Techno-Economic Analysis of the Potential Utilization of a Hybrid PV-Wind Turbine System for Commercial Buildings in Jordan

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Abstract- Though the Middle East boasts about 45% of global crude oil and natural gas reserves, not all countries in the region are endowed with such fossil fuel potentials. Jordan is one of such country with an energy dependency of about 96%. On the other hand, Jordan has tremendous renewable energy potentials as it abounds in the solar belt with solar irradiance ranging between 4 kWh/m² and 7 kWh/m² and good wind potential with wind resources exceeding 7m/s annually. Electricity tariff for commercial buildings is at $0.33 per kWh, and with governments' introduction of feed-in-tariff and net energy metering systems in December 2013, the potential of renewable systems looks promising for grid connected systems. This study simulates the potential of a stand-alone hybrid system comprising PV and wind turbine to adequately meet the annual electricity need of 34.4 MWh for a hotel in Jordan, the technical feasibility and economic viability of the system is analyzed. Its economic potentials are compared to an on-grid system of PV-wind turbine to feed the same load while observing the effect of the implemented feed-in policy. The technical analysis shows that a 20 kW PV system and a 10 kW wind turbine can sufficiently supply the demand. Also, the economic indices obtained from the stand alone system showed a net present cost of $147,485 over its 25 years life span, a savings-investment ratio (SIR) of 1.924 and a payback period of 11 years. The grid connected hybrid system showed greater potentials with NPC of $98,712, SIR of 2.84 and payback time of 8.07 years.

Keywords Renewable energy system, Hybrid System, Wind Turbine, Solar PV, HOMER software.

1. Introduction

Jordan's energy demand has steadily increased in recent years with an 8% increase in her population. This growth is majorly due to the influx of refugees from neighboring Syria and Iraq seeking shelter from Islamic state activities in the region [1]. With oil reserves under a million barrels when compared to its average yearly consumption. Jordan's energy sector is largely dependent on imported oil [2]. With little investment in renewable energies like wind and hydropower, the country spends enormous sums of money on energy bills and its electricity tariff has increased from 5 to 15 % in the past two years. In 2014, the country's imported fuels accounted for 40% of the national budget [1] which led to the government's resolve to remove all subsidies on electricity by 2017. Also, this is a country with vast solar and wind potentials. Jordan's national energy center has projected the countries solar power usage to reach 10 MW by 2020. Currently, this application is used in water pumping, desalination, lightening, telecommunication base stations, and schools. The high cost of investment in this technology and high payback period has meant that most residents and small/medium scale commercial businesses have shied away from investing in renewables. However, with the introduction of a feed-in-tariff system by the government in December 2012 [3], the potential profits of grid-connected systems are attractive with a 53% rebate for feed-in systems [3, 4]. The focus of this research is on the potential deployment of solar and wind energy systems in Jordan for electricity generation. The technical and economic possibilities of utilizing a hybrid renewable system to meet the power demand of a hotel in Ajloun situated 76 km northwest of Amman (the capital city) is studied. Ajloun is located in a high altitude region 750 m above sea level. It geographically lies between latitudes 32°21’0”N, 35°44’0”E and longitudes 32°35’0”, 35°73’0”. Due to its placement, the location has great wind and solar resource [5]. Extensive representation of the site’s wind and solar resource can be found in Anagreh and Bataineh [6].

Literature presents numerous publication [7 - 15] on the feasibility and Dalton et al., [16] showed that a hybrid PV/Wind stand-alone system could meet the needs of a medium and small tourists’ accommodation. From their conclusions, a hybrid system can feasibly meet the power needs at an acceptable price. Their results depict a ratio of the net present cost of their proposed system, against three similar configurations of 0.5, 0.7 and 0.77. Angreh and Al-Ghzawi [8] in their study on the same location reached the conclusion that a grid-connected wind turbine system would act as the most economical alternative to meet needs of the hotel being reviewed as it presents the least net present cost when compared to other possible systems. The results from [8] show similarities to those of Dalton et al., [11] whose study shows that on-grid wind systems, when pitched against other renewable energy options, obtained the least cost and as such provided the most economical option. Till now, no study has been able to attain 100% renewable energy standalone plant in Jordan that meets both technical and economic viability. Anagreh et al. [5], concluded that implementing such a system though feasible, isn’t economical in Jordanian homes due to its installation cost when compared with conventional grid-connected power supply. This research evaluates the work of Anagreh [5] to find out if an off-grid hybrid PV/Wind stand-alone system can meet the energy demands of a hotel while considering the effects of the new feed-in tariff policy to the cost of renewable energy deployment in Jordan.

