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Prospects of wind power generation in Jordan: the case of street lighting

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ABSTRACT. The main objective of the current study is to examine and analyze technical and economic issues affecting of the use of wind energy utilization in street lighting in Jordan.
As per the Meteorological Department of Jordan the minimum wind speed is 7 m/s in Jordan which is above the global average.
Technically it's fond that using a horizontal turbine with three blades is enough to produce the necessary energy for street lighting.
Taking into consideration the cost of the turbine and pole lighting and bulbs, operation and maintenance, it's found that the recovery of the cost of the system need about 12 year at wind speed 7m/s, thus, there is economic benefit equivalent of $1700.

Key words

Wind energy, street lighting, renewable energy, electricity generation, Jordan

1.Introduction

Jordan suffers from a sever lack in energy resources, at the same time the energy consumption in Jordan is increasing yearly as it has reached 6.15% of the GDP at the end of 2015, which creates an economic burden on the GDP and imposes a necessity for detailed search for alternative sources of energy.

Total Jordan's imports of energy constitute about 1,603 Billion JD (2.258 Billion US Dollar) in 2015 (Tab. 1), about 96 % of these needs from abroad, according to the World Bank report, which is so much relative to the Jordanian national product (Note that the Jordanian national product is equivalent to 0.00037 of global GDP for the same year [1].

The increasing value of the oil bill in Jordan is linked to number of internal and external factors, including:

1. The rate of population growth, which is considered high (about 2.2%) [2].

2.Increasing in the total number of operating vehicles (1,336, 667 vehicle) in 2015 [3].

Table (1): The Jordan energy bill.

Type of petroleum material	Value of imports, million JD	Percent of the total energy imports
Crude oil	886.78	%28.6
Diesel	529.53	%16.6
Fuel oil	289.58	%0.0
Lubricant	22.92	%3.7
Petroleum gases	218.92	%34.7
Gasoline	222.76	%15.4
Natural gas	47.54	%0.0
Electricity	40.07	%1.0
Total	2258	%100

3. Increased demand for A/C devices due to high temperatures resulting from climate change, which reached two degrees Celsius.

4. Jordan constitutes asylum to the refuges from neighboring Arab countries suffering from wars (Iraq and Syria). This issue contributed to increased energy consumption about 3% (equivalent 7.25 million US Dollars of the Jordan's energy bill) in 2011-2012 [4]. In the past few years, the Jordanian Government went towards diversifying energy taking into consideration the above-mentioned circumstances, namely toward the solar and wind energy, to ensure economic stability. Jordan has a countless source of wind and solar energy, provides an opportunity for the country to reduce both energy costs and reliance on hydrocarbons without burdening the budget. Jordan comes in the forefront countries in the Middle East Region in mobilizing private capital towards investment in the field of renewable energy. Since 2012 the private sector built nine solar power plants and one wind power plant to generate electricity.

In this context, the friendly countries to Jordan encourage and contribute to the provision of financial and technical support for the success of the Jordanian Government directed towards alternative energy as part of the main solution to economic problems.

The European Central Bank began to reconstruct, develop, and support renewable energy programs in Jordan since 2012, which included the financing of solar photovoltaic power plants with a capacity of 60 MW. In addition to a70-million-dollar loan for Green Watts LLC, to build a wind power plant with a capacity of 86 MW [5].

2.Wind energy theory

Wind power is extracted from wind energy for further a applications of energy, such as wind turbines to produce electricity and wind mills to generate mechanical power. wind turbine is a device which converts wind kinetic energy into mechanical energy. In case of electricity is the output of such energy then it is called wind generator or wind charger. Wind turbines are manufactured in a range scale of vertical and horizontal axis types. The smallest are used for limited applications such as battery charging or auxiliary power on sailing boats. whereas, large turbines are used increasingly as a major source of commercial electric power.
Even though the nature of the wind is discontinuous, wind patterns at particular places remain almost constant throughout the years. The average wind speed in hilly and coastal areas, is greater than at inland. This is probably because the wind tends to blow consistent pattern over the surface of the water. Moreover, wind speed increases with elevations. At 60 m elevation, the wind speed range is 30-60% greater than low altitude lands. Accordingly, wind blades are preferred to be installed at heights so that the maximum amount of wind leading continuous rotation.
Wind energy conversion systems classification mainly is based on different orientation as elaborated hereafter:

1. Axis of rotation
2. Output power
   a) DC Output
   b) DC generator
   c) Alternator rectifier
   d) AC Output
   e) Variable or constant frequency
3. Rotational speed
   a) Constant speed Vs. variable pitch blades
   b) Constant speed Vs. fixed pitch blades
   c) Variable speed Vs. fixed pitch blades
4. Output utilization
   a) Battery storage
   b) Direct connection to an electromagnetic energy convertor
   c) Other form of storage
   d) Inter connection with conventional electricity utility grids.

However, there are three basic factors influence the output of wind energy conversion system, viz:

a) Wind speed
b) Cross section of the windswept by the rotor.
c) Conversion efficiency of the rotor, transmission system generator or pump.

