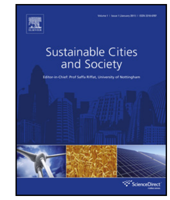
Sustainable Cities and Society xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs



Evaluation of wind energy potential and electricity generation at five locations in Jordan

Handri D. Ammari*, Saad S. Al-Rwashdeh, Mohammad I. Al-Najideen

Mechanical Engineering Department, Faculty of Engineering, Mutah University, P.O Box 7, Al-Karak 61710, Jordan

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Wind energy potential
Weibull distribution
Wind power
Wind power machines

ABSTRACT

Evaluation of the wind power from the knowledge of the mean monthly wind speeds of a typical year, and for five different locations in Jordan is analyzed and assessed. In addition, an investigation into the feasibility of using five different wind turbines of different rated power ranging from 100 kW to 3000 kW at each location to be employed in wind farms is examined. The data of the wind speeds over five years are fitted to the Weibull distribution, which is most frequently used and most appropriate, describing frequency distribution for wind moving over Jordan. The annual mean values of the wind speed and the frequency distributions were found for the five locations studied; Ras-Moneef, Azraq south; Safawi, Queen Alia Airport and Aqaba Airport. The locations included the eastern desert regions where wide plain lands are economically feasible to be used for wind farms. It is apparent from the results of the analysis that the highly promising sites of having good wind energy potential are Aqaba and Ras-Moneef, whereas, the desert sites of Safawi and Azraq South have only moderate potential and Queen Alia Airport have a lower potential. The annual mean values of the wind speed and power density of the observed and theoretical distributions are 5.5 ms^{-1} and 160 Wm^{-2} for Ras Moneef, 4.0 ms^{-1} and 175 Wm^{-2} for Azraq South, 4.5 ms^{-1} and 94 Wm^{-2} for Safawi, 3.13 ms^{-1} and 31 Wm^{-2} for Queen Alia Airport and 6.0 ms^{-1} and 215 Wm^{-2} for Aqaba Airport, respectively.

1. Introduction

The most significant threat to climate change is global warming due to the presence of greenhouse gases in the atmosphere arising from mankind's use of fossil fuels. The impact of climate change on environment, in terms of increased carbon dioxide emissions, has motivated the world energy policy to be focused on renewable energy sources of power. Wind power that would hardly be effected by such climate change for the lifespan of wind machines is one such renewable energy source that is increasingly being used throughout the globe. With wind machines of 15–20 years lifespan that can be implemented at sufficiently windy sites, wind energy can be competitive with other renewable energy systems for electricity generation.

Wind energy is presently widely and popularly used in many countries such as the USA, Germany, Spain, China, India, UK, Denmark and Canada. The cumulative global wind energy generating capacity topped 147 GW in 2008, with an increase of about 80% of new capacity that were installed worldwide during the past decade, according to preliminary estimates by the American Wind Energy Association (AWEA) and the European Wind Energy Association (EWEA). Global wind power generating capacity has been duplicated around five times from 31.128 GW in 2002 to reach over than 147 GW at the end of 2008 (WEC, 2014).

Using alternative energy resources and developing these resources are of great importance in order to prevent pollution of the environment and global warming, which have recently been imposing serious threats to the world. Limited reserves of fossil fuels and their negative effects on the environment lead institutions, organizations and governments to find technologies that are more efficient and new and renewable energy resources to be used for producing energy in the natural environment.

Today, the use of wind energy technology has been developing very fast. Given that wind power is a local resource and that it is a clean and environmentally friendly resource, it is vital to conduct the required technical and economical feasibility researches in order to make use of this energy to overcome the current energy crises (Ackerman & Söder, 2002).

There are a lot of studies regarding the determination of wind characteristics and feasibility analysis of various wind projects in the whole world (Acker, Williams, Duque, Brummels, & Buechler, 2007; Celik, 2007; Genç & Gökçek, 2009; Gökçek, Bayülken, &

* Corresponding author. Tel.: +962 77 7840660.
E-mail address: hanamm@mutah.edu.jo (H.D. Ammari).

http://dx.doi.org/10.1016/j.scs.2014.11.005
2210-6707/© 2014 Published by Elsevier Ltd.

Nomenclature

A	swept area (m^2)
C_f	capacity factor
c	Weibull scale parameter (m/s)
F	frequency distribution
E_V	energy output (kWh/year)
h	height (m)
k	Weibull shape parameter (dimensionless)
p	power of wind per unit area (W/m^2)
p_r	rated power (W/m^2)
V	wind speed (m/s)
ρ	air density (kg/m^3)
Γ	gamma function

Bekdemir, 2007; Gökçek, Erdem, & Bayülken, 2007; Luickx, Delarue, & D'haeseleer, 2008; Rehman et al., 2007; Shata & Hanitsch, 2006; Ucar & Balo, 2009). For example; a study on evaluating and determining of the most suitable sites for wind development, wind mapping process, and energy cost in Arizona State is carried out by Acker and others (Acker et al., 2007). Their study also includes analyzing of capacity factor, its seasonal variation, and cost of energy for four diverse sites in Arizona. Rehman et al. (2007) investigated the wind data and energy production analysis using three wind turbines with different power ranges in Rafha. Their results showed that the annual mean wind speed and frequency distribution plays an important role in energy production.

