New Technique for Identifying Optimal Generating Units Parameters

Radwan .H Abdel-Hamid, Maged A. Abu Adma, Ashraf A. Fahmy, and Sherief F. Abdel Samed

Faculty of Engineering, Helwan University, Cairo, Egypt
engsherieffouad@yahoo.com

ABSTRACT

This paper focuses on selecting optimal wind generator turbine according to the site wind information so that the output energy can optimized while maximizing the utilization of the wind power available at the location. The study presents an improvement to the site performance by identifying the best turbine parameters that should be erected at the selected site to maximize the power generation.

Applying the new developed parameter turbine selection index a unique point, at which the turbine develops its maximum performance characteristic and the optimal turbine speed parameters that match particular site information, can be located.

The new method is applied for identifying optimum wind turbine generator parameters for case study in the East Coast of the Red Sea in Egypt. The new method outstand the old method in the overall cost of generated energy unit.

Keywords: wind turbine generator, normalized power curve, capacity factor, turbine selection index, Egypt wind energy.

1 INTRODUCTION

Electricity generated from the wind replaces generation from conventional power stations, thus preventing the emissions of several greenhouse gases, including carbon and sulfur dioxides.

Wind energy can be generated locally and distributed directly to the local distribution network; this is known as embedded generation. This reduces the distance over which electricity has to travel, meaning less electrical losses in transmission and distribution, and therefore saving energy.

Today, wind turbines have to compete with many other energy sources. So that it is important to be cost effective. And it must meet any load requirements and produce energy at a minimum cost per dollar of investment.

The production of electricity by a wind turbine generator at a specific site depends upon many factors. These factors include the mean wind speed of the site and more significantly, the speed characteristics of the wind turbine itself namely, cut-in (V_c), rated (V_r), and furling (V_f) wind speeds including the hub height. There are many different models of wind turbine generators, commercially available, with same kW ratings. Each of these wind turbines has their own specifications and speed parameters. These speed parameters affect the capacity factor at a given specific site, and subsequently affect the choice of optimum wind turbine generator for the site

So we will focuses on selecting optimal wind generator turbine according to the site wind information so that the output energy can optimized while maximizing the utilization of the wind power available at the location. The study presents an improvement to the site performance by identifying the best turbine parameters that should be erected at the selected site to maximize the power generation. Using the normalized power and capacity factor curves versus the normalized speed curve, the best operating point for the wind turbine can be located between the two peaks of the maximum power and the maximum capacity factor curves.

Wind Turbine selection Index (TSI) is a newly introduced concept in this paper. It is shown that there exists a unique TSI curve for every site from which speed parameters of a turbine that will optimally match a site can be obtained. TSI curve is obtained from normalized power and capacity factor curves and is drawn on the common axis of normalized rated speed.

Case study will be taken for Zafarana wind site in the East Coast of the Red Sea in Egypt.

The wind characteristics were analyzed based on long-term recorded information of monthly mean-wind speed of eleven meteorological stations for statistical analysis to determine the wind characteristics and hence the best turbine in each of the selected site is identified. The new method outstand the old method in the overall cost of generated energy unit.

2 MATHEMATICAL MODEL FOR SELECTING WIND TURBINE

The site matching is based on identifying optimum turbine speed parameters that yield to higher energy production at higher capacity factor. The wind speeds are parameterized using cubic mean cube root and statistically modeled using Weibull probability density function [1].

The Weibull distribution gives a good match with the experimental data. This is also mentioned in references [1-6]. This distribution is characterized by two parameters: the shape parameter k (dimensionless) and scale parameter c (m/s).

