APPLICATION OF TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS IN IMPROVING THE POWER GENERATION IN WIND FARMS

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The objective of the study is to optimize the process parameters by applying the Taguchi method with orthogonal array robust design. Taguchi Parameter Design is a powerful and efficient method for optimizing the process, quality and performance output, thus a powerful tool for meeting this challenge. Off-line quality control is considered to be an effective approach to improve the performance. This procedure eliminates the need for repeated experiments and time. The approach is based on Taguchi method, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to study the performance characteristics. In this paper, the power parameters such as Diameter (m), Swept area (m²), Rotor speed (rev/min), Turbine capacity (kW) of wind farms are optimized in Tirunelveli region

.***Keywords***: *ANOVA, Design of Experiments, S/N Ratio, Taguchi Method.*

I. INTRODUCTION

In this project, operational experience of site-specific data of different wind farms located at Tirunelveli region (Southern part of India) are collected and interpreted in detail. The different factors which are being considered as diameter, area of swept circle, speed and the number of blades. It is a fact that wind energy production shows a wide range of variation due to climatic and technical factors. The stoppage time of the Wind Turbine Generators (WTGs) reduced the real availability for approximately 20%. So it is essential to conduct a performance, failure and reliability interpretation on the wind farms for further improvement. Here for this study we go for use Taguchi method of optimization to get an optimized output for our work. This project is useful for the Wind Energy Industries for the sustainable development of wind energy in India**.** All renewable energy (except tidal and geothermal power), ultimately comes from the sun. The earth receives 1.74 x 1017 watts of power (per hour) from the sun. About one or 2 percent of this energy is converted to wind energy which is about 50-100 times more than the energy converted to biomass by all plants on earth. Differential heating of the earth's surface and atmosphere induces vertical and horizontal air currents that are affected by the earth's rotation and contours of the land and wind.

II. LITERATURE SURVEY

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). About 16% of global final energy consumption comes from renewables, with 10% coming from traditional biomass, which is mainly used for heating, and 3.4%

from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 3% and are growing very rapidly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources. Renewable energy sources derive their energy from existing flow of energy, from on -going natural processes such as sunshine, wind, flowing water, biological processes and geothermal heat flows. A general definition for renewable energy sources is that renewable energy is captured from an energy resource that is replaced rapidly by a natural processes such as power generated from the sun or from the wind. Currently the most promising (economically most feasible) alternative energy source includes wind power, solar power and hydroelectric power.

III. RENEWABLE ENERGY IN INDIA

India is the fourth largest country with regard to installed power generation capacity in the field of renewable energy resources. Wind, Hydro, Solar, Biomass are main renewable energy sources. India has an estimated energy potential of around 85,000MW from commercially exploitable sources. The MNES (Ministry of Non-Conventional Energy Sources), Government of India, has undertaken measures to facilitate the growth of both grid and off-grid Renewable Energy power through specific programs.

III (A). Renewable Energy Installation in Tamil Nadu

Achievements of TEDA as on 31.10.2015 is given in the table 1.5. The total cumulative achievement upto 31.10.2015 is 7420.45 MW with Wind power contributing the maximum of 6548.00 MW. About 88.24% of the total renewable energy in the state is from wind power. The Bagasse Cogeneration is in the second position with 610.00 MW. The contribution of biomass, small hydro power, solar power, and waste to energy towards the Renewable Energy Systems in Tamil Nadu are 161.15 MW, 90.05 MW, 7.00 MW, and 4.25 MW respectively

Table 1. Cumulative achievement of RES in Tamil Nadu

Renewable energy program/Systems	**Cumulative achievement up to 31.10.2015 (MW)**
Wind Power	6548.00
Bagasse Cogeneration	610.00
Biomass Power	161.15
Small Hydro Power	90.05
Solar Power	7.00
Waste to Energy	4.25
Total	7420.45

IV. MINITAB

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was published 1986, and there has been no significant development since then. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State

College, Pennsylvania. Minitab Inc. also produces Quality Trainer and Quality Companion, which can be used in conjunction with Minitab: the first being an eLearning package that teaches statistical tools and concepts in the context of quality improvement, while the second is a tool for managing Six Sigma and Lean Manufacturing.

V. METHOD USED IN SOFTWARE

Taguchi knew statistical theory mainly from the followers of Ronald A. Fisher, who also avoided loss functions. Reacting to Fisher's methods in the design of experiments, Taguchi interpreted Fisher's methods as being adapted for seeking to improve the mean outcome of a process. Indeed, Fisher's work had been largely motivated by programs to compare agricultural yields under different treatments and blocks, and such experiments were done as part of a long-term program to improve harvests. However, Taguchi realized that in much industrial production, there is a need to produce an outcome on target, for example, to machine a hole to a specified diameter, or to manufacture a cell to produce a given voltage. He also realized, as had Walter A. Shewhart and others before him, that excessive variation lay at the root of poor manufactured quality and that reacting to individual items inside and outside specification was counterproductive.

