Performance Analysis of a 2.1MW Wind Turbine in a Wind Farm at Mulana in Jaisalmer District of Rajasthan

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***Abstract*—This paper analyses the performance of a 2.1 MW Suzlon S-88 wind turbine in a wind farm, located at Mulana, Jaisalmer district of Rajasthan. Wind farm consists of 49 turbines of 2.1 MW each with a total farm capacity of 102.9 MW. Various parameters such as machine availability, grid availability, system availability and energy production were obtained from available data of the wind turbine for one year during April 2015 to March 2016. Capacity factor is calculated from the data. The annual capacity factor of wind turbine is found to be 15.65% with the total energy production of 2886.41 MWh during April 2015 to March 2016. It is observed that grid availability is higher than machine availability during all the months of the year 2015-16.**

Keywords*— *Energy generation; capacity factor; machine availability; grid availability; system availability; rated power

I. INTRODUCTION

The performance of wind turbines can be estimated by annual energy generation and annual average power which vary according to wind speed and its distribution. Wind speed changes both in time and space and has seasonal patterns. A small variation in the wind speed and pattern effects the overall power output of the wind farm. The wind farm performance is influenced by many parameters such as machine available hours, grid available hours and low wind hours.

Saxena and Rao [1]-[2] analyzed the performance of wind power plant for the years 2011 and 2012 at Devgarh, and Jaisalmer, Rajasthan and described machine availability, grid availability and system availability of wind turbines. Kumar and Pandey [3] studied variation of various performance parameters such as total yearly generation, total availability of grid and total availability of machine for a wind farm situated on Jmgodrani hills and Nagada hill, near Dewas city in Madhya Pradesh, India. Chicco et al. [4] analyzed the performance of 27.5 MW wind power plant at south of Italy on a hilly terrain. Ghajur et al. [5] studied optimal site matching methods of wind turbines in a wind farm using availability factor and capacity factor.

Fig. 1. Suzlon S-88 wind turbines at site Mulana, Jaisalmer.

In the present study performance of a 2.1 MW wind turbine in a wind farm of 102.9 MW capacity with 49 of such turbines is estimated. The wind farm is as shown in Fig. 1.

Total monthly export of electricity to the grid from the wind farm consisting of the 49 turbines from January 2015 to December 2015 is shown in Fig. 2.

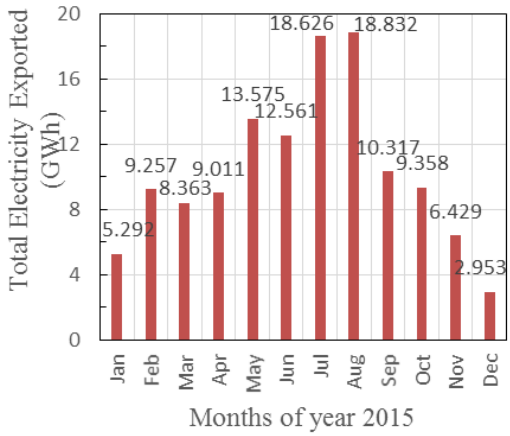

Fig. 2. Monthly distribution of electricity exported to grid during year 2015.

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The total energy exported to the grid in the year 2015 from the wind farm is 124.57 GWh.

The maximum electricity exported to grid is 18.832 GWh in the month of August and then followed by July, May and June with 18.626 GWh, 13.575 GWh, and 12.561 GWh respectively. Lowest electricity supplied to grid is 2.953 GWh in month of December 2015.

This paper is divided into five sections. Section I gives the introduction. Section II of this paper describes the details of the wind farm site and specification of the wind turbines. Section III, describes the methodologies which are used to analyze the performance of the wind turbines. Section IV represents discussion of results obtained from actual wind turbine data and section V gives conclusions.

II. Details Of Wind Farm And Wind Turbines

A 102.9 MW Wind Power Project of Oil and Natural Gas Corporation Ltd (ONGC), Govt. of India undertaking is located at Mulana site, Jaisalmer district of Rajasthan. The wind power plant was established in 2014. The altitudes of the location vary between 219 m to 273 m above mean sea level. The wind paths from west have no natural obstructions, thereby allowing for free flow of wind from this direction.

