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Hybrid wind-PV grid connected power station case study: Al Tafila, Jordan

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Abstract
In this paper, we are providing an attempt to highlight the importance of renewable energy, more specifically, the one produced from a wind-solar hybrid system. This purpose will be achieved through providing a detailed case study for such system that would be applied in Al-Tafila\Jordan. First and foremost site assessment has been conducted based on an intensive literature review for the data available regarding the availability of wind and solar energy in Jordan and resulted in the selection of Al-Tafila 2 district as the best option among all. Then, the components of the power station and its size have been selected based on specific criteria that make the station as much efficient and competitive as possible. To obtain the output of the different components with respect to the demand for a period of 25 years, a system model was built using HOMER. Finally, the total capital cost of the system was calculated and resulted to be (63400168) $ and with a cost of energy of (0.053) $/kWh which is a very competitive and feasible cost compared to similar international projects and to the conventional energy price.

Keywords: Hybrid; HOMER; Jordan; PV; Wind.

1. Introduction

Recently the term renewable energy has gain great interest in the world, Renewable energy is any technology that exclusively relies on an energy source that is naturally regenerated over a short time, derived directly from the sun, indirectly from the sun or from moving water or other natural movements and mechanisms of the environment it includes energy derived directly from the sun, wind, geothermal, hydroelectric, wave or tidal energy, or on biomass or biomass based waste products.

Jordan is a non-oil-producing country and imports 96% of the energy used. As a consequence, energy imports accounts for roughly 22% of the GDP. The population's growth rate is high; about 2.3% per year. This causes the demand on energy sources, mainly oil products to increase rapidly. Implementation of renewable energy resources such as solar energy, will lead to economical, social and environmental benefits [1].

The system with combination of different sources of energy is called hybrid system and the hybrid system is not new concept its has gained more consideration during the last two decades by many researchers such as Diaf et al [2]. They presented a methodology to perform the optimal sizing of an autonomous hybrid PV/wind system. Their methodology aims at finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value of levelized cost of energy and assumed PV/wind hybrid system to be installed at Corsica Island, their results showed that the optimal configuration, which meet the desired system reliability requirements loss of power probability (LPSP = 0) with the lowest levelized cost of energy LCE, is obtained for a system comprising a 125 W photovoltaic module, one wind generator (600 W) and storage batteries (using 253 Ah).

Nandi et al [3] evaluated the feasibility of a proposed wind-pv hybrid power system in Bangladesh and showed t hat wind–PV-battery is economically viable as a replacement for conventional grid energy supply for a community at a minimum distance of about 17 km from grid. Saheb-Koussa et al [4], designed a hybrid energy system consisting of wind and photovoltaic with battery storage with the backup of a diesel generator to ensure continuous power supply in Algeria. Dihrab et al [5], proposed a hybrid system as a renewable resource of power generation for grid connected applications in three cities in Iraq and showed that it is possible for Iraq to use the solar and wind energy to generate enough power for some villages in the desert or rural. Brito et al [6], presented a quality analysis of the electric energy supplied by a small PV-wind-diesel hybrid system to the community of Tamaruteua, located in the county of Marapanim, on the coast of the state of Para-Brazil.

Extensive research on renewable energies has been made in Jordan on the side of wind energy, Badran and Abdulhadi [7] used fuzzy logic methodology to assess wind sites in Jordan and to decide which sites should be given the highest priority with respect to their benefits and costs, and to predict the annual generation for different turbines in the best sites. Alghoul et al [8], collected and analyzed the daily mean wind speed for five locations in Jordan which are Amman, Aqaba, Der Alla, Irbid and Ras Muneef over a period of 9 years and showed that only Ras Muneef and Aqaba have good wind potential.

And on the side of solar energy Anagreh et al [9] conducted a study that aimed to constitute a database for the researchers interested in utilizing solar power in Jordan. It presents the investigation for seven sites distributed on all territory of the country,

Al-Soud et al [10] studied the feasibility of a 50 MW concentrating solar power plant for Jordan and showed that such technology is highly recommendable for Jordan. Different sudies were made on the hybrid systems as well.

This paper presents an analysis for a grid-connected wind – photovoltaic hybrid system for Al Tafila location in Jordan, and energy production costs and incomes are analyzed, the system configuration is simulated using the Hybrid Optimization Model for Electric Renewable (HOMER).

2. Site characteristics

The selected location for the project is Tafila 2 which is located in the south with the coordinates 30.76160^{o} N, 35.69096^{o} E. The solar and wind data are shown in the proceeding sections.

Figure 1 shows the location of Al Tafila in Jordan, while Figures 2 and 3 show the surface altitude and the project exact location respectively.

As shown Figure 2 Tafila 2 location elevation is 1400 m above sea level which guarantees high wind speeds. In Figure 3 the exact location of the project is shown, where there are vast available and level areas suitable for the project implementation.