Jordan, on the other hand, is a country of sun and wind. However, until recently, energy sources used were exclusively oil and gas fossil energies. It has been so, until the political changes in the Middle East in 2003, where Jordan lived in some sort of energetic comfort; Iraq used to provide Jordan with oil at preferential prices over the 80–90s of last century, while the 60–70s era witnessed support from the gulf in oil support. The interest in wind energy applications in Jordan began in 1979 at Royal Scientific Society (RSS). After the 2003 political changes, oil prices exploded on international markets and Jordan found itself in a difficult situation. To remedy the problem and make the country less vulnerable, the Jordanian government sat up a series of initiatives, and the establishment of a center for research on renewable energies "National Energy Research Center, NERC" is one of the steps undertaken. In addition, the royal scientific society had a department engaged in renewable energies since 1972. Today, 97% of the consumed energy is still from fossil sources and 96% is imported, while only 2% is renewable. This costs Jordan 20% of its gross domestic product.

Nowadays, Jordan is seeking to diversify its sources and is exploiting new energies, and a real work of research on wind and solar powers is taking place. In 2007, the government set an energy Strategy and work plan for 2007–2020, with the objectives of having 7% of the energy mix should originate from solar and wind energy, by 2015, and should be raised to 10% by 2020.

Solar energy systems such as photovoltaics, PV, are already explored in Jordan, where currently two large PV systems, of 100 MW total capacity, are under construction in the southern parts of Jordan, in particular Maan and Aqaba. However, solar PV systems would require larger land area in comparison with wind energy conversion systems for the same output power produced. In addition, wind energy systems have higher efficiency and capacity factor than PV systems. Both, PV and wind energy systems require some kind of maintenance, but the problem with dust accumulation on the PV arrays, especially on the southern parts of Jordan needs more efforts to keep the arrays clean. Economically, the current cost of kWh produced by wind energy systems is lower than that by PV systems, and the energy payback period of wind energy systems is much lower than that for PV systems. Moreover, some regions in Jordan have high average wind speeds that promise a good potential for implementing wind energy systems.

Jordan has had a pair of pilot wind farms producing 300 kW and 1.2 MW in the north of the country for the past two decades. However, Jordan southern region took the lead in large wind power; selected locations in the south Wadi Araba, Maan and Tafileh Governorate have the potential to produce hundreds of MW from wind energy. Already under construction, two wind energy projects of a capacity totaling about 150 MW in the Tafileh Governorate, and more projects are planned.

Many research studies have been carried out on potential, feasibility and assessment of wind energy at many locations in Jordan, e.g., (Ababneh, Kakish, Abu Mohareb, & Etier, 2009; Alghoul, Sulaiman, Azmi, & Abd. Wahab, 2007; Badran & Abdulhadi, 2009; Halasa, 2010; Sabra, August 1999). The work in most of these studies was concentrated on the south and hilly areas of Jordan. However, this work includes also locations in the eastern desert region of Jordan, the land of which are arid, plain, cheap in price, and have potential for wind speeds that makes them promising for consideration of installation of large wind farms.

2. Theory and mathematical analysis

Having the cubic relation with the power, the wind speed is the most critical data needed to appraise the power potential of candidate site. The wind is driven by the sun and the different seasons, and is never steady at any site. It is mainly influenced by the weather system, the local land terrain and the height above the ground surface. The wind pattern generally repeats over the period of one year. The wind site is usually described by the speed data averaged over the calendar months. Sometimes, the monthly data is aggregated over each season or the year for brevity in reporting the overall "windiness" of various sites. The wind-speed variations over the period can be described by a probability distribution function.

Knowledge of the wind speed frequency distribution is a very important factor to evaluate the wind potential in windy areas. If ever the wind speed distribution in any windy site is known, the power potential and the economic feasibility belonging to the site can be easily obtained. Wind data obtained with various observation methods has wide ranges. Therefore, in the wind energy analysis, it is necessary to have only a few key parameters that can explain the behavior of a wide range of wind speed data (Mominul Islam Mukut, Quamrul Islam, & Mahbubul Alam, 2008) [Mominul 08, 17]. The simplest and most practical method for the procedure is to use a probability distribution function. There are several probability density functions, which can be used to describe the wind speed frequency curve.

The Weibull, Rayleigh and Lognormal functions are commonly used for fitting the measured wind speed probability distribution. Here we use Weibull probability Distribution.

2.1. Weibull probability distribution

The variations in wind speed V are best described by the Weibull probability distribution function, with two parameters; the shape parameter, k, and the scale parameter, c. The probability of wind speed $F(V)$, during any time intervals is given by the following:

$$F(V) = \left(\frac{k}{c}\right) \cdot \left(\frac{V}{c}\right)^{k-1} . e^{-\left(\frac{V}{c}\right)^{k}} \quad \text{where } 0 < V < 8 \qquad (1)$$

In order to estimate Weibull k and c parameters, numerous methods have been proposed over last few years. In this study, the two parameters of Weibull are determined by using mean wind speed–standard deviation method (Gökçek, Bayülken, & Bekdemir,

Please cite this article in press as: Ammari, H. D., et al. Evaluation of wind energy potential and electricity generation at five locations in Jordan. *Sustainable Cities and Society* (2014), http://dx.doi.org/10.1016/j.scs.2014.11.005