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# A Review of Hybrid PV System Design, Utilization and Its Efficiency

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***Abstract*—The energy demand is increasing day by day. To meet our requirements, we need to produce more electricity. The utilization of solar energy is currently less than 1%. But it is the efficient way to produce more electricity with minimum pollution to the environment. A number of research works on the hybrid PV system is made. The aim of this paper is to identify the suitable Hybrid PV system for particular application and also to provide the various aspects of hybrid systems. A brief review on optimization techniques, efficiency and the carbon-di-oxide emission for hybrid PV renewable energy systems are also discussed.**

***Index Terms*— Hybrid photovoltaic (PV) system.**

## I. Introduction

Hybrid energy system is the combination of two or more energy resources to supply the load. The main power of the hybrid system comes from the photovoltaic panels and wind generators, while the fuel cell and batteries are used as backup units [1]. The fuel cell (FC) is an electrochemical device that produces direct current electricity through the reaction of hydrogen and oxygen in the presence of an electrolyte. They are an attractive option for use with intermittent sources of generation, like the PV, because of high efficiency, fast load response, modularity, and fuel flexibility. Unlike a battery, a FC does not require recharging [2]. The energy supply for isolated rural areas is usually provided by diesel generators. However, such fuel costs are generally high due to increases in diesel fuel prices and the additional costs of transport [3]. Higher environmental protection, greenhouse gas emission, especially CO2 and reduction in other pollutants emissions is expected due to the lower consumption of fuel. The cost of solar and wind energy can be competitive with nuclear and the diversity and security of natural resources who are free, abundant, and inexhaustible [4]. In this paper, we focus on the utilization of HRE (Hybrid renewable energy). The combinations of two or more renewable energy sources are discussed. The objective of this paper is to help the reader obtain an incisive overall understanding of HRE utilization, which is conducive to the promotion of HRE technology [5].

## II. Experimental Setup

### A. Hybrid Solar Collector

An experimental setup has been built for this purpose as shown in Fig.(1),which consists of solar panel absorption plate with the following dimensions; 148 cm long and 68 cm wide with an emissivity of (= 0.85)[19]; the solar panel worked as heat absorbing surface. The solar panel has been fitted inside an exterior frame consists of a wooden base entirely isolated from the sides and rear. In order to improve the electrical efficiency of the system, the heat drew directly by using air ventilator. The ventilator (air fan) connected to the outlet to draw the air outside of the system; the improvement happened because the losses are a function of the difference between the inner and the outer temperature in the collector, and as the air drawing continues, the temperature of the solar panel will reduce. A transparency glass cover had been used with 6 mm thickness at the front side of the system to reduce the heat losses and prevent the air leakage; the glass cover was fixed on the front side by using a material to prevent the air leakage [6].

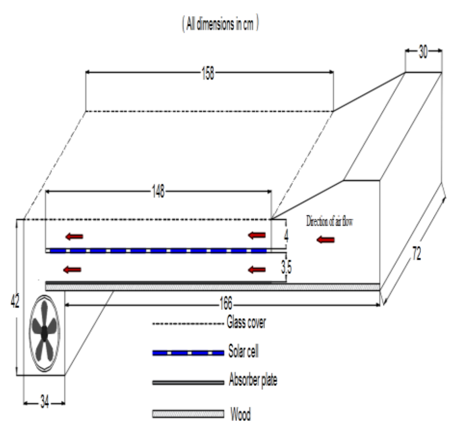

Fig. 1. Sketch of the experimental setup with dimensions

### B. Modelling of Photovoltaic System and Wind Turbine

The photovoltaic (PV) model designed in MATLAB/ Simulink environment is depicted in Fig. 2. The proposed model requires few parameters like shot circuit current, open circuit voltage, and the number of photovoltaic modules used as well as its temperature coefficient. Moreover, this model is appropriate for simulating the practical photovoltaic systems which consists of several PV modules and it represents the changes in temperature and solar irradiance that usually occur during the day [1], [2], [7].

