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# Designing an Optimal Nano-grid Using a Hybrid System

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***Abstract*—This paper proposes a power plant system consisting of solar and wind energy. System Advisor Model (SAM) designed and simulated the proposed system using average solar radiation and wind speed data. The photovoltaic (PV) system has the rated generated power of 4kW, and the wind system also has the capacity of 2.2 kW utilizing for a residential house in Florida. By implemented this hybrid system, the annual energy production found to be 9090 kWh per each year. By the cost of 10 Cent per each kWh, the amount of $ 909 will be saved in each year. Furthermore, the payback time of this system based on the simulation result of SAM is 14 years. As a result, using this system is both cost effective and successful in terms of removing harmful pollutants from the air.**

***Keywords—Renewable Energy, Wind Power System, PV System, SAM Software***

## I. Introduction

As a result of the rapid rise of population of the countries, electrical devices and electric cars, the world is experiencing a surge in energy consumption. The decline of conventional fuel sources has resulted in energy shortages in several countries [1]. In addition, the scarcity of fossil fuels has been a major source of concern in recent years, affecting people's daily lives. Rising energy demand is increasing the pressure on energy companies to expand power facilities, which is a costly and long process [2-4]. Another issue with utilizing fossil fuels is the release of pollution gasses into the atmosphere, which causes substantial difficulties in large cities [5, 6]. To addressing this issue, a hybrid renewable energy system might drastically reduce emissions [7]. Solar and wind energy are the most widely used renewable energy sources because they are widespread, abundant, and pollution-free. In actuality, due to the following facts, designing a hybrid solar-wind system is rather difficult [8]. To begin, the solar array's output power changes depending on weather conditions (sunny or cloudy days) and temperature [9]. As a result of the time of year and the limited reliability of the wind, the output power of the wind varies [10]. Third, a battery bank is required, which is somewhat expensive. Fig. 1, shows the hybrid system proposed in this paper.

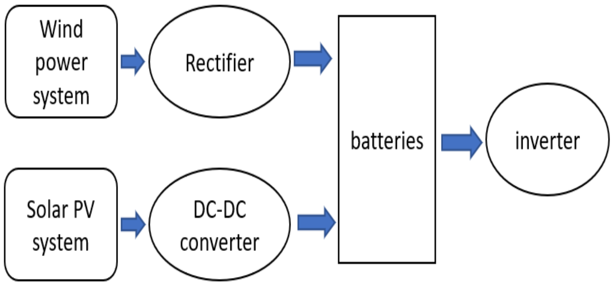


Fig. 1. Proposed hybrid system

A wind power system (turbines, towers, and generators), solar modules, dc-dc converters, rectifier, an inverter, and a bank of batteries are required for the proposed system, as shown in Fig. 1. Several studies on the design of hybrid solar-wind systems have lately been carried out. A solar-wind system was examined in [11], that has the potential to reduce battery storage capacity as well as total system cost. In [12] the modeling of another system utilizing multi agent technology was investigated with the goal of improving the system's intelligence and reliability. Optimal design was also examined by HOMER in [13], with the purpose of discovering the most cost-effective and high-performance solutions for meeting the load's requirements. In this paper, a hybrid solar/wind system is designed and simulated via SAM. The proposed hybrid system is able to provide required energy for any time of the year.

## II. System Design

The proposed system consists of two separate parts including a PV system and a wind system.

### *A. PV System*

Light is converted into power using photovoltaic (PV) systems. Fig. 2, depicts an analogous circuit for a solar cell, in which monocrystalline silicon cells are used in this study.

