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Development and Advantages of Renewable Energy Hybrid Systems (REHS)

Arshad Mehmood

Department of Mechanical Engineering, College of Engineering, University of Buraimi, Oman

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 22 °C, 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 55 °C, the voltage started dropping in both cases. Output from the wind turbine has also been measured on a working condition day, and different readings have been recorded with an interval of 15 mins 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.**

Keywords: Efficiency; P.V panels; Humidity; Temperature; Wind Speed; Wind Turbine; Renewable Energy Hybrid System (REHS).

I. INTRODUCTION

The project focuses on evaluating the performance of both solar and wind energy systems. It involves testing a single photovoltaic (P.V) panel and a configuration of 12 P.V panels in a rectangular array, examining their efficiency under varying environmental conditions like ambient temperature, relative humidity, wind speed, and solar radiation over an 8-hour period [1]. Additionally, a single wind turbine is tested at different operating wind speeds to comprehend wind power energy concepts. The data collected and analyzed from these experiments provide valuable insights into the effectiveness of these renewable energy sources, highlighting their potential for sustainable electricity generation and emphasizing the importance of harnessing solar and wind power to mitigate environmental impacts associated with traditional energy sources [2].

A Renewable Energy Hybrid System (REHS) combines individual solar and wind energy systems to create a sustainable and reliable power generation solution. By integrating solar panels for converting solar energy and wind turbines for converting wind energy into electricity, the REHS ensures a continuous power supply without harming the environment [3], [4]. This system is providing continuous sources of energy at all times, if one is absent the other is working, in day time with proper sunlight both sources could be the source of working [5]. 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 [6].

The most commonly used wind turbine is horizontal axis wind turbine as shown in Fig.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 [7]. 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.

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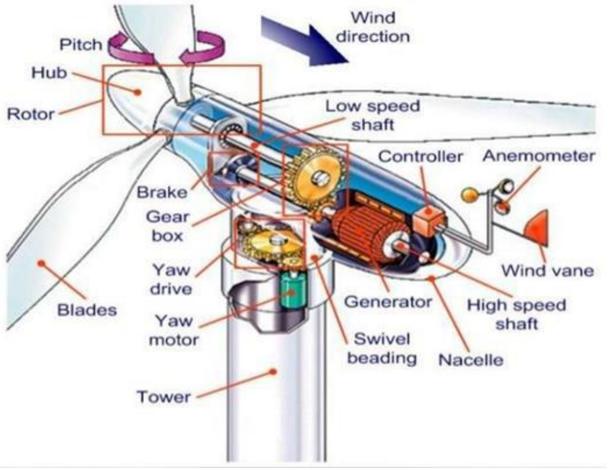

Figure 1: Horizontal wind turbine and its components

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 [8]. 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 [9], [10]. A study considers, effect of dust, humidity and air velocity on efficiency of photovoltaic cells, and found humidity and air velocity affecting the performance [11]. 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 [12].

A study established the effect of solar irradiance and temperature on the performance of monocrystalline module in Kakamega [13]. The performance of this module was evaluated in terms of its response variables open circuit voltage (*Voc*), short circuit current (*Isc*), fill factor (*FF*), efficiency (η), maximum power voltage (*Vmp*) , maximum power current (*Imp*), and maximum power (*Pmax*) as a function of solar irradiance and module surface temperature [14]. A study 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 [15]. Another study impact of wind on the output of P.V panel and solar illuminance/intensity [16]. 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 confirms that the ambient temperature has little or no direct effect on the module temperature [17]. A 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 [18].

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 [19]. 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. A design of a small wind generator for domestic use, 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 [20]. 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 [21]. 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.

