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Re-Powering of Wind Farms: State of Art

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ABSTRACT: Today the wind energy is experiencing a significant role in fulfillment of the energy needs of the whole world. Wind turbine technology and design has greatly improved in recent years with the development of megawatt class turbines. The aim of repowering is to generate the highest possible constant level of power output under all types of wind conditions in India. Repowering is a process of replacing the old technology in to a modern technology, which is the need to improve the energy crisis in developing countries. Wind energy has found favor due to its perceived with twin virtues of relativity lesser production cost and environment friendliness.

In this paper a detailed study of various performance indices necessary to determine the reliability and performance of a particular wind farm i.e. wind farm situated at Jamgodrani hills is presented as a case study. To carry-out the study an old wind farm located at Jamgodrani, Madhya Pradesh is selected. The wind farm was commissioned in 1990's with a capacity of approximate 13.05 MW, which consists of 58 Wind Turbines each with the capacity of 225kW. The purpose of this study is to predict the annual energy output of the wind farm after the repowering using WAsP (Wind Atlas Analysis Application Program).

Keywords: Re-powering; Modelling; Simulation; WAsP; Energy Yield; Wind Farm.

I. INTRODUCTION

Re-powering in wind energy means replacement of installed old wind turbines of lower capacity by modern turbines of higher capacity normally in lesser numbers. It also refers to replace first generation turbines installed for more than fifteen years back. It has generally been accomplished by installing fewer, larger capacity turbines. The modern commercial grid connected wind turbines are multi-megawatt machines equipped with advanced operation and control systems. As per a study carried out at Risoe Laboratory, Denmark, the process of re-powering will double the capacity, triple the energy yield with half the infrastructure. Another report of Leonardo Energy outlines the repowering programme for following factors:

(i) More annual energy production from the same site and land area as capacity is multiplied without additional land.
(ii) Fewer wind turbines than earlier which improves the appearance of landscape. The hub height is also increased after repowering.
(iii) Higher efficiency of individual turbines and higher array efficiency with usually reduced cost per unit energy generation.
(iv) Better visual appearance as modern wind turbines rotate with lower rotational speeds.
(v) Possibly better grid integration due to improved power electronics and power quality from multi-megawatt modern turbines.
(vi) Wind characteristics are known in terms of speed, direction, turbulence therefore better prediction of annual energy generation of an existing site.

A. Indian Scenario

According to Indian Wind Energy Institute the gross wind power capacity in the country is estimated to be about 49 GW at 50 m elevation and 102 GW at 80 m elevation with the assumption of 2 percent land availability. The installed capacity of wind power is more than 21 GW upto May 2014. It contributes about 67 percent to total renewable energy capacity of the country. More than 90 percent of wind power potential is concentrated in southern and western states like Tamilnadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat and Rajasthan. Wind farms in India were developed in the areas where the wind regime is often very good. Therefore, the best windy locations are occupied by old or first generation wind turbines. Wind energy development started in early 1990s and these turbines are of lower hub height, lower capacity and with old technology in terms generator, control mechanisms, power quality et cetera.

Therefore, land with good wind is occupied by older turbines of hub-height of 30 to 40 meters. These sites could benefit by replacing old turbines by modern machines of hub height of more than 80 meters. New locations for wind farms are becoming less and less available due to scarcity of land, environmental protection, green belt requirements and sometime resistance from local people. Re-powering can contribute to achieve national target of achieving installed capacity of 100 GW by year 2022 under National Mission for Wind Energy of Ministry of New and Renewable Energy, Government of India. It also contributes to reduction of level of CO_2 emission. Approximately 25 percent of turbines in India have rating below 500 kW of the total installed capacity to date in the order of 22,000 MW. It offers a huge opportunity and great technical and economical challege to replace roughly 5500 MW capacity old turbines. Re-powering priority is to be given for wind farms with plant load factor (PLF) less than 12 percent.

