International Journal of Engineering Research
Volume No.3, Issue No.10, pp : 624-627

ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

Parametric Study on a Horizontal Axis Wind Turbine Proposed for Water Pumping

Dr. Abdullateef A. Jadallah; Assistant Professor
Department of Electromechanical Engineering; University of Technology; Baghdad; Iraq
dr_abd.allateef@yahoo.com

Abstract: Water pumping is considered an economically competitive sustainable process of providing water to communities, rural areas and livestock's. A parametric analysis on HAWT is carried out to explore the influence of the performance parameters on the power generated and withdrawal quantity of water. Effect of wind speed, radius of rotor, ambient condition, well depth, and efficiencies of turbine, generator and the pump were studied and reflected in important generalized performance maps. These performance graphs are valuable in best understanding of on-design and off-design constraints of the horizontal axis wind turbine in water pumping. The blade geometry was also studied. Results showed the reasonable range of wind turbine performance and the corresponding water discharge within the abovementioned constraints. Rating and the effect of pitch angle on discharged water are also presented. Methodology necessary to achieve the abovementioned results is processed by a computer program written in Matlab.

Key Wards: Performance analysis, wind turbines, water pumping, pitch angle, tip speed ratio.

1. Introduction

Wind pumping is considered an economically competitive, sustainable means of providing water to communities without access to the electricity grid [1]. Renewable energy technologies such as wind have great potential for improving water supply in rural areas. Because the wind energy resource in many rural areas is sufficient for attractive application of wind pumps, and as fuel is insufficient, the wind pumps will be spread on a rather large scale in the near future [2]. Small wind turbines are especially appealing because they can be located further from the borehole, where the wind is strongest. Another crucial development with modern wind pumps is that they use only 6–8 blades of true airfoils, in contrast to traditional windmills, which have 15–18 curved steel plates. Using fewer blades decreases the cost. The rotor diameter of traditional wind pumps is 2–5 meters [3].

The so-called third generation windmills use a direct drive mechanism rather than a geared transmission. They are designed to produce high torque at low wind speeds and provide rotor speed control at high wind speeds.

The main objective of this design is to reduce the starting torque. Electrical wind turbine pumps offer a more promising technology. Modern wind generators can produce AC or DC electrical output and can pump water directly by connecting to AC or DC motors.

Electrical wind turbines rated as low as 50 W are commercially available, and generally require high wind speeds. For example, a small wind turbine of about 1.5 kW rated output requires an average wind speed of 4–5 m/s to start pumping, compared to mechanical wind pumps, which can start pumping at about 2.5 to 3.5 m/s. Larger wind turbines require higher wind speeds to start the rotor. They become competitive with windmills above average wind speeds of 5–6 m/s for water pumping applications [4]. The electrical and mechanical wind pump systems are illustrated in Fig. (1).

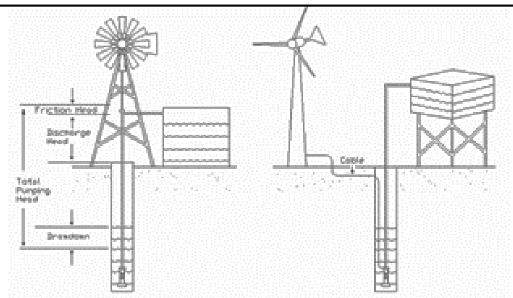

Fig. (1) Wind pump system (a) mechanical (b) electrical

In addition to selecting an appropriate wind turbine and pumping system, many other aspects need to be taken into consideration when designing a wind pumping system. These include the construction of a well or storage reservoir from which water is to be pumped, a storage tank at the desired water output location and all necessary plumbing.
The majority of water pumping applications require year round production and it is important to know the expected output at all times of the year.

This paper focuses on the performance analysis of wind turbines and attempts to show that it can play a viable role in wind energy's future through an assessment of pumping demands at which it is and is not feasible. Computations of power extracted and water discharge for different operating conditions were carried out. To do so, a computer program written in Matlab oriented to process all operating conditions sequentially. The computer program is outlined in the flowchart shown in figure (2)

2. Methodology:

In an attempt to better understand the potential of wind pumping, an analysis has been conducted to determine the required pumping heads and water demands that may be feasibly supplied for a range of average wind speeds.

