

# An Analysis for Repowering Prediction of Jamgodarani Wind Farm Using MATLAB

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## Abstract

The development of megawatt class turbines has led to the improvement of wind turbine technology and design. Re-powering in wind energy is a concept to replace and reduce the number of installed old wind turbines of lower capacity by modern turbines of higher capacity. It intends to generate the highest possible constant output power under all wind speed conditions. This research paper portrays economic viewpoints of the repowering procedure for different wind farms. The availability of wind energy in many regions of India encouraged a developing interest in the field of renewable energy and as a consequence this procedure was generated. Before 1998 all the equipments used in relevant research sites were outdated and low powered. But now modern wind turbines with higher efficiency are available to generate more power using considerably reduced infrastructure. This research work proves that repowering is a productive attempt for such old wind farms by using MATLAB (Matrix Laboratory) programming. Wind energy technology is favored due to the benefits of environment friendliness, relativity less installation time and economic competitiveness. A detailed study of necessary performance indices to determine the reliability and performance of a particular wind farm for repowering is done in this research work. An old wind farm located at Jamgodrani Hills, which is in a central part of India, is selected to study the implementation of repowering. This wind farm was commissioned in 1990 with a capacity of approximately 13.05 MW consisting of 58 wind turbines of 225 kW capacity each.

**Keywords:** Renewable energy, repowering, MATLAB.

## 1. Introduction

The technique of Repowering is a way to increase the total available power of the wind farms provided that the new wind turbines used are of a greater proficiency. Location mapping of new installations is involved in repowering a wind farm with the aim of expanding, altering and/or upgrading the hardware for ideal limit or effectiveness and augmenting its administration life and/or expanding its power, execution or accessibility. The installations are revamped for extending the service life of the wind farm and to obtain optimum capacity or efficiency.

### Advantages

Given the constant advances made in wind and generator technology, it is now possible for the same site to have a much higher energy production with new machines. They are quieter, their efficiency is higher (2 or 3 MW), and their start-up speeds (winds of 2.5-3 m/s) are much lower when compared to older turbines (0.1-0.65 MW, with start-up wind speed of 5 m/s). Moreover, higher hubs on the new machines make it easier to exploit the wind at greater heights. For this reason, repowering a wind farm leads to a considerable increase in farm production, although the number of generators installed is reduced. Another benefit is that since the new installations work at lower speeds,

their appearance is more calming making their utilization more feasible. Therefore repowered sites are more productive with fewer machines. Other advantages of wind farm repowering are as follows:

- It offers improved grid interactions and support.
- High-value resource areas are better utilized.
- It reduces visual impacts significantly as there are fewer turbines per overall capacity.

However, until the project is completely finished, the revenue will be lost temporarily. Hence the current grid facilities may require augmentation and upgrading as they are designed to support present generation capacities.

The rest of the paper is organized as follows. Site selection and characteristics are explained in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

## 2. Site Selection and Characteristics

### Study of jamgodrani wind farm

Since this paper is intended to research the aspects of repowering the wind farm of Jamgodrani, this section presents the physical

characteristics which involves the geological and wind properties and electrical characteristics of the current wind turbines.

**Physical Characteristics**

The Jamgodrani wind farm is located in district Dewas of state Madhya Pradesh in central India. The geographical coordinates of the farm is a latitude of 22° 59' 9", a longitude of 76° 9' 5 6.5" and at an altitude of 580 m from the sea level. The factors which may impact the characteristics of wind are urban cities Indore and Ujjain which are closest to the wind farm and the Kshipra River. The wind farm covers an area of approximately 12000 square meters which has non-uniform surfaces and contains a number of small water pools, farm lands and some manmade developments as shown in figure 1.