The wind plant comprises of 49 nos. of wind turbine generators (Model, S-88 Suzlon make), and each has 2100kW rated power. The wind turbine starts to produce power at cut-in speed of 4 m/s, and has a rated speed of 14 m/s and has a cut-out speed of 25 m/s at which the wind turbine stops producing power. It consists of induction generator at 690/600 V and two types of braking system i.e. aerodynamic brake with blade pitching and hydraulic disc brake. The power generated by the wind turbines is connected to grid through Mulana 33/220 KV Sub Station & further through the Akal RRVPNL 220/400 kV Sub-station.

The specifications of this turbine model are shown in Table I [6].

TABLE I. Main Specification of S-88 Model

Rated power	2100 kW
Hub height	80 m
Rotor diameter	88 m
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Rated wind speed	14 m/s
Survival Wind Speed	59.5 m/s
Gear box and ratio	3 stages (1 planetary & 2 helical) and 1:98.8
Tower	Steel tubular in 4 sections

III. Methodology

The wind energy production data of the wind turbines was collected from the ONGC Mulana site with the help of Suzlon Energy Ltd. for the performance analysis of 2.1 MW turbine in the year 2015-16. Various parameters taken from [1]-[2] have been used for analyzing the data which are described below:

A. *Capacity factor*

Capacity factor (CF) is a parameter which is used to describe performance of the wind turbine. It is determined by the ratio of the energy generated by wind turbine to the rated power output during a time period. It is calculated using (1)

$$CF = \frac{\text{energy output (kWh) in a month/year}}{\text{rated power (kW)} \times \text{total hours in a month/year}} \quad (1)$$

B. *Machine Availability*

The meaning of machine availability (MA) is that the wind turbine is ready for power generation. It is defined as the ratio of number of hours machine was available for generation power to the total hours in a period (day, month, and year). In a duration of hours, breakdown time of machine/technical fault time of machine are subtracted from the total hours for a particular time then remaining time is capable for power generation. Monthly/yearly machine availability is calculated by using (2)

$$MA = \frac{N_{Turbine}(h)}{\text{Total number of hours in a time period (h)}} \quad (2)$$

Where

$N_{Turbine}$ = number of hours wind turbine is in operation

C. *Grid Availability*

The meaning of grid availability (GA) is that the grid is able to absorb power from a wind plant. It is defined as grid available in hours to receive power from wind farm to the total hour in a time period. Monthly/yearly grid availability is calculated by using (3)

$$GA = \frac{N_{Grid}(h)}{\text{Total number of hours in a time period (h)}} \quad (3)$$

Where

N_{Grid} = number of hours grid is capable to receive power

D. *System Availability*

System Availability (SA) is the product of the machine availability and grid availability and is expressed as

$$SA = \text{Grid availability} \times \text{Machine availability} \quad (4)$$

IV. Results and Discussion

The related data of a wind turbine in the farm such as Monthly energy generation, machine availability, machine and grid down time, grid available hours of wind turbine from April-2015 to March-2016 is collected from the site. Monthly capacity factor, machine availability and grid availability are calculated for a typical turbine and analyzed its performance.

Table II shows data sheet available from wind farm site for a typical wind turbine for all the months from April 2015-March 2016. Table III gives calculated values of capacity factor, machine availability, grid availability and system availability for the same wind turbine for the same duration using site data of Table II.