2.1 Solar irradiation

Solar irradiance data for Tafila 2 location were obtained from different sources [11-13] The data obtained is shown in Table 1, the average solar radiation is about 5800 (Wh/m^2. Day), which is a very high value suitable for electrical power generation.

Figure 4 shows the average daily solar radiation incident on one square meter area (Wh/m^2. Day) for the year 2010.

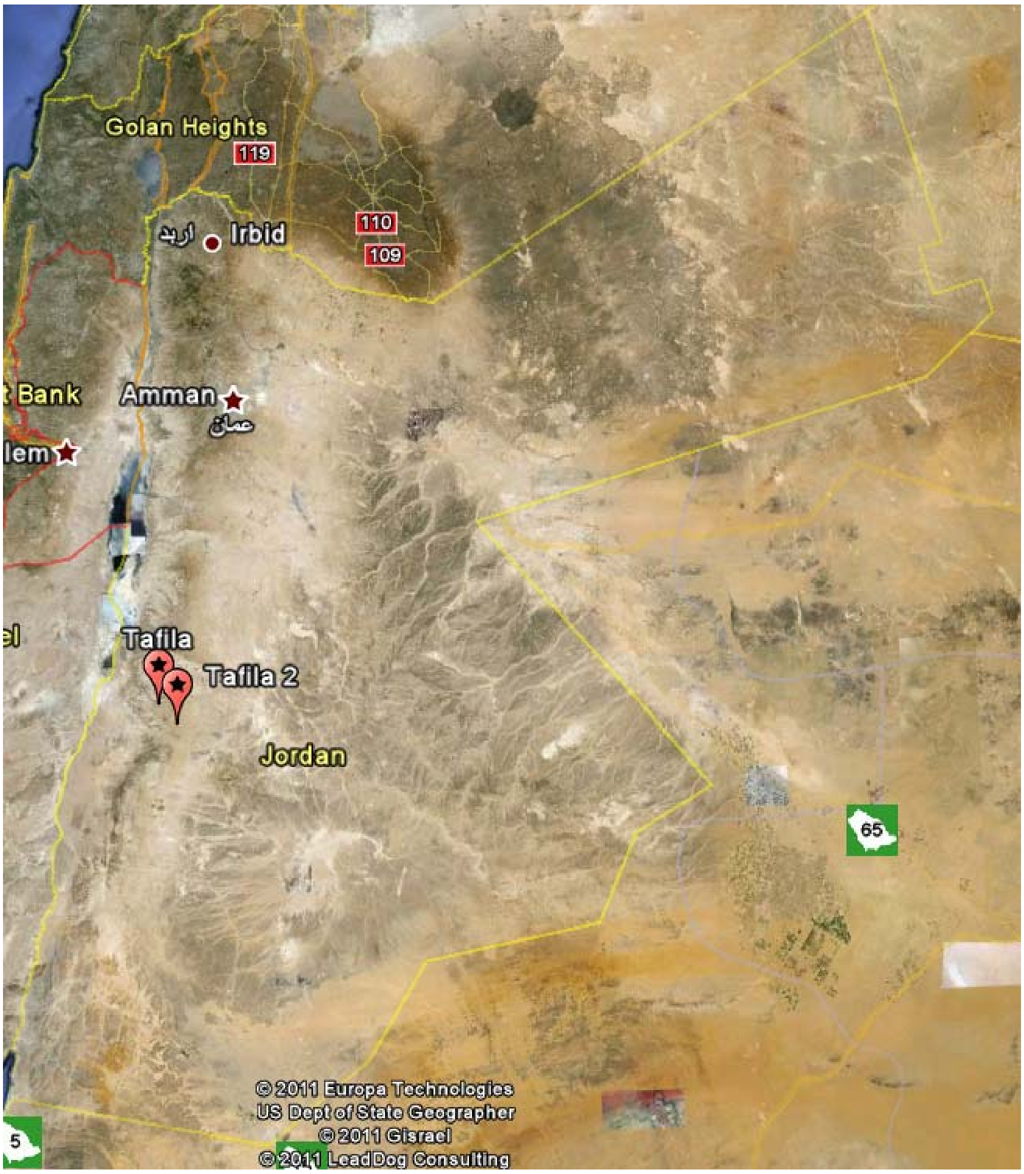

Figure 1. Location of Al Tafila in Jordan

Figure 2. Altitude of Tafila 2

Figure 3. Project exact location

Table 1. The average daily solar radiation incident on one square meter area (Wh/m^2. Day), Tafila 2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
2004	2970	3861	5352	6341	7596	8188	8154	7428	6313	5003	3764	3169	5678
2005	3072	4022	5469	6187	7461	8119	7963	7164	6418	5188	3641	3117	5652
2006	3106	3445	5993	6595	7882	8341	8314	7488	6238	4857	3608	3084	5746
2007	3402	4026	5524	6634	7495	8420	8204	7348	6488	4905	3846	3214	5792
2008	2976	4264	5970	6961	7877	8334	8327	7483	6219	4809	3632	3066	5826
2009	3535	4415	5952	6670	7638	8446	8397	7532	6507	4927	3603	3007	5886
2010	3562	4483	5978	6751	7981	8368	8084	7442	6142	5032	3638	3204	5889