The cost of all renewable energy components is predicted to decrease in the future, and with PV technology becomes widely deployed, this will consequently enable off-grid systems to become more alluring as an alternative supply option for a building’s power needs. The research aims at examining:

- If a hybrid renewable energy source RES can adequately meet the power requirements of the hotel’s operation

- The economic indices of the system based on net present cost NPC, payback rate, and savings-investment ratio.

- The Environmental issues (if any) of this Hybrid system.

- The cost implications of the new feed-in-tariff policy to the RES’s viability.

2. Methodology

2.1. HOMER software

The program is an application developed by the United States National Renewable Energy Laboratory. The application by way of simulation evaluates the technical and financial option for both grid and off-grid systems for remote, standalone and distributed generation applications. It accounts for the technological availability of resources and presents its users with various selection options. To evaluate the economic viability of a system the application determines this by using the net present cost which accounts for the initial capital cost, the cost of operations and maintenance of the system components and the cost of changing the parts throughout the project lifecycle. The optimal system is that system mix that satisfies all specified constraints at the minimal net present value [17].

2.2. Load Supply Data

To perform the feasibility analysis of the energy resource the first step is to insert the load profile and metrological information. The electricity demand data used were secondary data obtained by Anagreh, et al. [5] from the Jordanian Electricity Company which have detailed logs of the power consumption of its customers. Fig.1 shows the daily load of the hotel which can be divided into three parts.

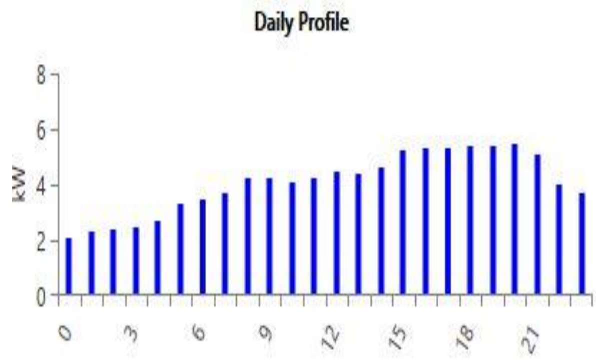

Fig. 1. Daily load demands of the building (Jordanian Electricity Company).

The load profile shows decreased power consumption between midnight and 9 AM, moderate power consumption which starts at 9:00 AM and ends at 4:00 PM and high consumption witnessed for the rest of the day. Monthly electricity demands for the building within 2012-2013 is shown in Fig.2 The annual energy consumption of the building is 34.4 MWh with its peak load demand being 9.40 kW during the year and the average power consumption per day at 97.6 kWh. From Fig.3 it is observed that July and August show high energy consumption due to the influx of tourists during this time of the year with these periods also representing the peak of summer, heavy utilization of air conditioners for cooling also adds to the high load profile. The month of March records a very low consumption due to reduced number of occupied rooms and little or no need for heating or cooling is required due to the moderate weather conditions during that period of the year.

The wind speed data for the location was obtained using Homer software which gets this data from the meteorology and solar energy database of the National aeronautics and space administration NASA. At the heights of 10 meters and 50 meters, the recorded mean wind speeds are 4.67 m/s and 6.26 m/s, respectively.

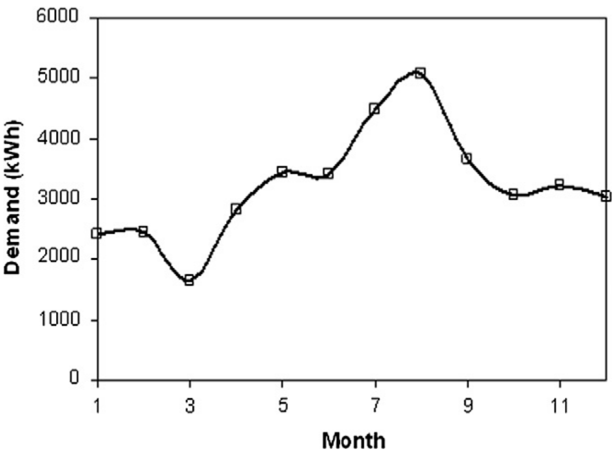

Fig. 2. Hotel annual load profile [3].

