as the temperature increases some electron receive energy and jump from valance band to the conduction band, creating electron (energy)-hole pairs. If the photon energy (incident solar radiation) is larger than valance band energy the electron-hole pairs produced, thus the solar radiation continues to fall and process continues and their exits an electric field in the semi-conductor materials and liberated electrons. The electrical forces caused electron to travel n-side and hole to its p-side of the diode.

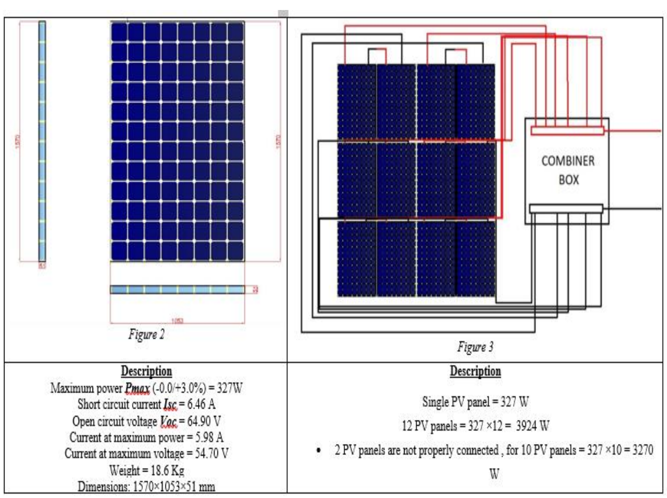


Figure 2: Multi View drawing of Single photovoltaic panel with dimensions and descriptions

P.V cell or solar cells are produced voltage difference when sunlight shine on it. A light can convert to energy by some materials was first discovered in 1839 by French scientist Edmund Becquerel. Later photovoltaics affects noticed by 'Adams' in 1876. Few years later American 'Charles F.' discovered first solar cell. Efficiency of the solar cell increased up to 6% by adding some impurities concluded by Chapin in 1954. Later more advancement comes due to energy crises in and after 1970's. A typical solar cell produced approximately 3 W at a 0.5 V D.C connecting P.V cells in series resulting P.V modules range from a few to 300W. In our case, a single P.V panel rated P_{max} is 327W with 96 cells on each panel. The details description of a single panel and 12 panels are shown in figure 2 and figure 3 by using AUTOCAD.

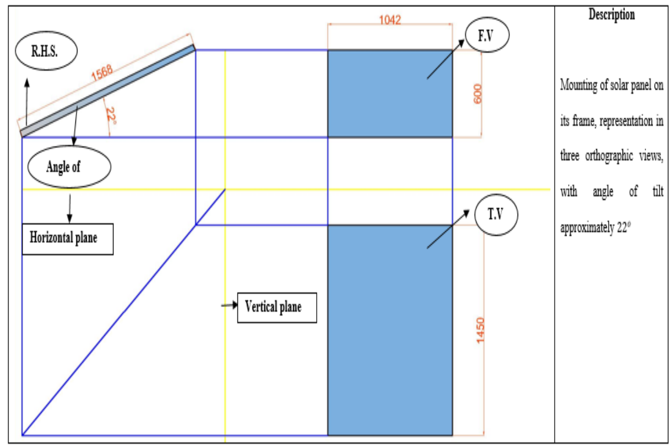


Figure 3: Orthogonal view of a single P.V panel in first angle of projection.

3. Experimental Method

Solar panels are installed behind 'D-building' at University of Buraimi, faced toward the sunlight during most of the day time. The pairs of two panel each connected in series (positive – negative connection), and each pairs of two are connected in parallel to from a rectangular array of 12 panels.
Three sets of readings were recorded during 2nd March 2020 to 4th March 2020 from 8 a.m. to 4 p.m. with a time interval of 1 hour. From the readings, power calculated from solar panels by using eq. (1). The maximum power and normalized power output efficiency are calculated by using eq. (2) and eq. (3). The open circuit depends on parameters like solar irradiance and temperature as defined in eq. (4) and eq. (5).
Measured power:

$$P_{meas} = V_{meas} \times I_{meas} \tag{1}$$

Maximum power:

$$P_{max} = V_{max} \times I_{max} \tag{2}$$

= 327 watts [single panel] and 3270 watts [10 panels]
Normalized power output efficiency

$$\eta_P = \frac{P_{meas}}{P_{max}} \times 100\% \tag{3}$$

Open circuit voltage

$$V_{oc} = \frac{KT}{q} \ln \frac{I_{sc}}{I_o} \quad (4)$$

Short circuit current

$$I_{sc} = bH \quad (5)$$

Light conversion efficiency of the solar system is given as:

$$\eta_{solar} = \frac{P_{max}}{A_c \times \text{solar irradiance}} \times 100\% \quad (6)$$

