Comparison of Performance and Cost Analysis of Single Rotor and Contra Rotor for Offshore Wind Energy System

Sandip Samanta[1]Hyacinth J Kennady[2]
[1]M.Tech Thermal Engineering, Hindustan University, Padur, Chennai, India
[2]Professor, Mechanical Engineering, Hindustan University, Padur, Chennai, India
[1]sandipsamanta18@gmail.com, [2]hyacinthjk@hindustanuniv.ac.in

Abstract—*Wind energy is one of the most promising solutions, especially considering its growth and technological advancements. The use of wind energy for electricity generation is growing rapidly across the world and in India. However, the geographical characteristics of the country along with the environmental restrictions imposed to these projects create limitations to the exploit of the onshore wind resource and the best onshore wind spots are already committed. So, the possibility of offshore wind farms in the India. Offshore wind farms also solve environmental obstacles such as the selection and acquisition of land for a site.*

Generally faster wind speeds are observed in offshore areas than in onshore areas. Therefore, for the development of offshore wind energy, is expected to be generated more electricity with low expenditure by using contra rotor wind turbine for Offshore Wind Energy System.

The aim of this paper is to determine the feasibility of improving wind energy performance and reducing the weight by utilizing a contra rotating wind turbine system. This kind of wind turbine has characteristic self-regulated on the speed due to the difference torque between two stages horizontal axis wind turbine and no need pitch controller to control the speed and cut off the wind turbine due to the high wind speed.

In this paper, the study of wind potential and weight estimation of single rotor and contra rotor for off-shore wind farms is calculated. For a site, the cost of energy is also calculated. For contra rotor the outcome of the analysis is cost effective utilization of the offshore wind energy.

Keywords:offshore wind farms, offshore wind energy, contra rotor wind turbine, wind potential, cost of energy.

I. INTODUCTION

Wind is a form of solar energy, created by the uneven heating of the earth's surface by the sun, and the earth's rotation. It is a renewable resource, nonpolluting, and abundant in many areas of the world. For the past decade wind energy has been the world's fastest growing energy source on a percentage basis. Wind-powered grain mills, ships, threshing machines and water pumps all exemplify that extraction of power from wind is an ancient endeavor. Wind turbines are now being used as a generic term for machines with rotating blades that convert the kinetic energy of wind into useful power. [6]

Recently, interest in the development of renewable energy is increasing due to the exhaustion of natural resources; renewable energy is now an essential study topic for economic development. A faster wind speed is observed in offshore than in inland areas. Therefore, offshore areas haves better conditions for the development of wind energy, because the electricity of wind power is in proportion to the cube of the wind speed. In developing offshore wind energy, is expected to be generated more electricity using the contra rotor wind turbine. Offshore wind farms also solve environmental obstacles such as the selection and acquisition of land for a site.

The production of electricity by a wind turbine generator at a specific site depends upon many factors. These factors are including the mean wind speed of the site and the speed characteristics of the wind turbine itself namely, cut-in, design, and cut-out wind speeds including the hub height. These speed parameters affect the capacity factor at a given specific site.

Modern turbines evolved from the early designs and can be classified as two or three-bladed turbines with horizontal axes and upwind rotors. Today, the choice between three-bladed wind turbines is merely a matter of a trade-off between aerodynamic efficiency, cost, complexity, noise and aesthetics. Most wind turbines in the world use a single rotor system that provides simplicity, reliability and durability. Over the years, [7] improvements have been made to enhance energy conversion efficiency of these single rotor systems. But a contra-rotating wind turbine has a number of attractive features: near zero reactive torque on the support structure, near-zero swirls in the wake, and high relative inter-rotor rotational speeds. This kind of wind turbine has characteristic self-regulated on the speed due to the difference torque between two stages horizontal axis wind turbine, than no need pitch controller to control [9] the speed and cut off the wind turbine due to the high wind speed.