The average wind speed of the location was recorded as 5.43m/s, and this data is presented in Fig.3. The recorded data for solar irradiance was acquired using HOMER software which accesses the database of the National renewable energy laboratory NREL. The average solar radiation of the city is 5.4 kWh/m²/day. The monthly solar irradiance data of this location as obtained from the Homer application can be seen Fig.4. Aside from the demand data and metrological resource information, the simulation requires the input of individual nameplate capacity of each of the system's part with their associated costs over the lifespan of the project.

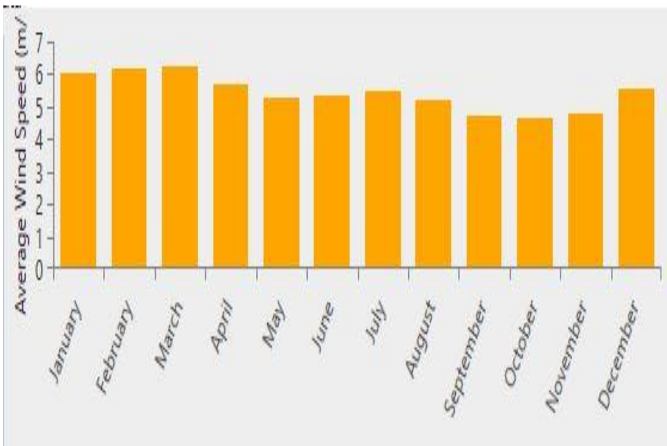

Fig. 3. Average wind speed at site location (Avg. 5.43 m/s) (NASA).

The energy flow diagram representing the interaction between the system's components are shown in Fig.5. The wind turbine is the only AC input into our system hence the need for an AC/DC converter for DC currents coming from the PV system and batteries.

2.3. Solar PV System

The capital and replacement costs of the PV system were specified at $2000/kW, with maintenance cost set at 2% of capital cost of the system [18]. A 20 kW system is to be installed with a derating factor of 90% and 25 years expected lifetime. The panel set up are fixed with a northward inclination at an angle of latitude 32°21' equaling the angle of latitude. An area of 139 m^2 will be needed to install the PV system.

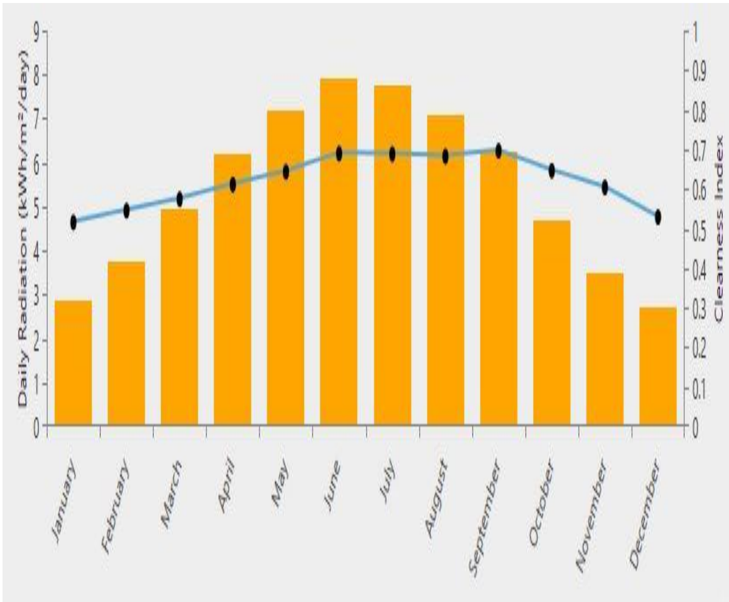

Fig. 4. Monthly solar radiation at the site location (Avg. 5.39 kWh/m^2/day).

2.4. Wind System

A Bergey Excel-10 10 kW Wind Turbine will be used. The power output of this system is represented in Table 1 below. An initial capital cost and cost of replacement of $28,000 is specified with operations and maintenance O&M cost set at 3% of installation cost. The power curve of the turbine could be seen in Fig.6. (Bergey Windpower Company).