TABLE II. ANNUAL ENERGY GENERATION, GENERATION HOURS, LOW WIND HOURS, GRID AVAILABLE HOURS AND MACHINE AVAILABLE HOURS OF A WIND TURBINE DURING APRIL 2015 TO MARCH 2016

Months 2015-16	Energy generation (kWh)	Generation hours[h]	Low wind hours[h]	Machine OK[h]	Grid OK[h]
Apr	157473	264.5	224.5	502.7	706.3
May	368422	453	153.9	627.9	723
Jun	328356	422.7	138.8	610	671.5
Jul	595162	506.5	125.6	655	721.1
Aug	468122	566.6	99.9	693	717.5
Sep	243805	431.8	262.1	706.5	707.4
Oct	206798	417.6	298.6	718.7	741.5
Nov	112769	366.7	348.1	714.8	720
Dec	52010	197.6	448.9	649.3	741.2
Jan	55343	208.8	505.4	726.1	732.1
Feb	126207	272.1	382.2	668.5	681.8
Mar	171947	360.7	338	707.7	735
Total	2886414	4468.6	3326	7980.2	8598.4

TABLE III. ANNUAL MACHINE AVAILABILITY, GRID AVAILABILITY, SYSTEM AVAILABILITY OF A WIND TURBINE DURING APRIL 2015 TO MARCH 2016

Months 2015-16	Machine Availability (%)	Grid Availability (%)	System Availability (%)	Capacity Factor (%)
Apr	69.82	98.10	68.49	10.41
May	84.40	97.18	82.01	23.58
Jun	84.72	93.26	79.02	21.72
Jul	88.04	96.92	85.33	38.09
Aug	93.15	96.44	89.83	29.96
Sep	98.13	98.25	96.41	16.12
Oct	96.60	99.66	96.27	13.24
Nov	99.28	100.00	99.28	7.46
Dec	87.27	99.62	86.94	3.33
Jan	97.59	98.40	96.03	3.54
Feb	96.05	97.96	94.09	8.63
Mar	95.12	98.79	93.97	11.01
Average	90.85	97.85	88.97	15.59

From table II, it is found that wind turbine produced electric energy of 2886.414 MWh with in a generation time of 4468.6 hrs during the period from April 2015 to March 2016. Maximum generation hours is found to be 566.6 hrs in August 2015 and minimum generation hours is found to be 208.8 hrs in January 2016.

Total energy generated by wind turbine is 2886.41 MWh during the year 2015-16. It is found that the maximum energy generation is 595.16 MWh in the month of July then followed by August, May and June. The energy generation time period starts to increase after April. In the month of November, December, January and February, the energy production is low.

From table III, it is found that annual average machine availability, annual average grid availability and annual system availability are 90.85%, 98.79% and 88.97% respectively during 2015-16. The capacity factor is varying from 3.33% in December 2015 to 38.09% in the month of July 2015.

A. Monthly energy generation and Capacity Factor

Values of monthly energy generation of a typical 2.1 MW wind turbine given in Table II is shown in Fig. 3 and Values of monthly capacity factor of a typical wind turbine given in Table III is shown in Fig. 4.

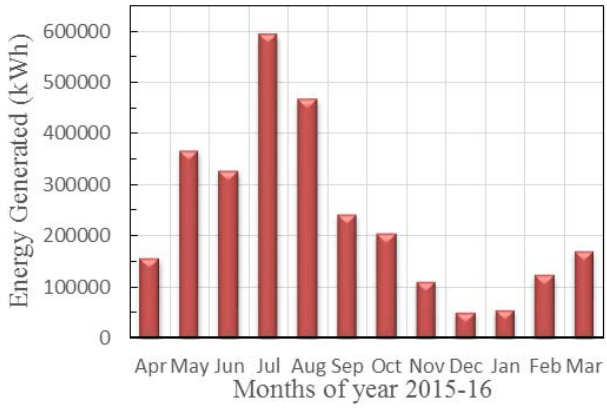

Fig. 3. Monthly electric energy generated by a typical wind turbine during the year 2015-16.

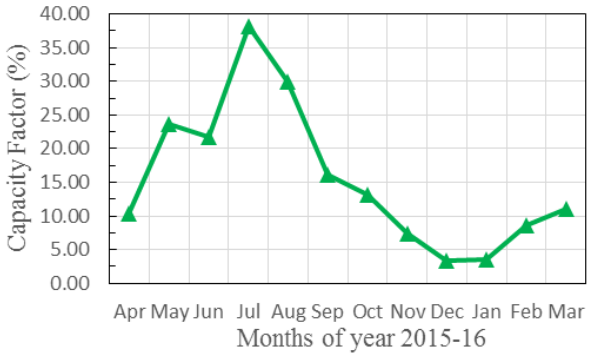

Fig. 4. Monthly capacity factor of a typical wind turbine during April 2015 to March 2016.