II. ENERGY CALCULAS

A. *Wind power density*

Wind turbines are designed with a cut-in speed or the wind speed at which it begins to produce power and a cut-out speed or the wind speed at which the turbine will be shut down to prevent its failure. Wind power that flows at speed v through a blade sweep area A increases with the cube of the wind speed and the areas:

$$P = (½)\, \rho A V^3 \quad (1)$$

ρ is density of air at sea level and a pressure of 1 atm (1.225 kg/m3) and *v* is the mean wind speed (m/s).

The power available [3] in a wind stream velocity V, per unit rotor area, is given by:

$$P/A = (½)\, \rho V^3 \quad (2)$$

The graphical representation of monthly average wind power density for the year of 2007 has been presented in Fig. 1.

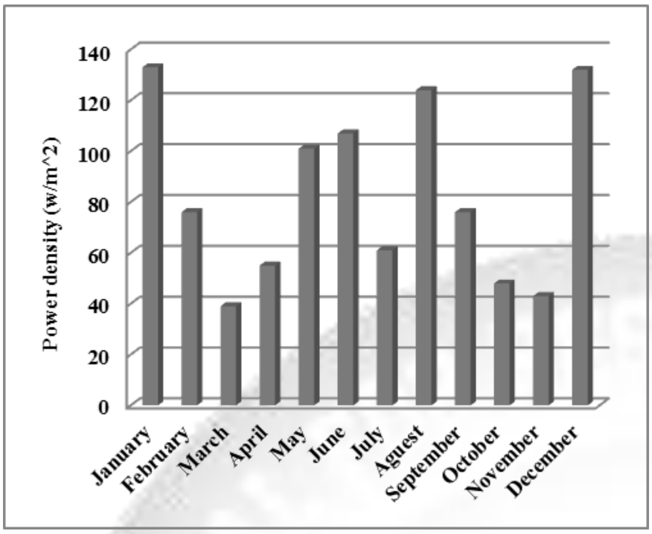

Fig. 1:Monthly average wind power density

B. *Wind energy density*

Wind energy density [3] for a desired duration can be Calculated as:

$E/A = (P/A)\, n\Delta t$ (3)

Where n is the number of measurement periods, Δt. This equation can be used to calculate the available wind energy for any defined period of time when the wind speed frequency distributions are for a different period of time.

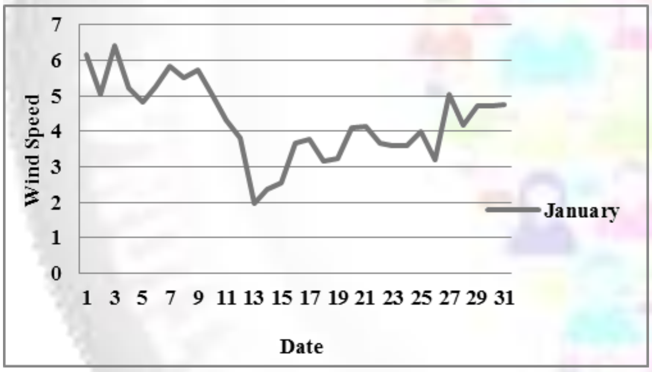

Fig. 2:Wind speed for the month of January

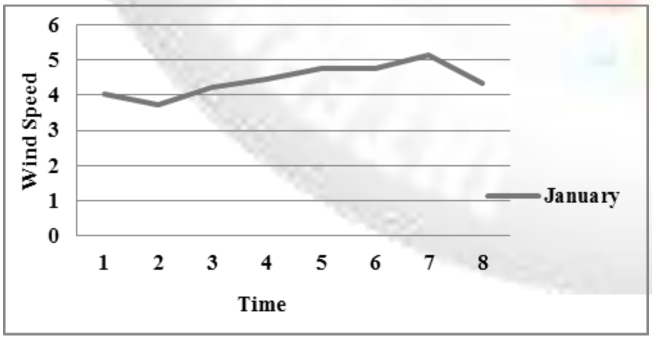

Fig. 3:Hourly average wind speed of the month January

The graphical representation of monthly wind speed and Hourly average wind speed for the month of January has been presented in Fig. 2 and Fig. 3.

