Conference Paper

Effect of Wind Turbine Classes on the Electricity Production of Wind Farms in Cyprus Island

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This paper examines the effect of different wind turbine classes on the electricity production of wind farms in two areas of Cyprus Island, which present low and medium wind potentials: Xylofagou and Limassol. Wind turbine classes determine the suitability of installing a wind turbine in a particulate site. Wind turbine data from five different manufacturers have been used. For each manufacturer, two wind turbines with identical rated power (in the range of 1.5 MW–3 MW) and different wind turbine classes (IEC II and IEC III) are compared. The results show the superiority of wind turbines that are designed for lower wind speeds (IEC III class) in both locations, in terms of energy production. This improvement is higher for the location with the lower wind potential and starts from 7%, while it can reach more than 50%.

1. Introduction

Renewable energy sources (RESs) are clean, inexhaustible, and environmental-friendly alternative energy sources with negligible fuel cost. The worldwide demand for renewable energy is increasing rapidly because of the climate problem, and also because oil resources are limited. Wind energy appears as a clean and good solution to cope with a great part of this energy demand.

Wind turbines present several advantages over conventional generation technologies for electricity generation. Reduction of greenhouse gases that contribute to global climate change and to local air quality is one of their major advantages. Additionally, they reduce the risk of fossil-fuel price fluctuations and decrease the electricity-sector dependency. However, developing a utility-scale wind project is a complicated and time-consuming process involving developers, landowners, utilities, the public, and various local

authorities. Although each wind energy project is unique and has different characteristics, basic features and related steps are common. In practice, the steps are iterative and overlap with one another depending on the specific project circumstances. The key steps of development and planning for a wind farm are site selection, detailed wind assessment, feasibility, construction, and operation [1].

This paper examines the effect of different wind turbine classes in the electricity production of wind farms in two areas of Cyprus Island that present low and medium wind potentials: Xylofagou and Limassol. Wind classes determine which turbine is suitable for the normal wind conditions of a particular site. Turbines with higher wind classes have larger blades and produce more energy in low and medium winds [2], but they are more sensitive in high wind gusts.

In order to examine the effect of wind turbine class on electricity production, wind turbine data from five different manufacturers have been used. For each manufacturer, two

wind turbines with identical rated power and different wind turbine classes (IEC II and IEC III) are compared for both sites. The rated power of chosen wind turbines is between 1.5 MW and 3 MW. The results of the present work show that for the studied sites, the increase in annual energy production of the IEC III wind class turbines, compared to IEC II class turbines, is significant in all cases.

2. Proposed Methodology

2.1. Wind Energy Basics. The wind speed at a given location is continuously varying. There are changes in the annual mean wind speed from year to year (annual) changes with season (seasonal), with passing weather systems (synoptic), on a daily basis (diurnal) and from second to second (turbulence) [3]. The essential characteristics of the long-term variations of wind speed can also be usefully described by a frequency or probability distribution. A convenient mathematical distribution function that has been found to fit well with data is the Weibull probability density function, which is expressed in terms of two parameters, the shape parameter k and the scale parameter c . The probability of wind speed being $f(V)$ during any time interval is given by

$$f(V) = \frac{k}{c} \cdot \left(\frac{V}{c}\right)^{k-1} \cdot e^{-(V/c)^k}. \quad (1)$$

In any decision about location and type of wind turbine to be installed, knowledge of wind speeds at heights of 20 to 150 m above ground is very desirable. Many times, these data are not available, and some estimate must be made from wind speeds measured at about 10 m. This requires an equation which predicts the wind speed V_{z1} at one height in terms of the measured speed V_{z2} at another lower height [4]. One popular equation that is used for this scope is the power law:

$$\frac{V_{z1}}{V_{z2}} = \left(\frac{z_1}{z_2}\right)^a, \quad (2)$$

where z_1 is the height at which a wind speed estimate is desired (usually equal to wind turbine hub height) and z_2 is taken as the height of measurement. The dimensionless parameter a is called power law exponent and is determined empirically, as it varies with height, time of day, season of the year, nature of the terrain, wind speeds, and temperature. Power law exponent can vary from 0.10 (smooth terrains) to 0.40 (very rough terrains). When no specific site information is provided, a value of a equal to 1/7 can be used.

2.2. Wind Turbine Classes. Wind turbine class is one of the factors which need to be considered during the complex process of planning a wind power plant. Wind classes determine which turbine is suitable for the normal wind conditions of a particular site. They are mainly defined by the average annual wind speed (measured at the turbine's hub height), the speed of extreme gusts that could occur over 50 years, and how much turbulence is there at the wind site. There are three wind classes for wind turbines, which are defined by an International Electrotechnical Commission (IEC) standard

TABLE 1: Specifications for wind classes.

Wind turbine class	Annual average wind speed (m/s)	Extreme 50-year gust (m/s)
IEC I high wind	10	70
IEC II medium wind	8.5	59.5
IEC III low wind	7.5	52.5

and correspond to high, medium, and low wind, as Table 1 shows.