Justus, Lysen, Darwish, Nafaoui, Jamil, Khogali and Vogiatzis, Have shown four different methods for the estimation of k and c parameters

We will use the convenient model for **Pe** that can be used in discussing any wind system. Pe is assumed to vary as V^k between cut-in and rated wind speeds,

And this model is used for obtain the normalized power and capacity factor curves.

$$Pe = 0 \qquad (V < Vc) \qquad (1)$$
$$Pe = a + bV^k \qquad (Vc \le V \le Vr) \qquad (2)$$
$$Pe = Per \qquad (Vr < V \le Vf) \qquad (3)$$
$$Pe = 0 \qquad (V > Vf) \qquad (4)$$

Where

$$a = Per\, Vc^k / (Vc^k - Vr^k) \qquad (5)$$
$$b = Per / (Vr^k - Vc^k) \qquad (6)$$

$$P_{e,ave} = \int_0^{\infty} Pe\, f(v)\, dv \qquad (7)$$

Where f(v) is a probability density function of wind speeds.

Use the model of Pe so:

$$P_{e,ave} = \int_{Vc}^{Vr} (a + b V^K)\, f(V)\, dV + \int_{Vr}^{Vf} Per\, f(V)\, dV \qquad (8)$$

$$Pe,ave = p_{er} \frac{e^{-\left(\frac{Vc}{C}\right)^k} - e^{-\left(\frac{Vr}{C}\right)^k}}{\left(\frac{Vc}{C}\right)^k - \left(\frac{Vr}{C}\right)^k} - e^{-\left(\frac{Vf}{C}\right)^k} \qquad (9)$$

$$P_{e,ave} = P_{er}(CF) = 0.5\, \eta o\, \rho\, A\, V_r^3\, (CF) \qquad (10)$$

$$CF = \frac{e^{-\left(\frac{Vc}{C}\right)^k} - e^{-\left(\frac{Vr}{C}\right)^k}}{\left(\frac{Vc}{C}\right)^k - \left(\frac{Vr}{C}\right)^k} - e^{-\left(\frac{Vf}{C}\right)^k} \qquad (11)$$

CF is the capacity factor.

Figure 1 is show the typical convenient model for electrical wind power.

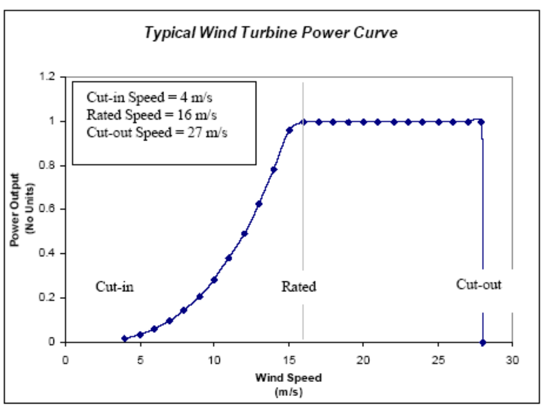

Figure 1: Typical Wind Turbine Power Curve

By normalizing the $P_{e,ave}$ equation we will get : -

$$P_N = \frac{p_{e,ave}}{0.5\rho\, \eta_o A C^3} = \frac{0.5\rho\, \eta_o A\, Vr^3 (CF)}{0.5\rho\, \eta_o A C^3} \qquad (12)$$

$$\mathbf{P_N = \left(\frac{V_r}{C}\right)^3 CF} \qquad (13)$$

Once we select turbine parameter to maximize the average power, we can find the rated power for a turbine with a given area and rated overall efficiency located at an elevation with a known average air density.[7]

Energy = (average power)(time)

Therefore, the yearly energy production of such a turbine is

$$Energy = Pe,ave\ (time) = (CF)Per\ (8760) \qquad (14)$$

From the normalized power equation we can plot the normalized power curve and capacity factor curve versus the normalized speed as shown in figure (2).