From Theoretical point of view, it may be impossible to obtain 100% efficiency through halting and preventing the passage of air through the rotor. However, no certain equipment can eliminate all the wind energy but only able to slow down the air column to one third of its free velocity. achieving 100% efficient wind generator can convert maximum up to 60% of available wind energy into mechanical energy. Moreover, such losses sustained in the generator or pump decreases the inclusive efficiency of power generation to 35% [6]. Figure 1 shows the general block diagram of the wind energy conversion system (WECS).

   a) Horizontal axis machines
   b) Vertical axis machines
5. Size if machine
   a) Minor scale (up to 2 KW)
   b) Intermediate scale (2-100 KW)
   c) Great scale (100 KW and up)

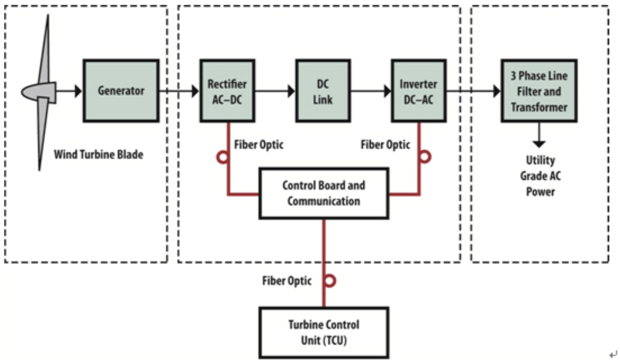

Figure (1): Block diagram of components of a wind energy conversion system [6].

The wind-electrical generating power plant with its components is shown in figure (2).
In order to best utilization wind power emerged what is known as onshore and offshore wind farms in some countries (Table 2 and 3).
The wind ranch comprises of several wind turbines located nearby at one place in order to produce electricity. Large wind ranch may consist of several hundreds of individual wind distributed on an extended area of turbines, yet the spacing between the turbines can effectively be used for farming or other purposes [7].

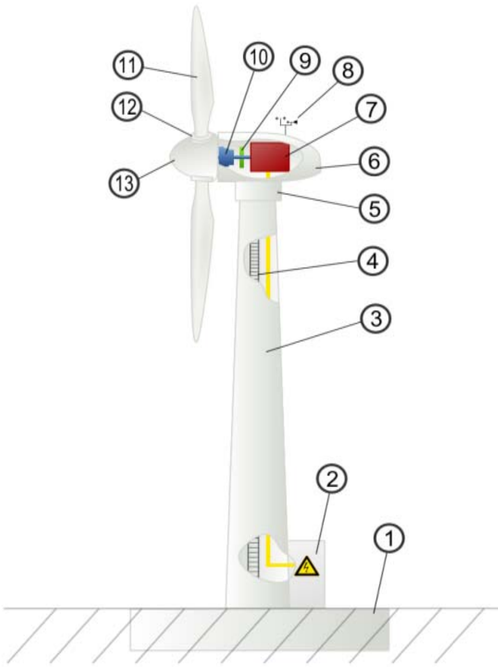

Figure (2): Typical wind turbine components [6]. 1-Foundation, 2-Connection to the electric grid, 3-Tower, 4-Access ladder, 5-Wind orientation control (Yaw control), 6-Nacelle, 7-Generator, 8-Anemometer, 9-Electric or Mechanical Brake, 10-Gearbox, 11-Rotor blade, 12-Blade pitch control, 13-Rotor hub.

Table (2): Onshore wind farm

Name of the wind farm	Production (M watt)	Country
Gansu	6,000	China
Alta	1,320	USA
Jaisalmer	1,064	India
Shepherds Flat	845	USA
Roscoe	782	USA
Horse Hollow	736	USA
Capricorn Ridge	662	USA
Ventnalh-Cogealac	600	Romania
Fowler Ridge	600	USA
Whitley	539	UK

3. Wind turbine Design and calculation

When comparing the characteristics and features of the horizontal and vertical turbine, it is found that the horizontal turbines are best suited for use in street lighting [8, 9, 10, 11].

Commercial wind turbines are built with a propeller-type rotor on a horizontal axis (i.e., a horizontal main shaft). Most horizontal axis turbines built are two or three bladed, although some have fewer or more blades.

Table (3): Offshore wind ranch.

Name of the wind farm	Power, Mwatt	Country	Turbine Type	Date of operation
London Array	630	UK	175 × SWT-3.6	2012
Greater Gabbard	504	UK	140 × SWT-3.6	2012
Aanholt	400	Denmark	111 × SWT-3.6-120	2013
Bard 1	400	Germany	80 Turbine5.0Bard	2013

The rewards of horizontal axis wind turbines are:

1. Sites, every 10 meters up the wind speed can increase by 20% and the power output by 34%.
2. Two-high efficiency, since the blades always moves perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of responding actions, requiring airfoil for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.
3. Variable pitch is possible by which the angle of attack of the turbine blades can be controlled.
4. The blades always move perpendicular to the wind. This leads to higher efficiency as the blades receive power throughout the revolution.