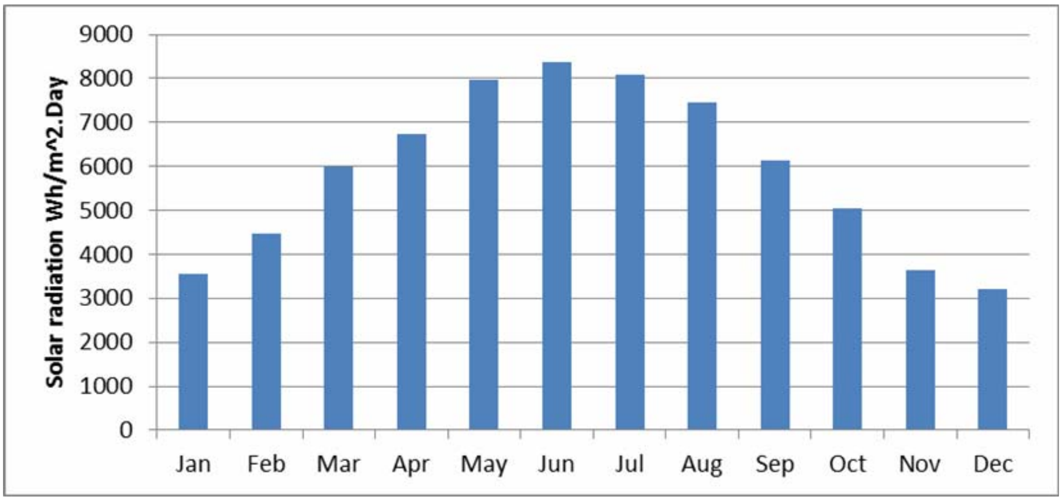

Figure 4. The average daily solar radiation incident on one square meter area (Wh/m^2. Day) for the year 2010

2.2 wind speed

As shown in Figure 5, the average wind speed for different locations in Jordan is about 6.5-7 m/s, and the highest average wind speed is in Tafila 2 location with a value of (8.54 m/s) [12, 13] followed by Al-Harir (8.4 m/s), which are both located in Al-Tafila. This fact gives a strong indication of the high wind potential for the implementation of electrical wind energy projects. Monthly average values of wind speed for the years (2008-2010) are shown in Table 2.

Figure 6 shows Monthly average values of wind speed (m/s) for the year 2010.