B. Issues and Challenges

Normally wind turbines are designed for a service life of 20 to 25 years. Replaced turbines due to re-powering are usually not installed on the same site, these can be sold for installation at elsewhere for their remaining service life or sold for scrap for recycling of different parts. In a wind farm, turbines are placed in rows, typically perpendicular to prevailing wind direction by micro siting process involving flow modelling, micro surveys and wind monitoring and determining array efficiency and turbulence in the downstream.

The challenges for re-powering are many and some are identified as:

Turbine ownership: Issue of ownership is to be resolved in cases where more number of turbines are replaced by few and one to one replacement is not possible.

Land ownership: Multiple ownership of wind farm land is to be resolved.

Power purchase agreement: PPA might have been signed for long duration and before end of that period re-powering may pose difficulties.

Electricity evacuation: The grid is designed to handle current power supply but enhanced power output due to re-powering may require modification or replacement of equipments and systems.

Additional cost: The decommissioning cost of existing turbine is to be estimated.

Disposal of existing turbines: Many options are to be analysed like scrap value, buy-back by manufacturer, relocation etc.

C. Re-powering Approach

To determine the re-powering potential of an existing wind farm site following technical aspects are to be considered:

(i) Wind resource of the site in terms of speed frequency distribution curve of past several years, Weibull parameters, wind power density, turbulence intensity, power law index, wind rose, prevailing wind direction and other characteristics.

(ii) Existing wind turbines, numbers of turbines, capacity, power curve, cut-in, rated and cut-out speed, rotational speed per minute, hub height, type of generator, rating, thrust and power coefficient etc.

(iii) Proposed wind turbine, capacity and detailed specifications.

(iv) Available area with necessary off-set from approach roads and dwellings.

(v) Estimation of annual energy production, gross and net energy production and array efficiency from proposed re-powering turbines at new hub height.

(vi) Plan(s) of proposed wind turbines with micro-siting and turbine array spacing(s).

(vii) Re-powering ratio of proposed turbines to existing turbines.

(viii) Energy yield ratio from proposed and existing turbines for same site or area.

(ix) Economic analysis of unit cost of energy after re-powering, dismantling cost of existing wind turbines, cost of new turbines installation and commissioning and cost of other modified facilities.

It is expected that off-shore wind farms will be developed in next 10 years in selected wind zones on Indian ocean and Arabian Sea. These wind farms will be repowered in next 15 to 20 years in future. Therefore it requires master plan approach to make the re-powering a dynamic exercise.

High capacity wind turbines are particularly well adapted for sites with higher average wind speeds. Report of Leonardo Energy outlines that: For utilities trying to scale-up their capacity to achieve set target put preference for larger wind turbines. The practical reason is that power output of a wind turbine is depending on square of rotor diameter therefore larger wind turbine is better than two smaller wind turbine of same capacity. The larger wind turbines are preferred for off-shore applications as it minimises installation cost per MW in terms of foundation cost which takes significant proportion of total cost of installation.

D. Techno-Economic Analysis

Flow modelling requires three essential set of technical data related to wind, site and turbine:

(i) Wind characteristics

(ii) Site characteristics, and Wind turbine characteristics

Wind characteristics: For the development of wind energy, the site characterization has to include following major parameters and information: annual average wind speed (WAsP requires the wind data measured at 10 minutes intervals by a meteorological mast in the same region), wind power density, wind rose, wind resource map, prevailing wind direction, speed frequency distribution and persistence, vertical wind speed profile, wind shear exponent, Weibull shape parameter (k), scale parameter (c), turbulence intensity, wind density and its variation vertically and seasonally, historical wind data (including frequency and intensity of past storms) etc.

Site characteristics: Location (latitude, longitude and mean sea level), topographic maps provide the analyst with a preliminary look at site attributes, including available land area, contour map, roughness class of the site, grid related data, transmission line map, positions of existing roads and dwellings, land cover (e.g. forests), political and administrative boundaries, parks, national parks, forest reserves, restricted areas, proximity to transmission lines, location of significant obstructions, potential impact on local aesthetics, cellular phone service reliability for data transfers, other infrastructural facilities.

