AUTONOMOUS WIND–PV HYBRID ELECTRICAL GENERATION: A CASE STUDY FOR RAS MUNEEF VILLAGE IN JORDAN

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Abstract - Jordan does not produce oil or gas, this make Jordan depends totally on imported oil for producing its required energy. And with the continuing petroleum and coal depletion the costs increases, as a consequence a high petroleum bill is to be paid by the country every year. This paper presents a suggested design of an arid mountainian village situated in Ras Muneef (Ajloun-Jordan), that can be supplied by hybrid wind-photovoltaic renewable electrical power system. After selecting the location, a study and analysis for system sizing and optimization was performed using the graphical method, and the sizing curves were built by the introduction of a ratio called the Wind/PV ratio which describes the power sharing between the wind and PV systems, it has been found that the production cost of the hybrid energy system composed of 81 wind turbines rated at 100 kW and 20347 PV panels 300 Wp each with two days of autonomy with all of the associated components is $0.082 / kWh which is a competent cost. The paper also presents a simulation of the elements of the system using Matlab Simulink and a sizing program was designed to apply the graphical algorithm used in the sizing optimization process.

Keywords - Autonomous energy system; wind–PV system; hybrid electrical generation; Jordan

I. INTRODUCTION

Renewable energy sources are solar radiation in origin in fact if we give a closer look to any renewable energy source it will eventually lead us to the sun, rain as a part of water cycle, wind which is caused by uneven earth surface temperature and rotation, the waves movement, alternative plants (biomass) are derived by the sun many millions of years . Producing energy from renewable sources is just a small part of a bigger philosophy which includes efficient use, low energy consumption, and less wasting of resources to ensure a bright future and to live in harmony with our planet, hence with ourselves. Our energy system is in crisis because it's a linear system and our planet is finite, a linear system can't run on a finite planet for an undetermined time [1]. The mixture of different power sources is called hybrid system and the hybrid system is not new idea it has gained more efforts by researchers [1-16]. Numerous studies were conducted in Ras Muneef for the availability of hybrid systems [17, 18].

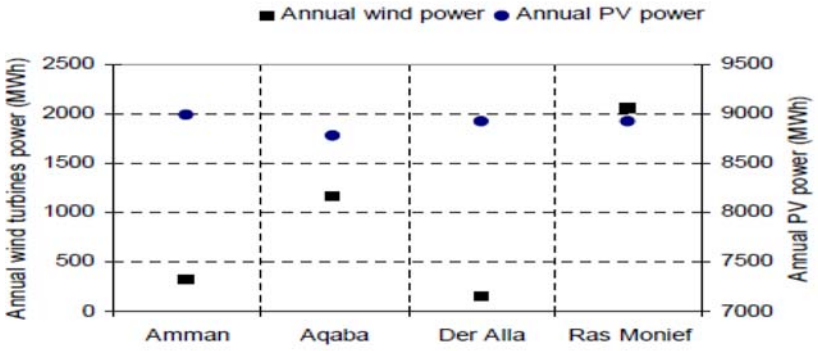

Fig 1(a) Annual total power sent to grid [12]

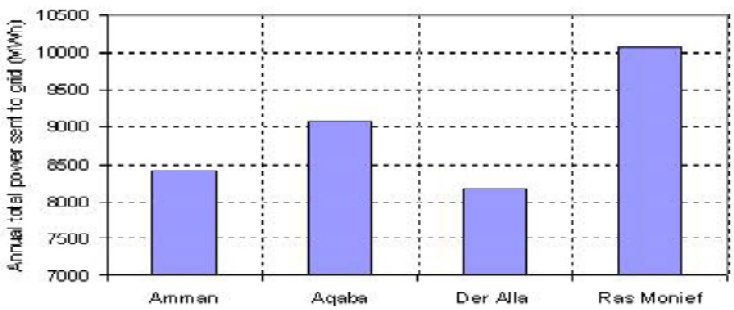

Fig 1(b). Annual individual power of wind turbines and PV systems [16].

Renewable Energy systems:

2.1. Renewable resources

Renewable resources used in this research concentrates on solar energy and wind energy. The two days data are considered for the system simulation one day in November and the other in May these specific months were chosen because they showed the greatest difference between wind speed and solar irradiance and will be used for the sizing.

2.2 Solar radiation and wind speed

The radiation and wind data considered here are assumed to be constant so that the resources may vary each hour and seasonally. Solar radiation data for Ras Muneefis obtained by[16], and it represented in figure 2.