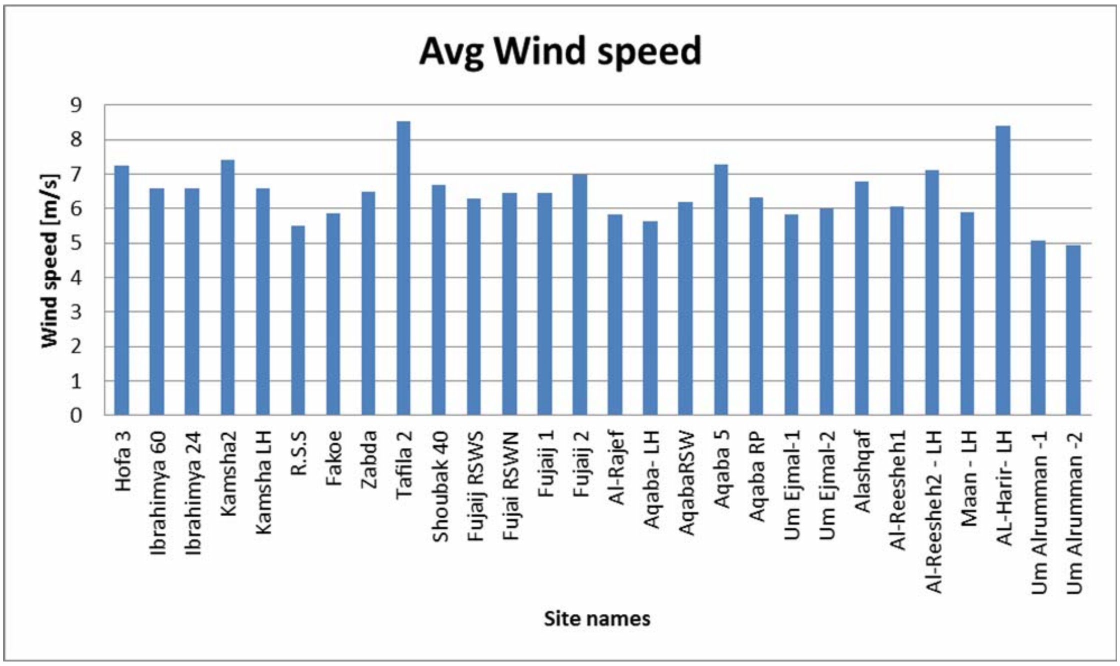

Figure 5. Average wind speed comparison for different locations

Table 2. Monthly average values of wind speed (m/s) for the years (2008-2010)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann Avg
2008	10.04	11.05	10.52	8.33	7.07	7.41	7.04	6.85	5.53	5.11	8.11	8.63	7.97
2009	10.69	9.23	9.69	9.08	7.82	8.16	7.79	7.6	6.28	5.86	8.86	9.38	8.37
2010	9.43	12.89	11.36	9.83	8.57	8.91	7.04	8.35	7.03	6.61	9.61	10.13	9.15
Monthly Avg.	10.05	11.05	10.52	9.08	7.82	8.16	7.29	7.6	6.28	5.86	8.86	9.38	8.50

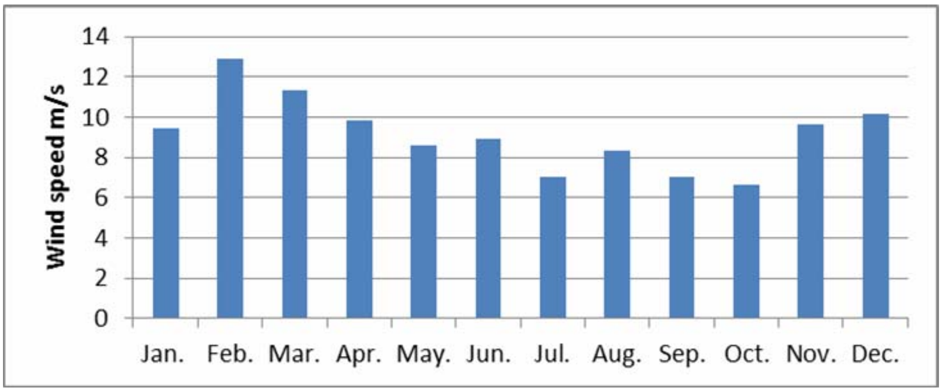

Figure 6. Monthly average values of wind speed for the year 2010

From all previous data it is clear that Al Tafila 2 is the best choice for the implementation of the Wind PV hybrid power station.

3. The load profile

The load data for Al-Tafila used in this project were obtained from [14], the data is given in 10 minutes intervals for every day of the year 2010 which amounted to 52560 data entry. The data were analyzed and summarized to an average day for each month which resulted in 12 average days and is shown in Table 3.

Table 3. Monthly average load MW per hour [14]

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00-1:00	10.09	8.53	9.98	10.66	12.26	10.75	10.48	9.90	9.38	8.11	7.64	9.33
1:00-2:00	10.04	8.19	8.94	9.97	11.85	10.75	10.48	9.90	9.38	8.11	7.64	8.79
2:00-3:00	9.27	7.52	8.43	9.61	9.83	9.79	10.48	9.90	8.85	8.11	7.64	8.79
3:00-4:00	8.98	7.52	7.92	8.90	9.83	9.60	10.48	9.90	8.64	8.11	7.64	8.79
4:00-5:00	8.99	7.52	7.92	8.90	9.83	9.60	10.48	9.90	9.06	8.11	7.64	8.79