The extreme 50-year gust values are based on the 3-second average wind speed. Each one of the above-mentioned classes (i.e., I, II, or III) can be categorized in two subclasses: A and B. In subclass A, the standard deviation of wind speed measured at 15 m/s wind speed (which is defined as I_{15} turbulence) is 18%. In subclass B, I_{15} turbulence is equal to 16%.

In order to select the proper wind turbine class for a specific site, all specifications of a wind turbine class (average speed, gust, and turbulence) must be fulfilled. Taking this into account, in a wind turbine designed for lower wind speeds, the design loads are going to be smaller; therefore its blades are larger and the hub height is taller. As a result, bigger rotors of class III capture more wind energy and yield higher capacity factors compared to class I or II rotors.

2.3. Description of the Examined Locations. The contribution of wind turbines in electricity production of Cyprus is significant. In 2011, Cyprus had a total installed wind capacity of 134 MW, an increase of 52 MW (38.8%) on the previous year, resulting in a 5.4% wind share in total electricity production [5].

Although Cyprus is suitable for electricity generation from wind, in most places the annual wind speed is below 5 m/s. Under such conditions, the installation of a wind farm is prohibitive. Moreover, there are few areas with very high wind potential (over 6.5 m/s). However, there is a considerable portion of Cyprus in which wind speed is between 5 and 6 m/s. This wind speed interval represents the marginal value in which a wind farm can be economically viable [6]. In these sites, the installation of wind turbines that can produce significant amount of power in low and medium wind speeds (i.e., they have high wind class) is critical. Figure 1 depicts a wind map of Cyprus [7]. It has to be noticed that the wind speeds in this map refer to a height of 10 m above the ground level. Considering higher heights (typical values for wind turbine hub heights are in the order of 70 to 120 m), the wind speed increases as (2) shows, so a larger number of areas in Cyprus may be suitable for a wind farm installation.

In this study, wind data for the sites of Xylofagou and Limassol have been used. These data are provided in the form of cumulative distribution functions and have been taken from [8]. Moreover, this reference provides information about the mean annual wind speed for these sites: 3.8 m/s for Xylofagou and 4.4 m/s for Limassol. These values refer to anemometer height equal to 7 m. Considering typical values

TABLE 2: Technical characteristics of considered wind turbines.

Wind turbine model	Wind class (IEC)	Rotor diameter (m)	Hub height (m)	Rated power (kW)
Sinovel SL 3000/105	IIA	105	90	3,000
Sinovel SL 3000/113	IIIA	113	90	3,000
Unison U88-2000	IIA	88	80	2,000
Unison U93-2000	IIIA	93	80	2,000
Vestas V90/3.0 MW	IIA	90	105	3,000
Vestas V112/3.0 MW	IIIA	112	119	3,000
Windey WD77-1500	II	77	80	1,500
Windey WD82-1500	III	82	80	1,500
WinWind 3/109	IIA	109	90	3,000
WinWind 3/120	IIIA	120	90	3,000

FIGURE 1: Wind map of Cyprus.

of 90 m for hub height and 1/7 for power law exponent, these values are increased to 5.5 m/s and 6.3 m/s, respectively, at the wind turbine height.

2.4. Estimation of Produced Energy and Capacity Factor. The power output of a wind turbine varies with wind speed, and every wind turbine has a characteristic power performance curve. With such a curve, it is possible to predict the energy production of a wind turbine without considering the technical details of its various components. The power curve gives the electrical power output as a function of the hub height wind speed. An important parameter of a power curve is the rated power, which is generally equal to the maximum power output of the electrical generator.

When the wind speed cumulative distribution function and the power curve data are known, the total electrical energy produced by a wind turbine for a specific period can be calculated. The procedure is shown in Figure 2. As a first step, the cumulative distribution function is transformed to probability density function for the wind speed. These data refer to the anemometer height, so they have to be transformed at hub height, using (2). In the wind speed probability density function, the integral between two specific wind speeds denotes the portion of the total time period in which the wind speed lies between these two specific values. In practice, this procedure can be implemented by using the histogram of wind speed. In this paper, the width of wind

speed bins has been considered as 0.5 m/s. By knowing the durations at each wind speed bin and the power curve data (i.e., produced electrical power for specific wind speeds), the electrical energy production of a wind turbine can be calculated. In the last diagram of Figure 2, the total wind turbine energy production is equal to the integral of the diagram.