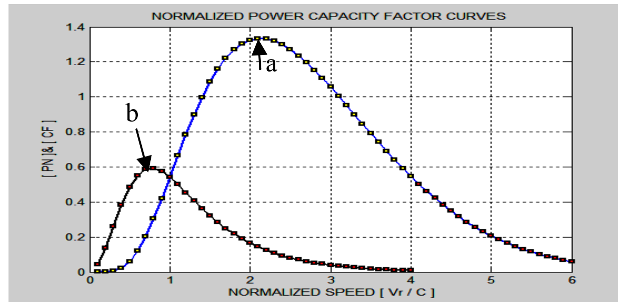

Figure 2: normalized power and capacity factor curve

3 TURBINE SELECTION INDEX

By studying the domain in figure 2 we can see clearly that when we want to extract the maximum output power from the site the best operating point at PN) max point (a) in the curve and at this point we can evaluate the energy output from the site and if we applied this selection strategy we will have disadvantage that when we select a larger value of PN we have large value of Vr for the chosen turbine and so the rated power Per will increase.

This is accompanied by a decrease in capacity factor CF. this increase in p_{er} for a given turbine raises the costs of the necessary generator, transformer, switches, circuit breakers and distribution lines.

Whereas the decrease in CF means that these items are being used proportionately less amount of time and if we using the point of maximum capacity factor point (b) in the curve result of this choice solve the problem of high machine cost in less time and it's the ideal point from the view point of cost and this point which maximize the average power that can extract from the rated power of the selected turbine that appear in equation (10) since as CF increase the average power increase but the problem in this choice is the very low rated speed which lead to choose Avery low rated power according to the value of the rated speed . So we must have a solution for choosing.

What we really want is the maximum energy production per dollar of investment, which may yield a different design than the one which strictly maximizes total energy. that there exists a value of the normalized speed at which the product of the two variables normalized power and capacity factor with respect to normalized speed will attain a maximum at which the individual values of PN & CF being far higher than their minimum value .

This value of normalized speed which corresponds to (PN * CF) max falls between the values of normalized speed at which PNmax and CFmax occurrence. This means that it is possible to choose a normalized speed for a site, at

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which the total energy produced is closer to the maximum at a higher capacity factor. This value of normalized speed is termed as the optimum normalized rated speed and corresponding optimum cut-in and cut-out speeds are evaluated. And our new method is depending on how to select the optimum value of this normalized speed.

The new method is developed from the normalized power curve and the capacity factor curve as we see from the given curve for explain example the maximum capacity factor is at normalized speed equal to 0.8 and at maximum normalized power occur at normalized speed equal to 2.1 so the best selected point is between normalized speed =0.8 to normalized speed = 2.1 by the knowledge of the Weibull scale parameter we can find the rated speed corresponding to each of the normalized speed in this range by assuming all efficiencies remain the same, the rated power will just be in the ratio of the cube of the wind speeds.

We can evaluate a number of turbine models of choice that can locate at the selected site with deferent Vr, Pr, CF and by this data we can also evaluate the output energy from each turbine if it place in this site from the following equation.

Vrated = normalized speed x C (15)

Vcut in = PVC x Vrated (16)

Vcut out = PVF x Vrated (17)

Pe,ave =Per x CF (18)

Energy = Pe,ave x time (19)

Where:

PVC is the cut in speed percentage from rated speed.

PVf is the cut out speed percentage from rated speed

Using the previous equation we can get the recommended turbine model with their rated power output energy and their rated power.

Figure (3) show the normalized power capacity factor and energy curves and figure (4) show the recommended turbine model that can used in wind turbine site according to its weibuill parameter and reference manufacturing data for wind turbine model

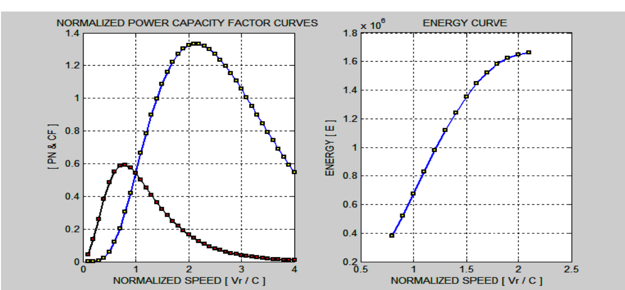

Figure 3: Normalized power curve, capacity factor Energy curve

From this data we can evaluate the new ranking parameter for choice which will define by Turbine Selection Index "TSI"

TSI = Δ Pr x Δ E (20)

Δ Pr = Pr) n+1 - Pr) n (21)

Δ E = E) n+1 - E) n (22)

We can now plot the new parameter TSI with the normalized speed to find the best operating point.