5:00-6:00	9.24	7.52	7.92	8.90	9.31	9.60	10.13	9.90	7.79	8.11	7.64	8.79
6:00-7:00	9.52	7.86	7.92	9.97	9.23	9.09	9.44	9.07	7.54	8.23	7.64	8.79
7:00-8:00	8.98	8.81	8.26	11.02	10.26	8.99	9.51	8.90	8.17	9.20	7.64	9.88
8:00-9:00	9.69	10.67	9.47	13.56	10.56	11.60	11.48	9.15	9.52	10.24	8.88	10.57
9:00-10:00	10.63	11.82	10.34	14.45	10.68	10.37	11.72	9.57	10.89	9.64	9.96	11.61
10:00-11:00	11.17	11.80	11.03	13.81	13.44	10.39	13.56	10.15	11.36	9.97	9.74	10.71
11:00-12:00	11.08	12.35	11.03	14.59	13.69	11.02	14.27	11.34	11.72	10.07	9.74	11.85
12:00-13:00	9.99	14.16	11.51	14.17	14.50	12.22	13.21	10.48	11.88	9.73	10.23	12.70
13:00-14:00	9.65	12.89	13.08	13.47	13.34	12.37	12.48	10.30	10.11	10.13	11.38	10.98
14:00-15:00	9.48	12.95	14.05	11.57	13.29	9.65	12.24	10.61	9.20	9.21	9.69	10.78
15:00-16:00	9.96	12.73	13.11	10.84	12.83	9.94	12.24	8.91	9.97	9.47	10.67	10.33
16:00-17:00	10.07	13.55	13.42	11.46	12.81	10.12	13.79	8.62	10.16	9.65	11.51	12.03
17:00-18:00	11.48	15.07	13.85	11.53	12.53	12.09	13.07	10.66	10.03	9.54	12.23	13.20
18:00-19:00	11.07	12.90	13.72	11.53	13.73	11.38	11.84	9.53	10.03	10.28	11.91	13.57
19:00-20:00	10.53	12.90	14.85	12.65	14.75	11.38	11.33	9.68	10.03	10.65	11.91	13.39
20:00-21:00	10.92	12.90	14.85	13.50	15.43	11.88	11.33	11.80	10.03	10.65	11.91	12.50
21:00-22:00	11.17	12.90	14.63	12.66	13.73	12.38	11.33	11.22	10.03	10.48	11.17	12.32
22:00-23:00	10.90	11.38	14.19	11.95	12.69	11.50	11.33	10.57	10.03	9.64	10.05	10.38
23:00-0:00	9.52	10.87	11.94	11.02	12.52	10.79	10.30	11.68	9.51	9.64	9.68	9.37