An analysis has been conducted from general assumptions and first principles to determine the maximum possible theoretical output and a water pumping system. Wind power is modeling is adapted to determine the output of any system with specifications of rotor diameter, average wind speed, required pumping head and system efficiency.

The ideal power extracted by the wind turbine from the available power with constant efficiency in the air is calculated from the well-known equation [6]:

$$p = \frac{1}{2} * \eta * \left({}^{P}\!/_{R * T}\right) * \pi * r^2 * V^3 \text{……..(1)}$$

When P is the power and V is the wind speed.

The rotor is usually designed to optimize the power generated for a given wind resource. On the other hand, the equation of the power required for withdrawing water may be calculated from the following equation:

$$P_w = \gamma * Q * H/\eta_p \quad \text{……….……….… (2)}$$

Thus, the discharge is calculated from the following equation:

$$Q = \{(\eta_T * \eta_{gen} * \eta_{gear} * \eta_p * P * \pi * r^2 * V^3)/(2 * R * T * \gamma * H)\} \quad \text{……………….......................... (3)}$$

Where Q is the discharge and H is the head

Similarly, equation (3) is processed for the specified operating condition considered for power extracted. A range of blade length (i.e. rotor radius) of the order (2m – 10m) is depended. The efficiency of the wind turbine is supposed to be in the range (20% - 40%) while the ambient temperature is taken in the range (0^oC – 50^oC).

One of the most important factors involved in the accounts of power resulting from the wind and that cannot be ignored is the number of blades.

A performance and design parameter is called the tip speed ratio (λ); it represents the ratio of the tangential speed at tip to the wind speed. It has a significant impact on the rotor power coefficient, (Cp) and highly recommended to be used in performance control. The coefficient of performance may be calculated in term of blade number (B) and the drag to lift ratio excited due to flow orientation and blade geometry from the following equation [7]:

$$Cp_{max} = \left({}^{16}\!/_{27}\right)\left\{\lambda * B * \frac{0.67}{[1.48 + (B*0.67 - 0.04)*\lambda + 0.0025*\lambda^2]} - \varepsilon[(1.92 * \lambda^2 * B)/(1 + 2 * \lambda * B)]\right\} \text{………. (4)}$$

The performance of wind turbine is experienced through equation (8) for a blade number in the range of (2-6) and ε in the range of (0 – 0.1). The impact of blade pitch angle is a critical parameter for the aerodynamic optimization of untwisted blades [8].

$$C_P = 0.5176\left(\frac{116}{\left(\frac{1}{\frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}}\right)} - 0.4\beta - 5\right) e^{-21/\left(\frac{1}{\frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}}\right)} + 0.0068\lambda \quad \text{…………………………………..…… (5)}$$

Equation (5) reveals the dependency of the turbine efficiency on the tip speed ratio and the pitch angle. This joins the coefficient of performance of the wind turbine with the blade number and pitch angle. It is useful in the control process.