He therefore argued that quality engineering should start with an understanding of quality costs in various situations. In much conventional industrial engineering, the quality costs are simply represented by the number of items outside specification multiplied by the cost of rework or scrap. However, Taguchi insisted that manufacturers broaden their horizons to consider cost to society. Though the short-term costs may simply be those of non-conformance, any item manufactured away from nominal would result in some loss to the customer or the wider community through early wear-out; difficulties in interfacing with other parts, themselves probably wide of nominal; or the need to build in safety margins. These losses are externalities and are usually ignored by manufacturers, which are more interested in their private costs than social costs. Such externalities prevent markets from operating efficiently, according to analyses of public economics. Taguchi argued that such losses would inevitably find their way back to the originating corporation (in an effect similar to the tragedy of the commons), and that by working to minimize them, manufacturers would enhance brand reputation, win markets and generate profits.

Such losses are, of course, very small when an item is near to negligible. Donald J. Wheeler characterized the region within specification limits as where we deny that losses exist. As we diverge from nominal, losses grow until the point where losses are too great to deny and the specification limit is drawn. All these losses are, as W. Edwards Deming would describe them, unknown and unknowable, but Taguchi wanted to find a useful way of representing them statistically.

Taguchi specified three situations:

1. Larger the better (for example, agricultural yield); ($S/N = 10 \log (\sum (y/n)^2)$)
2. Smaller the better (for example, carbon dioxide emissions); ($S/N = -10 \log (\sum (1/y/n)^2)$)
3. On-target, minimum-variation (for example, a mating part in an assembly).

The first two cases are represented by simple monotonic loss functions. In the third case, Taguchi adopted a squared-error loss function for several reasons:

It is the first "symmetric" term in the Taylor series expansion of real analytic loss-functions.

Total loss is measured by the variance. For uncorrelated random variables, as variance is additive the total loss is an additive measurement of cost.

The squared-error loss function is widely used in statistics, following Gauss's use of the squared-error loss function in justifying the method of least squares.

VI. ANOVA METHOD

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. ANOVAs are useful for comparing (testing) three or more means (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample t-tests, but is more conservative (results in less type I error) and is therefore suited to a wide range of practical problems.

VII. POWER IN THE WIND

Kinetic energy of the flowing across a wind turbine is used to derive electrical energy from wind. The power (P) contained in a flowing wind depends on its velocity (V) and the density of air (ρ).

It is given by the formula below:-

$\mathbf{P= 1/2\ \rho\ V^3A}$ in Watts

Where,

A = swept area (area covered by its rotating blade) in m^2.

ρ= Density of the air in kg/m^3.

V = Velocity of the air flow in m/s.

Power depends on the cube of the wind speed. If wind speed increases by a factor of two, the power output would increase by a factor of eight. Also, power is proportional to the area. Thus, a large wind turbine will convert more power from the wind. Wind power also depends on the density of the air, which varies under different conditions. Under standard temperature (25 deg C) and pressure (760 mm of Hg), the air density is considered as 1.22 kg/m^3. Considering the density of the air, a simple formula for the power can be written as:-

$P= 0.6\ V^3A$ in Watts

VIII. POWER EXTRACTED FROM THE WIND

The above equation gives amount of kinetic energy present in the wind in a particular area. Although all the kinetic is not converted into useful power. Therefore there is an equation to find how much energy the machine extracted from the wind. The simple formula is given below:-

$P=C_p*{}^{1}{}_{2}\ \rho V^3A$ in Watts

Where C_p= Coefficient of performance

The Cp value varies and depends upon the physical condition, type of blade used and its tip speed ratio. The value of Cp is 59% which is known as Betz limit.

IX. WORKING PRINCIPLE OF WTG

Wind turbines simply convert some of the kinetic energy of the wind (or speed of air at atmospheric pressure), from the air to rotor blade rotation, which rotates a shaft connected to a generator, which in turn converts the rotational energy to electrical energy.

The three basic parts of wind turbines are:-

1. The rotor blades which convert wind energy into rotational energy in form of angular momentum.
2. The Shaft which transfers this rotational energy to Generator.
3. The Generator which converts the rotational energy into electrical energy by means of electromagnetic induction.