The data set was fed to the Hybrid optimization for electric renewable (HOMER), and synthesized to 8760 hours; the main characteristics of the load demand are shown in Table 4.

Table 4. Al-Tafila Load profile characteristics.

Average (kWh/d)	254,164
Average (kW)	10,590
Peak (kW)	24,745
Load factor	0.428

The monthly load curve represents the average load and load variation through the different months of the year. This curve indicates the behavior of the load in each month. Figure 7 shows the monthly average load curve for Al Tafila.

It is the daily average load hourly variation. The points of greatest interests are: the peak demand, the peak demand duration and the peak demand hour. The daily average load curve gives details about the load demand at different hours of the day and let us compare between the different days of the year, Figure 8 shows the average daily demand for all the month of 2010 year in Al Tafila.

4. System configuration

The system configuration model was built using HOMER and it's shown in Figure 9. The system components are summarized in Table 5.

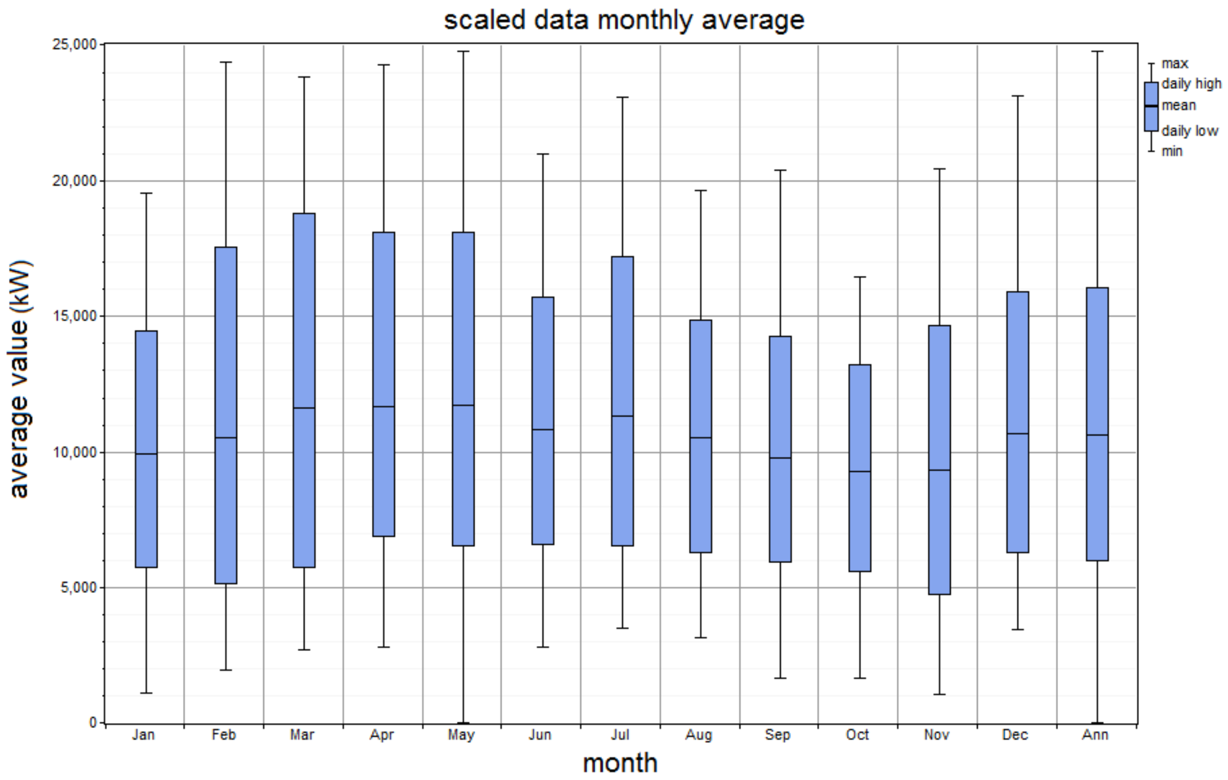

Figure 7. monthly average load curve for Al Tafila

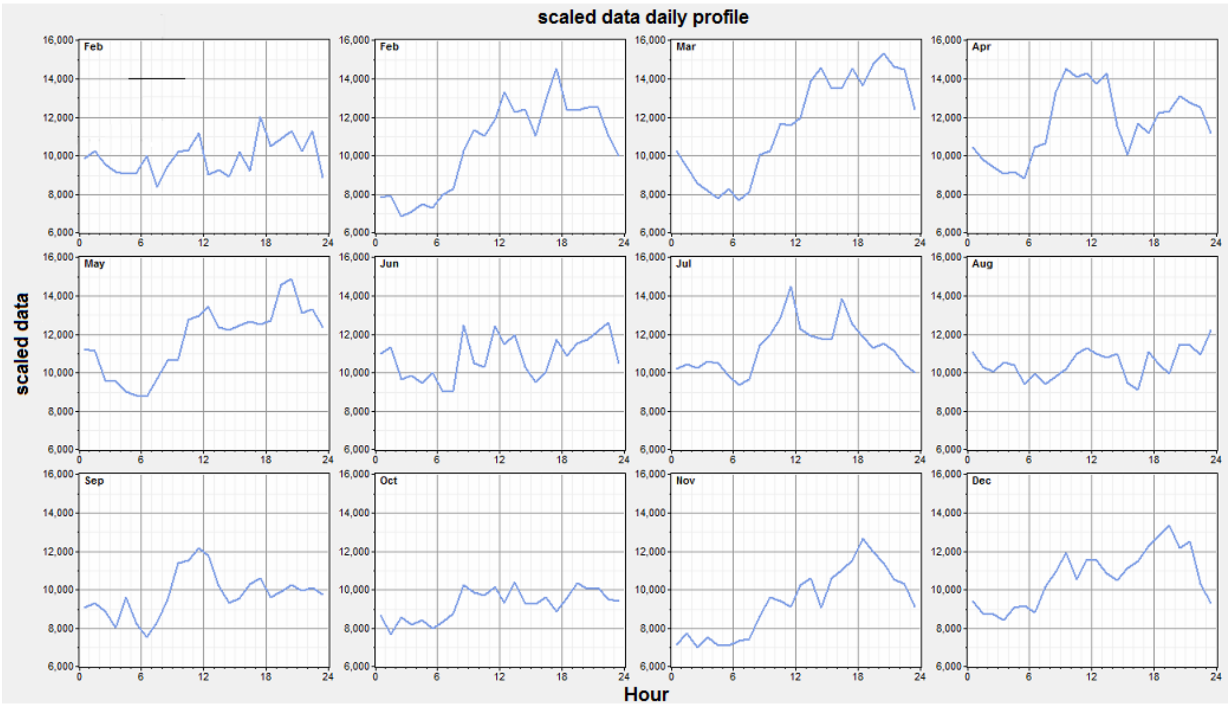

Figure 8. The average daily demand for all the month of 2010 year in Al Tafila

5. Results and discussion

After performing simulations of the system model, we get the following results:

5.1 Cost summary

The following Table 6 shows the capital, replacement, O&M, salvage and total cost for each component and for all the system and Figure 10 shows cash flow summary.