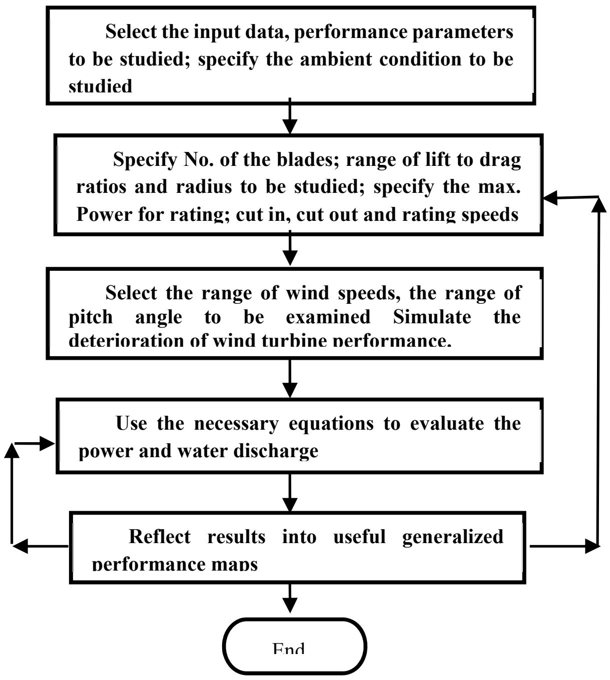

Fig.(2) Flow chart of the computer program

3. Discussion:

A pumping system should be reliable and fulfill the water demand. However, in many cases, the water resource determines the best type of pumping system.

The amount of water of a wind-powered water pumping system can deliver depending on the speed and duration of the wind, the size and efficiency of the rotor, the efficiency of the pump being used, and how far the water has to be lifted [9].

The power produced for a range of wind speed and different wind turbine spans and ambient temperature is presented in figure (3&4). The power is inherently increased with wind speed exponentially in the cubic order. Larger blade length leads to grater values of power as the exposed area of the wind turbine rotor increased.

Theoretically, the coefficient of performance of wind turbine (efficiency) reaches its maximum. The dependence of the coefficient of performance on tip speed wind ratio and the number of blades is presented in important generalized performance maps which have a viable role in the control of the wind turbine performance. These maps are shown in Figures

ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

(5 &6). The effect of blade number and geometry that experiencing drag scaled to the lift induced on the power coefficient is also explored. The ideal case is attained when no drag induced during facing the flow leads to maximum coefficient of performance. Increased drag (i.e. ε) because of setting and orientation of the blades reduces the coefficient of performance which leads to a sharp drop in coefficient of performance at high tip speed ratios. This is because the increases in accumulated drag of skin friction and drag due to wake excited see fig.(7). Unfortunately, this pushes the designers toward low speed ratios and small scale wind turbine. All wind turbines have some type of aerodynamic and/or electrical loading capability to prevent the wind turbine from going into overspeed.

Every wind pump system has certainly specified characteristics such as max. power, cut in speed, cut out speed and rating. These parameters are well interplayed, processed and reflected in generalized maps as shown in figures (8 &9). The pitch angle plays a great role in controlling the wing turbine. The influence of pitch angle for a range between -5 deg. and 15 deg. has experienced. Figures (10&11) show the effect of pitch angle on the performance of wind turbine. A range of water head of (6-15) m is processed to estimate the water withdrawal. This is because the wind pump system proposed to be used in rural areas.

4. Conclusions:

Even the wind speed in Iraq is categorized as speed regime with the exception to certain indicated regions; the wind power represents a significant power source especially in rural and off-grid areas. Many researchers conducted promising results to overcome the low wind speed problem. The use of direct pumps connected to the wind rotor may serve to ensure water for human and livestock in rural areas. Furthermore, the modern wind turbine systems use DC and Ac generators which can be utilized in lighting in parallel with water withdrawal.

6. References:

i. *Brett G. Ziter ,"Electric Wind Pumping for Meeting Off-Grid Community Water Demands" , Guelph Engineering Journal, (2), 14 - 23. ISSN: 1916-1107.Canda, ©2009.*

ii. *Mustafa Omer Abdeen, energy for water pumping in rural areas in sudan, Journal of Engineering and Technology , 2009.*

iii. *N. Argaw ;" Renewable Energy for Water Pumping Applications in Rural Villages"; NREL/SR-500-30361, 2003.*

iv. *Mohammed Hashim Siddig,, "Operation Theory of Wind Pumps", Mechanical Engineering Department, University of Khartoum, Sudan wind engineering journal , volume 34, NO. 4, PP 361–374 361, 2010.*

v. *Sathyajith Mathew;" Wind Energy: Fundamentals, Resource Analysis and Economics, © Springer-Verlag Berlin Heidelberg 2006, ISBN-13 978-3-540-30905-5.*