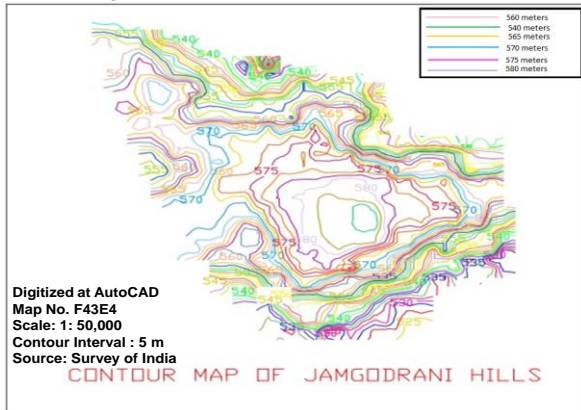


Figure 1: Contour map of research site

Table 1: Specifications of Existing and Proposed Turbines

Name	Parameters	
Make	NEPC India	Vestas
Model	WGL	WGL
Rating	225 kW	2.00 MW
Rotor Diameter	29.8 Meters	80 Meters
Hub Height	30 Meters	80 Meters
Number of Blades	3	3
Generator Type	Asynchronous	Asynchronous
Voltage	415 Volts	415 Volts
Wind Cut-In Speed	4 m/s	4 m/s
Wind Cut-Out Speed	25 m/s	25 m/s
Wind Rated Speed	15 m/s	15 m/s

**Electrical Characteristics**

The existing wind farm of the Jamgodarani project contains 58 numbers of turbines of 225 kW each which gives a total capacity of 13.05 MW. Now to get the same capacity we needed 7 numbers of modern wind turbines i.e. 13.05/2≈7 turbines of 2 MW each.

**The power analysis**

Table 2: Comparative AEP and CUF Analysis

BEFORE REPOWERING		
a.	Annual Energy Production (AEP)	114.186 GWhr per year
b.	The actual Annual Energy Output is	14.03 GWhr per year
c.	Capacity Utilization Factor (CUF) [c = b / a]	12.26 %
AFTER REPOWERING		
a.	Annual Energy Production (AEP)	122.640 GWhr per year
b.	The actual Annual Energy Output is	27.727 GWhr per year
c.	Capacity Utilization Factor (CUF) [c = b / a]	22.61 %

The theoretical maximum annual energy production (AEP) is given by

$$AEP_{max} = \frac{(R \times N \times 24 \times 365)}{1000} kWh \tag{1}$$

While the actual annual energy production is given by

$$AEP = (\sum_{m \in M} W(m) \times P(m)) \times \frac{N \times 24 \times 365}{1000} kWh \tag{2}$$

Where,

R = Rating of turbine.

N = Number of turbines.

W = Weibull Distribution.

P = Power Curve of Turbine.

M = Values of discrete wind speeds at which W and P are calculated.

The analysis shows that repowering can increase the capacity utilization factor from 12.26 % to 22.61 % hence about 10% boost could be achieved.

**3. Experiment and Results**

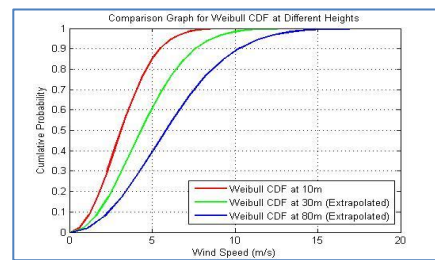


Figure 2: Comparison graph for cumulative distribution function (CDF)