Power production from a wind turbine is a function of wind speed. The relationship between wind speed and power is defined by a power curve, which is unique to each turbine model and, in some cases, unique to site-specific settings.
The amount of electricity produced from a wind turbine depends on three factors:

3.1 Wind speed

The power available from the wind is a function of the cube of the wind speed. Therefore, if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed average 8 m/s produce around 75-100% more electricity than those where the average wind speed is 6 m/s.

3.2 Wind turbine availability

This is the capability to operate when the wind is blowing, i.e. when the wind turbine is not undergoing maintenance. This is typically 98% or above for modern European machines.

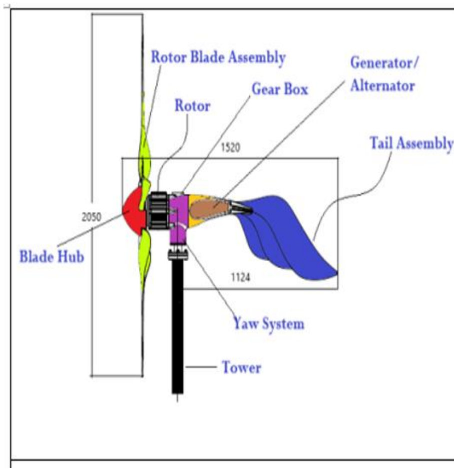
3.3 The way wind turbines are arranged

Wind farms are laid out so that one turbine does not take the wind away from another. However other factors such as environmental considerations, visibility and grid connection requirements often take precedence over the optimum wind capture layout.
The wind turbine HY1500 (small wind turbine) produced by HY (Chine) is used in this study and its description are listed as below:
A five blades wind turbine is used. The calculations on the power (output/input), and the efficiency of both wind turbine and solar panel systems are according to Kuwait data. The power stored in the wind is given by Eq. (7):

$$P_{in} = \frac{1}{2} \rho A v^3 \quad (7)$$

The efficiency of the wind turbine is referred to as power coefficient C_p, which is a measure that is often used by the wind power industry. The efficiency is a ratio of the actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at a specific wind speed.

$$C_P = \frac{\text{Actual Electrical Power Produced}}{\text{Wind Power into Turbine}} = \frac{P_{out}}{P_{in}}$$



Technical Specification	
Model	HY-1500
Rated Power	1500W
Max. Power	1800W
Rated rotation speed	750rpm
Start-up Wind Speed	2.0m/s
Cut-in Wind Speed	2.5m/s
Rated Wind Speed	12m/s
Survival Wind Speed	50m/s
Rotor Diameter	2m
Blades Quantity	5
Swept area	3.3m²
Strong wind protection mode	electromagnetic brake, blades aerodynamic brake
Wind Turbine Type	Upwind
Net weight	35kg
Package size	46kg

Figure 4: Orthogonal view of a single P.V panel in first angle of projection.

Wind power into the turbine from eq. (7). The electrical power output P_{out} can be obtained through the efficiency of the turbine according to the eq. (8) as below:

$$P_{out} = C_P P_{in} = \frac{1}{2} \rho A C_P v^3 \quad (8)$$

The power coefficient C_P can also be calculated from the following equations:

$$C_P = \eta_b \eta_m \eta_e \quad (9)$$

Where:

η_b: Blade aerodynamic efficiency.
η_m: Mechanical efficiency.
η_e: Electrical efficiency.
The Betz limit shows the maximum possible energy that may be derived by means of an infinitely thin rotor from a fluid flowing at a certain speed. The power coefficient Cp has a maximum value of Cp, max = 16/27 = 0.593. The **Betz limit** describes the maximum amount of energy a turbine can theoretically extract from the wind.