Wind turbine and farm characteristics: Wind farm layout of existing and after re-powering, power and thrust curve of the turbine(s), hub height, rotor diameter, pitch mechanism, braking mechanism, generator type, gear or gearless machine, type of power electronics, cut-in, rated and cut-out speeds, capacity factor etc.

In addition to above, the parameters related to machine availability, grid availability, transmission losses and WAsP prediction error is to be considered for arriving at annual energy production value. The annual energy production (AEP) of the wind farm after re-powering can be predicted by using industry standard WAsP (Wind Atlas Analysis and Application Programme) and simulation can be performed by using MATLAB. Following parameters are to determined after analysis for re-powering:

(i) Improvement in plant load factor (PLF)

(ii) Increase in annual energy production (AEP) or energy yield

(ii) Increase in installed capacity of wind farm

(iv) Change in reactive power consumption

E. Conclusion

Following conclusions are drawn from re-powering of existing wind farms:

(i) Annual energy production will increase as taller turbines access the increased wind speeds at higher altitude and thereby have better power-wind velocity curves;

(ii) The revenue generation will increase so business model will become more profitable in majority of cases;

(iii) Landscape appearance will improve due to newer turbines;

(iv) Number of turbines will decrease and more land will be available;

(v) Possible reduction in visual interference;

(vi) Possible reduction in noise level;

(vii) Possibly the new turbines will be placed at more acceptable locations.

II. CASE STUDY

A. Research Site

Jamgodrani, Distt. Dewas (Madhya Pradesh) in India about 131.3 km south west from Bhopal and 42.56 km from Indore. Jamgodrani is situated at a longitude of 76º 9'5 6.5" and latitude of 22º 59' 9" as shown in Figure 2. Dewas lies northeast of Indore, southeast of Ujjain, and southwest of Shajapur. The main river in Dewas is Kshipra, which is a holy river.

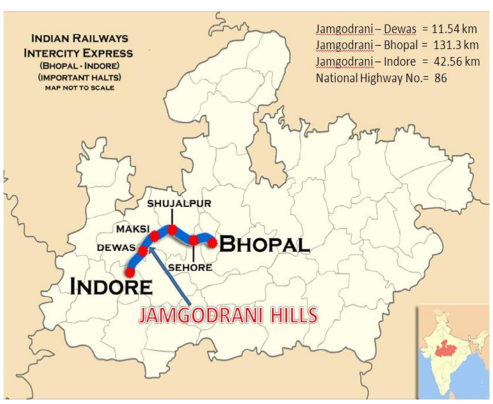


Fig. 1. Location of Study Site.

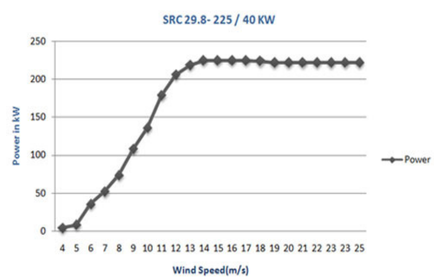
Fig. 2. Location of study area (Google earth image).

The topography map No.55 E/7 has been obtained from the Geological Survey of India in which the contours of the site near Dewas are shown. This site has been chosen for the study (Fig. 5). The site under consideration covers an area of approximately 12000 square meters in undulating topography, interspersed with water bodies, cultivated and barren land and semi urban dwellings. A satellite image of the area is shown in (Fig. 2). The map of the whole area was digitised with elevation contours at 5 m intervals (Fig. 6).

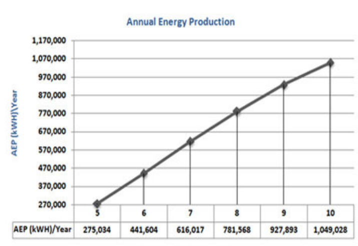
Table 1: Technical Specification of site.