Hindrances of horizontal axis wind turbines are:

1. The tall towers of the HAWT are difficult to transport and install, this problem solve with lamp column.
2. The downwind HAWT suffers from fatigue.
3. The large HAWTs require additional yaw control systems to point them into the wind.
4. The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear Rotations of blades result in cyclic stresses and vibrations in the main bearings of the turbine.

It found that street lighting need a minimum power of 120 watts, so to produce this amount from the power wind relation: An ideal wind turbine has a maximum power coefficient of 16/27. The theoretical limit cannot be exceeded and this caused by the aerodynamic losses due to conversion of angular momentum, tip and drag [12]. The calculation results are shown in table 4.

4- Economical feasibility

To find out the result of using wind energy in street lighting were identified cost-effectiveness compared with the costs of lighting currently used by the Jordanian electricity company- NEPCO (90 US Dollar per year) as a supplier of electric power for this purpose.
Taking into account the turbine cost, installation of lighting pillar, and the costs of operation and maintenance a humble economic feasibility study was conducted at different wind speed, for instance, 5 -14 m/s. The cash flow results are given in table 5.

Table (4): The calculation results.

wind speed "m/s"	power wind " W "	power mechanical "W"	power turbine "W"	rpm " N1 "	rpm "N2"	Torque “N.m"	Power electric "W"
3	74.81383088	32.16994728	30.56144991	119.4267516	358.2802548	0.809813947	27.50530492
4	177.336488	76.25468984	72.44195535	159.2356688	477.7070064	1.439669239	65.19775981
5	346.3603281	148.9349411	141.488194	199.044586	597.133758	2.249483186	127.3393746
6	598.510647	257.3595782	244.4915993	238.8535032	716.5605096	3.239255788	220.0424394
7	950.4127404	408.6774784	388.2436044	278.6624204	835.9872611	4.408987045	349.419244
8	1418.691904	610.0375187	579.5356428	318.4713376	955.4140127	5.758676957	521.5820785
9	2019.973434	868.5885765	825.1591476	358.2802548	1074.840764	7.288325523	742.6432329
10	2770.882625	1191.479529	1131.905552	398.089172	1194.267516	8.14 732745	1018.714997
11	3688.044774	1585.859253	1506.56629	437.8980892	1313.694268	10.88749862	1355.909661
12	4788.085176	2058.876626	1955.932794	477.7070064	1433.121019	12.95702315	1760.339515
13	6087.629127	2617.680525	2486.796498	517.5159236	1552.547771	15.20650634	2238.116849
14	7603.301923	3269.419827	3105.948836	557.3248408	1671.974522	17.63594818	2795.353952
15	9351.728859	4021.24341	3820.181239	597.133758	1791.401274	20.24534868	Power output 3kw
16	11349.53523	4880.30015	4636.285142	636.9426752	1910.828025	23.03470783	
17	13613.34634	5853.738925	5561.051979	676.7515924	2030.254777	26.00402563	
18	16159.78747	6948.708612	6601.273181	716.5605096	2149.681529	29.15330209	
19	19005.48392	8172.358088	7763.740183	756.3694268	2269.10828	32.48253721	
20	22167.061	9531.83623	9055.244419	796.1783439	2388.535032	35.99173098	
21	25661.14399	11034.29192	10482.57732	835.9872611	2507.961783	39.68088341	
22	29504.35819	12686.87402	12052.53032	875.7961783	2627.388535	43.54999449	
23	33713.3289	14496.73143	13771.89485	915.6050955	2746.815287	47.59906422	
24	38304.68141	16471.01301	15647.46236	955.4140127	2866.242038	51.82809261	
25	43295.04102	18616.86764	17686.02425	995.2229299	2985.66879	56.23707966	

Table 5: Cash flow.

wind speed " m/s "	Power electric "W"	$E_{(kWh)}$	Income, $	Payback period in year	Profit, $
5	127.3393746	1059.71828	119.4		
6	220.0424394	1831.19318	206.33	28.45738788	
7	349.419244	2907.86695	327.6	11.85401094	1698.8
8	521.5820785	4340.60606	489.1	6.673060486	4922.5
9	742.6432329	6180.27698	696.4	4.274316772	9068.2
10	1018.714997	8477.74621	955.2	2.950003195	14245.6
11	1355.909661	11283.8802	1271.4	2.140121938	20569.3
12	1760.339515	14649.5454	1650.7	1.609989463	28153.9
13	2238.116849	18625.6084	2098.7	1.245508453	37114.1
14	2795.353952	23262.9356	2621.7	0.985341027	47564.4

Conclusion

1. Jordan suffers from severe lack of energy resources, at the same time the energy consumption in Jordan is increasing yearly, which generates an economic overburden on the GDP.
2. The utilization of renewable energy (solar and wind) has become the foremost objective for the Jordanian Government in last few years to attain economic stability.
3. According to the Jordan Meteorological Department, the average wind speed in Jordan is 7 m/s, which is above the global average.
4. Using wind energy for street lighting becomes a valuable at a wind speed from 7 m/s, while cost recovery needs about 12 years. The benefits in this speed equalize 1700 US dollars.

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