$$P_{out,max} = \frac{1}{2} \times 0.593 \times \rho A C_P v^3 \quad (10)$$

The Efficiency of the wind turbine is shown in Eq. (11)

$$\eta = \frac{P_{output}}{P_{input}} \times 100\% \quad (11)$$

3.4 Renewable Energy Hybrid System (REHS)

The same specifications of the five blades wind turbine and the solar panels are used to create the hybrid renewable energy system that will be investigated. The total power output of the hybrid energy system is given by Eq. (12):

$$P_{Hybrid} = (N_W \times P_{Generator}) + (N_s \times P_S) \qquad (12)$$

The efficiency of the renewable energy hybrid system is given by Eq. (13):

$$\eta_{Hybrid} = \frac{P_{Hybrid}}{(A_c \times \text{solar irradiance}) + (P_W)} \qquad (13)$$

4. Result and Discussion

4.1 Solar Panels Readings

In experimental method, the voltage and current from the single panel and 10 P.V panels from combiner box were measured using clamp meter, ambient temp & % relative humidity using hygrometer, wind speed using anemometer, solar radiation by solar meter. Three sets of readings recorded.
Readings have been divided into two cases as single panel and 10 panels. The voltage and currents of each are separately recorded and other readings are same for both cases.
Each set of readings are recorded on each day for the time span of 8 hours, the purposes of doing this is to understand the performance of solar systems in variation with environmental conditions such as temperature and relative humidity. Usually temperature and relative humidity have an inverse relation, but their impact on solar systems are surprisingly noticed during working times.

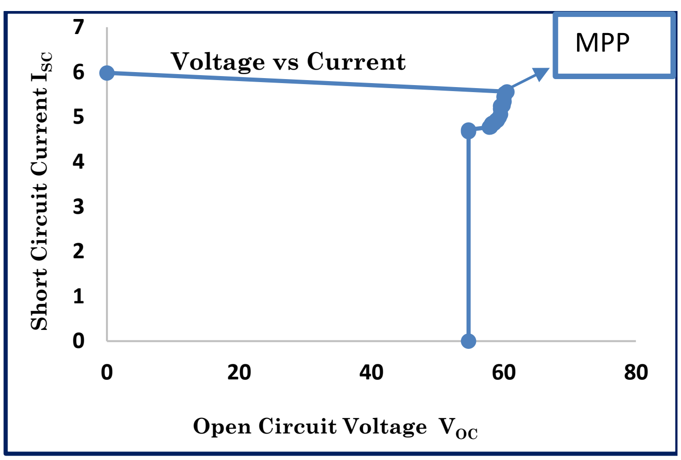


Figure 5: Single panel output's results

Bright and intense sunlight your solar panels produce more energy, it's not right. At a certain point, excessive heat can actually cause a decrease in energy output from your solar panels. The amount of energy produced by a solar panel is calculated by multiplying the current and the voltage. Based on its efficiency, a solar panel has a maximum amount of energy that it is able to produce.
However, the effect of single panel and 10 panels are not same, more losses occur in panels array arrangement such as DC wiring, mismatch loss, soiling loss, orientation etc.

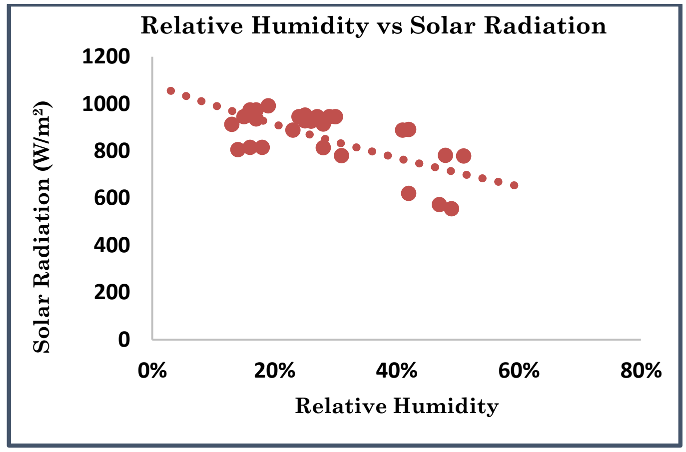


Figure 6: Variation of irradiance level with relative humidity

Figure 5 shows the V-I characteristics of a P.V module or array giving detailed description of solar energy conversion ability and efficiency. This curve is a typical representation of the operation of the solar cell or modulus summarizing the relation between current and voltage at existing condition of irradiance and temperature. V-I curve provides the information required to configure a solar system, so that it can be operated as close to its optimal peak power point (MPP) as possible.
Figure 6 shows the effect of solar radiation on relative humidity and when the light hits water droplets, three cases may happen. It may be refracted, reflected or diffracted. These effects plunge the reception level of the direct component of solar radiation. Humidity alters the irradiance non-linearly and irradiance itself causes little variations in V_{oc} in a non-linear manner and large variations in I_{sc} linearly.