C. *Weibull probability density function*

The Weibull distribution is often used in the statistical analysis of data. It is used to represent the wind speed distribution in wind energy analysis. The Weibull distribution function [11] is given by:

$f(v) = (k/c)\ X\ (v/c)^{k-1} \exp(-(v/c)^{k})$ (4)

where f(V) is the frequency or probability of occurrence of wind speed Z, c is the Weibull scale parameter with unit equals to the wind speed unit and ft is the unitlessWeibull shape parameter. The higher value of c indicates that the wind speed is higher, whiles the value of & shows the wind stability.

III. PERFORMANCE CALCULAS

A. *Annual Energy Output*

To get an estimate of the performance of a particular wind turbine use the formula [1] below:

$AEP = \sum P(v)\ X\ f(v)\ X\ 8760$ (5)

A. *Capacity Factor*

Capacity Factor [11] is an indicator of how much energy a particular wind turbine makes in a particular place**.**It compares the plant's actual production over a given period of time with mean wind speed the amount of power the plant would have produced if it had run at rated wind speed for the same amount of time.

C.F. (%) = AEP/ (Rated Power x 8760) + 100 (6)

IV. ECONOMICS

A. *Offshore project cost*

Offshore wind project cost cannot be fully evaluated by looking at the upfront capital investments, but because the industry is very new and life-cycle cost assessments are more uncertain. Offshore project cost are varies place to place and it depends on different wind turbines. The formula used to calculate the project cost [2] is specified by NREL. Costs used in these models are based on 2007 dollars.

	6 MW		9 MW	
	Component Costs $1000	Component Mass kgs	Component Costs $1000	Component Mass kgs
Rotor	2065	214759	1928	198928
Drive train, nacelle	2655	111068	3276	120721
Tower	1462	974037	1415	942967
Turbine capital cost (TCC)	7623	1464499	8095	1262616
Balance of station cost (BOS)	6252	0	11252	0

Table 1 Cost Estimation for Single Rotor

B. *Cost of Energy*

In simple terms, Levelized Cost of Energy (LCOE) [12] can be seen as the lifetime cost of the project per unit of energy generated.

It is defined as the sum of discounted lifetime generation costs divided by the sum of discounted lifetime electricity output. Generation costs include all capital, operating, and decommissioning costs incurred by the generator/developer over the lifetime of the project, including transmission costs. It does not necessarily correspond to the level of revenue that would be required to support the project; it is an expression of cost rather than revenue. The discount rate is the Weighted Average Cost of Capital (WACC) over the lifetime of the project; as determined by the capital structure and financing costs. LCOE is expressed for 2007.

$$COE = ((FCR \times ICC) + LCR)/ AEP_{net} + O\&M \quad (7)$$

where

FCR ≡ fixed charge rate (constant $) (1/yr)
ICC ≡ initial capital cost ($)
AEPnet ≡ net annual energy production (kWh/yr)
O&M ≡ levelized O&M cost
LRC ≡ levelized replacement/overhaul cost

SingleRotor	6 MW	9 MW
Rated Power (kW)	6000	9000
Rotor Diameter (m)	154	152
AEP (MWh)	17173	24967
C.F. (%)	26.14	30.42
COE ($/kWh)	6.627	6.128

Table 2: Estimation of Aep, C.F. And Coe

The tabular representation of offshore project cost and estimation of AEP, C.F., COE have been presented in Table 1 and Table 2. From the result available the machine with optimal capacity factor that is single rotor 9 MW has been recommended.