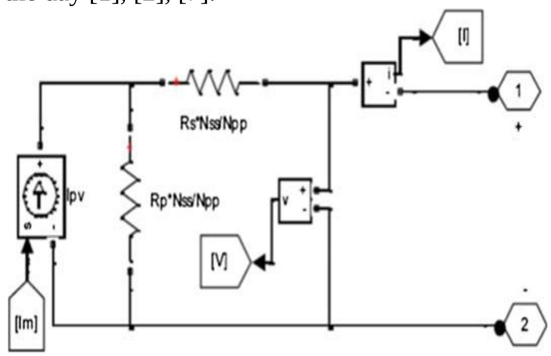


Fig. 2. Circuit-based PV model

### *C. Modelling of Power Conditioning System*

The power produced from the renewable energy sources (RES) like wind, PV, hydro, fuel cell, biomass, and micro turbine is either DC/AC with different voltage and frequency levels. Power electronic interface is necessary in order to interconnect RES with grid. The input parameters like irradiation and temperature of the PV system changes according to the environmental conditions which results in unregulated DC output voltage. In case of wind energy system the output power generated is in the form of AC which is converted to DC by using uncontrolled rectifier. The DC–DC boost converter is implemented to modulate the output power produced from the wind and PV sources. The regulated output power is supplied to the load and to the grid through voltage source inverter [7–9]. The schematic diagram of DC–DC boost converter is depicted in the following Fig. 3[7].

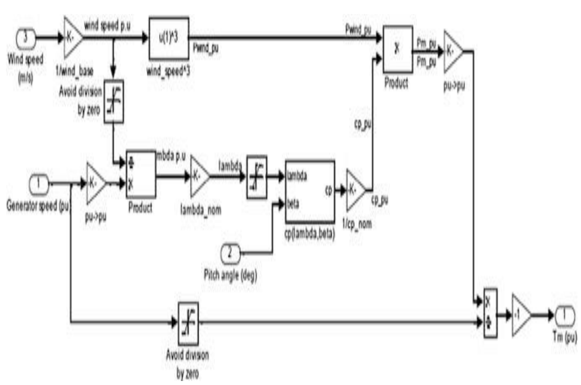


Fig. 3. The wind turbine is model in MATLAB/Simulink

## III. DESIGN OPTIMIZATION

### *A. Homer Simulation*

For the hybrid energy system, the design variables include number of wind turbine 255 generator (WTG), number of PV arrays, number of battery unit and converter[15].We build a hybrid energy system in HOMER with PV arrays, wind turbines and battery storage for the Catalina Island. The system configuration is shown in Figure 5. In this schematic Figure, renewable energy power is generated by PV arrays and wind turbines. The generated power plus the energy stored in the battery is used to meet the load demand. Catalina Primary Load is the electrical load that the system must meet in order to avoid unmet load. A converter is used to transform the energy from DC to AC to serve the load. Input information in HOMER includes hourly solar radiation, hourly wind speed and hourly load data, as explained in Section II [16].

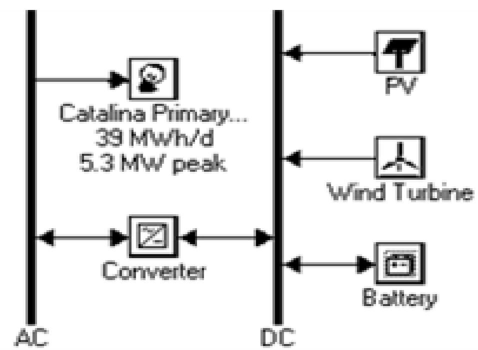


Fig. 4. The hybrid energy system with PV/ wind turbine/ battery storage for Catalina Island in homer.

### *B. Reflective Mirrors*

Two experimental models have been built as in Fig. 1 to compare the thermal and electrical performance of the hybrid thermal collector, which contain the main following parts: collector iron carrier, wooden structure, solar cells, reflecting mirror, and measuring devices. The first model consists of Mono-crystalline solar cell; the specifications of the solar cell modules used. The solar cells worked as heat absorbing surface. The solar panel has been fitted inside an exterior frame consists of a wooden base entirely isolated from the sides and rear. 4 mm thickness glass cover was mounted at the distance 2.5 cm from the solar cell; the glass cover was fixed on the front side by using a material to prevent the air leakage. Glass emissivity and equal to 0.88 (Khalil & Al-Jibouri, 2014). Lower and upper reflective mirrors with dimensions (120 cm length, 50 cm width) were used to increase the incident solar radiation on the solar cell. A movable iron structure was designed for the lower mirror, and can be moved in different directions. Heat exchanger as shown in Fig. 3 was closely fixed in the rear side of the solar cell, the dimensions of this heat exchanger was shown in Fig. 3-b. The second model was uncooled (still hot or warm) solar cell (does not contain heat exchanger below it and without mirror and glass cover). The aim of manufacturing two experimental models was to achieve a precise comparison of the effect of operational and designing variables which effect on the performance of the PV/T collector to get the relied of this comparison. Different thermocouples (K type) were used to measure temperature in different location in the experimental set-up. In the first model, two sensors were used to measure the inlet and outlet temperatures to the hybrid collector as shown in Fig. 4. Two additional sensors were used to measure the temperature of the front and rear of the solar cell and two thermocouples were used to measure the temperature of the heat exchanger, the seventh sensor was fixed in the middle of the glass cover to calculate its temperature, while the temperature of the second model (uncooled solar cell) was calculated by fixed two thermocouples on the front side of solar cell, the distance between them was (60cm). The electricity generated by the cells was stored in batteries. A pump connected to the batteries was used to pump the water to cool the solar cell. The voltage and current were measured using DC voltmeter and digital ammeter, respectively. Solar meter (SM 206) was used measured the intensity of the solar radiation and fixed at the same height of the solar cell. Wind speed was also measured and the load. Flow meter was used to measure the mass flow rate of water entering the hybrid PV/T collector. Four lights (DC-current) were used with capacity of 12 W, as a load of solar cell. Fig. 5 shows the sketch of used device. The cold inlet water entered at the bottom of collector and the hot water outlet was taken from the top of collector. The mass flow rate of load water was regulated by a valve at the inlet of the collector. The load mass flow rate was measured by timing the water collected in a graduated vessel of 1 l capacity [19].