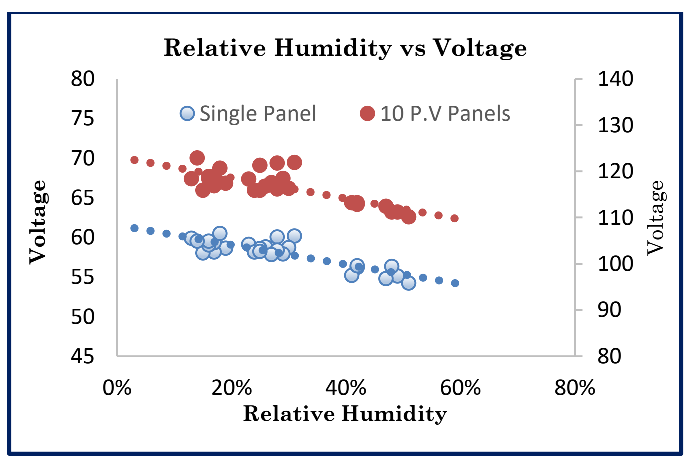


Figure 7: Graph of voltages against humidity

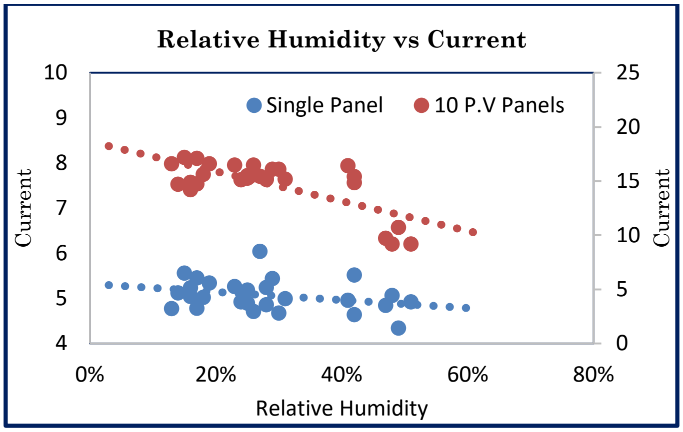


Figure 8: Graph of currents against humidity

Figure 7 shows the effect of relative humidity on voltages of single and 10 P.V panels, it's clear that the voltage decreases as humidity increases, usually in morning and evening time. This is due to more moisture content in the atmosphere, resulting a decrease in performance. Nature of variation in both cases are almost similar.

Figure 8 is the variation of single panel and 10 panels currents due to humidity, and their patterns are also similar to voltage, but unlike in voltage, here currents nature are not similar, with high humidity single panel current decreases gradually, while in 10 P.V panels drop in current rapidly as the humidity increases.

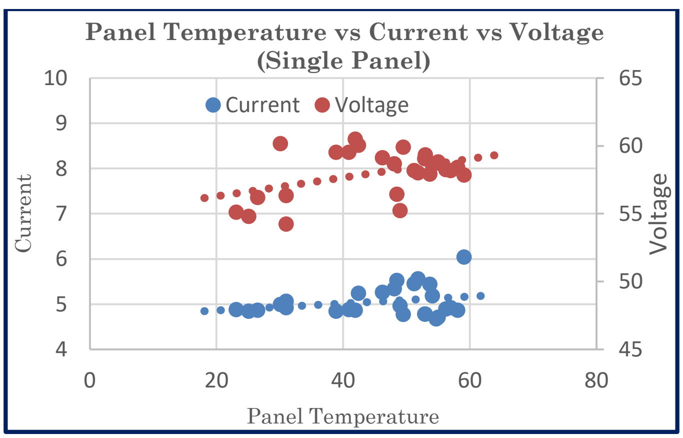


Figure 9: Variation of current and voltage due to panel temperature of a single panel

Figure 9 shows that between 25ºC and 50ºC current increases. With further increase in temperature, voltage remains fairly stable and beyond approximately 53ºC, voltage begins to drop indicating that temperature has significant effect on the voltage output.

Figure 10 shows that current increases with temperature from 30 ºC up to 53 ºC, where a peak in current is observed around 50ºC which is an operating temperature of panels and beyond this temperature, current begins to drop, this indicating the maximum operating temperature of the photovoltaic module. Voltage output from the panels is almost constant around peak temperature at 50ºC. Voltage drop takes place with further rise in panel temperatures.