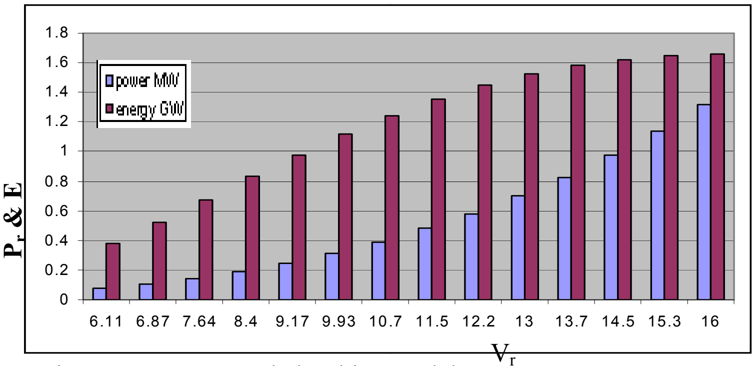

Figure 4: recommended turbine model

Figure (5) show the turbine selection index versus the normalized wind speed that can use for selecting the best wind turbine for specified wind site.

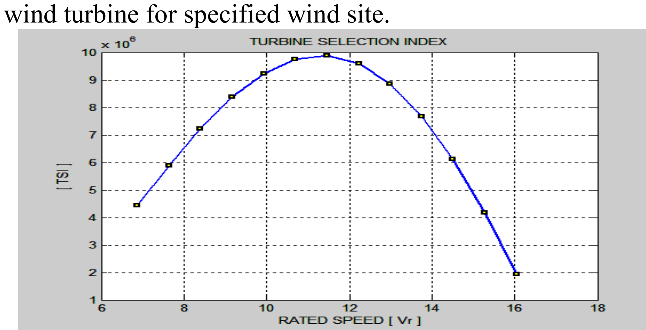

Figure 5: Turbine selection index

We will use the turbine selection index curve as the base for identify the wind turbine parameter and this can done by evaluating the turbine selection index at each operating point for the varying on the normalized speed of the turbine until we get the maximum turbine selection index point and hence predicate the turbine parameter .and at this case we can predicate the overall efficiency and the total output energy extracted from the site.

4 CASE STUDY WIND ENERGY IN EGYPT

Zafarana which is one of the most promising site for wind energy application .its lie on the east coast of red Sea zone in Egypt between latitude angel equal to 32□36□ longitude angel equal to 29□06□ the following figure represent the suitable location of the installed wind farm .

Figure 6: Overview map for Zafarana

The following chart represent the variation of wind speed through the year in Zafarana The wind speed has a maximum value of 8.5 m/s at Zafarana in September, Annual mean wind speed is about 7.3 m/sec and the Wind direction is 360 N .The annual values of the monthly average wind speeds for the stations under study are estimated and have been analyzed using the Wind Atlas Analysis Application Program (WASP) to predict the complete annual mean frequency distribution of the year for the site

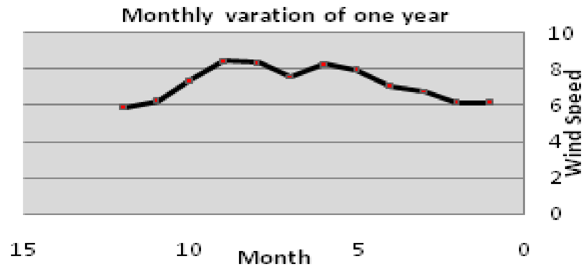

Figure 7: monthly variation of wind speed in Zafarana

The frequency Distribution is used also to identify the most suitable wind turbine for the site using the Weibull distribution function to evaluate the Weibull parameter {C & K} for the site.