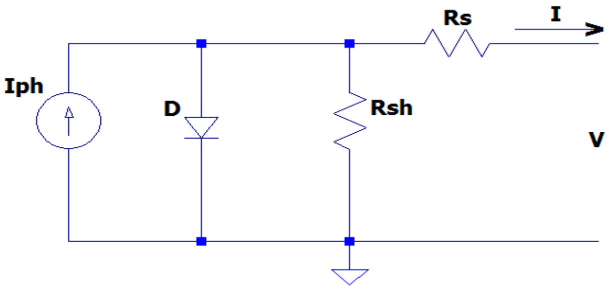


Fig. 2. A one-diode circuit of a solar cell

According to Fig. 2, the output current is computed as follows:

$$I = N_P I_{SH} - N_P I_S \left[ \left( \frac{q\left(\frac{V}{N_S} + \frac{IR_S}{N_P}\right)}{KTA} \right) - 1 \right] - \frac{\left(\frac{N_P V}{N_S} + IR_S\right)}{R_{SH}} \quad (1)$$

In the Eq. (1), $R_S$ and $R_{SH}$ are the series and parallel resistance, I and V are the output current and voltage, $I_S$ is the diode's saturation current, $N_S$ and $N_P$ are the number of cells in series and parallel, T is the cell temperature in terms of Kelvin, and A is the diode ideal coefficient, K is Boltzmann's constant is equal to $K = 1.23 \times 10^{23}$ and $q = 1.6 \times 10^{-19}$ is the charge of an electron in units of coulomb (C), and $I_{SH}$ is the photovoltaic current [14]. To match the load with the solar array, in order to absorb the maximum power, a buck, boost, or buck-boost DC-DC converter is used which has to be with maximum power point tracking system (MPPT) or Distributed maximum power point tracking system DMPPT [15-17]. The proposed system is for the residential building in Florida with the latitude angle of 27.93 degree and the longitude angle of 82.93 degree. Table 1 shows the characteristics of the rooftop PV system that is being employed.

TABLE I
FEATURES OF THE ROOFTOP PV MODULE UNDER STC CONDITION

| | | | |
|---|---|---|---|
| Cells per module | 96 | Tilt angle | 28° |
| Operation temperature | -40 - 85 °C | Latitude angle | 27.93° |
| modules | 14 | Longitude | -82.46° |
| Efficiency | 16.8% | Azimuth | 180° South |
| Rated DC power | 289.8 W | Frame | Anodized Aluminum |
| $V_{oc}$ | 43.9 V | Weight | 16.6 kg |
| $I_{sc}$ | 9.2 A | SIZE | (1.66 * |

| | | | |
|---|---|---|---|
| | | | 0.99) |
| | | | m |
| $I_{MPP}$ | 8.6 A | Type of module | Mono-Silicon |
| $V_{MPP}$ | 33.7 V | Mounting system | Fixed rack |

In Table 1, all of the required parameters are listed, including: Rated DC power, short-circuit current, Open-circuit voltage, Voltage at maximum power point, and Current at maximum power point. According to Table 1, the system reported in this paper has a rated DC power per module of 289.8 W, an open circuit voltage of 43.9 V, a short circuit current of 9.2 A, and the area of 23 square meters.

### *B. Wind System*

An isolated footing shallow foundation in the shape of a circular, hexagonal, or octagonal is required to design the wind turbine foundation. In addition, geotechnical data is required, which varies depending on the location. The kind of soil (clay or sand) and layers of soil in the basement foundation's effect zone, bearing capacity, and water table information are all included in this data. Water table may be examined on the ground's surface since Florida has a humid subtropical climate and is located near the ocean. In addition, statistics on the weight of the turbine and the lateral force of the wind are required, both of which are distinct in terms of turbine type and the location throughout Florida. The design is based on a safety factor of three (Fs=3) in order to have higher safety.By slowing down the wind, a wind turbine converts the energy of the wind into electricity. The quantity of power that can be extracted from the wind is determined by both the wind speed and the area of the revolving turbine blades [18, 19]. Table 2 shows the characteristics of the wind system that is being employed.

TABLE II
FEATURES OF THE WIND SYSTEM

| | |
|---|---|
| User-defined rated output | 2.2 kW |
| User-defined rotor diameter | 3.7 m |
| Maximum Cp | 0.42 |
| Maximum tip speed | 40 m/s |
| Maximum tip-speed ratio | 6.5 |
| Cut-in wind speed | 3 m/s |
| Cut-out wind speed | 25 m/s |

Also Fig. 3, indicates the power curve of the proposed wind system.

