Network for Research and Development in Africa

International Journal of Information, Technology & Innovation in Africa
ISSN: 2360-9772. Volume 12, Number 4
Pages 01-10 (December, 2021)
www.arcnjournals.org

Comparative Study between Wind and Photovoltaic (PV) Systems (Case Study of Borno State)

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Abstract: *This paper reviews two renewable energy systems; wind and photovoltaic (PV) systems. The common debate between the two of them is to conclude which one is better, in terms of feasibility in the region under study (Maiduguri). The main components and parameters that play major role in determining the overall efficiency of wind and solar PV systems are the wind turbine generator (WTG) and the PV systems respectively. The developed methodology has been applied to simulate PV and wind system in MATLAB/SIMULINK environment. The inputs parameters are monthly average solar radiation, temperature and wind speed data obtained from Nigeria Meteorological Department, Maiduguri, and data covered four years average monthly from 2016 to 2019.The inputs to the software are; solar radiation and temperature for the solar PV array, and wind speed for the wind turbine. The output parameter that comprises of solar power and wind power. Generally, the overall result indicates that efficiency of PV systems is higher than wind systems. A reduction in effectiveness can be caused by the difference between working temperature at the site. The power generated by the PV modules is linearly dependent on the radiation, except for small values of radiation.*

Keywords: *PV systems, wind power, Simulink and Comparative Study*

1.0 Background

Renewable energy Technologies offer the promise of clean and abundant energy gathered from self-renewing resources such as the sun, wind, waterfalls, and plants/ Virtually all regions of the world have renewable energy of one type or another. It offers important benefits compared to those of conventional energy sources. Worldwide, more energy reaches the surface of the earth from the sun than is released today by fossil fuels. Photovoltaic and wind generation are receiving considerable attraction due to their reliability and minimal environmental damage (Pazmino, 2007). Life nowadays cannot be imagine without electricity. The human needs are growing, Nonetheless, a man searching for renewable energy sources to reduce global warming and prevent further pollution of the atmosphere (kazem *et al*, 2016), in addition , the importance role of electricity generations attached to it. While the negative impacts of gas emissions as a result of climate change is increase, the positive potential of renewable energy to reduce the level of negative environmental impacts as energy demand also continues to increase (kazem *et al*, 2015). Besides the proven environmental benefits, autonomous renewable energy solutions offer energy certainty and stability in areas where political and social issues or the geographic situation could otherwise restrict access to the fuel or power grid, especially in remode communities (Al maamary.H.M. *et al*, 2016). There are many reasons for implementation of renewable energy systems;

these includes the implications for the environment and human health, the electricity generations and difficulty in accessing fuels in distant communities (Khosravi *et al*,2018).Though in some cases prevailing challenges need to be considered with some focus as well as novel solutions; the intermittent supply, incoherent energy sources (i.e. daily sunlight, speed of wind) and, most importantly, initial system costs can cause such systems to be less practicable than fossil fuel systems (Hassan R.A.*etal*,2018).The economic and efficiency considerations play a key role for decision makers in determining the most feasible system option .So, the use of renewable energy to satisfy the commercial and technical needs has to be investigated.

Increased population growth and economic development are accelerating the rate at which energy, and in particular electrical energy is being demanded. So meeting this growth in demand, while safe guarding the environment poses a growing challenge. Each of the renewable energy technologies is in a different stage of research, development, and commercialization and all have differences in current and future expected costs, resource availability, and potential impact on greenhouse gas emissions (Berruezo *et al*, 2006). Khosravi *et al*. (2018) examined a system that uses solar and wind energy. The system includes a combined system of wind turbines, photovoltaic systems, hydrogen reservoirs, electrolyzers as well as fuel cells. The energy and cost analyses are conducted for the system. The result of the economic analysis reveals that the energy storage system (electrolyzer + hydrogen tank + fuel cell) represents 50% as a contribution to the investment.

Khalid, F. *et al* (2016) investigates the subject by proposing energy systems that can satisfy the present and future forecasts of energy consumption of one building. The study evaluates a multi system which integrates different combinations of biomass, solar and wind systems by using HOMER software to calculate the optimum levelled cost of power. The lowest of the environmental impacts as well as the share in every system for Oshawa, Canada. result revealed that a combines concentrated solar panels with biomass modules is the cheapest and most feasible option with a net present cost of 0.117$ per kWh.

