Analysis of Offshore Wind Energy Potential using Curve Model

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***Abstract*— offshore wind energy potential curve modeling is an important tool in offshore site wind data primary investigation. Recently a report on offshore wind profile measurement preliminary studies and measurement campaign for Dhanuskodi, Tamil Nadu was released by National Institute of Wind Energy, Government of India for public. This report consists of monthly mean wind speed and corresponding wind power density measured at various heights (10m, 20m, 50m, 80m, 100m and 110m) from October 2013 to September 2014. There are several statistical techniques to fit the empirical wind power density and wind speed. In this paper, we study eleven (linear, logarithmic inverse, quadratic, cubic, compound, power, spline, growth, exponential and logistics) of these methods to estimate the wind power density. The performance of the presented methods are evaluated and compared using wind speed, wind power density data at different heights in Dhanuskodi and the accuracy of each method is checked by using R^2 and Standard Error.**

Keywords- Offshore Wind Energy, Curve Model, Wind Speed, Wind Power Density, Dhanuskodi, SPSS

I. Introduction

Wind power is a prominent and viable alternative and to traditional sources. In India, Ministry of New and Renewable Energy (MNRE) has already estimated 103 GW of wind energy potential. Government of India is looking at renewable energy as a way to achieve energy security and to curb greenhouse gas (GHG) emissions happening due to the electricity sector. Therefore, renewable energy development is high on government agenda. Recently, India set 60 GW of wind capacity additional target by 2022. So the Wind frame performance evaluation is one of the most essential and critical activities in wind plant. The wind frame performance will cover both technical and economical aspects. Wind speed is playing important role for wind frame performance. India has 7500 km of coastal line, therefore there is huge scope for power production through on shore wind energy and off wind energy.

II. OFFSHORE WIND POTENTIAL IN INDIA

Offshore technology wind turbine technology is being considered as an important sources of energy not only carbon reduction but also to meet the growing energy demand. The results of measuring offshore wind potential in the Dhanushkodi region have been encouraging, according to the National Institute of Wind Energy (NIWE), India. In its report on offshore wind profile measurement at Dhanushkodi, the NIWE said its assessment showed there was a good possibility of achieving over 45 per cent capacity utilisation factor for the offshore wind plants with the existing onshore turbine technology in the region. Capacity utilisation factor is the percentage of a power plant’s maximum potential that is actually achieved over a period of time. With India’s long coastline, the government is planning to push development of offshore wind power projects. Last year, the government issued comprehensive guidelines for development of on-shore wind power projects in India. Certain blocks in Gujarat and Tamil Nadu (especially in Rameswaram and Kanyakumari regions) coastline were identified to study the potential of offshore wind energy. The NIWE was assigned the task of doing the wind resource assessment in these areas. The NIWE reported that it installed a 100-metre met mast at Dhanushkodi and monitored the wind data. It also pointed out that some studies concluded that there is a possibility to develop 1 gigawatt offshore power each at Rameswaram and Kanyakumari. Therefore effective integration of wind power into the power systems requires accurate estimation of wind energy as well as performance monitoring of wind speed.

III. CURVE ESTIMATION MODEL

The Power curve of wind turbine presents the electrical power output ratings of the machine for different wind speed. The power relates to wind speed. Wind power density is the ratio of wind power and cross-sectional area of the air parcel. Carrillo C et al (2014) and Parajuli A (2016) developed empirical realtion between wind speed and wind power density based on Weibull and Rayleigh method. Shokradeh Shahab (2014) have done power curve modeling with wind speed and wind power using parametric and non parametric methods .There are several statistical methods to fit the empirical relation between the wind power density and wind speed. The Curve Estimation is one of them and its procedure produces curve estimation regression statistics and related plots for 11 different curve estimation regression models. The eleven curve estimation regression models are linear, logarithmic, inverse, quadratic, cubic, power, compound, S-curve, logistic, growth, and exponential. The following 11 formulas for 11 different curve estimation regression models. [2]

A. Linear : $Y = b_0 + (b_1 * X)$ (1)

B. Logarithmic : $Y = b_0 + (b_1 * \ln(X)$ (2)

C. Inverse : $Y = b_0 + (b_1 / X)$ (3)

D. Quadratic : $Y = b_0 + (b_1 * X) + (b_2 * X^2)$ (4)

E. Cubic : $Y = b_0 + (b_1 * X) + (b_2 * X^2) + (b3 * X^3)$ (5)

F. Power : $\ln(Y) = \ln(b_0) + (b_1 * \ln(X))$ (6)

G. Compound : $\ln(Y) = \ln(b_0) + (\ln(b_1) * X)$ (7)

H. S-curve : $\ln(Y) = b_0 + (b_1/X)$ (8)

I. Logistic : $\ln(b_0) + (\ln(b_1) * X)$ (9)

J. Growth : $\ln(Y) = b_0 + (b_1 * X)$ (10)

K. Exponential : $\ln(Y) = \ln(b0) + (b1 * X)$ (11)

From the above 11 equation, Y is wind power density and X is Wind speed. Therefore, it is important to investigate the performance of different statistical procedures for power curve fitting and decide which method produces better results for the given data set.

TABLE I AVERAGE WIND SPEED AT DIFFERENT HEIGHTS AND DIFFERENT PERIOD

Month	102 m	100 m	80 m	50 m	20 m	10m
Oct	8.45	8.34	8.28	8.21	7.92	7.57
Nov	7.35	7.46	7.39	7.33	7.12	6.8
Dec	8.91	9.05	8.94	8.83	8.49	8.03
Jan	9.58	9.75	9.62	9.49	9.13	8.64
Feb	7.37	7.48	7.4	7.33	7.11	6.77
Mar	7.62	7.71	7.63	7.57	7.33	6.95
Apr	5.51	5.43	5.34	5.36	5.24	5.05
May	10	9.9	9.8	9.7	9.29	8.81
June	9.96	9.92	9.8	9.69	9.3	8.86
Jul	10.2	10.2	10.1	9.95	9.53	9.08
Aug	9.82	9.74	9.6	9.56	9.21	8.78
Sep	8.61	8.52	8.4	8.36	8.06	7.71

TABLE II AVERAGE WIND POWER DENSITY AT DIFFERENT HEIGHTS AND DIFFERENT PERIOD

Month	102 m	100 m	80 m	50 m	20 m	10 m
Oct	538	515	506	487	430	374
Nov	303	319	310	301	274	235
Dec	542	569	549	529	466	392
Jan	562	592	568	544	484	408
Feb	318	334	323	312	282	240
Mar	343	357	345	335	301	254
Apr	144	137	131	131	122	108
May	772	742	723	693	602	510
June	713	704	683	652	569	487
Jul	789	790	757	715	618	528
Aug	779	766	742	715	623	530
Sep	580	566	546	526	461	396

We apply the methods in section on proprietary wind power density and wind speed of a wind farm in Dhanuskodi. We observe average wind speed and wind power density at different height various heights (10m, 20m, 50m, 80m, 100m and 110m) from October 2013 to September 2014 in table I and table II [1]. Results for Curve estimation are presented using wind data at altitude of 102 m and 100 m in the table III and IV using SPSS software. Curve estimation plot are presented in figure 1 and 2. Similarly results for curve estimation are presented using wind data at altitude of 80 m and 50 m in the table V and V I using SPSS software. Curve estimation plot are presented in figure 3 and 4.

TABLE III RESULT FOR CURVE ESTIMATION MODEL AT 102 m

Sl. No	Curve Estimation Model	b_0	b_1	Sig.	R^2 Value	Stand. Error
1	Linear	144.13		0.00	0.93	56.97
2	Logarithmic	1117.43		0.00	0.90	69.05
3	Inverse	-8243.37		0.00	0.85	85.49
4	Quadratic	-28.10	10.61	0.00	0.94	54.55
5	**Power**	**2.77**	**1.283**	**0.00**	**0.97**	**0.09**
6	Compound	1.42		0.00	0.95	0.113
7	S-curve	-20.96		0.00	0.96	0.100
8	Logistic	0.705		0.00	0.95	0.11
9	Growth	0.348		0.00	0.95	0.113
10	Exponential	0.348		0.00	0.95	0.113

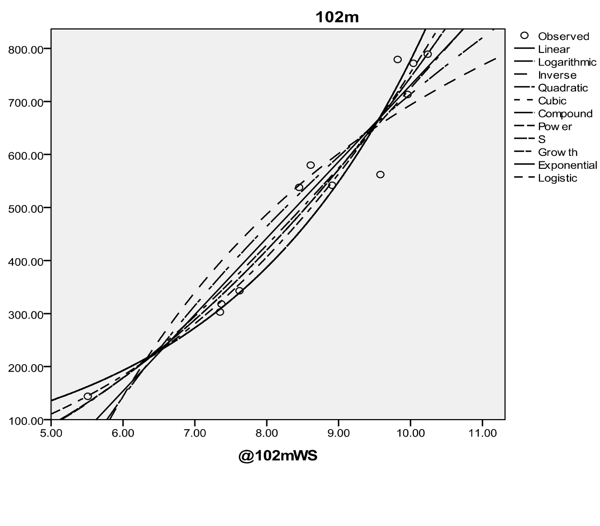

Figure 1. Plot for Curve Estimation Model at 102 m

TABLE IV RESULT FOR CURVE ESTIMATION MODEL AT 100 m

Sl. No	*Curve Estimation Model*	b_0	b_1	*Sig.*	R^2	*Stand. Error*
1	Linear	140.57		0.00	0.93	54.69
2	Logarithmic	1080.2		0.00	0.91	66.44
3	Inverse	-7870.5		0.00	0.85	82.82
4	Quadratic	-3.5	8.93	0.00	0.94	53.35
5	Power	-3.51	8.93	0.00	0.94	53.36
6	Compound	1.42		0.00	0.95	0.118
7	***S-curve***	***-20.63***	***8.64***	***0.00***	***0.97***	***0.09***
8	Logistic	0.705		0.00	0.95	0.118
9	Growth	0.348		0.00	0.95	0.11
10	Exponential	0.35		0.00	0.95	0.118

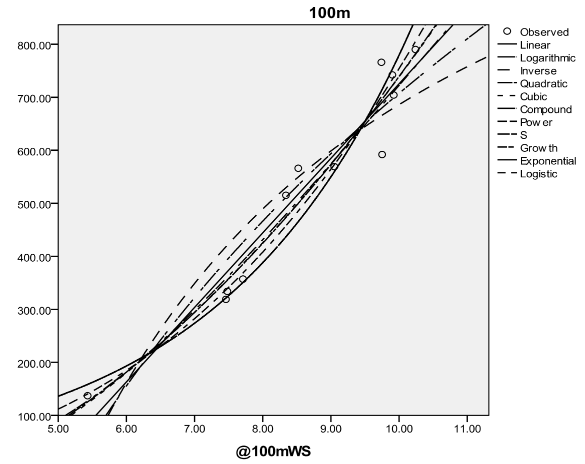

Figure 2. Plot for Curve Estimation Model at 100 m

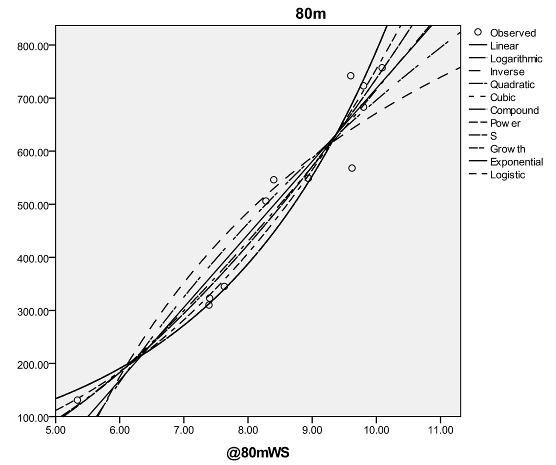

Figure 3. Plot for Curve Estimation Model at 80 m

TABLE V RESULT FOR CURVE ESTIMATION MODEL AT 80 m

Sl. No	*Curve Estimation Model*	b_0	b_1	*Sig.*	R^2	*Stand. Error*
1	Linear	137.441		.000	.932	54.76
2	Logarithmic	1039.61		.000	.901	66.10
3	Inverse	-7448.14		.000	.848	81.85
4	Quadratic	-6.27	9.04	.000	.942	53.48
5	Power	1.426		.000	.950	.094
6	Compound	2.758		.000	.970	.120
7	***S-curve***	**-20.329**	**8.606**	**.000**	**.966**	**. 099**
8	Logistic	.355		.000	.950	.120
9	Growth	.355		.000	.950	.120
10	Exponential	.701		.000	.950	.120

TABLE VI RESULT FOR CURVE ESTIMATION MODEL AT 50 m

Sl. No	*Curve Estimation Model*	b_0	b_1	*Sig.*	R^2	*Stand. Error*
1	Linear	133.647		.000	.938	49.67
2	Logarithmic	1006.836		.000	.908	60.11
3	Inverse	-7205.95		.000	.858	74.71
4	Quadratic	-4.853	8.77	.000	.947	48.42
5	Power	1.427		.000	.953	0.088
6	Compound	2.750		.000	.972	.114
7	***S-curve***	**-20.217**	**8.606**	**.000**	**.969**	**. 093**
8	Logistic	.356		.000	.953	.114
9	Growth	.356		.000	.953	.114
10	Exponential	.701		.000	.953	.114

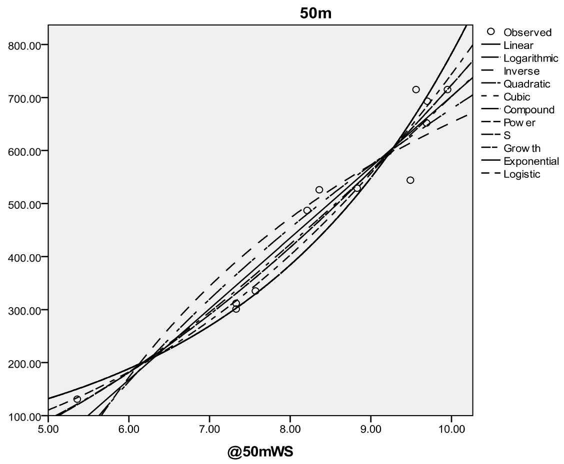

Figure 4. Plot for Curve Estimation Model at 50 m

IV. RESULT AND DISCUSSION

R^2 values should be higher and standard error should be less. We have not only considered R^2 values and standard error but also significant values, ten models (other than cubic models) are fitted. Then only a model can be called best model. The Cubic model could not be fitted due to near-co linearity among model terms at 100 m, 102 m, 80 m and 50 m.

From the table III,

Curve estimation model for 102 m height altitude
Power curve : *ln(Wind Power Density) = ln(2.77) + (1.283 * ln(Wind Speed))* (12)

From the table IV,

Curve estimation model for 100 m height altitude
S-curve : ln(Wind Power Density) = -20.63 + (8.64/ Wind Speed) (13)

From the table V,

Curve estimation model for 80 m height altitude
S-curve : ln(Wind Power Density) = -20.329 + (8.606/ Wind Speed) (14)

From the table VI,

Curve estimation model for 50 m height altitude
S-curve : ln(Wind Power Density) = -20.217 + (8.606/ Wind Speed) (15)

The observation points on the curve of the graphs (Ref : Figure 1,2,3 and 4). It shows that the curve model is best fit.

V. CONCLUSION

We analyzed wind speed and wind density data at 100 m 102 m, 80 m and 50 m. Out of 11 empirical models, 10 models fit the wind data. At 102 m, Power model was best fit model and 100 m, 80 m and 50 m, S-curve model was best fit model. Similar curve fitting operations can be carried out at the altitudes of 20 m and 10 m, and empirically fit models can be found.

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BIOGRAPHICAL INFORMATION

Mr.Kaja Bantha Navas has completed B.E Mechanical Engineering and M.E Industrial Engineering Degree. He has four years experience in power industry and 4 years experience in teaching. He has a good analytical mind in solving Industrial engineering problems and published more than 10 publication with Six Scopus Indexed. He has substantial knowledge in key industrial processes, design of experiments, its simulation, modelling and Optimisation. Now, he is doing Phd in Sathyabama University Intelligent Analysis for Wind Resources Forecasting System using Machine Learning Techniques

Dr.K.V.Narayanan started his career in Sathyabama University as a Lecturer and climbed up various steps to the post of Professor due to his diligent and sincere work. He represents the university's collective commitment to excellence in teaching, learning and research. He has contributed research papers in various reputed International, National Journals and conferences. His areas of interest include Thermal Engineering, Energy Management, Renewable Energy. He is also a Peer Reviewer in many International Journals in Engineering, which has very Good Impact Factors like Renewable Energy, Biomass and Bioenergy etc. He is also currently guiding Ph.D scholars in the area of Energy.

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