X. COMPONENTS OF WTGs

The main components of WTGs are

1. Tower
2. Nacelle
3. Rotor
4. Gearbox
5. Generator
6. Braking System
7. Yaw System
8. Controller
9. Anemometer

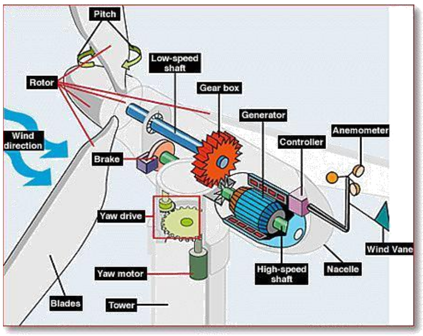


Figure 1 Components of WTG

XI. DATA COLLECTION

Table 2. Technical specifications of WTGs of Make '1'

Specifications	**225 kW**	**250 Kw**	**400 Kw**
ROTOR			
Diameter	29.8 m	28 m	31 m
Area of swept circle	697.46 m²	600 m^2 (approx)	754.8 m^2
Speed	37.5 rpm	45 rpm	30.5 rpm
Number of blades	3	3	3
ROTOR BLADES			
Material			
Weight of blades		830 kg	
Performance	Stall	Stall	Stall
Regulation		NACA 63 – 200	
GEAR			
Type			Plane/tooth
Ratio	1:40	1:40	wheel gear
			1:42.5
Design data			
Rotor output	225 kW	250 kW	400 kW
Wind speed – cut in		3.5 m/s	4 m/s
Wind speed – cut out		28 m/s	25 m/s
Survival wind speed		67 m/s	60 m/s
Tower structure			

Construction	Tubular	Tubular	Tubular
Height of tower	30 m	30 m	36 m

Table 3 . Technical specifications of WTGs of Make '2'

Specifications	**750 kW**	**1650 kW**
ROTOR		
Diameter	48.2	82 m
Area of swept circle	1824 m^2	5281 m^2
Number of blades	3	3
Speed	20	16
ROTOR BLADES		
Material	LM Glass fiber	
Weight of blades	3.1 Tonnes	
Performance regulation	Stall	Active stall
Profile	NACA 63 – series	
GEAR		
Type	1 step planet 2 step	Planetary/helical stages
Ratio	parallel shaft	
	1:67.5	
Generator		
Type	Asynchronous water	Asynchronous water
Rated output	cooled	Cooled
Main voltage	750 kW	1650 kW
Frequency	690 V	230/110 V
	50 Hz	50/60 Hz
Design data		
Rotor output	750 kW	1650 kW
Rated wind speed	17 m/s	14 m/s
Wind speed – cut in	< 3.5 m/s	3.5 m/s
Wind speed – cut out	25 m/s	20 m/s
Survival wind speed	60 m/s	52.5 m/s
Tower structure		
Construction	Tubular	Tubular
Height of tower	55 m	78 m
Weights		
Complete nacelle	22000 kg	52 tonnes
Complete tower	46000 kg	115 tonnes
Rotor	13500 kg	
Total machine	81500 kg	

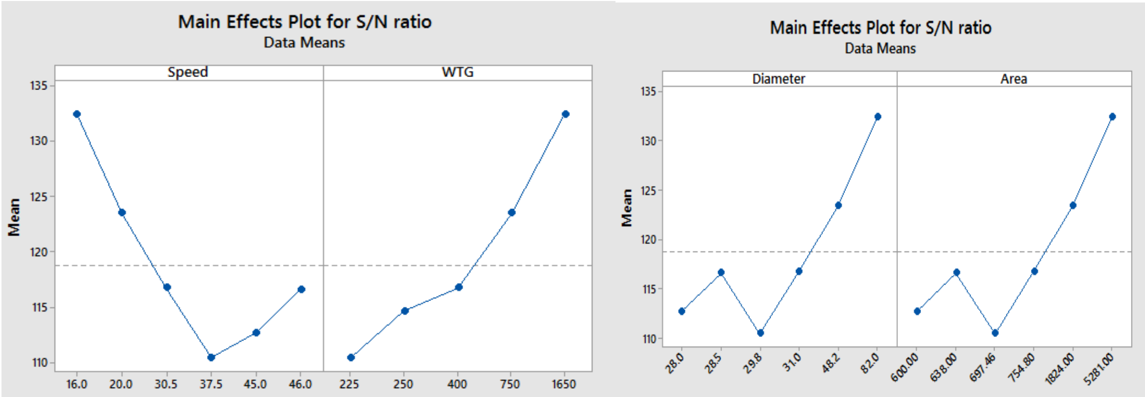
Table 4 . Technical specifications of WTGs of Make ‘3’

Specifications	**250 kW**
ROTOR	
Diameter	28.5 m
Area of swept circle	638 sq.m
Speed (max)	46 rev/min
Number of blades	3
ROTOR BLADES	
Material	GRP
Weight of blades	650 kg each
Performance regulation	Stall effect
Profile	NACA/WORTMANN
Width : Base	1255 mm approx.
Tip	450 mm approx.
Twist	28 degrees
GEAR	
Type	Planetary gear
Ratio	1:38.7
Cooling	Oil in sump – splash
Generator	
Type	Asynchronous
Pole changing	4/6
Rated output	25/80 kW
Main voltage	400 V ± 10%
Frequency	50 HZ ± 5%
Design data	
Rotor output	250 kW
Rated wind speed	14 m/s
Wind speed – cut in	4 m/s
Wind speed – cut out	23 m/s
Survival wind speed	58 m/s
Max. output coefficient	0.44
Tower structure	
Construction	Welded
Corrosion protection	Hot dip galvanized
Height of tower	30 m