Khalid *et al.* (2015) was analyzed the integration of power source from natural gas and enewables (solar, wind, biomass) power sources. He was found that the mean energy efficiency of the systems is between 20 % and 27. % .He was classified the natural gas system as the one with the highest efficiency but with the warning of C02 emissions as a disadvantage of the system, whereas he classified of the system includes thermal photovoltaic with a steam refrigeration chiller as the system with the lowest performance.

2.0 Solar and wind Energy Resources in Nigeria

Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. Most of the energy radiated by sun is transmitted radially as electromagnetic radiation which comes to about 1.5kW/m^2 at the boundary of the atmosphere. After traversing the atmosphere, a square metre of the earth‟s surface can receive as much as 1kW of solar power, averaging to about 0.5 over all hours of day light. The huge energy resources potential from the sun is available for about 26% of the day. Nigeria is also having some cold and dusty atmosphere which is experienced during the harmattan in the northern part which usually occurs for four months period (November to February) annually. The dust from the harmattan has an attenuating on the radiation intensity of the solar Studies relevant to the availability of the solar energy resources in Nigeria (Sambo, et al, 1986,) have fully indicated its viability for practical use.

Nigeria is endowed with daily sunshine that is averagely 6.25 hours, which is ranging between about 6.25 hours and 3.5 hours northern region and southern region of the nation respectively. It also has an annual average daily solar radiation of about 3.5 KWm2/ day in the coastal area which is in the southern part of the country and 7.0KWm2/ day at the northern boundary (Bala, *et al*, 2001). The country also receives average annual sum of 2200kWh/m^2 in Sokoto, Gusau, Kano, Yobe and Maidugri in the far north, to 600kWh/m^2 in Port Harcourt, Calabar, Aba in Abia and Warri all in the Southern part of the country. Nigeria also receives about 4909.212 kWh of energy from the sun which is equivalent to about 1.082 million tons of oil; this is about 4000 the current crude oil production per day, and also put at about 13 thousand times of daily natural gas production based on energy unit.

The amount of economically extractable power that is available from wind is said to be more than the current human power use from all sources, according to estimation, there is about 72 TW of wind power on earth that is commercially viable (Ben, *et al*, 2000) it was calculated that wind turbine can provide power to about 300 homes during its life span. Nigeria, globally, is located within low moderate wind energy zone. A research was conducted about the wind energy potentials for a number of Nigerian cities which shows that an annual wind speed ranges from 3.89 m/s in far north to a figure of 2.32 m/s in the south (Sambo, 2008).

3.0 Methodology

This chapter outlines the methodology applied to carry out the modeling and analysis of hybrid solar and wind power generation under Maiduguri weather. The first step of the methodology is the equations modeling and then transferred these equations into MATLAB/SIMULINK software to observe the power generation. Solar radiation, temperature and wind speed are used as input to the SIMULINK block to generate solar power output and wind power output. The appropriate PV array model and Wind Turbine model is chosen to produce the power generated from these renewable sources. The solar radiation is converted into electrical power using PV Array Model which takes technical data to produce the results. The power generated from the wind turbine depends on several characteristics such as wind speed, wind measurement height, geographical boundary of the site and turbine model.

3.1 Power Output of PV Module

Thus, once the solar radiation on PV panels and ambient temperature are known, the power output of the PV module can be calculated easily and accurately. Making use of the definition of fill factors the maximum power output delivered by the PV module can be written as:

$$P_{module} = \frac{v_{oc} - ln(v_{OC}+0.72)}{1+v_{oc}} . \left[1 - \frac{R_S}{V_{OC}/I_{SC}}\right] . \frac{V_{OC1}}{1+\beta ln\frac{G_0}{G_1}} \left[\frac{T_0}{T1}\right]^{\gamma} . I_{SC1} \left[{G_1}/{G_0}\right]^{\alpha} \quad (1)$$

Then the PV module is used to finally model the solar PV array.

3.2 PV Array

PV modules represent the fundamental power conversion unit of a photovoltaic system but a single PV module has a limited potential to provide power at high voltage or high current levels. It is mandatory to connect PV module in series and in parallel in order to scale up the voltage and current to tailor the PV array output.