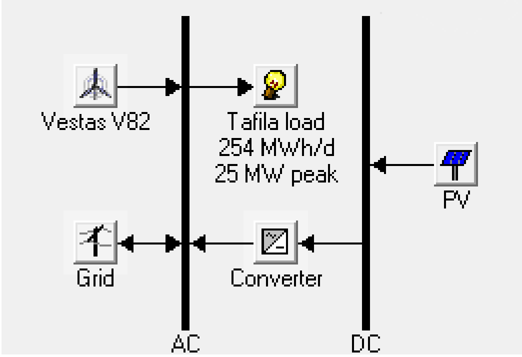

Figure 9. System model configuration

Table 5. System components parameters

Wind Turbines		
Parameter	**Value**	**Description**
Turbine type	Vestas V82	Determines the type of wind turbine used in the model, there are a large number of preset wind turbines or create your own wind turbine if needed
Costs		
Quantity	1	The quantity over which the costs are calculated
Capital ($)	2171400 [15]	The capital cost of the wind turbine in US dollars
Replacement ($)	1500000	The replacement cost associated with the replacement of the wind turbine after the expiration of the lifetime of the unit
O&M ($/year)	50000	The costs associated with the operation and maintenance of the wind turbines per year and it's considered to be 2% of the capital cost
Size to consider		
Quantity	12	The number of wind turbine to be used in the system, according to the sizing model
Other		
Lifetime	25	the number of years the turbine is expected to last before it requires replacement
Hub height	78	the height above ground in meters of the hub (the center of the rotor)
PV Panels		
Costs		
Size (kW)	1	The size in kW over which the costs are calculated
Capital ($/kW)	3100 [16]	The capital cost of the PV panel in US dollars per size
Replacement ($/kW)	2400	The replacement cost associated with the replacement of the PV panel after the expiration of the lifetime of the unit
O&M ($/year)	0	The costs associated with the operation and maintenance of the PV panels per year
Size to consider		
Size (kW)	10641.500	The total size of the PV plant to be used in the system, according to the sizing model
Properties		
Output current	DC	Whether the PV array produces AC or DC power. All PV cells produce DC electricity, but some PV arrays have built-in inverters to convert to AC.
Lifetime	25	the number of years the panels is expected to last before it requires replacement

Table 5. (Continued)

Derating factor	90%	A scaling factor applied to the PV array power output to account for reduced output in real-world operating conditions compared to operating conditions at which the array was rated.
Slope	30.7667	The angle at which the panels are mounted relative to the horizontal determined according to the latitude of the area.
Azimuth	0	The direction towards which the panels face.
Ground reflectance	20%	The fraction of solar radiation incident on the ground that is reflected.
Advanced		
Tracking system	No tracking	The type of tracking system used to direct the PV panels towards the sun.
Converter		
Size (kW)	1	The size in kW over which the costs are calculated
Capital ($/kW)	245 [17]	The capital cost of the converter in US dollars per size
Replacement ($/kW)	145	The replacement cost associated with the replacement of the converter after the expiration of the lifetime of the unit
O&M ($/year)	1	The costs associated with the operation and maintenance of the converter per year per kW which sums to 11000 $/Year
Size to consider		
Size (kW)	11000	The total size of the Converter to be used in the system, according to the sizing model
Inverter inputs		
Lifetime	25	the number of years the converter is expected to last before it requires replacement
efficiency	90%	The efficiency with which the inverter converts DC electricity to AC electricity, in %.
Inverter can operate simultaneously with an AC generator	Off	Check this box if the inverter can operate at the same time as one or more AC generators. Inverters that are not able to operate this way are sometimes called switched inverters.
Rectifier inputs		
Capacity relative to inverter	0	The rated capacity of the rectifier relative to that of the inverter, in %.
Efficiency	0	The efficiency with which the rectifier converts AC electricity to DC electricity, in %.

Table 6. Cost summary of the system

Component	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total($)
PV	32,988,650	0	0	0	32,988,650
Vestas V82	26,056,800	0	7,670,019	0	33,726,820
Grid	0	0	-8,926,190	0	-8,926,190
Converter	2,695,000	497,329	140,617	-278,725	3,054,221
Other	0	0	2,556,673	0	2,556,673
System	61,740,448	497,329	1,441,117	-278,725	63,400,164

The most important value of the previous table is the total cost of the project and it’s equal to 63,400,164 $. It is an acceptable cost for such projects. This fact will be made clearer when the cost of energy (COE) or the total levelized cost of the project is considered. The COE and yearly operation costs are shown in Table 7 which shows the summary of the most important aspects of the project.

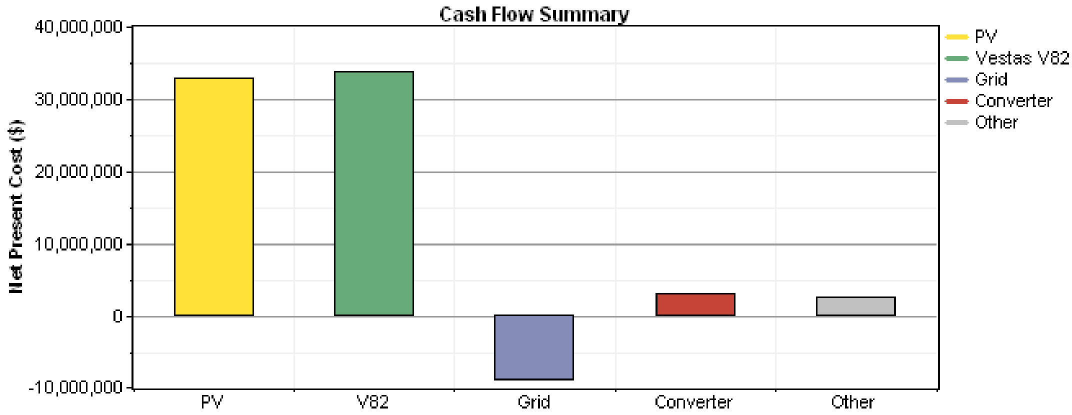

Figure 10. Cash flow summary

Table 7. System summary

System architecture	
Component	**Size**
Electric grid	24,318 kW
PV plant	10,642 kW
Wind farm	12 Vistas v82
Inverter	11,000 kW
System cost	
Total net present cost	63,400,168$
Levelized cost of energy	0.053$/kWh
Operating cost	129,835$/yr

5.2 The production and consumption of electricity by the system

The details about the annual production and consumption of electrical energy by the system and the total amount of energy that went to serve the system's electrical loads, plus any shortage or surplus are shown in Tables 8, 9 and 10.