The annual capacity factor of wind turbine is found to be 15.65% during April 2015 to March 2016. The wind turbine has maximum capacity factor of 38.09% in month of July. Lowest capacity factor of 3.33% was found in the month of December.

B. Monthly grid Availability and Machine Availability

The monthly grid availability and machine availability of a typical wind turbine represented in Table III for the year April 2015 to March 2016 are shown in Fig. 5.

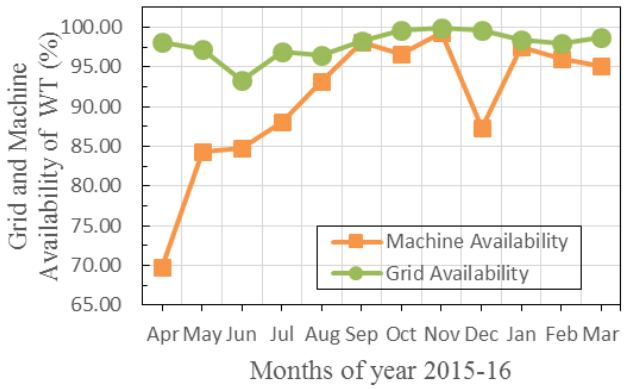

Fig. 5. Monthly grid and machine availability of a typical wind turbine during the year 2015-16.

The wind turbine has annual grid availability and machine availability of 97.89% and 90.85% respectively in the year 2015-16.

It is noticed that the grid availability is always higher than machine availability during April 2015 to March 2016.

C. System Availability

The monthly system availability of a typical wind turbine represented in Table III is shown in Fig. 6.

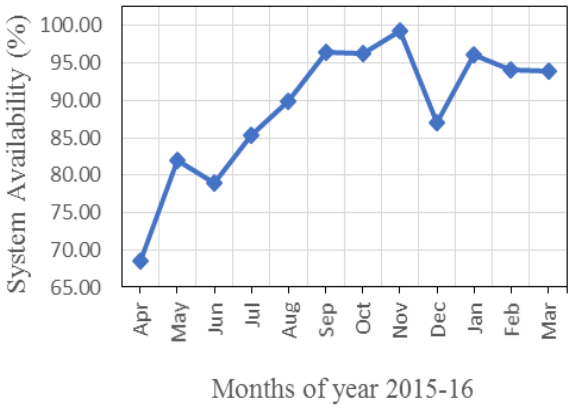

Fig. 6. Monthly system availability of a typical wind turbine during the year 2015-16.

The annual average system availability of wind turbine is 88.97% in the year 2015-16. Wind turbine has maximum system availability of 99.28% in the month of November and minimum system availability of 68.49% in the month of April.

V. CONCLUSIONS

This paper presents the performance of a typical 2.1 MW wind turbine by using energy production, grid availability, machine availability and system availability for one year data during April 2015 to March 2016, of a wind farm consisting of 49 wind turbines each having a capacity of 2.1 MW.

Wind turbine produced annual energy of 2886.41 MWh with annual capacity factor of 15.65% during April 2015 to March 2016.

The annual average grid availability and annual average machine availability of wind turbine is found to be 97.88% and 90.85% respectively in the year April 2015- March 2016.

It is observed that the maximum energy production is 595.16 MWh in July then followed by August, May and June with 468.12 MWh, 368.42 MWh and 328.35 MWh respectively. Minimum energy production is 52.01 MWh in the month of December and 55.34 MWh in the month of January 2016.

It is found that the grid availability and machine availability are low in the wind season (May to August). The annual energy production of the wind farm can be increased by making grid availability and machine availability (thereby system availability) improved during wind season from May to August.

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