**Wind Speed Probability Distribution Function (PDF) and Weibull Cummulative Distribution Function (CDF)**

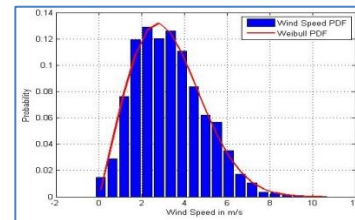


Figure 3: Wind speed function at 10 meter height

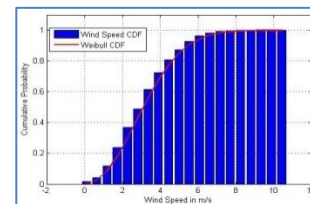


Figure 4: Wind speed function at 10 meter height

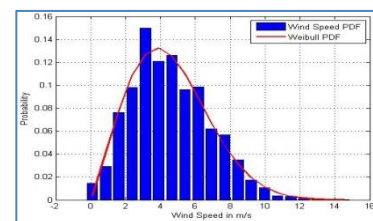


Figure 5: Wind speed function at 30 meter height

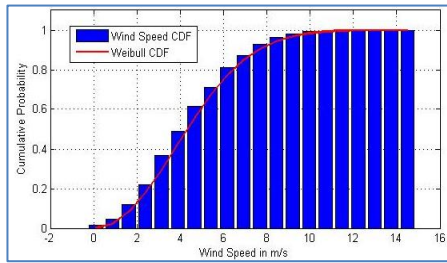


Figure 6: Wind speed function at 30 meter height

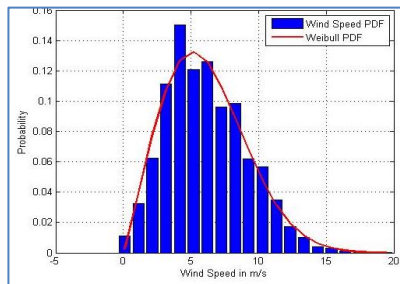


Figure 7: Wind speed function at 80 meter height

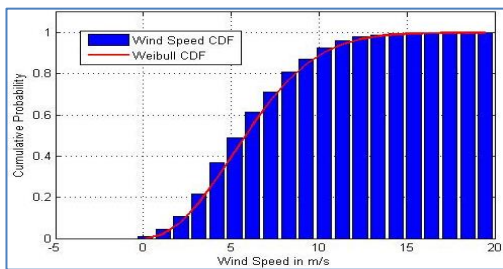


Figure 8: Wind speed function at 80 meter height

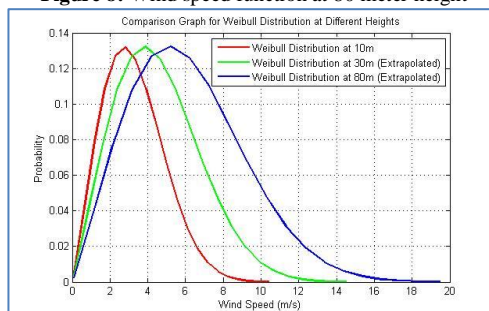


Figure 9: Comparison graph for Weibull Distribution Function

### Extrapolation of Wind Speed

Wind speed measuring instruments in local weather station are generally placed at a single height (as we have taken at 10 m). But different applications need this data at different heights hence it is usually required to interpolate the measurements to the required height. The most commonly used and the simplest of these expressions is the Hellmann Exponential Law (also known as the Power Law) that correlates the wind speed readings at two different heights and is expressed by:

$$\frac{v}{v_0} = \left(\frac{H}{H_0}\right)^\alpha \tag{3}$$

In which  $v$  is the speed to the height  $H$ ,  $v_0$  is the speed to the height  $H_0$  (frequently referred to as a 10-metre height) and  $\alpha$  is the friction coefficient or Hellman exponent. This coefficient is a function of the topography at a specific site and frequently assumed as a value of 1/7 for open land. The value of  $\alpha$  for different Landscape type is presented in table 3.

Table 3: Friction Coefficient or Hellman Exponent Value [6]

Landscape type	$\alpha$
Lakes, ocean, smooth ground	0.1
Grasslands (ground level)	0.15
Tall crops, hedges and shrubs	0.2
Heavily forested land	0.25
Small town with some trees	0.3
City with high rise buildings	0.40

### Weibull Distribution

The Weibull distribution is a two-variable function used to fit the wind speed vs. frequency distribution (the wind speed probability density function), also known as wind speed distribution [7]. The Weibull function (equation 2) provides a convenient representation of the wind speed data for wind energy calculation [1].

$$PDF(v) = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \tag{4}$$

The cumulative distribution is given by

$$CDF(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \tag{5}$$

Where  $v$  is the wind speed,  $k$  is the shape parameter and  $c$  is the scale parameter (Zhang, W., Markfort, C.D., Porté-Agel, F., 2013).

The estimation of weibull parameters for a given wind speed distribution can be calculated by using maximum likelihood method as follows:

$$k = \left(\frac{\sum_{i=1}^n v_i^k \ln(v_i)}{\sum_{i=1}^n v_i^k} - \frac{\sum_{i=1}^n \ln(v_i)}{n}\right)^{-1} \tag{6}$$

$$c = \left(\frac{1}{n} \sum_{i=1}^n v_i^k\right)^{\frac{1}{k}} \tag{7}$$

Where  $n$  is the non-zero wind speeds for which the wind speed distribution is given. The technique runs iteratively by taking initial guess for  $k$ .

### 4. Conclusion

This research paper presented both the financial and electrical aspects of repowering the Jamgodarani wind farm. By using MATLAB programming we analysed the power output and efficiency obtained by using different heights. The paper pointed out a number of advantages in this analysis showing that repowering of the considered wind farm could increase its Annual Energy Production (AEP) by 10% (from 12.26 % to 22.61 %) at the same time reducing the number of turbines presently in use from 58 to only 7, which also reduces the environmental impact. Considering the economic aspects, the calculation shows that the repowering cost can be recovered within 8 years and 7 months, while we did not consider the scrap cost of old systems. Government subsidies are also helpful in reducing the cost burden of repowering. This research work shows that repowering is a profitable investment in electrical, economic and environmental aspects.