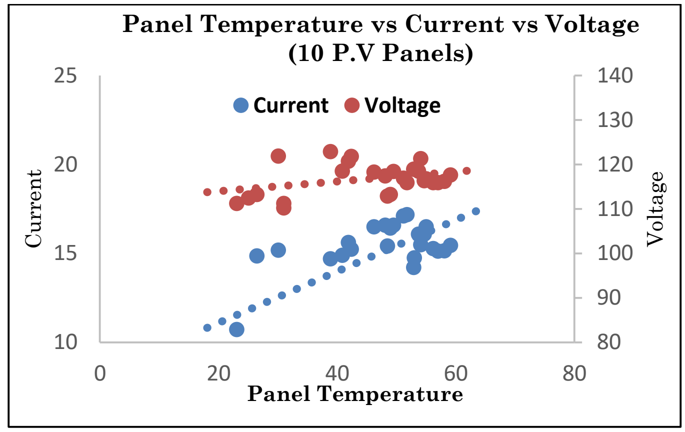


Figure 10: Variation of current and voltage due to panel temperature of 10 P.V panels

4.2 Wind Turbine

Figure 11 shows the different expected powers with respect to wind speed. Generally, an increase of the wind speed leads to an increase of the power output. The available power P_{inp} increases continuously, whereas P_{outmax} and P_{out} are bounded by the turbine capacity.

A typical example of the relationship between the wind speed and the power generated by the wind turbine is shown. The blades start to move around 2.5 m/s, and performance of turbine would be optimum. Above the cut out wind speed, the turbine has to be stopped in order to avoid damages. Then, the power carried by the wind, the

Maximum power from the Betz Limit and the power produced in the University of Buraimi using this setup are compared in the figure 9. After that, a complete wind profile including the variation of the wind power depending upon the wind velocity, the maximum possible power output at different wind velocities are estimated and presented.

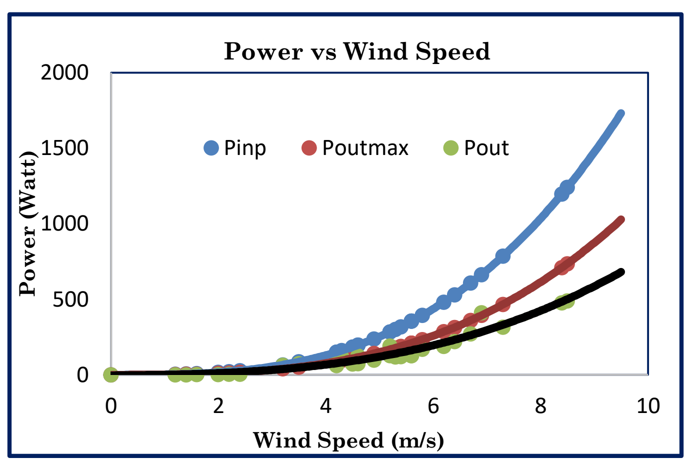


Figure 11: Power curve for a 1500 kW turbine

4.3 Renewable Energy Hybrid System (REHS)

The Renewable Energy Hybrid System (REHS) is comprising of two or more input energy sources. The power is calculated with the help of eq. (11), and results are as shown in graph below,

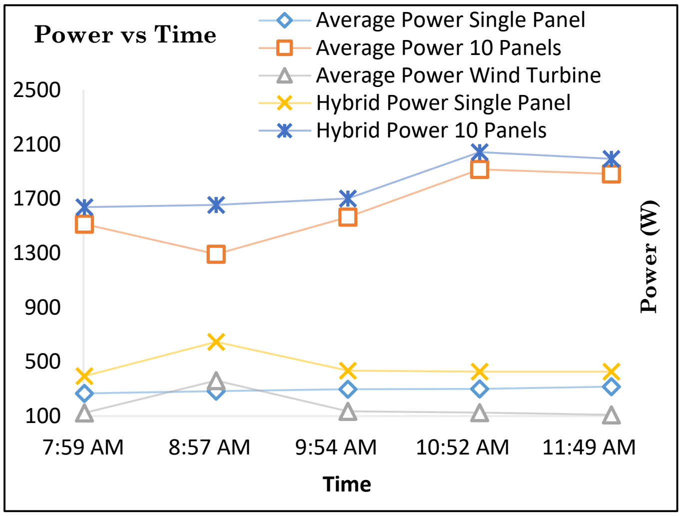


Figure 12: Power output measured with time for the three individual renewable energy systems compared with two hybrid systems.