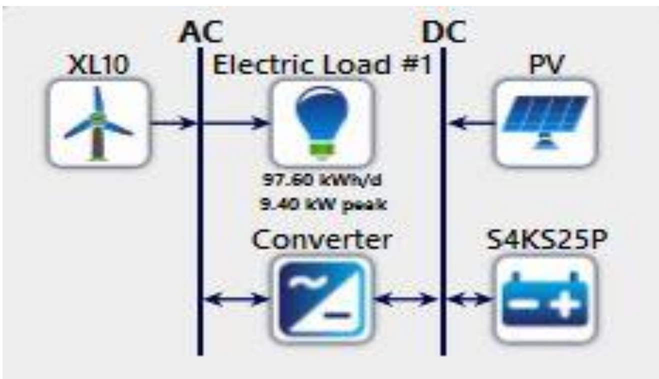

Fig. 5. Energy flow diagram of the system.

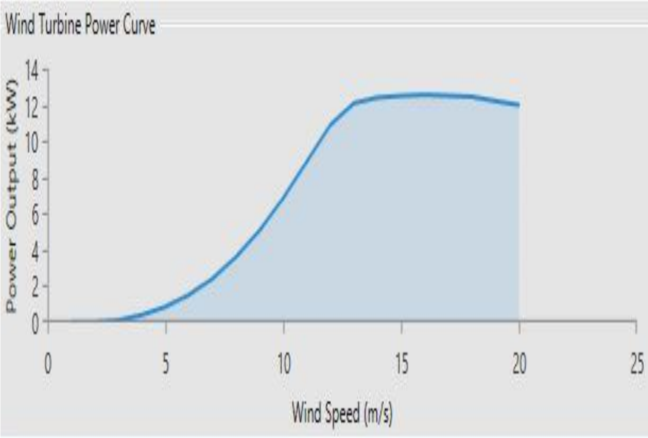

Fig. 6. Power curve of Bergey Excel 10KW wind turbine.

Table 1. Production output of wind turbine.

Quantity	**Value**
Total rated capacity	10.0 kW
Mean output.	1.69 kW
Capacity factor	16.87%
Total production	14,781 KWh/yr.

2.5. Inverter and Converter

The efficiency of the inverter and rectifier which determines their operational output be placed at 90% and 85% respectively for the 7 kW system in use. The installation Cost is $300 and with no operations cost.

2.6. Utility Tariff

The tariff of the Jordanian National Electricity Power Company for commercial buildings is 230 fils per KWh ($0.33) sell back rate is fixed at 125 fils per KWh ($0.176) (National Electric Company of Jordan).

3. Economic Analysis

This project lifetime is set at 25 years and interest rates set at 5.8%. To be feasible, the system must satisfy all constraints. HOMER discarded systems that do not meet specific constraints and would therefore not be seen in the result view of the program. HOMER will require another constraint from the user known as the capacity shortage fraction (CSF) before it runs the simulation. The capacity shortage fraction would represent a percentage of unmet load demand by the power system. From literature, Reference [19] and [17] proposed a CSF of 5% which is used in this study.

The economic indices used for this paper are the NPC, payback period, and savings-investment ratio. The NPC is defined as the total cost associated with the project over its lifetime. These costs include the initial capital cost of installation, its replacement cost, the operations and maintenance cost and finally the salvage cost of all parts over the 25 years period of the project [2]. The mathematical representation of this is given by equation (1) below [3]:

$$NPC = AC / CRF \qquad (1)$$

Where AC is the sum of the annualized costs of components that constitutes the renewable energy system and the capital recovery factor CRF is expressed by equation (2) below from [3]:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (2)$$

Where i is the interest rate, and n represent the number of years. The Discount Factor (DF) accounts for the present value of money in any year within the project lifetime. It is represented mathematically by [2]:

$$DF = \frac{1}{(1+i)^n} \qquad (3)$$

The optimization program computes the values of DF once the interest rate i and the project period n is inputted into the economic inputs window of the program.

The renewable factor (RF) can be defined as a ratio that represents the sum of all energy produced by the renewable technology to that consumed by the load. It is expressed mathematically by:

$$RF = \frac{E_c}{E_p} \qquad (4)$$

Where E_p and E_c represent the sum of all energy produced and the sum of all energy consumed respectively.

The payback period (PB) is the number of years it would take for the net investments in the system to become positive. This could be mathematically expressed by [17]:

$$-IC + \sum_{j=1}^{p} \frac{CF_j}{(1+i)^j} = 0 \qquad (5)$$

Where IC is the initial cost, CF is cash flow, i represents interest rates and j number of years. HOMER assesses its economic outputs based on net present cost and renewable factor. The payback period is also used in this paper as indices.