	Contra Rotor 9 MW (Upwind 6 MW and Downwind 3MW)	
	Component Costs $1000	Component Mass kgs
Rotor	2167	223916
Drive train, nacelle	3791	135796
Tower	1709	1139306
Turbine capital cost (TCC)	8776	1298018
Balance of station cost (BOS)	9152	0
Rated Power (kW)	9000	
Rotor Diameter (m)	125	
AEP (MWh)	23299	
C.F. (%)	30.18	
COE ($/kWh)	5.914	

Table 3: Estimation Of Project Cost, Aep, C.F. And Coe For Contra Rotor

The tabular representation of contra rotor project cost and estimation of AEP, C.F., and COE has been presented in Table 3. After comparing single rotor and contra rotor, the result available the machine with optimal capacity factor, AEP and COE that is contra rotor 9 MW has been recommended.

V. CONCLUSIONS

This paper presents a methodology for assessment of offshore wind data and the capacity factor of wind turbines for their suitability to be used for harnessing offshore wind energy in a better fashion as depicted by the results. The performance of a CRWT equipped with upwind 6 MW and downwind 3 MW turbines are studied. The main result of the study is that CRWT performs well at different wind speeds. The viability of an offshore wind project is highly dependent on the net annual energy production and project cost, which in turn, relies on the wind turbines chosen. This not only helps to choose a better turbine but also to maximize the system performance.

ACKNOWLEDGEMENT

The authors acknowledge thankfully the support extended by Indian National Centre for Ocean Information Services, (INCOIS) Hyderabad for providing necessary offshore wind data for Chennai (India) offshore area. The authors also wish to thank Dr.Mrs.Hyacinth J Kennady, Professor of Hindustan University and Dr. Kari Appa, Managing Director of Wind Turbine Systems (P) Ltd., for their valuable comments and kind assistance.

REFERENCES

[1] A. Mostafaeipour, A. Sedaghat, A.A. Dehghan-Niri, V. Kalantar (2011), Wind energy feasibility study for city of Shahrbabak in Iran, Renewable and Sustainable Energy, Iran, pp. 2545– 2556.
[2] D.J Malcolm and A.C. Hansen (2006), WindPACT Turbine Rotor Design Study, National Renewable Energy Laboratory, US.
[3] D. Saeidi, M. Mirhosseini, A. Sedaghat, A. Mostafaeipour (2011), Feasibility study of wind energy potential in two provinces of Iran: North and South Khorasan, Renewable and Sustainable Energy, Iran, pp. 3558-3569.
[4] J A Clarke, G Connor, A D Grant, and C M Johnstone (2006), Design and testing of a contra-rotating tidal current turbine, Power and Energy, **1**, 22, pp. 171-179.
[5] J.D. Booker, P.H. Mellor, R. Wrobel, D. Drury (2010), A compact, high efficiency contra-rotating generator suitable for wind turbines in the urban environment, Renewable Energy, **9**, 35, pp. 2027–2033.
[6] JydskCentraltrykkeri (2002), Guidelines for Design of Wind Turbines, Risø National Laboratory, Denmark.
[7] Kari Appa (2002), COUNTER ROTATING WIND TURBINE SYSTEM, Renewable Energy Technologies, California.
[8] Namhyeong Kim and Jung Woon Jin (2012), Sensitivity Analysis of Offshore Wind Turbine Tower Caused by the External Force, Journal of Civil Engineering, Korea, pp. 859-864.
[9] PriyonoSutikno, Deny BayuSaepudin (2010), Design and Blade Optimization of Contra Rotation Double Rotor Wind Turbine, International Journal of Mechanical & Mechatronics Engineering, **1**, 11, pp. 17-27.
[10] SanjeevMalhotra (2011), Selection, Design and Construction of Offshore Wind Turbine Foundations, Parsons Brinckerhoff, Inc., United States of America.
[11] Sathyajith Mathew, Geetha Susan Philip and Chee Ming Lim (2011), Analysis of Wind Regimes and

Performance of Wind Turbines, Wind Energy, Brunei, pp. 71-83.

[12] W. Musial and B. Ram (2010), Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers, National Renewable EnergyLaboratory,US.