II. 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

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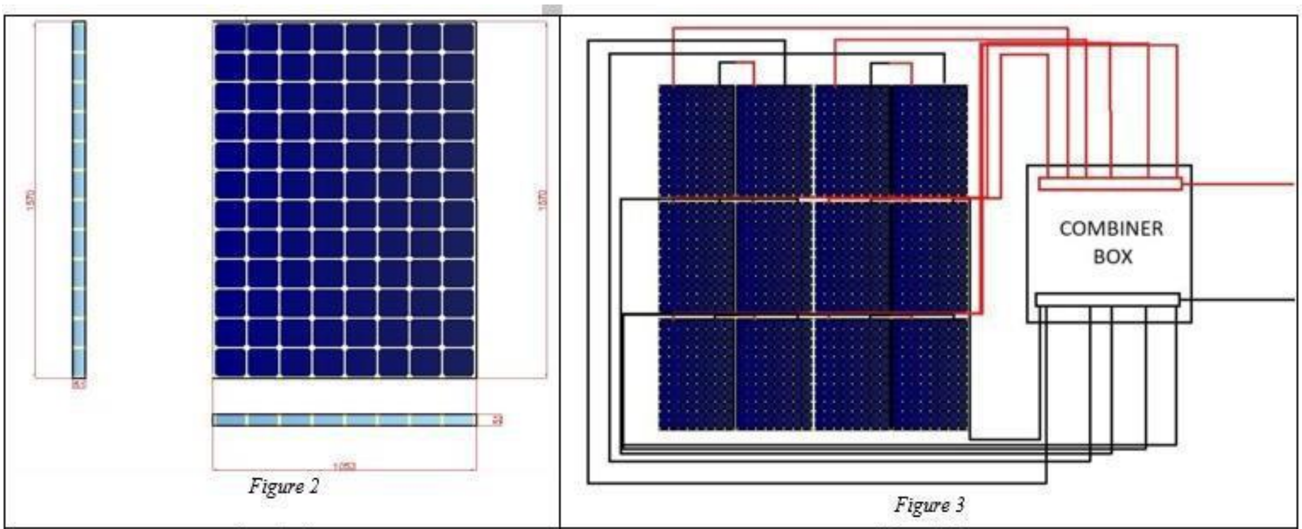
conduction band, creating electron (energy)-hole pairs. If the photon energy (incident solar radiation) is larger than valance band energy the electron-hole pairs produced, thus the solar radiation continues to fall and process continues and their exits an electric field in the semi-conductor materials and liberated electrons. The electrical forces caused electron to travel n-side and hole to its p-side of the diode.



Description	Description
Maximum power Pmax (-0.0/+3.0%) = 327W Short circuit current Isc = 6.46 A Open circuit voltage Voc = 64.90 V Current at maximum power = 5.98 A Current at maximum voltage = 54.70 V Weight = 18.6 Kg Dimensions: 1570×1053×51 mm	Single PV panel = 327 W 12 PV panels = 327 ×12 = 3924 W • 2 PV panels are not properly connected , for 10 PV panels = 327 ×10 = 3270 W

Figure 2 and 3: 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 Pmax is 327W with 96 cells on each panel. The details description of a single panel and 12 panels are shown in Fig. 2 and Fig. 3 by using AUTOCAD.

Fig. 4 illustrates the orthogonal view of a single P.V panel in a first angle projection. It depicts three orthogonal views: front view (F.V.), top view (T.V.), and right-hand side view (R.H.S.). The panel is mounted at a tilt angle of approximately 22 degrees, which is crucial for maximizing solar irradiance absorption. Measurements are provided for each dimension of the panel, helping in understanding its physical configuration and orientation for optimal solar energy capture.

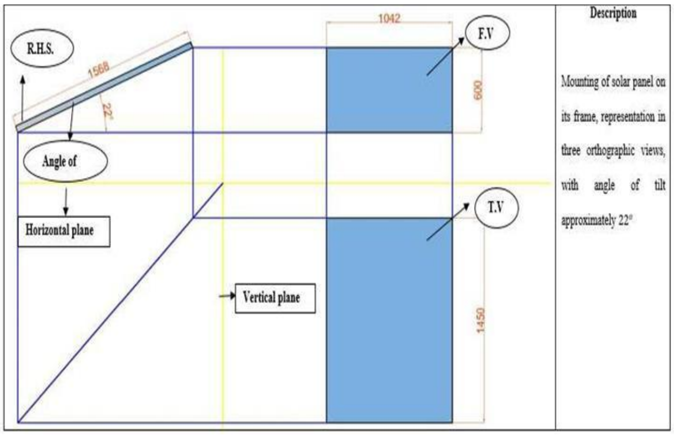


Figure 4: Orthogonal view of a single P.V panel in first angle of projection

III. 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 pair 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 4 th March 2020 from 8 a.m. to 4 p.m. with a