Figure 11 shows monthly average electric production of the three sources of energy. It's readily seen from Figure 11 that the most part of the energy is supplied by the wind farm as planned. January is the month which shows the highest wind energy produced and the lowest PV energy which is related to the high wind speeds and low peak sun hours. It can also be noticed that the nature of wind energy is more variable than the nature of solar energy which varies much less.

Table 8. The annual production of electrical energy by the system

Production	**kWh/yr**	**%**
PV array	22,356,518	17
Wind turbines	86,614,280	65
Grid purchases	23,862,686	18
Total	132,833,488	100

Table 9. The annual consumption of electrical energy by the system

Consumption	**kWh/yr**	**%**	**Description**
AC primary load	92,769,864	71	The amount of energy that went towards serving the AC primary load.
Grid sales	37,828,008	29	The total amount of electricity sold to the grid during the year.
Total	130,597,872	100	The total amount of electrical load served during the year.

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Table 10. The annual excess and unmet load

Quantity	**kWh/yr**	**%**	**Description**
Excess electricity	0.277	0.00	The total amount of excess electricity that occurred during the year.
Unmet electric load	0.105	0.00	The total amount of unmet load that occurred during the year
Capacity shortage	0.00	0.00	The total amount of capacity shortage that occurred during the year.
Quantity	**Value**		
Renewable fraction	0.82		The fraction of the total electrical production that is produced by renewable sources.

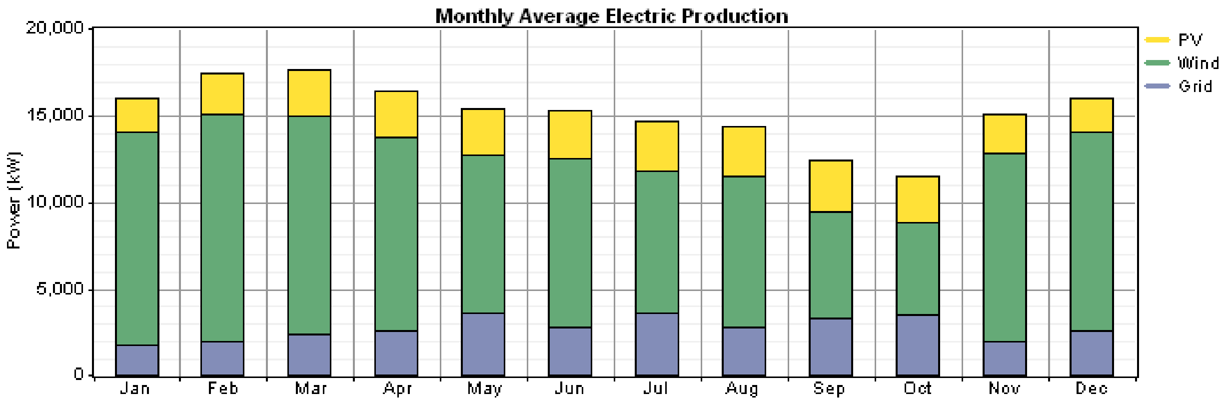

Figure 11. Monthly average electric production.

6. Conclusion

Jordan has faced high growth rate of population and urbanization in the last decades, and consequently, the rate of energy consumption is rising rapidly. Jordan is an oil importing country and, at the same time, oil is the dominant energy sector for Jordanian hard currency is spent to import crude oil and to refine petroleum products. Nowadays, utilization of renewable energy resources, especially wind and solar, is one of the main concerns of the Jordanian government. This is due to the expected economical and environmental benefits which will be acquired by utilizing stand-alone or hybrid renewable energy system.

the optimal number of PV panels and wind turbines resulted to be (35472) PV panels and (12) Wind turbines. The simulation results showed that the yearly energy demand is (92,769,864) kWh/year, on the supply side the annual Energy supplied from the wind farm is (86,614,280) kWh/year which forms (65%) of the produced energy, while the Annual PV produced energy (22,356,518) kWh/year forming (17%).The load demand directly supplied by the renewable energies is (82%) of the total demand, the remaining (18 %) was purchased from the grid, the renewable energy generated which was higher than the demand was sold back to the grid and was used as a form of energy storage which amounted to (29%) of the total energy generated.

The total capital cost of the system resulted to be (63400168) $ and with a cost of energy of (0.053) $/kWh which is a very competitive and feasible cost compared to similar international projects and to the conventional energy price.

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