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Assessment of wind energy potential for selected areas in Jordan

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ABSTRACT

This paper presents a technical assessment of wind power potential for seven locations in Jordan using statistical analysis to determine the wind characteristic based on the measured wind data. Rayleigh distribution is used to model the monthly average data and used to estimate the wind power in the selected locations. Energy calculations, capacity factors and cost of wind energy production were determined for the selected locations with wind machines of different sizes ranging between 1.65 MW and 3 MW. The quantitative estimates of the technical and economic potential are presented graphically. Rayleigh parameter is adjusted to the hub height using one seventh power law to estimate the power output of the machine. The energy cost analyses show that all selected sites have high economic potential with unit cost less than $0.04/kWh of electricity. The lowest unit cost per kWh is obtained by using GE 2.5 MW at Tafila site. Finally, the results of this study reveal that Jordan has high potential wind energy and its environmental and energy policy targets can be met by exploitation wind energy.

1. Introduction

1.1. Energy situation and wind energy in Jordan

The global technical potential of wind energy is very large, estimated between 630,720 and 1,489,200 TWh/year which could be extracted in a practical and cost-competitive manner [5]. Over twenty years ago, studies of wind energy potential in Jordan have concluded that Jordan has a significant wind energy potential on several locations [1–4]. However, the recent development in harvesting wind energy, the low prices of new technology, the increased capacity of wind turbines, accessibility to power stations and higher oil prices entail further assessment criteria for the feasibility of using such technology. The mentioned studies above did not consider population density around the selected sites nor considered the proximity to the power stations. Furthermore, a detailed and satisfactory evaluation of the cost of electricity produced by WECS has by no means been carried out in this field in Jordan.

Jordan depends almost entirely on the imported oil for meeting its needs of commercial energy at the crushing cost of up to 25% of Jordan's annual GDP [6–9]. The annual growth rate of energy and electricity demand is amounted to 4% [10,11]. In 1997, the demand for primary energy was 4.7 million ton oil equivalent (TOE) while it reached over 7.6 million TOE in 2009. The total installed electricity generating capacity in the country was 1265 MW while the current Total Nominal is about 3309 MW. The rising cost of importing energy resources has forced the government to reconsider its energy consumption policies. Jordan's national energy strategy requires that renewable energy must constitute 10% of the energy mix by 2020, and has adopted comprehensive renewable energy laws and policies to attract investment in new wind and solar technologies, which is to be complemented by energy efficiency. The plans aim to increase the renewable energy share in the energy mix from 2% to 7% by 2015 and to 10% by 2020. The government aims to generate around 600 MW by 2015 and to double this capacity by 2020. Solar power is also expected to contribute by 600 MW of generation by 2020.

Jordan has significant wind energy resources that could be exploited for power generation. The exploitation of wind energy sources can help Jordan achieve many of its environmental and energy policy targets including reducing the energy import dependency. The country's Wind Atlas indicates that some areas in the Northern and Western regions of the country have wind speeds that exceed 7 m/s. Two wind pilot projects exist in the County with a capacity of 1.5 MW. They have been running since early 1990. Currently, two wind projects are proceeding. The first one is "Al-Khamshah" with a capacity of 30–40 MW and the second one is "Al-Fujeij" with a capacity of 80–90 MW.

1.2. Site selection

Wind data analysis and accurate wind energy potential assessment are key requirements for valuable development of wind power at any site. The study of wind speeds, characteristic parameters of the

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Nomenclature

agl	above ground level
c	Weibull scale paramter (m/s)
C_f	capacity factor
k	Weibull shape factor
P	power density (W/m^2)
P_r	rated power of wind turbine (W)
V_m	Weibull mean wind speed (m/s)
v	wind speed (m/s)
v_i	cut in speed(m/s)
v_o	cut out speed(m/s)
v_r	rated speed (m/s) r
ρ	air density (kg/m^3)
σ	Rayleigh scale paramter (m/s)

wind, topography, local wind flow and measurement of the wind speed are very essential in wind resource assessment for successful application of wind turbines. The annual wind energy production depends on the wind availability, the height of installation above ground, the effect of wind gusting and micrositing of WEGs.

The wind atlas of Jordan established in 1987 shown in Fig. 1 provides the annual average wind speed all over the country. The National Energy Research Center (NERC) has conducted a wind measuring campaign in the potential sites in Jordan for several heights (10, 30, 40, 50, and 60) meter above ground level in order to obtain more reliable wind data in the period between 2001–2008 [12]. After the investigation of the wind potential, the grid expansion and the power substations, seven sites were chosen in three regions, particularly: North (Hofa, Ibrahimya and R. Monief), Middle (Tafila and Zabda), South (Fujaij, Aqaba 5). Table 1 lists some geographic information of the selected sites. Fig. 2 gives an overall picture of the selected sites and the closest power plants to those sites. Table 2 lists the mean monthly wind speed for the selected sites at different measuring levels. This wind data obtained from Ref. [12] was measured over a period of time ranging from 2002 to 2008 as shown in Table 2.