Assume that the fill factor of a PV array, composed of a string of identical PV modules, equals that of single PV module (Zhou.w.*et al*,2007).The maximum power output of the PV array can be calculated by:-

$$P_{pv}=N_p.N_s.P_{module}.\ \eta_{oth}.\ \eta_{mppt} \quad (2)$$

Where η_{mppt} is efficiency of the maximum power point tracking, although it is variable according to different working condition, a constant value of 95% is assumed to simplify the calculations (Zhou.w.*et al*, 2007). η_{oth} is the factor representing the other losses such as losses caused by cable resistance and accumulative dust, P_{pv} is power generated by the pv array, N_p is the number of pv module connected in parallel and $N_s$is the number of pv module connected in series.

Thus, once the solar radiation on the module surface and the PV module temperature are known, the power output of the PV system can be predicted.

3.3 Solar PV Module

The table below shows the parameters of a KD 315 PV Module used to observe the solar energy characteristics of the area. The KD315 PV module polycrystalline solar photovoltaic was chosen to produce electrical energy due to its high module and cell efficiency and it has wide application in developing countries such as Nigeria (mustapha *et al*, 2011).

Table:1 KD 315 PV Module parameters

Maximum power(P_{mp})	Voltage at maximum power(V_{mp})	Current at maximum power(I_{mp})	Open circuit voltage(V_{oc1})	Short circuit current(I_{sc})	Power tolerance(P_{tol})
315W	39.8V	7.92A	49.2V	8.50	+5/-3%

3.4 Wind Energy Generation

The generation of electricity from wind energy is mainly dependent on the wind regime in the region of interest. Reliable long term wind measurements (at least one year) need to be studied before making a decision on where to locate your wind generation station (strack *et al*, 2004). In this work, measurements from meteorological weather stations have been used to map out the wind characteristics and gauge the amount of electricity that a wind power system can generate in the most interesting site. The reliability of wind statistics increases with the length of the period of collection as long term data makes prediction of future trends more accurate. In this case, the data in use has been provided from meteorological weather station and covers the ten year period between 2002 and 2011; measurements have been taken for everyday at 10 meters above the ground in meter per second (m/s). The electrical power generated by wind turbine is given by:

$$P_w = \frac{1}{2} C_e \rho A v_1^3 \qquad (3)$$

Where, P_w is power extracted from wind turbine with changes in wind speed, C_p is the fraction of upstream wind power, which is captured by the rotor blades and has theoretical maximum value of 0.59, it is also referred to as the power coefficient of rotor or rotor efficiency.V_1 is the wind velocity in m/s, ρ is the air density in (kg/m^3) and A is the area swept by the rotor blades in (m^2) (Rohit sen,2011).

3.5 Wind Turbine

Small horizontal axis wind turbine with rotor diameter of 3.5m, power rating of 20kW has been considered because of it availability and robustness, not only that but it is also efficient in supplying electricity for battery charging, for stand-alone applications and for connection to small grids. Therefore, the selected wind turbine must match the wind characteristics at the site and it should yield an optimum energy to meet the electrical energy demand. The table below shows the wind turbine specification data (Patel R, 2006).

Table: 2 Wind turbine data table

Manufacturer	Type	Nominal rotor diameter(m)	Swept area,(m2)	Nominal power,(kW)	Rated wind,(m/s)
Bergey wind power	P10-20	3.5	9.6	10	15

Source:[Sandor Bartha,2009]

RESULT AND DISCUSSION

4.0 Introduction

The modeling of PV modules includes obtaining solar radiation of the site, and then the modeling of the maximum power output of PV modules with the calculated total solar radiation. The electricity power generated by photovoltaic (PV) systems is directly related to the solar energy received by the PV panels. The model of the PV module was implemented using a MATLAB program. Also Modeling of wind energy conversion system (WECS) There main factor which determine the power output of a whole wind energy conversion system (WECS) is the power output curve determined by power efficiency of a chosen wind turbine, and the wind speed of a selected site where the wind turbine is installed. The simulink block was used to determine the power output curve of the area under research based on the maximum wind speed available on the site i.e. 15m/s and the result is presented in figure below.