## IV. Performance Analysis

HOGA provides the simulation results in terms of optimum system and optimum control strategy. The optimization results of the renewable hybrid system. HOGA posts a list of configurations which it noted feasible for this project. The evolution of the best Total Net Present Cost found with HOGA as a function of the genetic algorithm in an optimization, where the number of generations in the genetic algorithm is 20 [21]. It is clear that they highly depend on weather data of the chosen location (IUR Rabat). The yearly average of energy production from a PV array is 9581.76 kWh, while the yearly average of energy production by the wind turbine is 1404 kWh. Thus, this configuration can ensure 10822.85 kWh/Year to power the ELD of Bituma (ship carrying chemical) Prototype. The electrical energy production of the chosen week (March 20–26) is presented; the hybrid production in the blue1 curve is composed of PV array/Wind turbine electrical energy production. Excess energy serves to charge the battery bank. It may happen that the hybrid produced power doesn't cover the load demand at a specific period of the day. In that case, the battery can ensure the needed energy until its discharge. When that happens, the system can connect to the grid in order to feed the loads .For the chosen period from 18th to 24th of June; an important part of the produced energy is illustrated in the blue curve. PWHS is in its maximum productivity. Excess energy is stocked in the battery and used to cover energy demand at night times. It appears that PWHS covers all the load demands with minimal grid connection. A dynamic simulation during the chosen period from 17th to 23rd of September is illustrated. During the second day, the hybrid production did not reach its nominal value. Even though it covered the load demands during the daytime, it did not supply sufficient power to fully charge the batteries. Consequently, the hybrid system should be switched to grid the next day .However, power produced during the final period (18th to 24thDecember), was able to cover the load demands for almost the whole period, where during the 24th the hybrid system was tied to the grid[22].

## V. Reduction In $CO_2$ Emission

Diesel generator (DG) is used in proposed HRES which produces a number of harmful gases such as carbon monoxide (CO), Carbon Dioxide (CO2), Sulphur dioxide (SO2), nitrogen oxides, particulate matter and unburned hydrocarbons of all harmful gases, carbon dioxide takes up the largest share of emissions. Because of this reason, the penalty cost is considered only for carbon dioxide in the proposed case [24]. Recently, published research papers have proposed several novel approaches of HRE utilization that deserve attention. Nocera and Pamela [135] from Harvard University developed a hybrid solar-biosynthetic system based on a biocompatible earth-abundant inorganic catalyst system to split water into molecular hydrogen and oxygen with the assistance of solar energy. Ralstonia eutropha (Bacteria found in soil and water) is employed to synthesize bio fuel by consuming the produced $H_2$ in low concentrationCO2. Compared with the conventional HRE utilization, bio fuel can be produced and $CO_2$ is directly utilized. Yang et al. [136] from UC Berkeley proposed a hybrid solar self-augmented biological system. A non-photo synthetic bacterium, Moorella thermoacetica (Bacteria belonging to firmicutes), with cadmium sulfide nano particles on its surface was prepared. Biologically precipitated cadmium sulfide nano particles use solar energy and release electrons to the inner Moorella thermoacetica enabling photo synthesis of acetic acid from $CO_2$. Coincidentally, the above two studies are implemented based on the idea of synthesizing chemicals including bio fuel by consuming $CO_2$. The mentioned reaction cycles are all driven by solar energy [5].