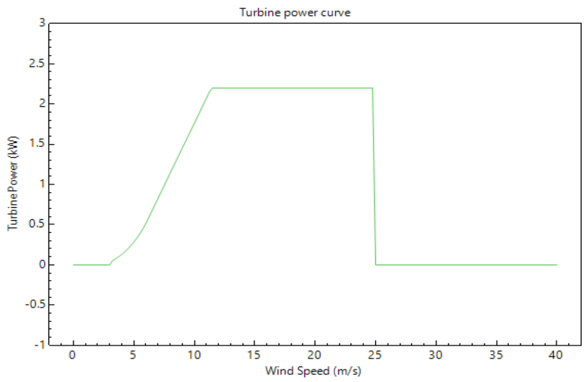


Fig. 3. Power curve of the proposed wind system

The tip speed of a wind turbine blade divided by the wind speed is known as the tip speed ratio (TSR) [20].

$$\lambda = \frac{\omega R}{V} \qquad (2)$$

TSR is defined by Eq. 2, where w is the mechanical frequency of the turbine and v is the wind velocity [21]. When the TSR is equal to its maximum value $\lambda_{max}$ the power coefficient $C_p$ obtains its maximum value, as seen in Fig. 4.

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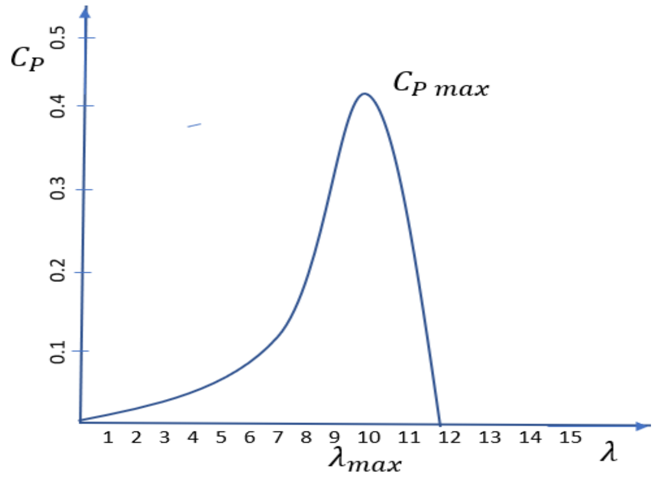



Fig. 4. The relationship of $C_p$ versus $\lambda$

The wind turbine's maximum output power is:

$$P_m = \frac{1}{2}\rho s v^3 C_p \qquad (3)$$

Where s is the area swept by the blade of the wind turbine and $\rho$ is the air density [22]. In the next section the simulation and result are shown.

## III. SIMULATION AND RESULT

Please Fig. 5, shows the sun radiation and the wind speed data. As it is obvious, the sun radiation is near to 1000 $\frac{w}{m^2}$ and wind speed data is up to 20 $\frac{m}{s}$.

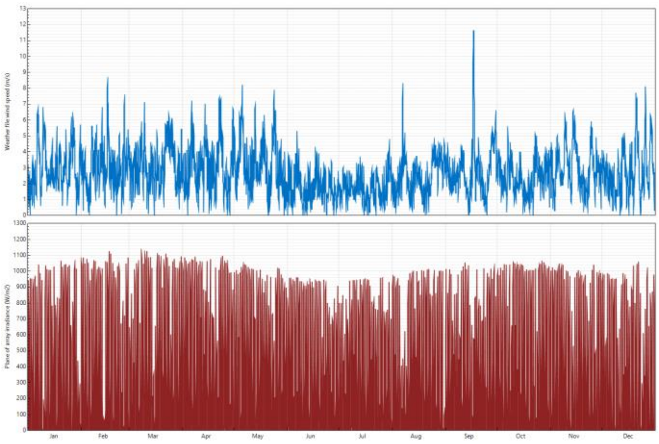


Fig. 5. Sun radiation and wind speed data.