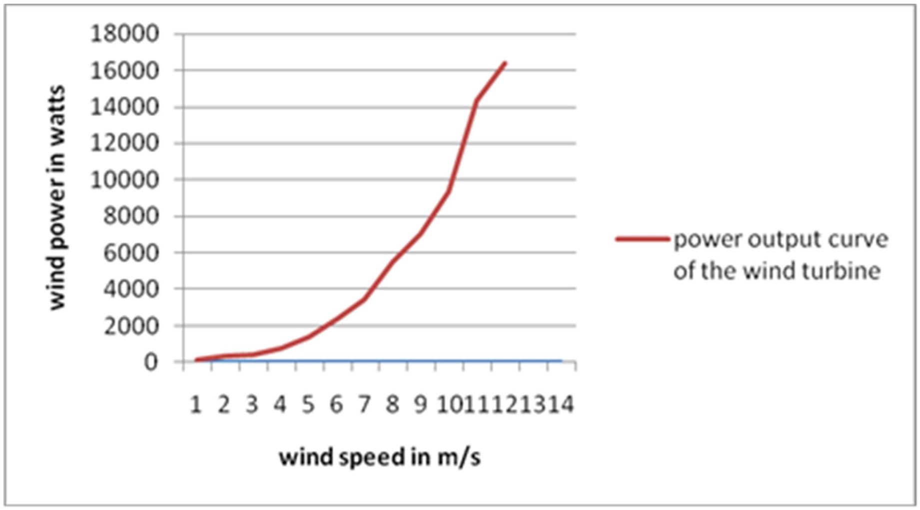

Figure 1: Wind Power output curve

For small-scale wind turbines, the cut-in wind speed is relatively smaller. The variation of wind speed with elevation influences both the assessment of wind resources and the design of wind turbines. It can be seen from the figure above this cut-in mind speed is very small, the characteristics shows that more energy can be generated with increased in the wind speed of the area. The rated wind speed of the area was found to be 15m/s but the highest recorded was 12.6m/s and the lowest wind speed of 1.6m/s was recorded which generate very little amount of power in the range of 369.9watt,therefore the generation increases with the increase in wind speed.

Good solar resources and wind energy resources validate the potential applications of solar and wind energy resources, while good complementary characteristics between solar energy and wind energy testify the feasibility and reliability of hybrid solar-wind applications. Generally the contribution of wind and solar energy in the hybrid energy system depend on the intensity and the duration of availability of the respective sources of energy.

The results can be analyzed and discussed in terms of it generation capability to meet the demand. The feasibility assessment of the site is carried through MATLAB/SIMULINK software which comprises solar and wind power system components (PV array and wind turbine). The inputs to the software are; the monthly average solar radiation and temperature for the solar PV array, and wind speed for the wind turbine. The output parameter that comprises of solar power and wind power, and the result presented below. The output parameters evaluated using monthly average solar radiation, temperature and wind speed data obtained from Nigeria Meteorological Department, Maiduguri.

Figure 2 below present the generation of electricity from solar PV array and wind turbine in the year 2016.The result revealed that the contribution of solar PV array is more than that of wind turbine. For example more power is produced from February to June, these is due to the fact that the solar radiation are high during those month, but the result becomes different between July to September where the generation drops to somewhere below 1500W because of the low solar radiation experience during the rainy season. Generation start to increase between October and November, and then drop sometime between Decembers to January during the harmattan season which is characterized by low solar radiation. The result also shows the power generation from wind turbine alone at different wind speeds. It can be seen that more power is generated from January to July with maximum generation of 2270.1W at a wind speed of 6m/s .generation drops from August to December when the wind speed drops to 4m/s below. It can also be observed that the maximum power generated by the wind turbine in June is almost 5-times than the generated power in November. These indicate that, the higher the wind speed the more power is generated by the wind turbine.