vi. *Prof. Shireesh B. Kedare; " Wind Energy Conversion Systems ", energy systems engineering; Indian institute of technology, Bombay, 2011.*

vii. *Ahmet Z. Sahin · Ahmet Bolat · Abdulrahman Al-Ahmari, " Investigation of the Capacity of Underground Water Pumping UsingWind Energy in Dhahran, Arab Jor. of Sci Eng , 36:879–889 DOI 10.1007/s13369-011-0076-2, 2011.*

viii. *Jaan Lepa, Eugen Kokin, Andres Annuk, Vahur Poder, " wind power stations performance analysis and power output prognosis". engineering for rural development Jelcava. 29.-30.05.200X., 2010.*

ix. *Xiaojing Sun,1 Wanli Zhou, Diangui Huang, and Guoqing Wu;" Preliminary study on the matching characteristics between wind wheel and pump in a wind-powered water pumping system"; journal of renewable and sustainable energy V3,023109 ,2011.*

x. *Renewable Energy Technologies for Rural Development. united nations conference on trade and development unctad current studies on science, technology and innovation 2010.*

xi. *Slootweg, J.G. ; Polinder, H.; Kling,W.L.," Dynamic Modeling of wind turbine with doubly feed induction generator ", Power Engineering society Summer Meeting, 2001 . IEEE, vol.1, no., pp.644-649 vol.1, 2008.*

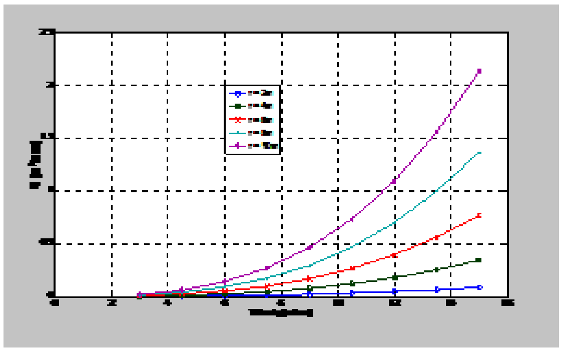

Fig.(3) Discharge versus velocity for different Rotor diameter

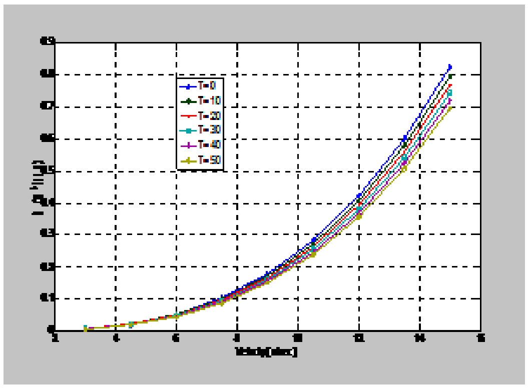

Fig.(4) Discharge versus velocity for different ambient temperature

International Journal of Engineering Research
Volume No.3, Issue No.10, pp : 624-627