S.No.	ITEM	Capacity (225 kW)
1.	Make	Southern W/F (NEPC India)
2.	Model No.	GWL
3.	Rating in kW	225/40
4.	Rotor Diameter (m)	29.8
5.	Hub Height (m)	30
6.	Type of tower (Tubular/Lattice)	Tubular
7.	No. of blades	3
8.	Power regulation Pitch/ Stall	Stall
9.	Type of Generator (Synchronous/Asynchronous)	Asynchronous
10.	Single speed/ Dual speed/Variable speed (Generator)	Dual Speed
11.	AC/DC system (Yes/No)	No
12.	Rated voltage	415 V
13.	Geared/Gearless	Geared
14.	Cut-in wind speed	4.0 m/s
15.	Cut-out wind speed	25 m/s
16.	Rated wind speed	15 m/s
17.	Survival wind speed	60 m/s
18.	Weight a. Tower (kg) b. Nacelle (kg) c. Rotor (kg) d. Total (kg)	 32000 8500 5200 45700

(Source: Directory Indian Windpower 2013)



Wind Speed (m/s)	4	5	10	12	14	17	18	19	25
Energy(kWH)	4	18	136	206	225	225	224	222	222



Wind Speed (m/s)	5	6	7	8	9	10
Energy(kWH)	275034	441604	616017	781568	927893	1049028

Power Curve and Annual Energy Production Curve for 225kW NEPC Turbine

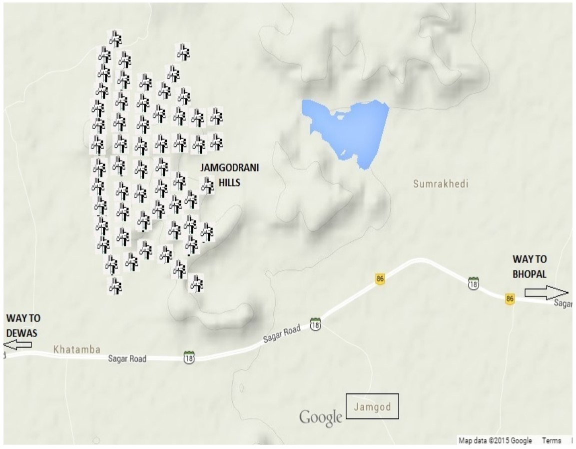


Fig. 3. Wind-farm before repowering.

Fig. 4. Wind-farm after repowering.

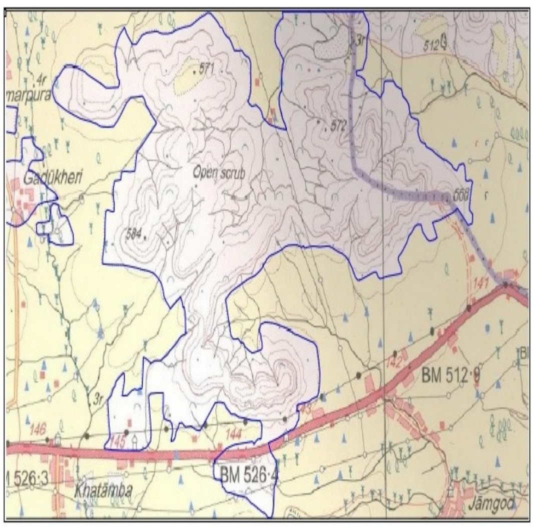


Fig. 5. Topography map of the area.

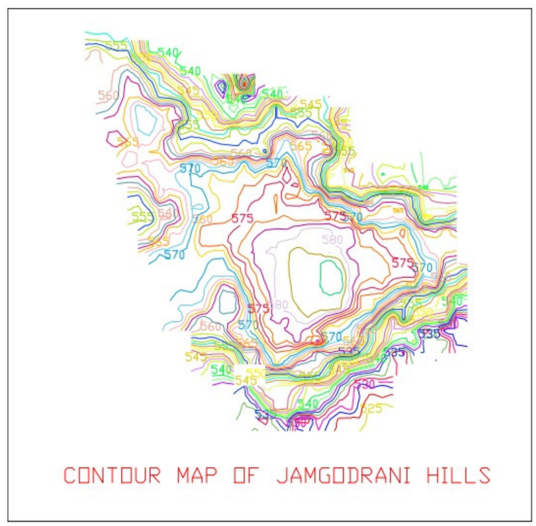


Fig. 6. Digital contour map of the area under study.

