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Performance analysis of 30 MW wind power plant in an operation mode in Nouakchott, Mauritania

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ABSTRACT

In this paper, the performance analysis of a 30 MW wind power plant is performed. The farm consists of fifteen (T1-T15) G9 7/2000/GAMESA 2 MW grid-connected turbines. The farm is in operation mode installed 28 km south of Nouakchott city in Mauritania. The analyzed data are monitored from July 1st, 2015 (the first operation day of the power plant) to December 31st, 2019. The parameters of performance evaluation are power generation, capacity factor, machine availability, grid availability, and system availability. It is observed from data analysis, the wind farm supplies a total energy of 507.39 GWh to the power grid and have a high average capacity factor of 42.55%. T1 produces the highest amount of electrical energy among the other turbines with a total energy output of 35.46 GWh, an average capacity factor of 44.97%, and operating hours of 33,814 hours. While T12 produced the minimum amount of energy in this period, the difference in energy compared to T1 is 4.563 GWh. It is observed that the availability of the network is unstable and needs improvement, varying between 90.86% in 2016 and 93.16% in 2018. In the first year of operation, 97.06% of the turbines were available. However, the average availability of the wind farm is approximately 94% during the total study period.

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1. INTRODUCTION

Like most countries in the Middle East and North Africa, Mauritania has abundant solar resources and considerable wind resources [1]. International Renewable Energy Agency considered Mauritania's wind potential is more localized around the coastal zone between N'Diago and Nouadhibou, and the wind speeds over 7 m/s [2]. Thus, to study the real potential of wind energy in Mauritania, it would be important to estimate the potential of wind power generation to understand the reliability of these parks under the local climate. By extension, for regions with a close climate such as those described by the authors [2]-[4]. Other authors have analyzed the performance of wind power plants [5], [6]. These authors described the availability of the machines, the availability of the grid with the availability of the wind turbine system. Similarly, the authors in [7]-[9] studied the variation of various performance parameters such as total annual production, total grid availability, and total machine availability for a wind farm located on the Jmgodrani and Nagada Hills near the city of Dewas in Madhya Pradesh, India. Also, in this sense, Chicco and its collaborators have analyzed the performance of a 27.5 MW wind power plant located in the south of Italy, on hilly terrain [10]. Not forgetting Ghajur, who studied matching methods based on the performance of wind turbines, which can be estimated by the annual energy production and the average annual power, which vary according to the wind speed and its distribution [11]. Wind speed is considered a variable in time and space and has seasonal characteristics and wind direction [12]-[14]. The first turbine consumes the wind energy at the front point (a) resulting in less energy for the rear turbine/s (b) as shown in (1).

$$E_b = 0.5m\left(V^2 - {V_b}^2\right) \qquad (1)$$

where E is the energy at the rear point, m is the mass of the air, and V is the speed.

The results considered in this work show that a small variation in wind speed and configuration has an impact on the overall energy production of the wind power plant [15]. Many authors show that wind farm performance is influenced by many parameters such as machine uptime, grid uptime, and low wind hours [16]. Thus, several studies that have been cited have focused on analyzing the performance of wind power plants, but to date, none have focused on a comparative study of this performance. It is in this sense that the present work aims to fill the gaps identified in the scientific literature by carrying out an in-depth performance analysis of this technology on a real pilot unit [17]-[20]. This study assesses the performance of the 30MW wind power plant which is located at pk 28 km on the Nouakchott-Rosso road, connected to the SOMELEC (National Electricity Company) grid and which is commissioned in 2015 [21].

The objectives of this paper are related to the simplified evaluation of the performances through different parameters of a wind power plant implanted on a site in Nouakchott in operating mode connected to the national electricity grid. The second originality is related to the analysis of meteorological data to establish the conditions and parameters for which it is possible to give a score on the evaluation of the energy available on the site. Finally, the third originality is related to the presentation of the production model to compare the production balances of each wind turbine of the park for several years.

2. THE WIND POWER PLANT

This wind power plant with a nominal capacity of 30 MW was the first installation of this type connected to the grid in Mauritania. It is composed of 15 wind turbines of 2 MW each of GAMESSA brands distributed on three medium voltage lines of 33KV. It also includes control and command devices for the electrical equipment needed to operate the facility and is connected to the Nouakchott service stations [22]-[24]. For this reason, the wind power plant is shown in Figure 1.

(a) (b)

Figure 1. The wind farm site, (a) The farm location scene, (b) The farm map of wind turbines

In this section, the configuration of the wind turbine positions for the proposed plant is comprising fifteen G97/2000/ Gamesa 2 MW wind turbines with a hub height of 90 m has been provided [25]. The specifications of the wind turbines have been provided in Table 1. They have been analyzed in conjunction with the results of the wind resource analysis to highlight the overall performance of the 30 MW Nouakchott power plant. It should be noted, the wind power plant has a data acquisition system that records data in 10-minute increments [26]-[29]. Each wind turbine is equipped with a set of intelligent sensors that record data in real-time for the monitoring station. The recorded data has been processed before analysis. The data used in this research work is monitored continuously from July 2015 to December 2019.

Table 1. The datasheet of the installed turbines

Turbines Model	G97/2000/ Gamesa
Nominal rating	2000KW
Cut–in Wind speed	2,5 m/s
Rated wind speed	14 m/s
Cut-out Wind speed	25 m/s
Diameter of rotor	97 m
Tower	Steel tubular
Height	90 m

3. PERFORMANCE EVALUATION PARAMETERS

The International Electrotechnical Commission (IEC-61400) has described the set of measures that are proposed for the performance evaluation of wind farm installations. It is also important to underline that these measures are carried out in this work using the equations (2)-(6) [30]. The performance models of a wind farm in operating mode are Capacity Factor (CF), Annual Run Time (AF), Machine Availability (MA), Grid Availability (DR), System Availability (DS), and Equivalent Run Time (NQ). These quantities of factors are also used to describe the performance of the wind [31].