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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:

$$P_{meas} = V_{meas} \times I_{meas} \qquad (1)$$

Maximum power:

$$P_{max} = V_{max} \times I_{max} \qquad (2)$$

327 watts [for single panel] and 3270 watts [for 10 panels]

Normalized power output efficiency:

$$\eta_P = \frac{P_{meas}}{P_{max}} \times 100\% \qquad (3)$$

Open circuit voltage:

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

Short circuit current:

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

Light conversion efficiency of the solar system is given as:

$$\eta_{solar} = \frac{P_{max}}{A_c \times solarirradiance} . 100\% \qquad (6)$$

Where P_{meas}: measured power, P_{max}: maximum power, η_P: normalized power output efficiency, V_{oc}: open circuit voltage, I_{sc}: short circuit current, η_{solar}: light conversion efficiency, A_c: area of solar panel, K: Boltzmann constant, T: absolute temperature, q: elementary charge, b: proportionality constant, and H: solar irradiance. 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 (China) is used in this study and its description are listed in Fig. 5. 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).

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

The efficiency of the wind turbine is referred to as power coefficient Cp, 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.

$$C_P = \frac{ActualElectricalPowerProduced}{WindpowerintoTurbine} = \frac{P_{out}}{P_{in}}$$

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

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

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

$$C_P = \eta_b \times \eta_m \times \eta_e \qquad (9)$$

Where:

η_b: Blade aerodynamic efficiency
η_m: Mechanical efficiency
η_e: Electrical efficiency

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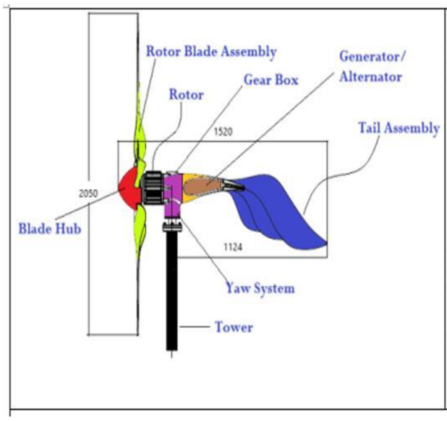

Technical Specification	
Model	HY-1500
Rated Power	1500W
Max. Power	1800W
Rated rotation speed	750rpm
Start-up Wind Speed	2.0m/s
Cut-in Wind Speed	2.5m/s
Rated Wind Speed	12m/s
Survival Wind Speed	50m/s
Rotor Diameter	2m
Blades Quantity	5
Swept area	3.3m²
Strong wind protection mode	electromagnetic brake,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

Figure 5: Orthogonal view of a single P.V panel in first angle of projection

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.

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

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

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

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):

$$\eta_{Hybrid} = \frac{P_{Hybrid}}{(A_c \times solarirradiance) + (P_w)} \qquad (13)$$