To calculate the re-powering potential of any site or wind power project, the following important technical aspects need to be considered.

1. Wind resource at the site.
2. Existing installed capacity (MW), rating of turbines.
3. New technology selection (higher capacity turbine specifications).
4. Available land area and necessary set-off.
5. Estimation of new installed capacity after re-powering
(with different micrositing or turbine-spacing criteria and turbine-rating selection, the estimation of new capacity will vary).
6. Estimation of gross and net energy generation (with different micrositing criteria).
7. Energy-yield ratio (ratio of new generation to old generation from same land area or same project location).
8. Re-powering ratio (ratio of new wind power project capacity to old project capacity).

B. Site Characteristics

Location. The wind farm site selected to carry out the study on repowering is located at site Jamgodrani, Dewas Road in Madhya Pradesh which is around 144 Km from Bhopal as shown geographically the site is located in 22˚59’9’’latitude, 76˚9’56.5’’ longitude at an altitude of 580 m from the sea level. The winds in this area are predominantly from the north-west direction.

Terrain Description. The terrain of the site is complex and gently sloping from the wind turbine towards the western direction.

Proposed Specification for wind farm (2000 kW)

Rotor Diameter: 80 m Area swept: 5,027 m^2 Nominal revolutions: 16.7 rpm Operational interval: 9.0 to 19 rpm Number of blades: 3 Power regulation: OptiTip® pitch and variable speed Air brake: Full blade feathering with 3 pitch cylinders.	Operational data IEC Class: IEC IA Rated power 2,000 kW Cut-in wind speed: 4 m/s Nominal wind speed: 15 m/s Cut-out wind speed: 25 m/s Temperature: -20° to +40° C
Generator Type: 4-pole asynchronous with variable speed Nominal output: 2,000 kW Operational data: 60 Hz 690 V	Gearbox Type: 3-stage planetary/helical Tower Standard hub heights: 80 meter

C. Wind Characteristics

Meteorological mast. The meteorological mast 70 m in height and it is a guy supported galvanized lattice steel structure. In Jamgodrani the average wind speed on a yearly basis is approximately 7 m/s at a height of 70 m.

Wind data. WAsP requires the wind data measured at hourly intervals at stations in the same region for a year.

D. Turbine characteristics

Characteristics of existing wind turbines. The wind farm was commissioned in 1990's with a capacity of 10.125 MW, which consist of 45 Wind Turbines each with the capacity of 225kW.

New technology selection. For Repowering Vestas 2.0 MW were selected. It is doubly fed induction generator with rotor diameter of 80m.

III. ESTIMATION OF ANNUAL ENERGY OUTPUT AND POWER QUALITY ANALYSIS OF EXISTING WIND FARM

The software used to estimate the annual energy output is Wind Atlas, Analysis, and Application Program (WAsP).

WAsP was Developed and distributed by the Wind Energy Department at Riso DTU, Denmark.

It is a PC program for predicting wind climate, wind resources and power production from wind turbine and wind farm- includes complex terrain flow model, roughness change model, and model for sheltering obstacles. Its Predictions are based on wind data measured at 1 hour intervals at stations in the same region for a year, and site details such as contour map, turbine location, turbine characteristics, etc.

A. Input files for calculation of wind farm generation

Wind data file. The wind data file has been created from the frequency distribution and wind statistics of one year. The WAsP input image is shown below in Fig. 7.

Contour map. A contour map is a map illustrated with contour lines, for example a topographic map. Contour lines are curved or straight lines on a map describing the intersection of a real or hypothetical surface with one or more horizontal planes.

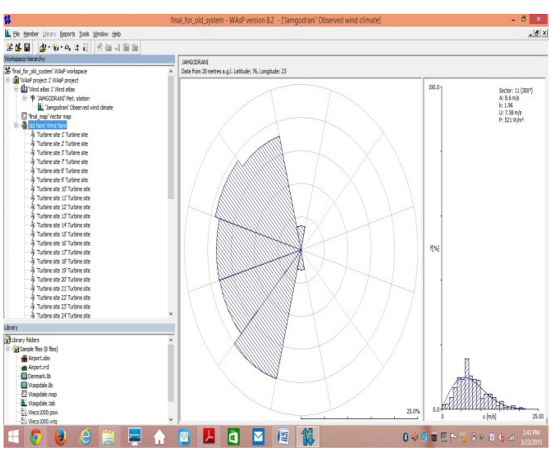


Fig. 7. Wind data WAsP Input file.