Furthermore, Fig. 6, indicates the cell temperature and hourly generated power form the PV part.

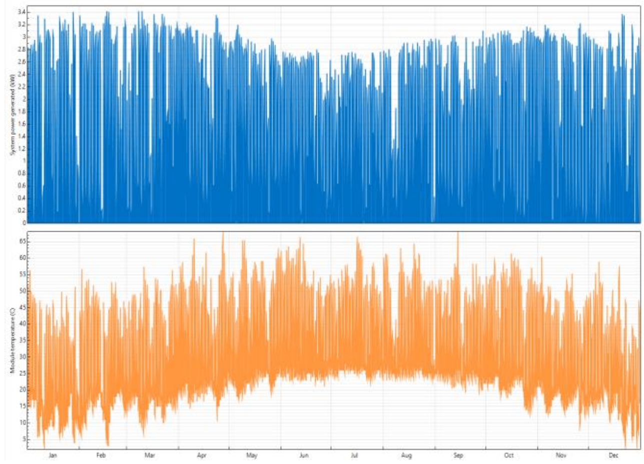


Fig. 6. Cell temperature and hourly generated power form PV

The required load for the calendar year is depicted in Fig. 7. According to the graph, the amount of energy required is substantially higher during the summer months since individuals use more electricity to cool their homes.

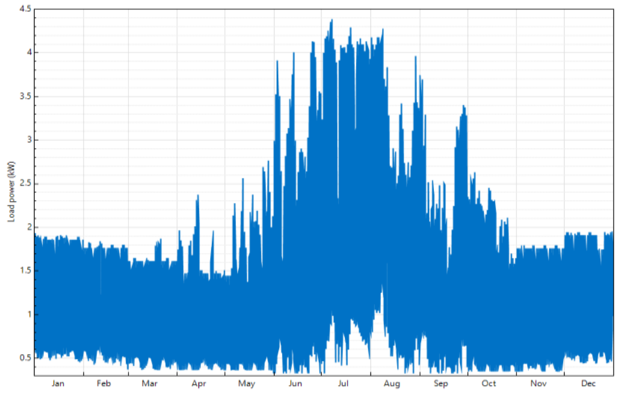



Fig. 7. Load power for the entire year

Fig. 8, shows the power generated by PV system. As it can be seen the monthly output power is higher during summer months.

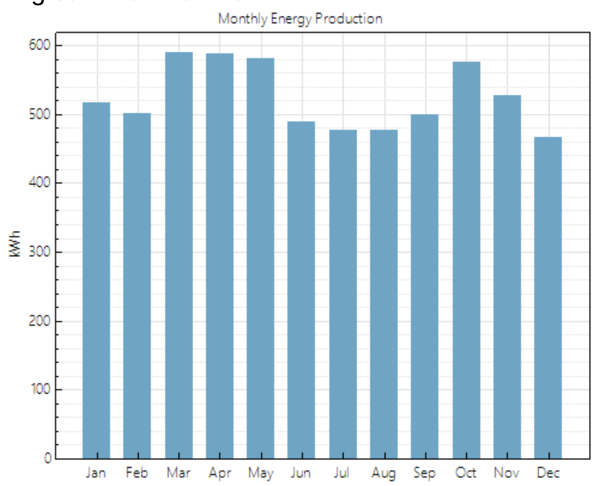



Fig. 8. Output power by the PV system

The heat map of the PV system is shown in Fig. 9. This heat map depicts a window of time between 9 a.m. and 3 p.m. during which the solar system is able to generate electricity due to solar radiation.