IV. 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 is surprisingly noticed during working times.

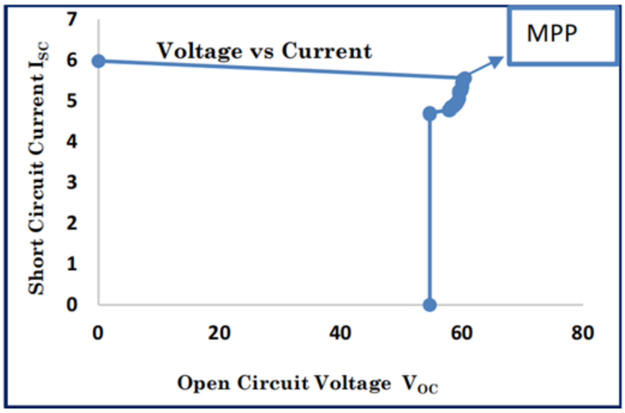

Figure 6: Single panel output's results

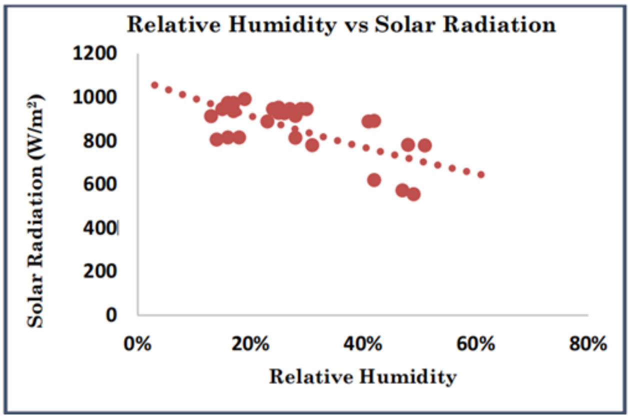

Figure 7: Variation of irradiance level with relative humidity

Bright and intense sunlight does not always mean that your solar panels will produce more energy. In fact, excessive heat can lead to a decrease in energy output from your solar panels. The energy output of a solar panel is calculated by multiplying the current by the voltage. Each panel, based on its efficiency, has a maximum energy production capacity. However, the impact differs between a single panel and an array of 10 panels; the latter experiences more losses due to factors like DC wiring, mismatch loss, soiling loss, and orientation. Fig. 6 displays the V-I characteristics of a PV module or array, providing a detailed description of its solar energy conversion ability and efficiency. This curve represents the typical operation of a solar cell or module, summarizing

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the relationship between current and voltage under current irradiance and temperature conditions. The V-I curve is crucial for configuring a solar system to operate as close as possible to its optimal peak power point (MPP). Fig. 7 illustrates the effect of solar radiation on relative humidity and what happens when light hits water droplets—three outcomes are possible: refraction, reflection, or diffraction. These interactions reduce the reception level of the direct component of solar radiation. Humidity affects irradiance non-linearly, causing slight variations in open-circuit voltage (Voc) in a non-linear manner and significant changes in short-circuit current (Isc) linearly.

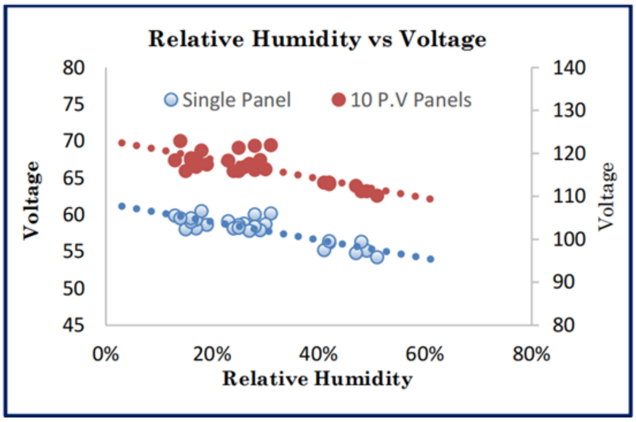

Figure 8: Graph of voltages against humidity

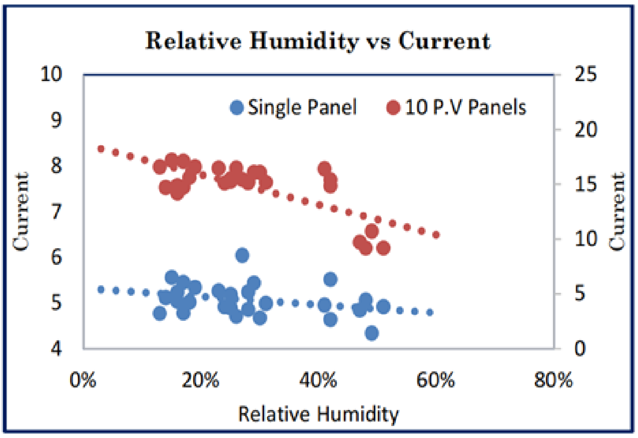

Figure 9: Graph of currents against humidity

Figure 8 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 is almost similar. Fig. 9 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.