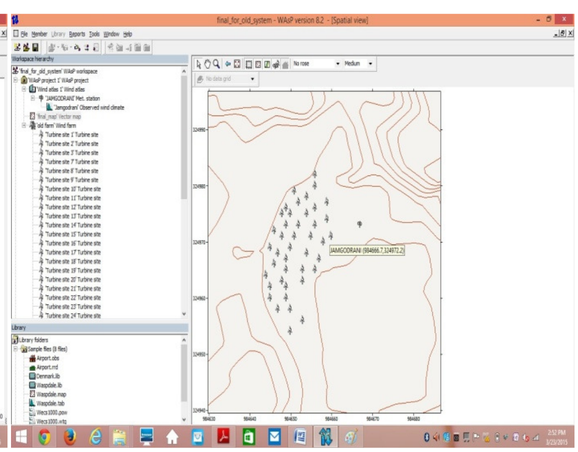


Fig. 8. Jamgodrani Contour map.

It uses contour lines to join points of equal elevation (height) and thus show valleys and hills, and the steepness of slopes. The created contour map is shown below in Fig. 8.

For old wind farm site the total Annual Energy Production = 2562.77 MWhr

For proposed wind farm site the total Annual Energy Production = 11725.2 MWhr

B. Observation from the comparison of WAsP estimated output and actual generation

1. The actual generation of the wind farm is very low when compare to the WAsP predicted output
2. The reason behind is, the efficiency of the machines is reducing due to the ageing of the machines
3. The above can be eliminated by repowering with high capacity (megawatt) machines with only two rows and by accurate micrositing

C. Energy yield ratio and Re-powering ratio

Energy yield ratio. It is the ratio of new energy generation to the old generation from the same land area or from same project location.
Old generation (AEP) = 2562.77 MWhr
New generation (AEP) = 11725.2 MWhr
Energy Yield ratio = 1 : 4.5

Repowering ratio. It is the ratio of new wind power project capacity to old project capacity. The repowering ratio for this repowering project became 1.08. (Old wind power project capacity-13.05MW and New project capacity12 MW).

IV. COST ANALYSIS

The cost of the old wind turbine having capacity of 225 kW of 58 numbers is 1.20 crore. However the cost of proposed wind turbine having capacity of 2.0 MW of 6 numbers is 15.0 crore.
Therefore, the total cost of old wind farm site is = 58 × 1.20 = 69.6 crore
the total cost of proposed site is = 6 × 15 = 90 crore
It is observed that the total cost of commissioning is more than the exists farm.

REFERENCES

[1]. B.S.Nivedh, R.P.Kumudini Devi, E.Sreevalan. "Repowering of Wind Farms:A Case Study." *Wind Engineering* **37**, no. 2 (2013): 137-150.
[2]. Goyal, Mohit. "Repowering- Next big thing in India." *Renewable and Sustainable Energy Reviews* **14**, no. 5 (2010): 1400-1409.
[3]. Pablo del Río, Anxo Calvo Silvosa, Guillermo Iglesias Gómez. "Policies and design elements for the repowering of wind farms: A qualitative analysis of different options." *Energy Policy* **39**, no. 4 (2011): 1897-1908.
[4]. R.Wiser. "Barriers and Incentives for Wind Repowering in Europe and Elsewhere." 2007.
[5]. Verma, Rohit. "Repowering Potential of Wind Farm in India." *International Journal of Enhanced Research in Science Technology & Engineering* 2, no. **12** (2013): 132-138.
[6]. Kharul, R.2010. Repowering old wind farms in India opportunities and challenges. *International Conference on Wind Energy: WE20 by 2020, February2010, New Delhi.*
[7]. Directory Indian Windpower 2014