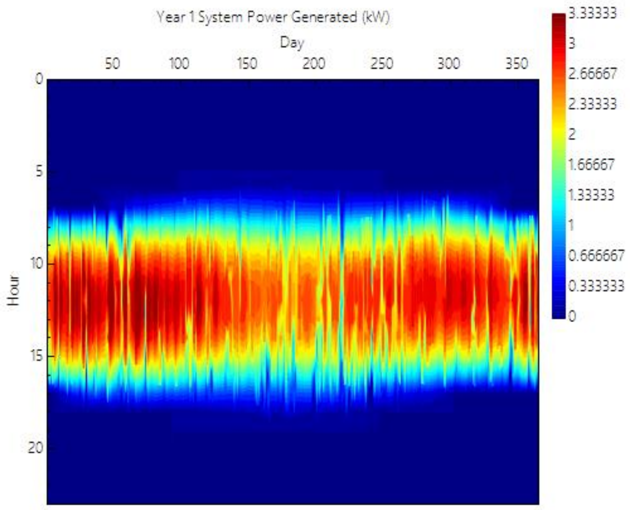



Fig. 9. Heat map of the yield power by the PV system

The yield power of the wind system is depicted in Fig. 10. As can be observed, wind energy is less during the summer months and higher throughout the spring and fall months.

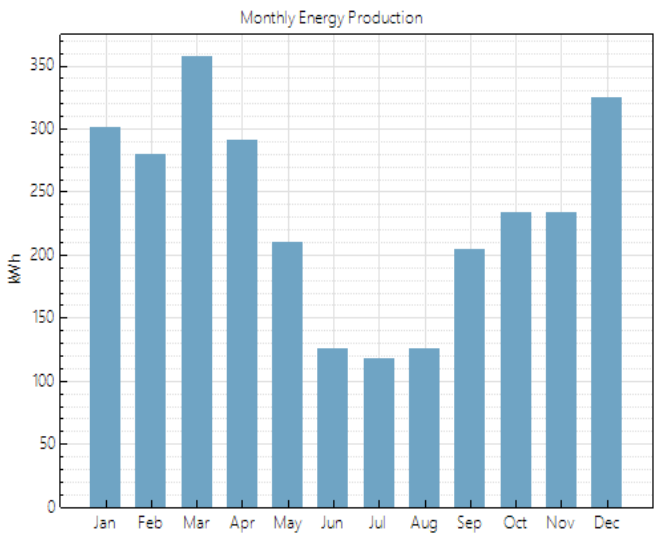



Fig. 10. Output power by the wind power system

Fig. 11, indicates the wind system's heat map. In contrast to solar energy, wind is available throughout the day, rather than just during the noon hour.

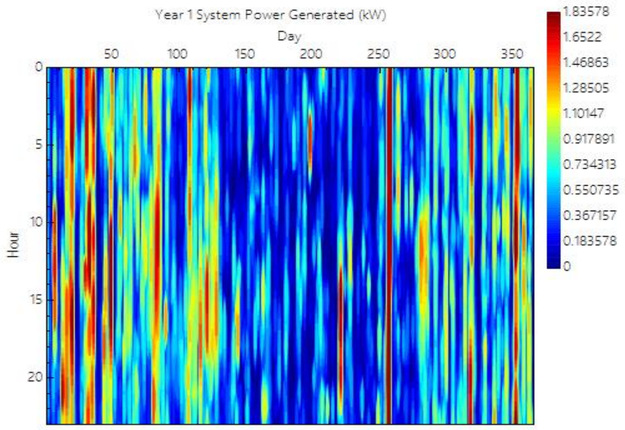
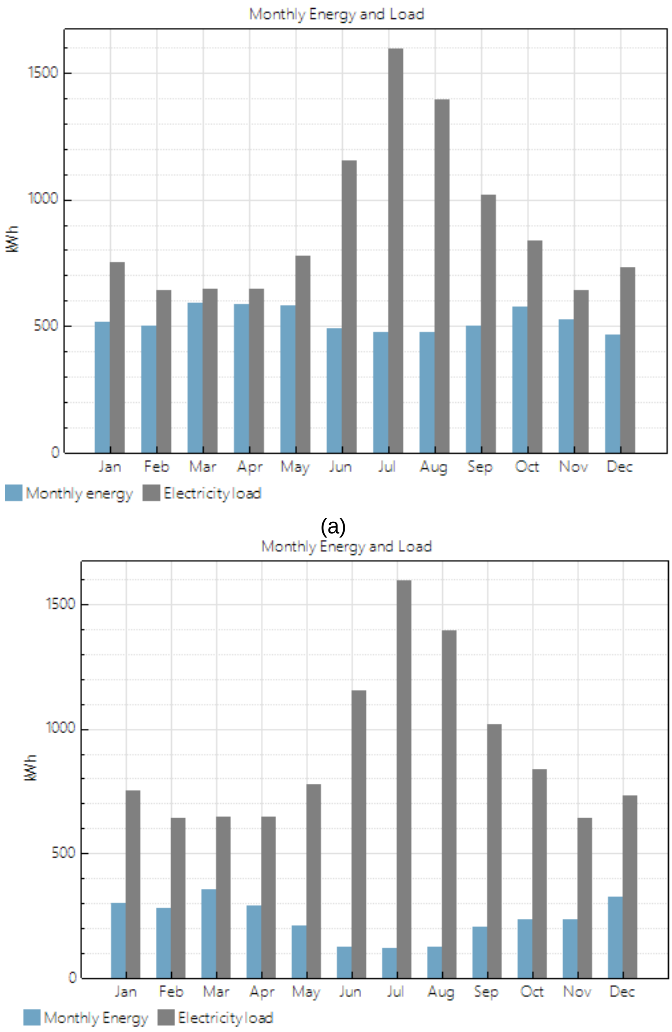