ISSN:2319-6890)(online),2347-5013(print)
01 Oct. 2014

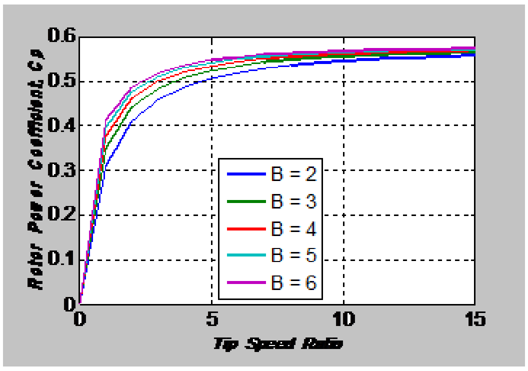

Fig.(5) Cp versus tip speed ration different blade no. and ε = 0.0

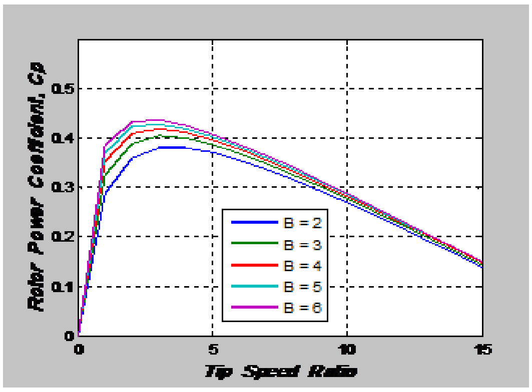

Fig.(6) Cp versus tip speed ration different blade No. and ε = 0.05

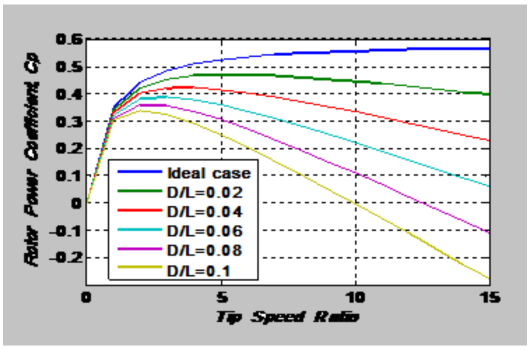

Fig.(7) Cp versus tip speed ration for different drag to lift ratio

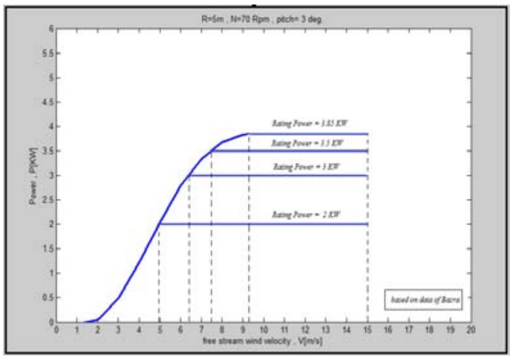

Fig. (8) Cut in, rating and cut out of the wind pump

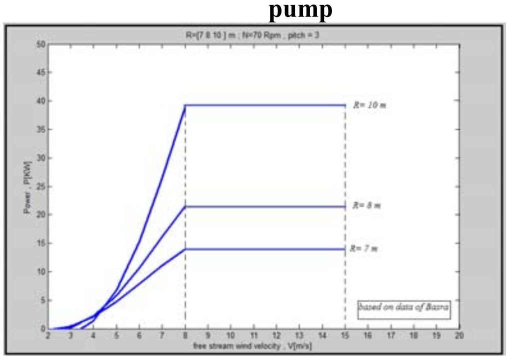

Fig.(9) Rating power for different rotor diameter

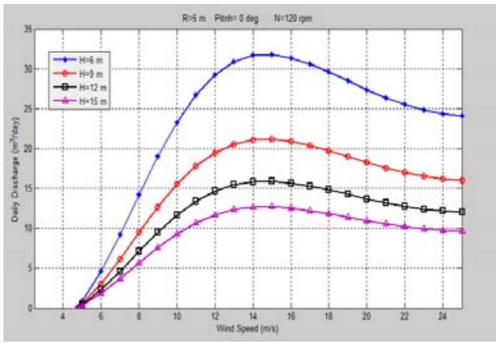

Fig.(10) Daily discharge for different heads and 0° pitch

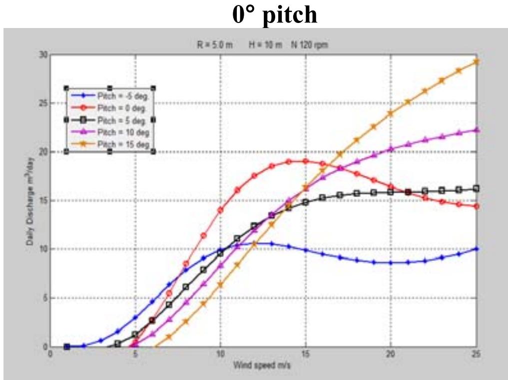

Fig.(11) Daily discharge for different heads and different pitch angles