C= 8.23 m/sec & K= 2.7

Selection the suitable turbine according to maximum turbine selection index so the following figure represent the normalized power & capacity factor & output energy curves for Zafarana site and followed by the recommended turbine model and hence the turbine selection index curve and the table which preview the result turbine parameter and its performance .

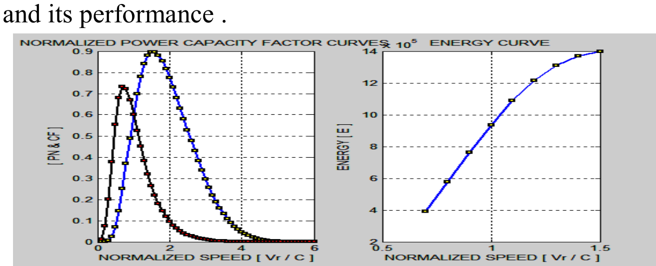

Figure 8: Power energy curves for Zafarana

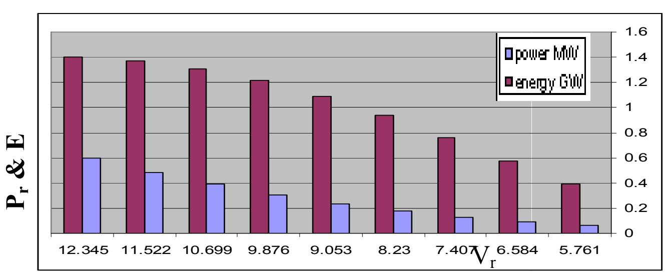

Figure 9: recommended turbine model for Zafarana

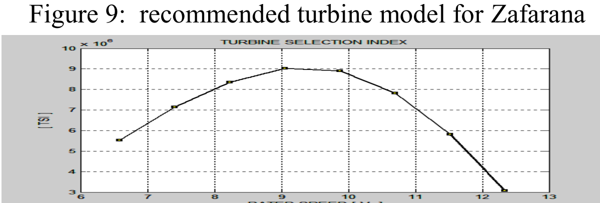

Figure 10: Turbine selection index curve for Zafarana

Turbine parameter	value	Turbine parameter	Value
Normalized power	0.69	Rated power	236
Capacity factor	0.53	Average power	124
Rated speed	9	Output energy	1089MWh
Cut in speed	3.6	Reduced in Per	60 %
Cut out speed	18	Reduced in E O/P	22 %

Table 1 : turbine parameters according to maximum TSI

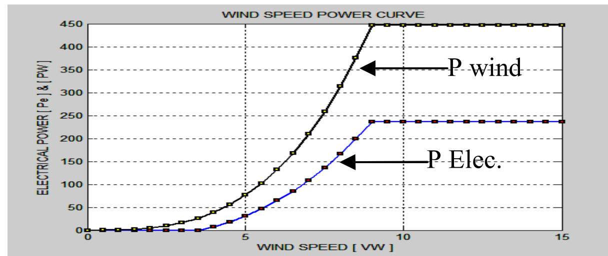

Figure 11: Wind & Electrical power curve for site

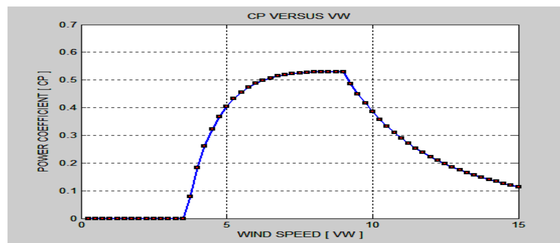

Figure 12: power coefficient curve for site

As we see from the previous result the selected turbine is approximately have efficiency of 53% and this is higher value for the efficiency of wind energy system so if the new technique is performed for the selection of wind energy will make us use the wind farm as possible as we could.

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