After the calculation of annual wind energy $E_{W\text{Year}}$, the annual capacity factor can be calculated. The capacity factor of a wind turbine at a given site is defined as the ratio of the energy actually produced by the turbine to the energy that could have been produced if the machine ran at its rated power P_R over a given time period. A higher capacity factor value shows that the exploitation of the wind potential for the specific site is better. Considering time period equal to one year (8760 hours), the annual capacity factor is

$$\text{Annual Capacity Factor} = \frac{E_{W\text{Year}}}{P_R \cdot 8760 \text{ h}}. \quad (3)$$

3. Wind Turbine Data

The effect of the wind class in the wind turbine energy production is examined for five different wind turbine manufacturers. For each manufacturer, two wind turbines with identical rated power and different wind turbine classes (IEC II and IEC III) are compared for both sites. The technical characteristics of the ten considered wind turbines are shown in Table 2. The five manufacturers are namely Sinovel [9], Unison [10], Vestas [11], Windey [12], and WinWind [13]. The study of Table 2 shows that six wind turbines have rated power of 3 MW, two of them have rated power 2 MW, and the remaining two have rated power 1.5 MW. It can be also seen that the wind turbines of class III have larger diameters compared to their corresponding wind turbines of class II. Moreover, with the exception of Vestas, all wind turbines of the same manufacturer have identical hub heights. Figures 3, 4, 5, 6, and 7 depict the power curve comparison for each manufacturer. In each diagram, the better performance of the class III wind turbines in low and medium wind speeds is obvious, especially in the case of Vestas models (Figure 5), which also present the greatest difference in rotor diameter (90 m for class II, 112 m for class III).

FIGURE 2: Calculation procedure of the annual electrical energy produced by a wind turbine.

FIGURE 3: Comparison of Sinovel power curves.

FIGURE 4: Comparison of Unison power curves.

4. Results and Discussion

The results for the two considered locations (i.e., Xylofagou and Limassol) are presented in Tables 3 and 4. At each table, the annual produced electric energy and the annual capacity factor are calculated as well as the difference in energy production between wind turbines of the same manufacturer. It has to be noticed that the calculation of annual energy production cannot be accurate due to lack of detailed information for the specific sites. This information would include full data series of wind speed and wind direction, description of the terrain and the surrounding obstacles at the wind farm site, atmospheric pressure and air temperature data,

and estimation of wake effects. However, the relative differences between the models of each wind turbine manufacturer refer to the same conditions and considerations, and therefore they can show more accurately the benefits of installing a higher class wind turbine in these locations.

From the comparison of differences in Tables 3 and 4, it can be seen that in Xylofagou location (which has the lower wind potential) the improvement achieved by the class III turbines is higher than that in Limassol. With the exception of Vestas models, the differences lie at the same order of magnitude (11–18% for Xylofagou, 7–10% for Limassol). The enormous differences in Vestas models can be

FIGURE 5: Comparison of Vestas power curves.

FIGURE 6: Comparison of Windey power curves.

FIGURE 7: Comparison of WinWind power curves.

TABLE 3: Results for the Xylofagou location.

Wind turbine model	Annual produced energy (MWh)	Annual capacity factor	Difference
Sinovel SL 3000/105	5,575	21.21%	11.61%
Sinovel SL 3000/113	6,222	23.68%	
Unison U88-2000	3,495	19.95%	14.48%
Unison U93-2000	4,001	22.83%	
Vestas V90/3.0 MW	4,809	18.30%	55.71%
Vestas V112/3.0 MW	7,488	28.49%	
Windey WD77-1500	2,796	21.28%	13.59%
Windey WD82-1500	3,176	24.18%	
WinWind 3/109	5,514	20.98%	18.04%
WinWind 3/120	6,509	24.77%	

TABLE 4: Results for the Limassol location.

Wind turbine model	Annual produced energy (MWh)	Annual capacity factor	Difference
Sinovel SL 3000/105	7,700	29.30%	6.88%
Sinovel SL 3000/113	8,230	31.32%	
Unison U88-2000	4,932	28.15%	8.11%
Unison U93-2000	5,332	30.44%	
Vestas V90/3.0 MW	6,998	26.63%	33.31%
Vestas V112/3.0 MW	9,329	35.50%	
Windey WD77-1500	3,845	29.26%	7.54%
Windey WD82-1500	4,135	31.47%	
WinWind 3/109	7,647	29.10%	9.77%
WinWind 3/120	8,394	31.94%	

used as an upper bound for these areas (55.7% for Xylofagou and 33.3% for Limassol), and they are mainly explained by the remarkable difference between rotor diameters (90 and 112 m). The contribution of the different hub height (105 and 119 m) is not significant: by considering identical hub height of 105 m for both models, the difference would be 53% for Xylofagou and 31% for Limassol.

5. Conclusion

This paper examined the effect of wind turbine classes II and III on the electricity production of two locations in Cyprus Island that present low and medium wind potentials. It is proved that the class III wind turbines produce significant larger amounts of energy, mainly at the location with the lowest wind potential, which under specific circumstances can surpass 50%. Due to the fact that in the majority of areas with high wind potential (which usually represent a very small portion of the overall area) a wind farm already exists, the need for class III wind turbines installation seems to be now more commanding than ever, as it can be proved to be an economically viable investment which can be implemented at a significant larger number of alternative locations.

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