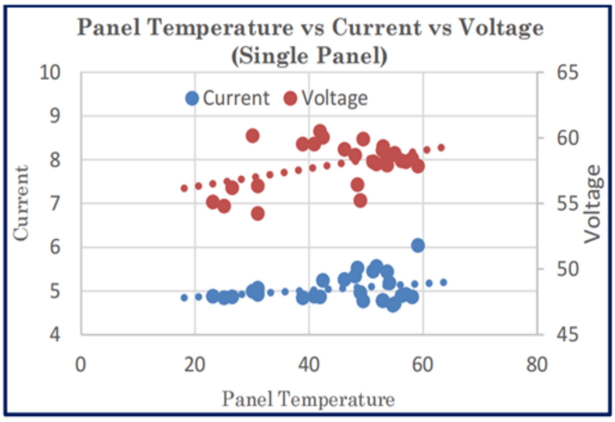

Figure 10: Variation of current and voltage due to panel temperature of a single panel

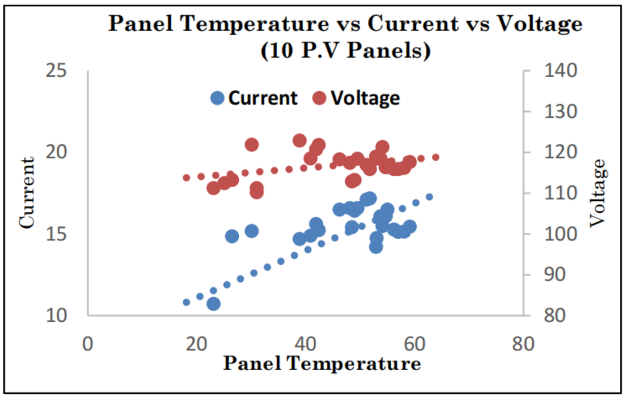

Figure 11: Variation of current and voltage due to panel temperature of 10 P.V panels

Figure 10, shows that between 25 ^{o}C and 50 ^{o}C current increases. With further increase in temperature, voltage remains fairly stable and beyond approximately 53 ^{o}C, voltage begins to drop indicating that temperature has significant effect on the voltage output. Fig. 11 shows that current increases with temperature from 30 ^{o}C up to 53 ^{o}C, where a peak in current is observed around 50 ^{o}C 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 50 ^{o}C. Voltage drop takes place with further rise in panel temperatures.

4.2 Wind Turbine

Figure 12 illustrates the varying expected power outputs in relation to wind speed. Generally, an increase in wind speed leads to an increase in power output. The input power (P_{inp}) increases continuously, while the maximum output power ($P_{out\ max}$) and actual output power (P_{out}) are limited by the turbine's capacity. A typical example showing the relationship between wind speed and power generated by the wind turbine is

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depicted. The blades begin to rotate at a wind speed of 2.5 m/s, at which point the turbine's performance is optimal. Above the cut-out wind speed, the turbine must be stopped to prevent damage. Additionally, Fig. 9 compares the power carried by the wind, the maximum power according to the Betz Limit, and the power produced at the University of Buraimi using this setup. Following this, a complete wind profile that includes variations in wind power based on wind velocity and the maximum possible power output at different wind velocities is estimated and presented.

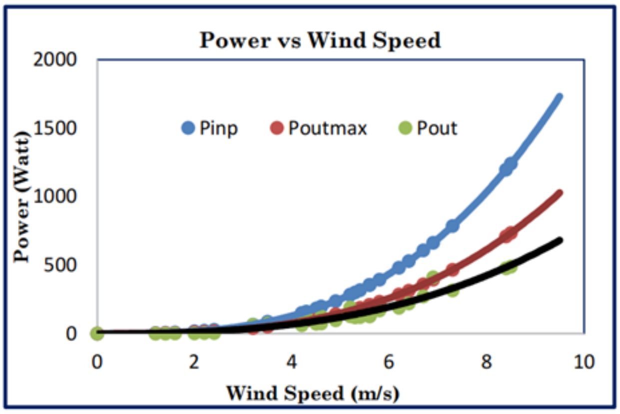

Figure 12: Power curve for a 1500 kW turbine

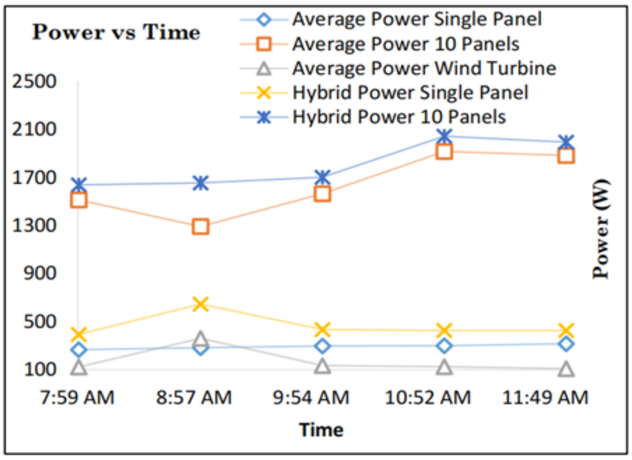

Figure 13: Power output measured with time for the three individual renewable energy systems compared with two hybrid systems