Fig. 2 illustrates the annual mean wind speeds for all sites. In general, from Fig. 2, it can be taken that the average wind speed exceeds 6.5 m/s for all selected sites. Hofa, Zabda and Tafila are the windiest stations with annual average wind speed that is greater than 7 m/s.

1.3. Wind turbine selection

Four wind turbine models are chosen in this study, namely; (Torres) TWT 1.65 MW, Nordex 2.5 MW, GE 2.5 MW and Vestas 3 MW. Table 3 lists the main characteristics of wind turbines selected for this study. It is important to mention here that TWT 1.65 MW hub height is 71 m and the other wind turbines are 80 m. Also, the rotor diameter is different for each wind turbine.

The main objective of this study is to present a technical assessment of the power generation for the four commercial wind turbines (1.65 MW–3 MW) in the seven potential sites located in Jordan. To achieve this objective, the evaluation of wind energy at the promising sites is estimated using statistical modeling (i.e., Rayleigh distribution function) followed by a breakdown of the

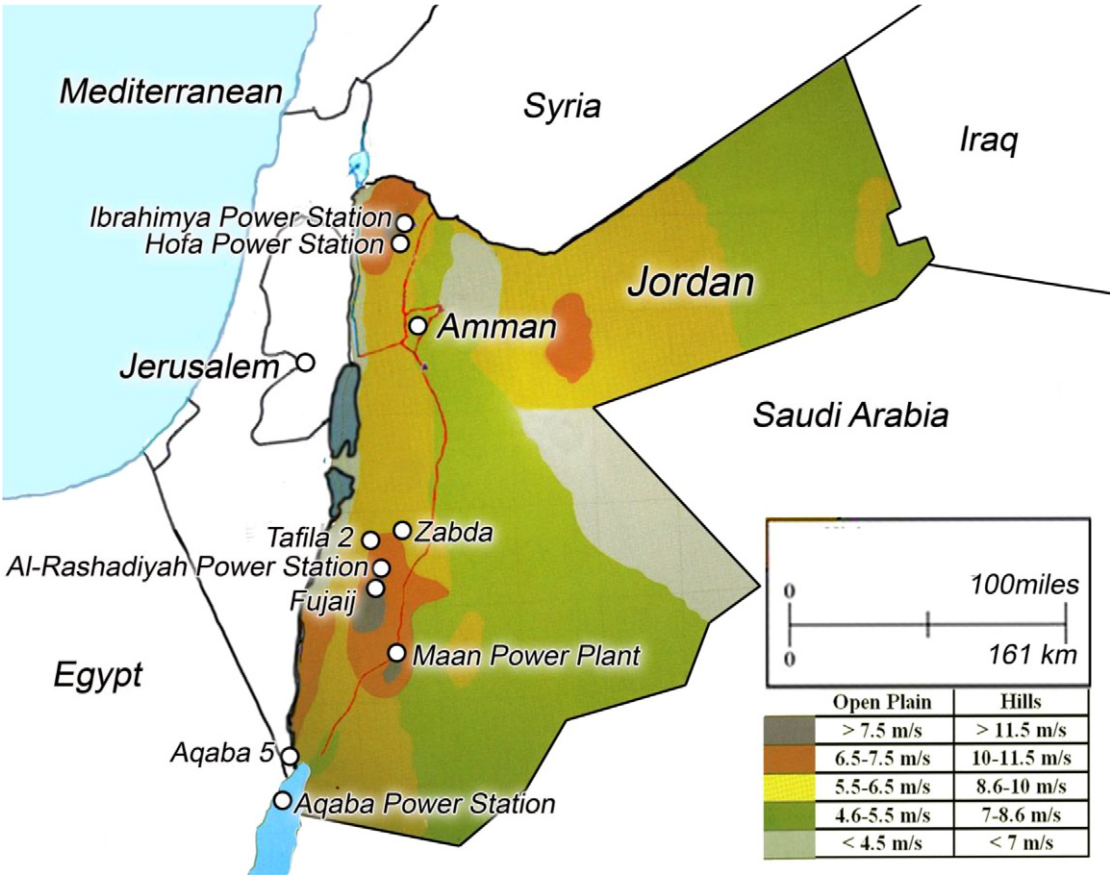

Fig. 1. The wind atlas for Jordan [10], selected sites and the closest power stations [12].