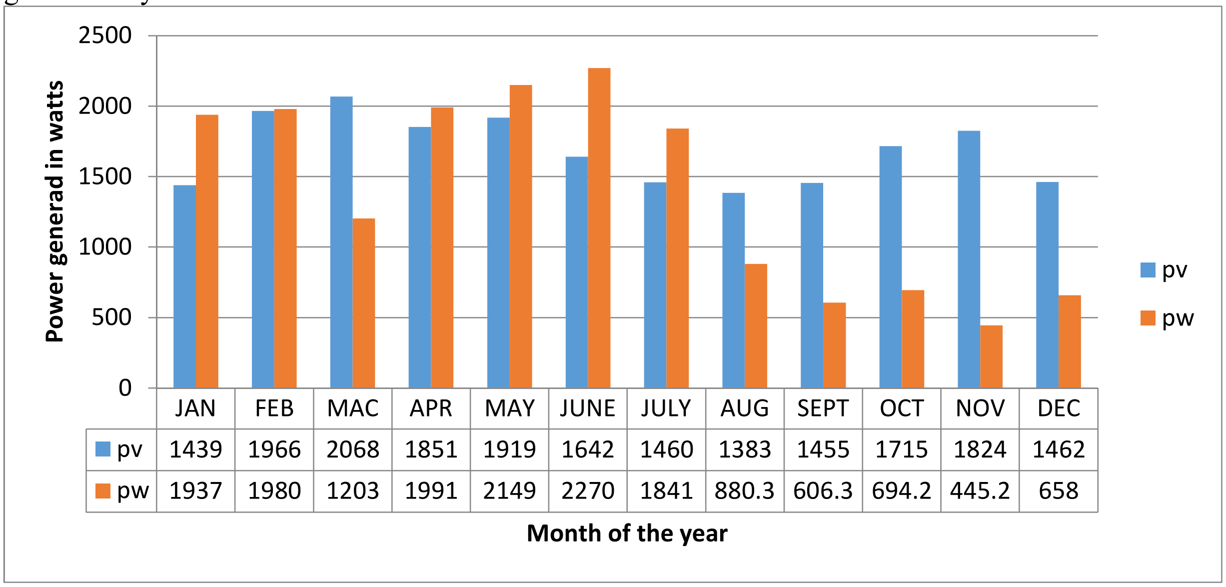

Figure 2: Monthly Average power produced by wind turbine and PV array 2016.

The Figure below shows that, the monthly average power produced by the PV array, as well as monthly power produced by the wind turbine in 2017. The high power yield from the PV array over the wind turbine is a true reflection of the amount of solar radiation is higher than the wind speed in the region.

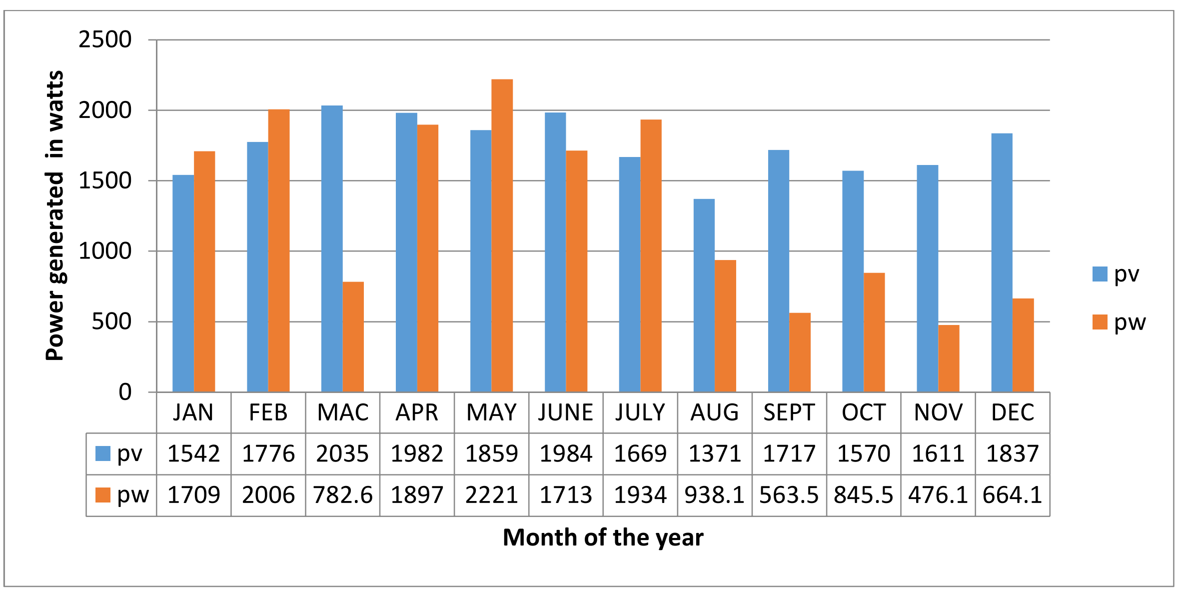

Figure 3: Monthly Average power produced by wind turbine, and PV array in 2017.