4.3 Renewable Energy Hybrid System (REHS)

The Renewable Energy Hybrid System (REHS) consists of two or more input energy sources. Power calculations are made using eq. (11). The goal of a renewable hybrid system is to provide a continuous power supply under various weather conditions. Initially, individual tests are conducted on the energy systems: a single solar panel, 10 solar panels, and a wind turbine. These systems are tested over three days, each for an eight-hour period from 08:00 AM to 04:00 PM, under different weather conditions, with readings recorded hourly. Following individual testing, the hybrid systems—comprising both the solar panel(s) and the wind turbine—are analyzed analytically. Two types of hybrid systems are constructed: one combining the wind turbine with a single panel (Hybrid System 1), and the other linking the wind turbine with 10 solar panels (Hybrid System 2). Results are calculated analytically using simple formulas, and the outcomes for both systems are illustrated in Figure 12. This figure compares the power outputs of individual and hybrid systems.

Overall, the comparison of power outputs is visible in the graphs presented in Figure 12. When compared under similar weather conditions, the hybrid system shows an increase in power output compared to the individual system. Notably, the configuration with 10 solar panels produces a higher power output than that with a single panel. Furthermore, power output in the hybrid system remains continuous, unlike in the individual systems, where the power from the wind turbine alone drops to zero. In the hybrid system, power only decreases when there is no wind; it does not drop to zero, thanks to the additional power source. The power output from a single panel in a hybrid setup increases gradually, while that from 10 panels increases drastically due to the surplus current supplied by multiple panels. Additional factors such as cost, availability, quality, installation, durability, and efficiency also influence the feasibility and performance of the chosen setup.

V. CONCLUSIONS

This experimental study observes the effects of relative humidity on current, voltage, and solar irradiance. It also confirms that ambient temperature has minimal impact on module temperature. The study applied photovoltaic technology (conversion of solar energy to electricity) during the first week of March at the installed location. A comparative analysis was conducted on the effects of relative humidity on electricity generation from a single panel versus 10 panels. The following observations were made:

- High relative humidity is typically experienced in the morning and evening, while low relative humidity occurs around noon due to the direct proportionality between temperature and relative humidity.
- In Al Buraimi, Oman, the average relative humidity is 28% during the first week of March, attributed to the geographical location.

The study also discusses other environmental factors that influence the performance of solar cells in various ways, either positively or negatively. Temperature reduction decreases solar cell performance, leading to lower power output. Humidity affects both the lifespan and power output of solar cells; it initiates rusting in solar cell modules, which directly impacts the lifespan of solar panels. Conversely, wind enhances solar panel performance by lowering the surface

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temperature of the modules. Light intensity directly correlates with solar panel efficiency; higher light intensity results in more photons hitting the panel's surface, which boosts solar cell output and efficiency.

Additional factors like clouds and visibility also play a role. The portion of absorbed solar radiation not converted to electricity turns into thermal energy, decreasing module efficiency.

The study also examined wind energy production using a small wind turbine with a rated output power of 1500 KW and a cut-in speed of 2.5 m/s. The turbine, equipped with five blades on its rotor, is designed to operate most efficiently under specific conditions. With advancements in commercial wind turbines for high wind velocities, research is now focusing on small wind turbines at low wind velocities. The performance of hybrid systems utilizing both solar and wind energy as renewable sources was analytically investigated, demonstrating the advantages of maximizing power output and maintaining a continuous power supply. Results in various weather conditions show that significant and continuous power is seldom achieved with just a wind turbine. A comparison between a single solar panel and 10 panels revealed that the hybrid systems generally increased power output. Specifically, the system with 10 solar panels produced more power than the single-panel setup when combined with the wind turbine. Additionally, the power output in the hybrid system was more continuous compared to the wind turbine alone and was higher than that of 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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