Savings-To- Investment Ratio (SIR) is another indicator used in this work. It evaluates the ratio of the lifetime savings of the project to the total investments made in the project. A SIR value greater than 1 is necessary for the project to be regarded as cost-effective.

$$SIR = \frac{\text{Lifetime Savings}}{\text{Investment}} \qquad (6)$$

4. Results and Discussions

4.1. Technical Feasibility

An analysis of the technical feasibility shows that our hybrid system can produce 49.2 MWh/year which adequately meets the hotels' load demand of 34.45 MWh/year. The excess electricity of 10.56 MWh/year is available to be sold back to the grid. Monthly electricity generation is shown in Fig.7, and when compared to the load demands of Fig.1, all load requirements of the building can be adequately met. Details of the individual system percentage power generation and annual unused power can be seen in Tables. 3 and 4.

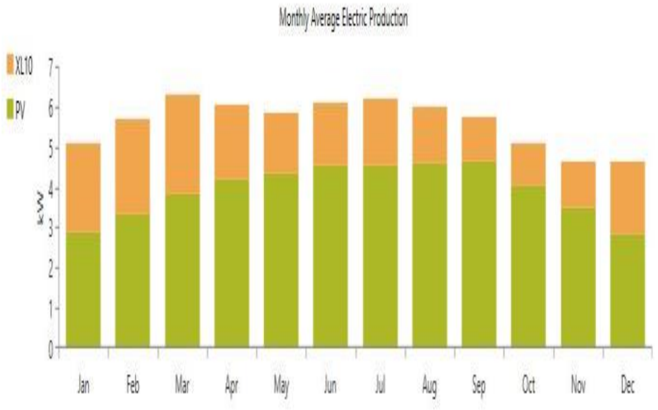

Fig. 7. Monthly average electricity production.

Table 2. Power generated.

Production	kWh/yr.	%
PV array	34,416	69.96
Wind turbines	14,781	30.04
Total	49,197	100

Table 3. Unused power.

Quantity	kWh/yr.	%
Excess electricity	10,561	21.5
Unmet electric load	119	3.4
Capacity	174.4	4.9

4.2. Environmental Aspect.

The proposed system shows zero emissions for all possible carbon, sulfur, and nitrogen oxide emission as well as particulate matter. The sound pressure level associated with the wind turbine systems measured by the manufacturers (Bergey Windpower Company) at 10m is 90.14db. The effect of this on wildlife such as birds and bats been disadvantage.

4.3. Economic Viability

The main economic output was total Net Present Cost. The result obtained from the cost optimization gave an initial capital cost of $107,660 with operating cost of $2,024/year. The total NPC was $147,485, SIR of 1.95, and a system simulated discount rate of 8% with the inflation rate at 2%. A payback period of 11 years and Levelized cost of energy of 0.331 $/kWh which equals the cost of grid-connected systems. The excess electricity of 10,561 kWh in a feed-in-tariff system as implemented by the government is to be sold back to the grid at the specified rate of 0.176 $/kWh. This would reduce the annual cost of the system to $1,950 per annum with a savings of $48,772 over the project's lifetime thereby, reducing the NPC to $98,712 for grid connected system. For the feed-in system, a payback period of 8.07 years and a SIR value of 2.84 was obtained proving good viability for the project with both systems achieving 100% RF.

The results present a fairly general analysis that could be used as an initial appraisal for power demands of buildings of similar load profile, intending to adopt a stand-alone renewable energy system.

5. Conclusion

An analysis was carried out to ascertain the potentials of a stand-alone power supply (SPS) system to feed the electrical needs of a commercial building adequately. The analysis was carried out using real-time demand data from the hotel located in Ajloun city in Jordan. The load data were obtained as secondary data from [8], over a one-year duration. Energy optimization software HOMER is used to ascertain the viability based on NPC, RF, SIR and payback period. The simulations show in principle that a stand-alone system is adequate and reliable in supplying the load demand of the hotel. Optimization modeling also shows that it is viable to obtain a 100% renewable factor consisting of a 20kW PV, a 10kW Bergey XL10 wind turbine system with a 7kW converter and eight 16 V batteries of the capacity of 1900 Ah. The simulation shows no environmental pollution regarding of greenhouse gasses, and the system is also economically viable with SIR greater than 1.

The model also shows high potential for the deployment of stand-alone power systems in buildings having similar load profile metrological resources.

Finally, the feed-in-tariff policy introduced by the government helped improved the financial gains of our system by presenting a more attractive energy supply option to individuals and commercial bodies considering deployment of renewable technologies for power generation.

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