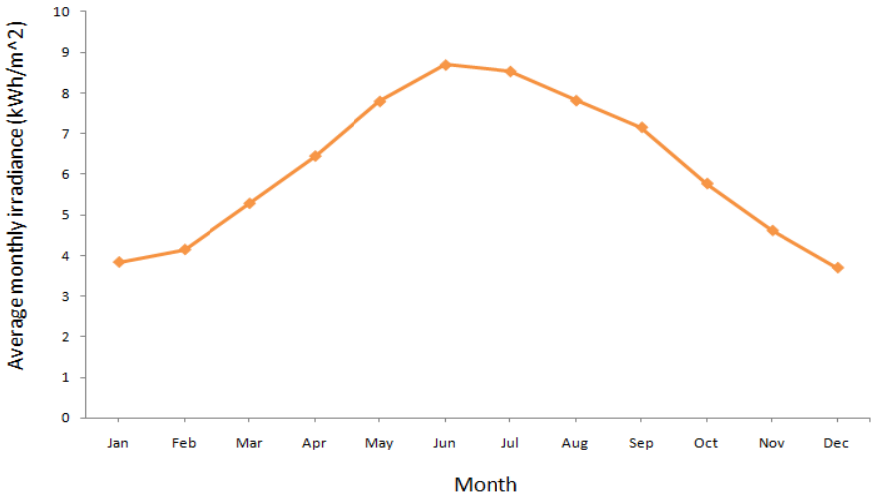

Fig2: Average incident irradiation for Ras Muneef

Figure2 shows that the maximum irradiation happens in summer months; between the months May and September more than 7000 Wh / m^2 it can also be noticed that the irradiation level through the whole year is very high even in the winter months and which is a clear sign of the potential of the site for a photovoltaic project.Wind speed data for Ras Muneef was obtained from [13], and it's shown in figure 3. It can be seen that the average wind speed is very high in Ras Muneef it reaches an annual average value of 6.26, and 6.49 in winter[13] that's due to its high elevation and mountainous nature several recent studies showed great interest for this region [13,16,17,18].

Two different days are taken into consideration and the hourly wind speed variation and solar irradiance is plotted for, an average day of May and an average day of November these two days were chosen because the month of May is one of the highest irradiance months through the year while having relatively low wind speed, on the other hand the month of November exhibits the opposite phenomena, this can be observed in figure 4 which is a comparison of the solar irradiance and wind speed for the year. From figure 4, it's clear that wind speed peaks are in the month were solar irradiance is lower than the average and that proves the clear complementary characteristic of wind speed and solar irradiance for Ras Muneefwhich it is suitable for a hybrid power project. Figure5 shows the solar irradiance and wind speed for the average day of May while figure6shows the average day of November.

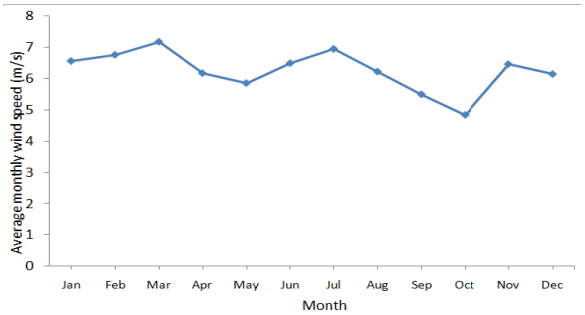

Fig 3: wind speed distribution during the year for Ras Muneef

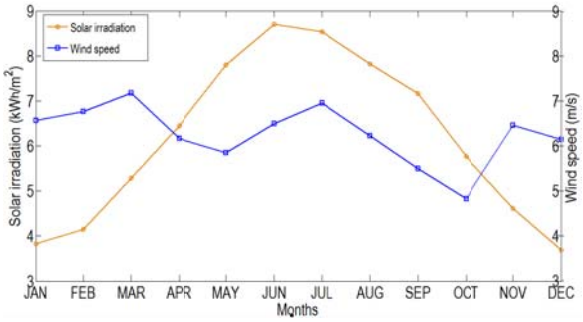

Fig 4: comparison of annual wind speed and solar irradiation for Ras Muneef

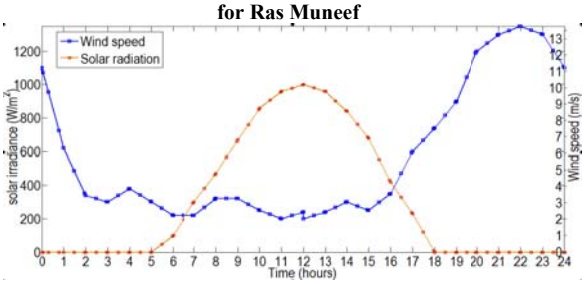

Fig 5. wind speed and solar irradiance for May.