### References

- [1] Indhumathy D, Sesaiah CV & Sukkiramathi K, "Estimation of Weibull Parameters for Wind speed calculation at Kanyakumari in India", International Journal of Innovative Research in Science, Engineering and Technology, Vol.3, No.1, (2014).

- [2] Verma R, "Repowering Potential of Wind Farm in India", *International Journal of Enhanced Research in Science Technology & Engineering*, Vol.2, No.12, (2013), pp.132-138.
- [3] Sachinkumar & Pandey P, "Survey and Performance Evaluation of Jamgodrani Hills and Nagda Hill Wind Farm in Madhya Pradesh, India-A Case Study", 4th International Conference on Advances in Energy Research, (2013).
- [4] Diwakar N, Ganesan S, Ahmed S & Sethi VK, "Prediction of wind power potential by wind speed probability distribution in a hilly terrain near Bhopal, Madhya Pradesh", *International Journal on Emerging Technologies*, Vol.1, No.1,(2010), pp.80-86.
- [5] Chen YC, Bundy D & Hoff S, "Modeling the Variation of Wind Speed with Height for Agricultural Source Pollution Control", *Agricultural And Bio systems Engineering Publications*, (1998).
- [6] Bañuelos-Ruedas F, Angeles-Camacho C & Rios-Marcuello S, "Methodologies used in the extrapolation of wind speed data at different heights and its impact in the wind energy resource assessment in a region", *Wind Farm-Technical Regulations, Potential Estimation and Siting Assessment*. InTech, (2011).
- [7] Seguro JV & Lambert TW, "Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol.85, (2000), pp.75-84.
- [8] Castro-Santos L, Vizoso AF, Camacho EM & Piegari L, "General economic analysis about the wind farms repowering in Spain", *Journal of Energy and Power Engineering*, Vol.6, No.7,(2012), pp.1158-1162.
- [9] Lantz E, Leventhal M & Baring-Gould I, "Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects", United States, (2013).
- [10] Himpler S & Madlener R, "Repowering of Wind Turbines: Economics and Optimal Timing", FCN Working Paper No. 19, (2011).
- [11] Sucevic N & Djuricic Z, "Influence of atmospheric stability variation on uncertainties of wind farm production estimation", *Am. Energy Assoc., EWEA Present*, (2012).
- [12] Van den Berg GP, "Wind turbine power and sound in relation to atmospheric stability", *Wind Energy*, Vol.11, (2008), pp.151-169.
- [13] Wharton S & Lundquist JK, "Atmospheric Stability Impacts on Power Curves of Tall Wind Turbines-An Analysis of a West Coast North American Wind Farm", LLNL-TR-424425, (2010).
- [14] Wu YT & Porté-Agel F, "Large-eddy simulation of wind-turbine wakes: Evaluation of turbine parametrisations", *Bound.-Layer. Meteorol.*, Vol.132, (2011), pp.129-149.
- [15] Zhang W, Markfort CD & Porté-Agel F, "Wind-turbine wakes in a convective boundary layer: a wind-tunnel study", *Bound.-Layer. Meteorol.*, Vol.146, (2013), pp.161-179.
- [16] Ramalingam V, "Experimental and numerical studies on the wake behavior of a horizontal axis wind turbine", *J. Wind Eng. Ind. Aerodyn.*, Vol.128, (2014), pp.54-65.
- [17] Abkar M & Porté-Agel F, "Influence of atmospheric stability on wind-turbine wakes: a large-eddy simulation study", *Phys. Fluids*, Vol.27, No.3,(2015), pp.1-19.
- [18] Iungo GV & Porté-Agel F, "Volumetric lidar scanning of wind turbine wakes under convective and neutral atmospheric stability regimes", *J. Atmos. Ocean. Technol.*, Vol.31, No.10,(2014), pp.2035-2048.
- [19] Martini M, Guanche R, Losada IJ & Vidal C, "Accessibility assessment for operation and maintenance of offshore wind farms in the North Sea", *Wind Energy*, Vol.20, No.4,(2017), pp.637-656.