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Technical note

# Design and implementation of wind energy system in Saudi Arabia

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ABSTRACT

This paper introduces an accurate procedure to choose the best site from many sites and suitable wind turbines for these sites depending on the minimum price of kWh generated (Energy Cost Figure (ECF)) from wind energy system. In this paper a new proposed computer program has been introduced to perform all the calculations and optimization required to accurately design the wind energy system and matching between sites and wind turbines. Some of cost calculations of energy methods have been introduced and compared to choose the most suitable method. The data for five sites in Saudi Arabia and hundred wind turbines have been used to choose the best site and the optimum wind turbine for each site. These sites are Yanbo, Dhahran, Dhulom, Riyadh, and Qaisumah. One hundred wind turbines have been used to choose the best one for each site. This program is built in a generic form which allows it to be used with unlimited number of sites and wind turbines in all over the world. The program is written by using Visual Fortran and it is verified with simple calculation in Excel. The paper showed that the best site is Dhahran and the suitable wind turbine for this site is *KMW-ERNO* with 5.85 Cents/kWh. The worst site to install wind energy system is Riyadh with minimum price of kWh of 12.81 Cents/kWh in case of using *GE Energy 2* wind turbine.



## 1. Introduction

Wind energy applications require open area or available shores for wind energy plants. Saudi Arabia is a vast country with wide open areas and long shores. The wind speed in most of these areas is high enough to make the application of wind energy economical. Saudi Arabia authorities recognize the importance of renewable energy, especially, wind, and they will invest billions in this promising sector of power. Even though Saudi Arabia has huge resources of oil, it is keenly interested in taking an active part in the development of new technologies for exploiting and utilizing renewable sources of energy [1]. The electricity production from wind will save oil that can be exported for increasing national income. Also, the production of electric power from wind energy will reduce environment pollution that could be generated from conventional power plants. Recently, a lot of researches in the evaluating the applications of wind energy systems in Saudi Arabia are introduced. Most of these researches recommend wind as a promising and economical source of energy in Saudi Arabia [2–10]. While the wind resource potential in Saudi Arabia is significant, there are many issues surrounding its development. These include the intermittency of the resource, its seasonal and diurnal characteristics, its geographically remote locations, and the electrical grid infrastructure that must be used to transmit the wind energy to load areas. All of these issues pose significant technical barriers to the full development of Saudi Arabia's wind potential.

The matching between the site and wind turbine has been introduced in many literature [11,12]. Most of these researches did not take into account many important issues like the suitable economical situation in Saudi Arabia and the energy balance between the required load and the generated power. Also, the market available software such as Homer, Retscreen, and etc are not flexible enough to change the cost calculations and it is not able to extract much information as those available from the new proposed computer program.

This paper introduces an accurate procedure to choose the best site from many sites and suitable wind turbines for these sites depending on the minimum price of kWh generated from wind energy system. In this paper a new proposed computer program has been introduced to perform all the calculations and optimization required to accurately design the wind energy system and matching between sites and wind turbines.

Starting any program of using wind energy system in a utility scale in any country in the world requires many steps. The first step is to collect accurate wind speed data for many sites to be used in the selection process of the best site. The second step is to determine the load curves which required to be supplied. The third step

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is to collect the data of available wind turbines in the market. This leads to the question 'What is the most appropriate wind turbine for a particular site?'. The aim of this research is to provide an accurate answer to this question. A new proposed computer program is designed in this paper to answer this question and many other questions. The function of the proposed program is to decide which the best site from many available sites is, and which the suitable wind turbine for each site and the minimum price for generated kWh. This decision requires very accurate statistical calculations. Another information can be extracted from this computer program such as the Weibull parameters, capacity factor and other information that may be helpful for researchers. The steps of these processes are very long and require long time and great efforts for calculations and optimizations. The new proposed computer program will solve this problem in a very short time and gives accurate results in a flexible fashion. This computer program can be applied in any region in the world because it has the flexibility to change the economic calculation to suit any country and it is able to handle unlimited numbers of sites and wind turbines.

## 2. Design of the proposed computer program

The flowchart of the computer program is shown in Fig. 1. The program has a main part and five subroutines. Each subroutine will perform a certain function as shown in the following sections. This program has been applied to the five sites in Saudi Arabia. The performance data of hundred of market available wind turbines were used to select the most suitable one for each site.