The peak sun hours in May are 7.8 [16] which is a extraordinary value and is suitable for a photovoltaic system, it can be seen that the sun rises at 05:30 and sets at 18:00 this is a typical day from May to September which shows the potential of the site for a PV system, the wind speed is also good with an average wind speed of 5.85 [9]and it's one of the lowest average wind speeds in Ras Muneef it can be seen that the low wind speeds occurs during the 8:00 – 16:00.

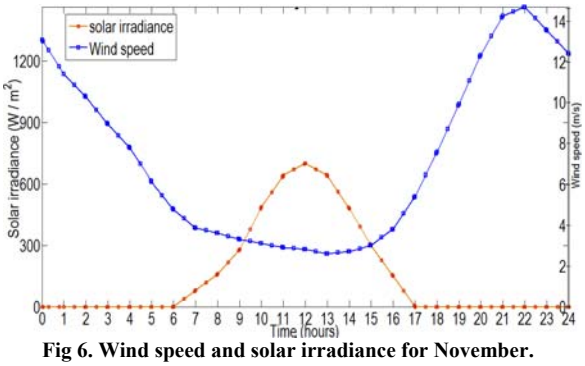

Fig 6. Wind speed and solar irradiance for November.

As it can be seen in figure 6, the solar irradiance in November is much lower with an average peak sun hour of 4.61 hours on the other hand the wind speed is very good with an average wind speed of 6.5 m/s. The figure also shows that the wind speeds during 8:00 – 16:00 are the lowest similar trend to the month of May. From Figures5 and 6.

2.3 PV-panel and wind turbine output power

In Figure 5 and 6, the powers that can be extracted from the RESs can be calculated as preliminary output. The average hourly insolation data on a single PV-panel shown by Figure 5 and 6 can be converted into power output from the PV with the following equations [19].

$$P_{pv}(t) = Ins(t) A_{pv} \eta_{pv} \qquad (1)$$

$$P_{pv}(t) = Ins(t) A_{pv} \eta_{pv} \eta_{dd} \qquad (2)$$

Where, $P_{pv}(t)$ = the PV-panel power (W)
I_{ns} (t) = insolation data/ time t (W/m^2)
A_{pv} = area of a single PV-panel (m^2)
η_{pv} = PV-panel overall efficiency
η_{dd} = the DC/DC converter efficiency (regulator)

From the average hourly wind speed profile Figure 5and 6 will be evaluated by:

$$P_{wind}(t) = \frac{1}{2} \rho A_{rot} v(t)^3 C_p \qquad (3)$$

The wind turbine output power referred at the DC-bus where the PMSs are applied can be given by:

$$P_{wind-dc\,bus}(t) = \frac{1}{2} \rho A_{rot} v(t)^3 C_p \eta_{ad} \qquad (4)$$

Where, P_{wind} (t) = power output from the PV-panel (W)
ρ =Air density (Kg/m^3)
A_{rot}= Rotor area (m^2)
V (t) = Wind speed (m/s)
C_p = Efficiency of wind turbine
η_{ad} = Efficiency of AC/DC

Power from a PV and a wind turbine,are the manufacturer datasheets M72 – 300watt panel [21]and Polaris P 19-100 wind turbine [22]. From the above equations 1 and 2 and Figures7and 8.

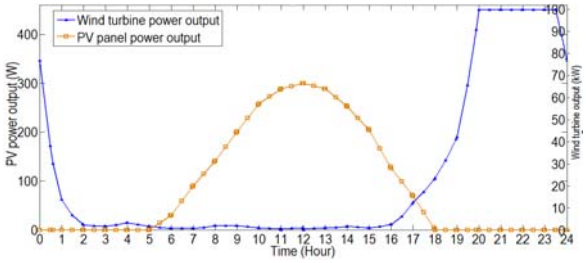

Fig 7. The power of wind turbine and PV for month of May

It can be seen from the figure 7 about 300 W and 100 kWmaximum can be found.