Fig.11. Heat map of the yield power by the wind power system

The monthly energy production vs the electrical load for the building is depicted in Fig. 12. As can be seen, combining solar and wind energy will provide nearly all of the energy required for the house.




(a)

(b)

Fig. 12. Monthly energy production energy versus the electricity load for the building (a) solar versus load (b) wind versus load

Table 3 shows the annual power generation from both renewable energy sources. In addition, the PV and wind systems have capacity factors of 17.9% and 14.6% respectively.

Table III

METRIC FEATURES OF PV AND WIND SYSTEM (a) PV SYSTEM (b) WIND SYSTEM

| Metric | Value |
|---|---|
| Annual energy (year 1) | 6,285 kWh |
| Capacity factor (year 1) | 17.9% |
| Energy yield (year 1) | 1,571 kWh/kW |
| Levelized COE (nominal) | 10.39 ¢/kWh |
| Levelized COE (real) | 8.29 ¢/kWh |
| Electricity bill without system (year 1) | $1,514 |
| Electricity bill with system (year 1) | $847 |
| Net savings with system (year 1) | $666 |
| Net present value | $1,513 |
| Simple payback period | 14.4 years |
| Discounted payback period | NaN |
| Net capital cost | $10,886 |
| Equity | $0 |
| Debt | $10,886 |

(a)

| Metric | Value |
|---|---|
| Annual energy (year 1) | 2,805 kWh |
| Capacity | 2 kW |
| Capacity factor (year 1) | 14.6% |
| Levelized COE (nominal) | 46.70 ¢/kWh |
| Levelized COE (real) | 37.08 ¢/kWh |
| Electricity bill without system (year 1) | $1,744 |
| Electricity bill with system (year 1) | $1,324 |
| Net savings with system (year 1) | $421 |
| Net present value | $-7,751 |
| Simple payback period | NaN |
| Discounted payback period | NaN |
| Net capital cost | $22,000 |
| Equity | $4,400 |
| Debt | $17,600 |

(b)

## IV. CONCLUSION

The small solar wind power plant in this study aids in the production of environmentally friendly energy while also saving money on utility costs. Because of the restricted space for panel installation and the sun's inaccessibility at night and on cloudy days, a hybrid solar-wind system is chosen. The goal of this research is to conduct a complete feasibility analysis of a hybrid PV/wind hybrid system in Florida. This article was developed using SAM to do a technical and economic analysis on a wind/solar hybrid system in order to save money and maximize efficiency. Therefore, even with varying solar irradiation and wind velocity, a constant residential load is maintained. Furthermore, the hybrid system asynchronous nature makes them a more suitable and stable power system for generating the required power.

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