## 3. Program input data

Wind speed variation of the site and the performance characteristics of wind turbines are the main factors that affect the performance of wind energy system and affect the cost of kWh generated from it. The data required for the program are:

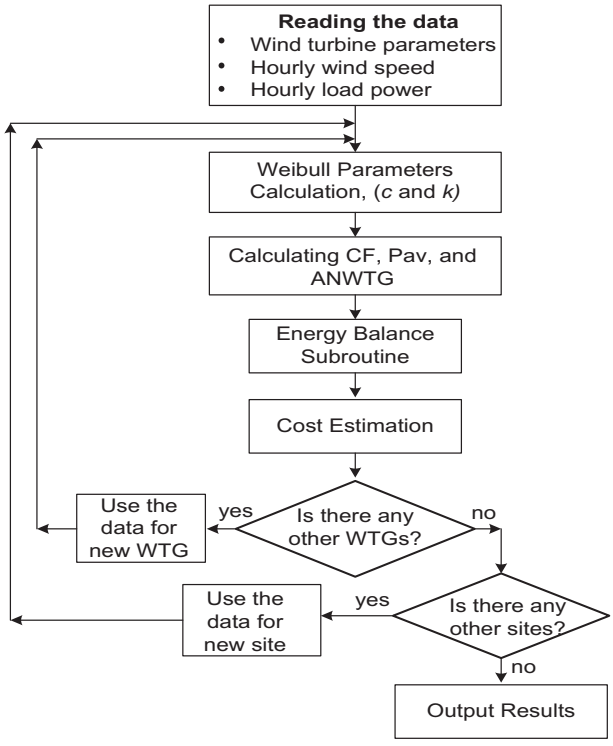


**Fig. 1.** Simple block diagram of the computer program.

1. Hourly wind speed data for Yanbo, Dhahran, Dhulom, Riyadh, and Qaisumahsites of Saudi Arabia will be used. The hourly wind speed data of these sites will be processed using statistical procedures. The computer program can perform the optimization for unlimited number of the available data sites. Wind data is collected from many sources as metrological authority and over the internet. Wind speeds can be collected for many sites for different period of times. Meteorologists generally conclude that it takes at least 5 years of wind data to determine a reliable average and variance of the wind speed. Some researchers claim that shorter period of time may be acceptable for designing renewable energy system with acceptable confidence [12]. It is better to have a small interval between each reading of the wind speed data. Thirty minutes are recommended interval between each two points of data. But, this may not available for all sites under study because some of these sites have one-hour interval. So, the interval used in this research paper is one-hour to fit all available data.
2. Performance data for market available wind turbines are introduced, such as rated power, hub height, diameter of swept area, cut-in speed, rated speed, cut-out speed, price of wind turbine, and efficiency of the mechanical and electrical system. In this step hundred market available wind turbines are introduced to the computer program. The computer program can perform the optimization for unlimited number of wind turbines.
3. Hourly loads required to be supplied from the wind energy system. The load data used in this program is actual data for small city in Saudi Arabia. The average power required for this load is 22.5 MW.

## 4. Steps of the proposed computer program

The main computer program reads all the data mentioned in previous section. After that, the flow will go to subroutines to make the calculations, comparisons, and optimizations. Each subroutine makes a certain function and then sends its results to the next subroutines. The function of each subroutine is illustrated in the following:

### 4.1. Weibull parameters calculations

The purpose of this subroutine is to determine the Weibull, scale and shape parameters, $c$ and $k$. A good estimation for $c$ and $k$ can be obtained quickly as the following [13]:

$$c = 1.12U \quad (1.5 \le k \le 3.0) \tag{1}$$

Also, if the mean and variance of the wind speed are known, then approximation for $k$ from Ref. [13] can be used as shown in (2);

$$k = \left(\frac{\sigma}{U}\right)^{-1.086} \tag{2}$$

The variance of the Weibull density function can be shown to be:

$$\sigma^2 = c^2\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right] = (U)^2\left[\frac{\Gamma(1+2/k)}{\Gamma^2(1+1/k)} - 1\right] \tag{3}$$

This is a reasonably good approximation over the range $1 \le k \le 10$. Once $k$ has been determined, $c$ can be obtained as the following: