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Performance Evaluation of Wind Turbines on the basis of Power Generation

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Abstract: ***Wind energy is one of the promising solution for future demand and need of energy. Main application of wind energy is in electricity sector. India is having potential for wind installation which is not yet fully explored. This paper compares the results from test rig small scale wind turbine and scale up data for different sizes of turbine as power from small size turbine was very low. A mathematical formulation for wind power is developed for finding total power from the available wind at certain speed. Three factors considered for analysis of three responses. Factors are Wind Speed, Rotor diameter and Swept area for getting response for wind power, torque and wind power density. For different wind speed and different rotor diameter wind power, torque and wind power density calculations done. Response surface method is used to design the experiments and ANOVA (Analysis of Variance) is used to analyze that experiment results are significant or not. Wind data analysis shows that wind speed gives a fairly good response in the range of wind speed 8m/s to 12m/s in practical grounds.***

***Index Terms*: Wind Turbine, Power performance, Wind speed, Performance evaluation.**

I. INTRODUCTION

As energy demand is increasing day by day rapidly due to which conventional sources of energy are depleting. We required a solution for the same which gives attention to all renewable sources of energy out of which wind energy sector is growing very fast. When compared with other sources wind energy has its own advantages.

Wind turbine are widely available for different size of rotor and hub height. General hub height range for wind turbine is in the range of 25m to 150m. latest hub height is upto 230m.

Wind energy is one of the solution for emerging need of power in this modern world. As per the 2018 wind energy installed capacity it's now reached up to 600 Gigawatt worldwide. This amount of wind energy is quite sufficient for supplying 6% electricity demand of the world. In the year 2018 alone 53,9 Gigawatt capacity was added in the wind energy sector. If we compare it with the last year of installed which was 52,552 megawatt with the rate of growth of 10.8% in this year the rate of growth is slightly declined as it is 9.8%.

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Wind turbine conversion system is made up of wind turbine, gear box, and generator. Here we have considered horizontal axis 3 blade rotor wind turbine. For optimization if numerical values are combined with graphical analysis it is better to understand the results and findings in the experimental work.

II. LITERATURE REVIEW

For total installed capacity and prospects [8] give a detail study for the same. A. Kaushik [9] provided solution methodology for performance of wind farm and performance curves for power, rotor diameter and blade pitch. R. Palllabazzer[5] provided simple method for evaluating energy output of wind turbine.

A. Lombart [10] and his team worked for optimal siting of wind turbines and discussed wind resource evaluation methods.

R. K. Pachuari [7] emphasis on assessment of wind energy potential. M.Z. Jacobson [6] provided information for saturation of wind potential which gives information that by by 3030 for remote areas wind will surpass other energy systems. S.N. [1] discussed design of energy conversion system for next decade. Signe [14] and his team used a statistical approach with analysis of Variance ANOVA test for determining the parameters for better usage of wind power in Douala. Kim [13] used ANOVA test for clarifying whether the differences in efficiencies among NRE are significant. G. Aqila [12] taken four year wind data for getting accurate wind speed average data for power generation.

II. MATHEMATHECAL MODELLING OF WIND TURBINE

To understand the behavior of wind turbine and power output from wind turbine at different parameters a mathematical model is essential. To optimize the wind turbine design and decreasing the cost of power production using wind energy modelling.

In order to harness the wind energy the wind turbine rotor must allow some amount of wind to pass through its blades to move on behind the rotor.

We know that, fundamental law of mechanics states that energy can be extracted only from a flow system. If air of mass m flowing at a speed v has kinetic energy E, then this mechanical energy is converted to electrical power, energy produced per unit time is

$$P = work/ time$$

$$P = K.E. / t$$

$$P= dE/ dT$$

$$P= \frac{1}{2} \quad v^2$$

dw/dt

We know that mass flow rate is

$dm/dt = \rho A\, dx/dt$ [$v= dx/dt$]

$dm/dt= \rho A V$

$E = ½ m v^2$

Where

V= wind speed (m/sec).

ρ = density of air 1.225 Kg/m^3 at 15 º C and normal pressure.

$m = \rho A d$ (density ×Area × Distance)

A = Swept Area

L= length of turbine blade (m)

$A = \pi r^2$ [$l =r$]

Therefore total power contained in the wind flowing through the swept area A will be

$P_{total} = ½$ (mass flow rate) v^2

$P_{total} = ½ (\rho Av) v^2$

$P_{total} = ½ \rho Av^3$

This formulae shows that wind speed plays crucial role in power generation so micro siting of wind power plant is very important for producing more power from the same wind power plant.

The actual power that we can extract from the wind is very less than figure suggests. The actual power will depend upon several factors, such as the type of machine and rotor blade design, friction losses and losses by the other equipment in the system.

It can be shown theoretically (Betz limit) that any wind mill can only extract a maximum of 59.3% of the power from the wind. In reality, coefficient of performance is less that Betz limit

$P_m = ½ \rho Av^3 C_p$

P_m = power output in watt available from the generator.

C_p = coefficient of performance.

C_p = rotor power / Dynamic Power.

$C_p = 4 a (1- a^2)$

Value of a is 1/3 it is decrease in wind velocity between the free stream and the rotor plane.

$C_p = 16/27 = 0.5926$.

This value of C_p is maximum value which is not possible in practical working condition. The real value is 0.35 to 0.45 which is applicable is best designed models of wind turbines. Taking into consideration other factors that contributes only 10 to 30% is the actual amount which is converted into electricity from the wind turbine.

III. DESIGN SUMMARY

Initial design is selected for study is Box-Behnkn, design model is quaderatic and three factors are cosidered with their actual low and high values which is shown in table 1. The responses of these three factors gives the three responses which is shown is Table 2 for their mimmun and maximun values.

Table 1 : Factors considered for design

Factor	Name	Units	Type	Low Actual	HighActual
A	Wind Speed	m/s	Numeric	3.50	44.00
B	Rotor Dia	m	Numeric	50.00	120.00
C	Swept Area	M sq	Numeric	1964.00	11314.00

Table 2 :Responses recied from Factors.

Response	Name	Units	Obs	Min	Max
Y1	POWER	KW	KW	17.15	2.370E+005
Y2	TORQUE	KN.m	KN.m	24.67	53850.82
Y3	DENSITY	W/m sq	W/m sq	8.73	20954.45

3 Factors: A, B, C

[Intercept] = Intercept + BC + B^2 + C^2

[A]=A

[B] = B - 5 * BC - 4.86 * B^2 - 4.94 * C^2

[C] = C + 5 * BC + 4.86 * B^2 + 4.94 * C^2

[A^2]=A^2

[AB]=AB

[AC]=AC

Degrees of Freedom for Evaluation

Model	6
Residuals	8
Lack Of Fit	*8*
Pure Error	*0*
Corr Total	14

Table 3 : Design Matrix of Evaluation (Omitting Aliased Terms)

Term	StdErr**	VIF	Ri-Squared	1/2 Std. Dev.	1 Std. Dev.	2 Std. Dev.
A	0.43	1.51	0.3382	8.2 %	18.0 %	54.2 %
B	2.85	81.50	0.9877	5.1 %	5.3 %	6.1 %
C	2.85	81.50	0.9877	5.1 %	5.3 %	6.1 %
A^2	0.60	1.01	0.0117	11.4 %	31.3 %	83.1 %
AB	3.64	81.75	0.9878	5.0 %	5.2 %	5.7 %
AC	3.65	81.54	0.9877	5.0 %	5.2 %	5.7 %

IV. RESULT AND DISCUSSIONS

In order to more rigorously clarify whether the power from different size of turbines at different wind speed with a statistical approach of analysis of Variance (ANOVA) for different wind speeds, different diameter and swept area for getting wind power, torque an density was utilized. Results of ANOVA test is shown in fig 1 & fig 2 for wind power.

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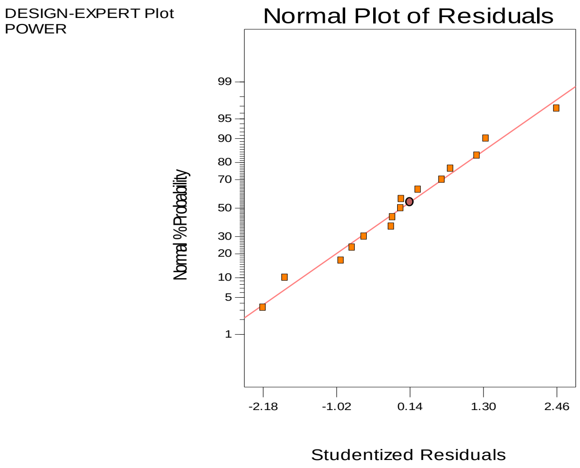

Fig1: Power plot between residuals and normal % probability.

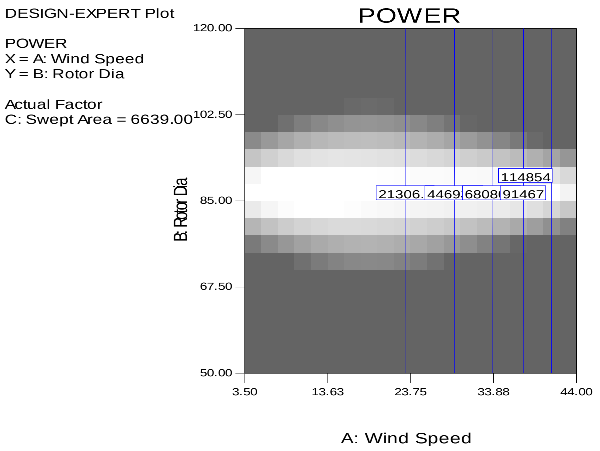

Fig 2: Power plot between Wind speed (m) and nRotor dia (m sq.)

For Torque results are shown in Fig 3 and Fig 4.

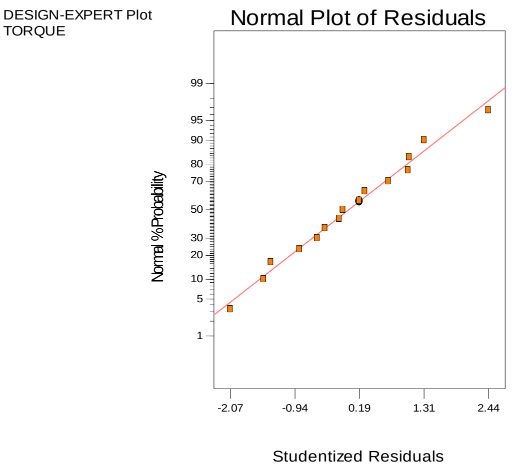

Fig 3: Torque plot between residuals and normal % probability.

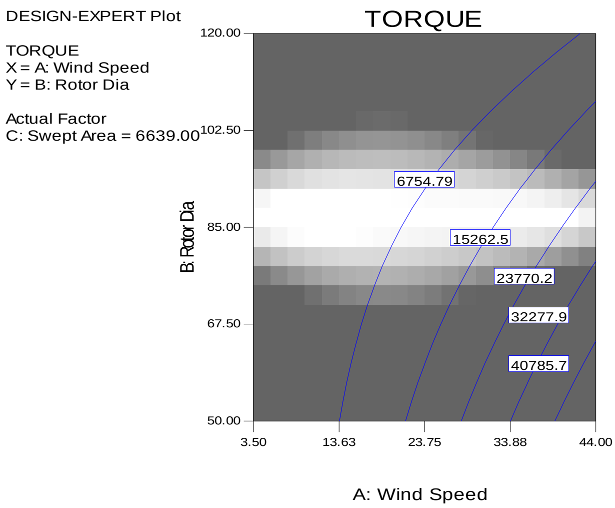

Fig 4: Torque plot between Wind speed (m) and Rotor dia (m sq.)

For Density results are shown in Fig 5and Fig 6.

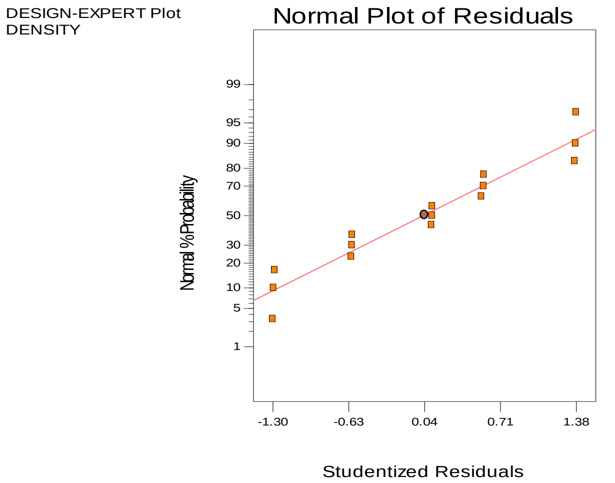

Fig 5: Density plot between residuals and normal % probability.

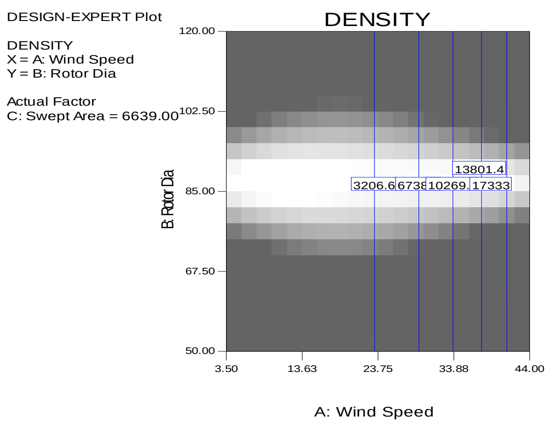

Fig 6:Density plot between Wind speed (m) and Rotor dia (m sq.) After calculating wind power at different wind speed. If a graph is plotted between Wind speed on x axis and Wind power on Y axis result is shown is Fig 7, which shows that wind gives best performance in terms of power output at the range of 8 m/s/
to 12 m/s.

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At very high wind speed more that 25 m/s it is not recommended to operate wind turbine because it is not the safe value for wind machine to operate.

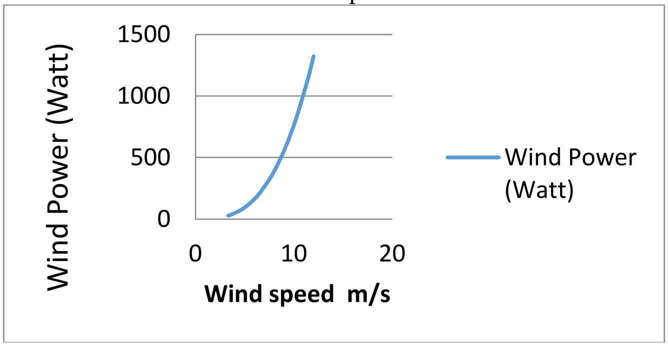

Fig 7 : Curve between wind speed(m/s) and Wind Power (Watt)

V. CONCLUSION

Many studies have already shown that wind speed data have many degrees of uncertainties for a primary assessment of wind power at different wind speed and for different sizes of wind turbines values are considered in the range of as low as 3.5m/s to as high as 44 m/s and rotor diameter considered from 50 m to 120m. It has been observed from the experiments that the result from ANOVA are as observed below

Maximum Prediction Variance (at a design point) = 0.823
Average Prediction Variance = 0.467
Condition Number of Coefficient Matrix = 545.112

G Efficiency (calculated from the design points) = 56.7 %
Scaled D-optimality Criterion = 7.04

Determinant of $(X'X)^{-1}$=5.021E-3

Trace of $(X'X)^{-1}$ = 43.598

Fig 8 shows the relation between wind speed, wind power and swept area. It shows that with the increase in wind speed power is increasing rapidly and higher swept area producing larger amount of power for same wind speed.

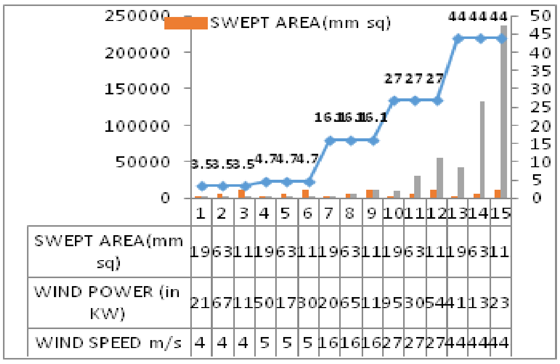

Fig 8: Curve between swept areas, wind power and wind speed.

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Somya Tiwari is research scholar in Mechanical engineering department of School of Engineering & Technology, Ansal University, Gurugram. Her area of interest is Wind energy, renewable energy sources and mechanical system design. She has published 10 technical papers in various national and international repute journals and conferences. She has passion of teaching and having 15+ years of experience in her credit.

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