II. HYBRID POWER SYSTEM SIZING

In order to obtain a feasible and efficient hybrid power system the elements of the system has to be sized to exactly and not to supply excess energy cause that will result in an waste of money and waste of energy and in unnecessary equipment.Extensive research was made in the sizing of the [23-27].

3.1. Sizing of System Elements

Considering each system elements independently, the initial sizes of the PV-arrays, Wind turbines, and Battery bank and power converters are discussed in the next sections.

3.2. Battery sizing

The battery sized according to the higher energy needed and is defined as :

$$E_{daily_load_{demand}} = \int_0^{24} P_{load}\, dt \qquad (5)$$

$$BC = \frac{E_{daily_load_demand}}{\eta_b} \frac{DOA}{DOD}(Wh) \qquad (6)$$

Where $E_{daily_load_demand}$ is the total daily energy demand

IV. MATHEMATICAL MODELING & SIMULATION

In order to have an appreciable sense of our design and calculations of the different elements of the system a mathematical model is built to each element

that reflects its actual physical behavior, in this section we will design the simulation of the hybrid system and will explain the working algorithm that manages the whole operation.The simulation is built in Matlab Simulink environment.Simulink [28,29,30]

4.1 The load model

To operate our hybrid Wind-PV system a load simulation is needed to add to the total simulation in order to analyze the system performance, these load values in the load model were realistic load profiles and were compared to typical houses load in Jordan. These data were fed into a simulink signal builder.

4.2 The graphical sizing theory algorithm

The graphical theory for sizing [22] of the hybrid system will be built using iterations and increasing the $R_{W\text{-}PV}$ ratio each iteration to a determined $R_{W\text{-}PV}$ and when this value is met the season is changed and another curve will be built using the same algorithm but for the new season and the new load and weather, the number of curve will be equal to the number of seasons, in this paper we will use two curves the May curve and the November curve, Figure 8, shows the algorithm of the curve builder used to draw the curves of the sizing.

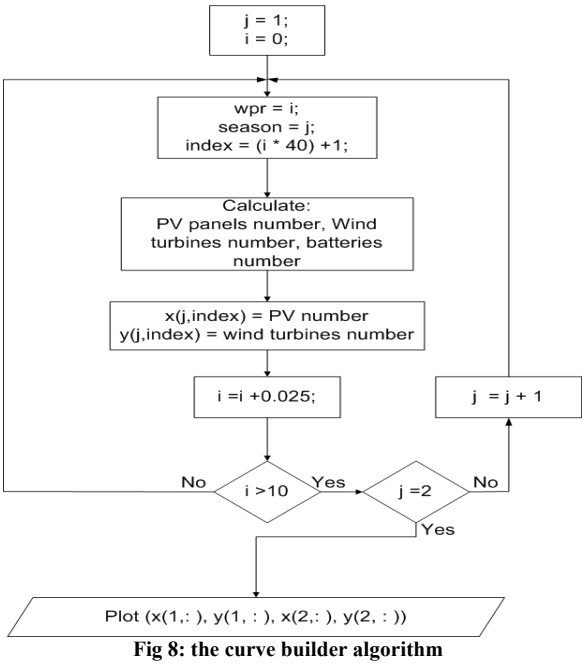

Fig 8: the curve builder algorithm

CONCLUSION

In this paper a proposed village situated in Ras Muneef (Ajloun, Jordan) was selected for erecting a hybrid power station. The proposed village is designed for 300 families with all related facilities to be electrified by wind- Photovoltaic hybrid power system (HPS).

The most important part after selecting the location is the sizing of the HPS components the sizing method used in this paper is the graphical sizing method. This method considered the two distinct seasons having different loads and of different weather profiles were considered to size the HPS.A mathematical simplified model was built for each element in order to get an analytical point of view to check and calculate the values for the hybrid power system elements sizing and economic analysis.In addition to the sizing and simulation an estimation of the production cost was performed for the complete system in order to get an idea of the project feasibility, the production of an estimated Loss of power probability equal to zero and two days of battery autonomy with Wind/PV (R_{W_PV}) ratio equal to two was found to be \$0.082/ kWh which is an excellent and competitive cost.The results obtained are very realistic because all the efficiencies and losses results considered in the simulation,and all the characteristics applied to each element of the model gave very accurate predictions and very competitive power generation cost compared to the conventional power supply.

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