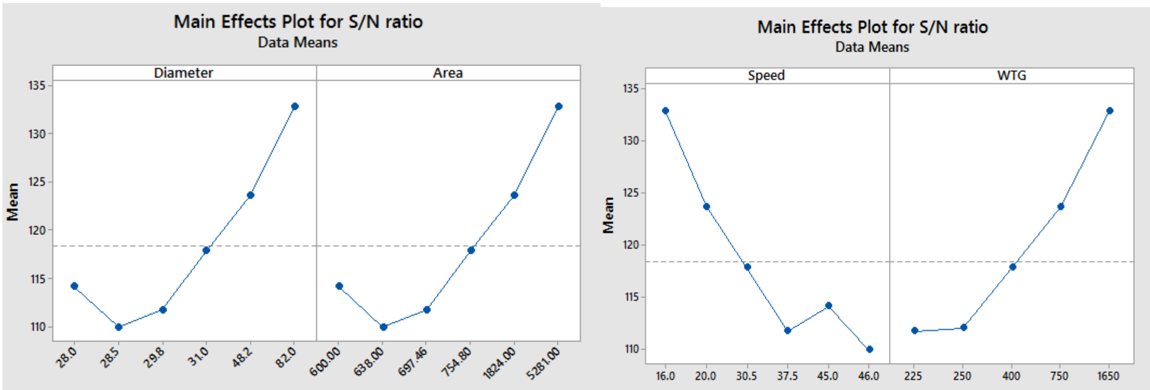
XII. RESULTS AND DISCUSSION

Table 5. Result and responses

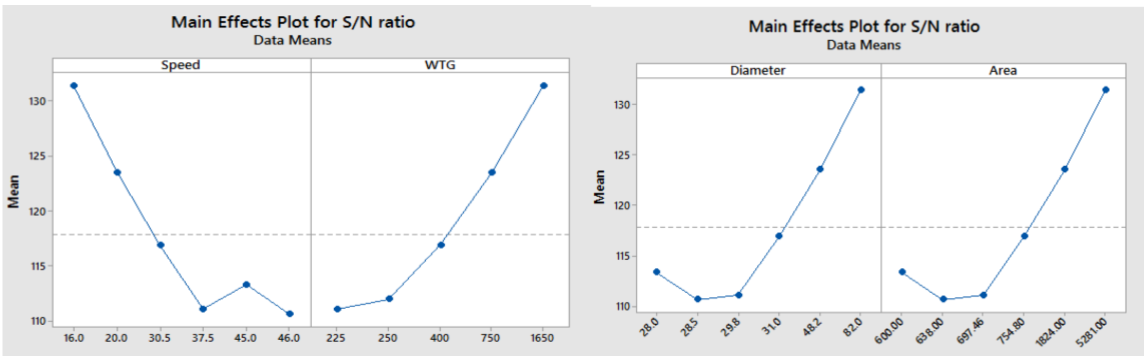
Sl. No.	Type	WTG Capacity Y (KW)	Diam Eter (m)	Area Of swept circle (m²)	Spee D (rev/ min)	Numbe r of Blades	2015	2016	2017
1.	M1	225	29.8	697.46	37.5	3	333967.5	384365.67	358171.4
2.	M1	250	28	600	45	3	431174.6	507554.4	463725.8
3.	M1	400	31	754.8	30.5	3	686550.6	778747.5	700325.7
`4.	M2	750	48.2	1824	20	3	1488475.57	1523807.86	1502825.57
5.	M2	1650	82	5281	16	3	4169238.5	4370091.4	3709722.6
6.	M3	250	28.5	638	46	3	382728.1	313284.6	341922.5



GRAPH 1. Optimized result for the year 2015



GRAPH 2. Optimized result for the year 2016



GRAPH 3. Optimized result for the year 2017

Signal to Noise ratio is taken as per the choice of Larger the better in the graphs.

From the above graph it clearly shows that the optimized input parameters are WTG capacity 1650 (KW), Diameter 82 (m), Area of swept circle 5281 (m^2) and Speed 16 (rev/min).

XIII. CONCLUSION

Using ANOVA in Minitab software, the characteristic optimization is being found out for the four parameters such as diameter, area of swept, speed and capacity for the wind turbine generators. The generator having a capacity of 1650(KW) influences the most when compared to 225(KW), 250(KW), 400(KW), 750(KW), 250(KW) wind turbine generator.

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