## VI. Results and Discussion

Due to advance material and better manufacturing process the price of solar photovoltaic system will be reduced in near future. Hence, by considering PV panel price as a sensitivity variable, system should be simulated. Several prices of panels are checked against the cost of energy and it is observed that if the panel price reduced to 20% cost of energy changes from 0.4 to 0.1$/kWh [1]. Two case studies have been discussed and compared. The first was for Masirah Island 12MW hybrid PV–Wind solar plant and the other one was for Al Halaniyat Island where the CoE found to be 0.182$/kW hand 0.222$/kWh, respectively, which sound that HRES is promising in Oman. It is found that there is Potential of solar-wind energy. However, Iterative and Artificial Intelligence optimization techniques used shows more accuracy and fast comparing with other optimization techniques [4]. The zigzag mode of variation of energy efficiency with respect to the time is because of different wind velocities that caused different overall loss coefficient. Also, it is notice there are high increases in the energy efficiency through the first hours of the working interval 8–10 a.m. This is due to the great increase in the net solar energy absorbed, accompanied with comparatively small heat losses from the hybrid system to the environment. Also, the energy efficiency for the clean collector reaches its maximum value 42 % at 11.15 a.m. and then decreases. The maximum value for a dusty collector was 38 % at 11 a.m. and then decreases [6].

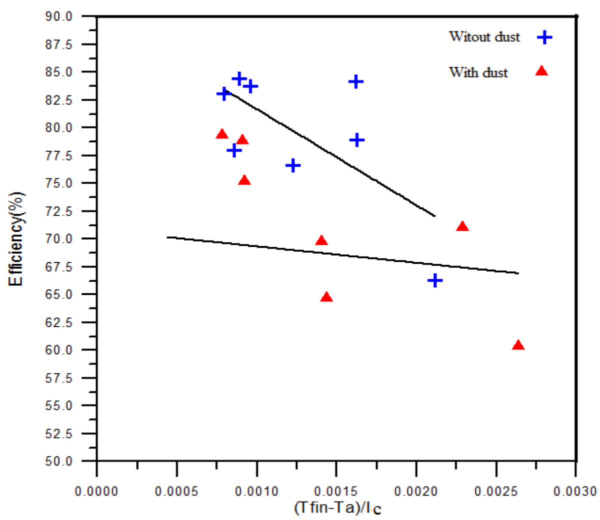


Fig. 5. Mode of variation

The grid current is about 50 A from 0 to 0.2 s, it is reduced to 40 A when a load of 4 kW is connected through the breaker at 0.2 s and it is reduced further to 30 A when another load of 7.5 kW is connected through the breaker at 0.5 s. Similarly, the load current is about 20 A from 0.2 to 0.5 s and it is 50 A from0.5 to 0.9 s. The grid voltage and inverter voltage is about 325 V. In this work, control strategy is developed for grid connected hybrid system. Implementation of control strategy for stand-alone hybrid system can be done to supply power to the local loads. In order to increase the reliability, battery energy storage system can be connected across the DC link [7]. PV power does not depend on the module power, but rather, by including an economical consideration, a 125 W module configuration is better than a 50 W one. Configuration including battery storage (253 Ah) appears to be better than that using battery storage (102 Ah). The rating of the PV panels in this project is 11.7 kWp, the battery bank is 120 kW h and the diesel generator rating is 20 kV A. The performance of the system was monitored for 6 months. The economic analysis after this period of monitoring indicated that the COE production was about 0.65 $/kWh. The same analysis appeared that the COE by the diesel only scenario was around 0.75 $/kW h [32]. The COE production for the hybrid PV/diesel scenario considered in this study as indicated in Table 6 is 0.398 $/kW h. The decrease in COE production compared to the Atouf project is due to decrease in capital costs of the various components in the near past years. As indicated in the same table, the COE for the PV/microturbine hybrid system is less when compared with other scenarios [12].

## VII. Conclusion

From the review of Hybrid PV system, it can be concluded that

1) The yearly average of energy production from a PV array is 9581.76 kWh, while the yearly average of energy production by the wind turbine is 1404 kWh. So, the power generated by Hybrid PV system is comparatively high.
2) The emission of CO2 level is greatly reduced by using Hybrid PV system when compared with usage of diesel generators.
3) By using ventilators and transparency glasses, the heat loss is reduced. Therefore, efficiency is increased due to preventing air leakage.
4) By using the reflective mirrors, the intensity of the light is increased. Thus the efficiency also gets increased.
5) From the expenditure analysis, it can be seen that the cost of producing power through Hybrid PV system is minimum when compared with Diesel generators used in rural areas.
6) Thus we are using renewable energy sources, In future, the availability of the sources will not be reduced and it can also be implemented in urban areas.

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