The result obtain from simulation looks almost the same as that of 2016 because of similarity in weather data. It can be seen that the power generated by solar PV array is almost throughout the year except in August where the generation drop to 1370.7W as a result of the rainy season which characterized by low solar radiation. but looking at wind power generated the result remain the same as in 2016,that more power are generated between January to June while generation drop in august to December during which low wind speed is experience in the year. The present that the lowest generation by the wind turbine is in November that amount to 476.11W and this is 75% less than the energy produced by solar PV array in November; these categorically indicate that the energy from the PV array is higher than that of wind turbine.

The revealed that there is sufficient generation in all twelve month of the year because of much power generation that comes from solar PV array which indicates the viability of the solar energy in the region.

Figure 4 shows the power generated by the solar PV array and wind turbine for the year 2018. The result shows that power generated varies with seasons. For example more power is generated in the dry season (March to June) than the power generated in the rainy season (July to September) by the solar PV array.

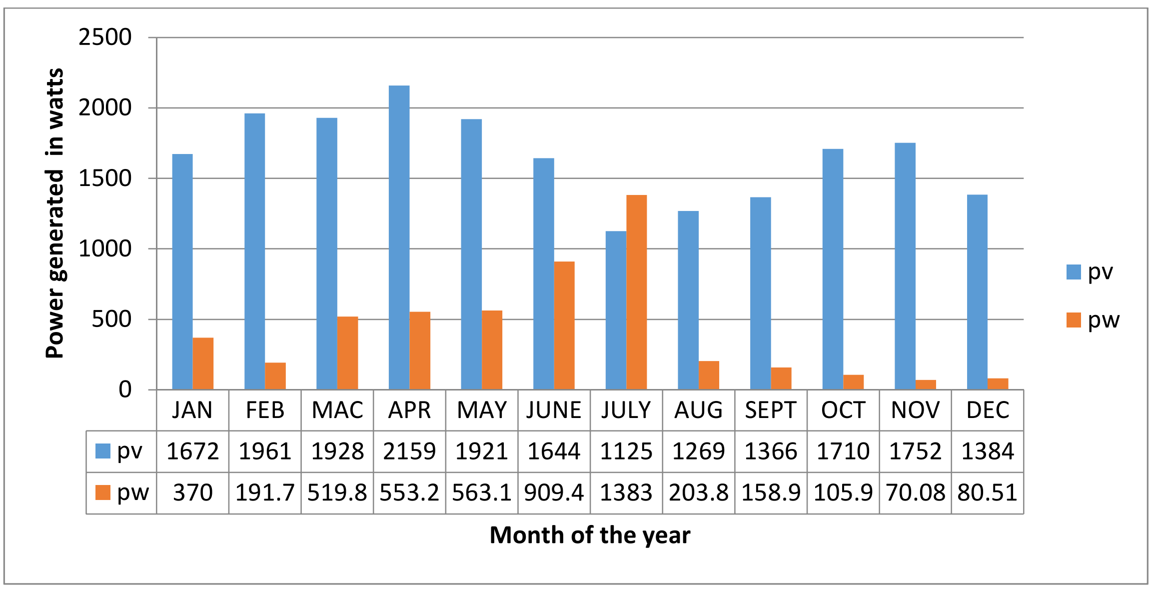

Figure 4: Monthly Average power produced by wind turbine and PV array in 2018.