The aim in a renewable hybrid system is that the system will be able to give continuous supply of power in different weather conditions. Firstly, it's the individual testing of energy systems a single solar panel, the 10 solar panels and the wind turbine. The individual systems were tested in 3 days with a duration of eight hours from 08:00 AM until 04:00 PM with different weather conditions. The readings are recorded every one hour._After testing the systems individually, the hybrid systems are analysed analytically comprising with the solar panel(s) and wind turbine. Two types of hybrid systems are made, one is the wind turbine with the single panel (Hybrid System 1), and the other is the wind turbine with the 10 solar panels connected together (Hybrid System 2). Moreover, the results are calculated analytical with simple formulas and the two systems results are plotted in figure 12. This will show the comparison between having an individual system and a hybrid system.

Overall, the power output comparison can be seen in graphs shown in figure 12. The hybrid system is compared to the individual system with the most similar weather conditions. It shows that the power output increased when having a hybrid system. However, the 10 solar panels give higher power output than the small solar panel. Moreover, the power output is continuous in the hybrid system unlike the individual system, where the power is zero for the wind turbine. In the hybrid system, when there is no wind the power decreases only. It does not reach zero like a single system due to having another source of input power._Hybrid power with single panel increases gradually whereas hybrid power due to 10 panels increases drastically, this is due to surplus supply of current from multiple panels. The alternative factors that can affect such as cost, availability, quality, installation, durability and efficiency of the selected idea.

5. Conclusions

This experimental study shows that the effect of relative humidity on current, voltage and solar irradiance are observed. The study also confirms that the ambient temperature has little effect on the module temperature. The application of photovoltaic technology (conversion of solar energy to electricity) performed in month of March (first week) at the installed location.

Comparative study of the effect of relative humidity on the solar electricity generation was carried out for single panel and 10 panels. The following points are observed.

- High relative humidity is experienced in the morning and evening hours while low relative humidity is experienced in the noon hours, because temperature is directly proportional to relative humidity.
- Relative humidity in Al Buraimi, Oman is of the average of 28%, first week of March, this is due to geographical location.

Other environmental factors are discussed which affect the performance of solar cell in many way i.e. it may be positive change or negative change. The temperature decreases the performance of solar cell which results in less power output. The humidity which affects both life and power output of solar cell, is responsible for less power output this is due to humidity the rusting starts in solar cell module which directly impacts the life of solar panel. The wind, it improves the performance of solar panel by reducing the surface temperature of the solar panel module. Light intensity is directly related to efficiency of solar panel i.e. higher the light intensity means higher the number of photons falling on surface of solar panel which increases the output of solar cell and directly leads to an improved efficiency of solar panel module. These all factors decide the efficiency of solar cell along with some other factors like clouds, visibility and some other.

The portion of the absorbed solar radiation that is not converted into electricity gets converted into thermal energy and causes a decrease in module efficiency. We have conducted a study on wind energy production with small wind turbine with rated output power of 1500 KW. The cut in speed is of 2.5 m/s. The small size of the wind turbine with five blades attached to rotor. A wind turbine is always designed to work in certain conditions at which it is most efficient in converting wind energy into electricity.

The technology for commercial wind turbines at high wind velocities have become sufficiently advanced, therefore prompting researchers to focus on small wind turbines and at low wind velocities.

Analytically investigated the performance of hybrid systems that utilized both solar and wind energy as renewable sources. The advantage of maximizing the power output and keeps a continuous source of power supply were proved. The results show in different weather conditions that a continuous and significant amount of power is hardly achieved using wind turbine only. The comparison was between the single solar panel and the 10 panels. Finally, the data and results were recorded for hybrid system in two different cases. It showed that the power output increased with the both hybrid systems in general. However, the 10 solar panels give higher power output than the single solar panel when connected to the wind turbine. In addition, the power output is continuous in the hybrid system in comparison with the wind turbine individually, and in hybrid system the power output was higher in comparison with the individual solar systems.

Future work

For further study and better results in identifying the performance of a hybrid system that utilized both solar and wind energy as renewable sources of energy in Oman:

This study could be repeated on Sohar beach with many wind turbines and with standard quality of 12 P.V panels in the next year on April month. Sohar beach is a windy and sunny place, mostly in spring season in every year, it's phenomenal to make the hybrid system work more efficiently, gets more power generated and acquires more suitable results.

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