It is could be observed that, power generated in April is 47 % more than the power generated in August which is the least sunny month of the year. It can be seen in figure that the amount power generated by the wind turbine from January to December range between 105.89W-909.45W which is very much low compared with what is generated by solar PV array. The reason is that the year 2018 is highly characterized by low wind speed that brought about low power generation from the wind turbine. The Results also show that the strong seasonal variations in wind Speed, make a total generation drop to lowest minimum in 2018, while the solar PV array power remain average from February to May with generation highest of 2158.5W which is almost 2-times than the highest power produced by wind turbine in that year. However in July the energy generated by wind turbine is higher than that of solar and is the only month where the wind energy is more than that of solar. It can be observed that power generated during dry season is 39% greater than the power generated in the harmattan season. Therefore, more power is expected in the dry season than rainy season or harmattan period.

Figure 5 below presents the power generated wind turbine and solar PV array system in 2019. The result indicate that power generated in 2019 is almost similar as in the other years in the case of solar power generated, while in the case of wind turbine there is clear difference as a result low wind speed recorded throughout the year (2019). The data recorded for all the four years goes similar in nature in the case of solar radiation but somehow random in the case of wind speed that brought about difference in power generated by the wind turbine.

The result shows that the maximum power generated by the solar PV is in the month of May which is 2927.1W, this is because of the fact that the maximum solar radiation recorded in that year, i.e.27.4 w/m. The lowest generation was in November with solar radiation of 14.82w/m which generated 1345.2W.

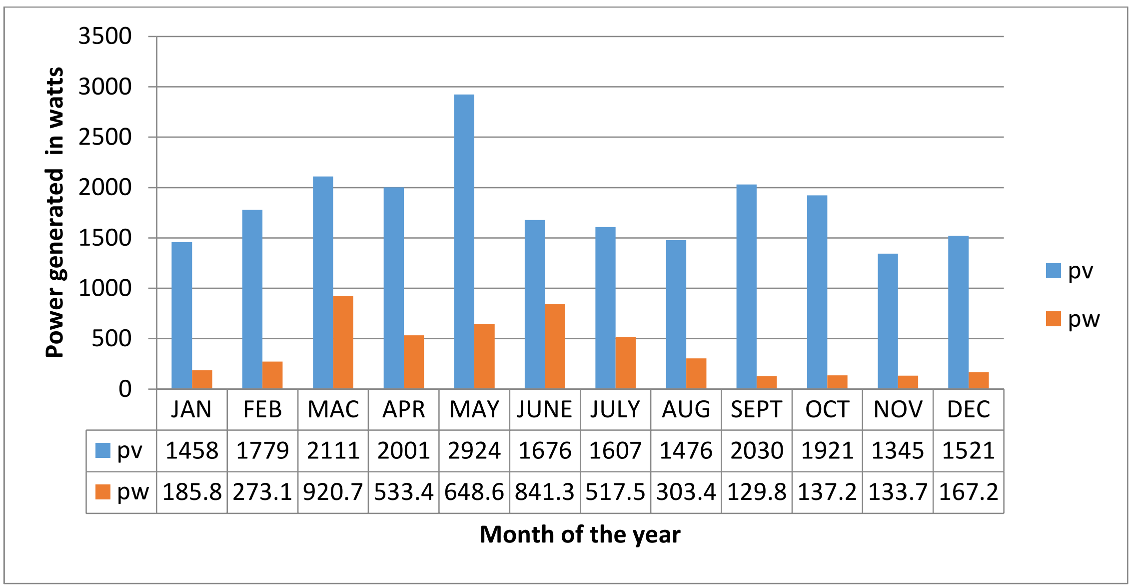

Figure 5: Monthly Average power produced by wind turbine and PV array system in 2019.

Conclusion

This paper has reviewed two renewable energy sources, wind and solar, considering the major components and parameters that influence the overall efficiency of both systems. Good solar resources and wind energy resources validate the potential applications of solar and wind energy resources, while good complementary characteristics between solar energy and wind energy testify the feasibility of solar-wind applications. To be able to compare overall efficiency between wind and PV system, wide research including all different parameters for the two systems has been taken into consideration. Generally, the overall efficiency of PV systems is higher than wind systems. A decrease in efficiency can be caused by the difference between working temperature at the site and the condition at STC. The power generated by the PV modules is linearly dependent on the radiation, except for small values of radiation, System performance analysis shows that the efficiency of the PV array is not only strongly depends on radiation but also depend on the module temperature

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