3.1. Capacity factor

It is defined as the ratio of the energy produced to the energy output that would result from operating at full rated power for each hour of the year.

$$CF = \frac{Energy\ production\left(\frac{\frac{kWh}{month}}{year}\right)}{Nominal\ power\ (kW) \times Hours\ per\ year} \tag{2}$$

3.2. Availability of the machine

The ratio between the actual hours of operation and the number of hours that wind speeds were within the operating range.

$$DM = \frac{The\ Time\ of\ turbine\ operation\ (h)}{Time\ of\ rated\ wind\ speed(h)} \tag{3}$$

3.3. Network availability

Grid availability means that the grid is capable of absorbing energy from a wind turbine. It is defined as the grid available in hours to receive energy from the wind farm at the total hour in a period.

$$DR = \frac{Grid\ feeding\ time\ (h)}{Number\ of\ hours\ of\ feeding\ time(h)} \tag{4}$$

3.4. System availability

System availability is the product of machine availability and network availability.

$$DS = Machine\ availability \times Network\ availability \tag{5}$$

3.5. Equivalent Duration of Use

It is also named Equivalent Number of Hours (NQ) which is defined as the ratio of the energy produced by the wind turbine to the rated output power.

$$DR = \frac{Energy\ production\ (kWh)}{Rated\ power\ (kW)} \tag{6}$$

4. RESULTS ANALYSIS AND DISCUSSIONS

Variations in wind speed over the year set high influence performance parameters. For this reason, to study these influences, it was proposed to identify monthly and annual performance indicators. The 30MW wind farm is evaluated by calculating a set of monthly and annual performance indicators during the monitoring period [32].

T1 has been chosen to analyze the performance parameters for one turbine of this wind farm. Table 2 shows the calculation of grid availability, machine availability, system availability, equivalent hours, and wind turbine capacity factor using the preceding equations for each month of the year 2017. during the year 2017 for the monthly analysis and from 2016 to 2019 for the annual analysis of the fifteen turbines according to the following parameters: energy production (kWh) for each turbine, production time (h), time available on the grid (h), time available on the machine (h), and the number of hours during which the wind speeds were in the operating range (h), etc. The performance indicators will be analyzed for each turbine. The overall performance of each wind turbine is evaluated using these different parameters [20]. Table 2 shows the monthly performance indicators such as wind speed (m/s), energy (kWh), operating hours (h), grid hours ok (h), wind speed hours ok (h), for T1 for the period 2017.

The calculation of performance parameters presented in Table 3 contains the calculations of grid availability, machine availability, system availability, and equivalent hours and capacity factor for T1. Figure 2 depicts the monthly energy produced by T1 and its power factors for the months of 2017.

Table 2. Calculations of performance parameters for T1

Month	Wind Speed (m/s)	Energy (kWh)	Turbine Operating Hours	Hours of Grid	Hours of operation Speed (h)
January	9.04	783 332	575	687	687,00
February	9.28	906 410	656	669	670,00
March	8,8	908 160	731	744	744,00
April	9.39	858 894	631	705	705,00
May	9.15	744 044	602	606	602,00
June	8.10	678 908	615	616	616,00
July	7.47	573 920	684	707	706,00
August	6,88	507 586	673	724	723,00
September	6,86	425 498	557	623	619,00
October	7.56	306 558	358	648	525,00
November	7.35	584 136	687	716	705,00
December	9.15	931 176	675	706	706,00
Annually	8,25	8 208 622	7444	8151	8008

Table 3. Calculation of energy parameters

Month	DM (%)	DR (%)	DS (%)	CF (%)	NQ (h)
January	83,70	92.33	77.28	52,64	391,67
February	97,91	99.55	97.47	67,44	453,21
March	98,25	100	98.25	61,03	454,08
April	89,50	97.91	87.63	59,65	429,45
May	100	81.45	81.45	50,00	372,02
June	99,84	85.55	85.41	47,15	339,45
July	96,88	95.02	92.05	38,57	286,96
August	93,08	97.31	90.57	34,11	253,79
September	89,98	86.52	77.85	29,55	212,75
October	68,19	87.09	59.38	21,28	153,27
November	97,45	99.44	96.9	40,57	292,07
December	95,61	94.89	90.72	62,58	465,59
Average	91,69	93,08	86,24	46,85	4104,3

It shows that the energy produced by T1 reached 931,176 Wh for December and the minimum energy was produced for October with 306,558 kWh. The total accumulated energy production for the 12 months of operation is 8,208,622 kWh, according to Table 2. The capacity factor varies from 21.28% in October to 67.44% in February throughout the year, marking an annual average of 46.85%. Figure 3 represents the machine availability (DM), network availability (DR), and system availability (DS) generated by T1 during the months of the year 2017.

Figure 4 proves that the machine availability of T1 is 100% in May but 68.19% in October with an annual average value of 91.69%, which means that T1 is in good reliability for the year 2017 except in October. The availability of the distribution network varies between 100% in March and 81.45% in May, giving an annual average of 93.08%. These results give that the machine system-network varied between a minimum of 56.38% in February and 98.25% in March giving an annual average of 86.24% which implies that the machine system T1 is working on its planned production. The equivalent number of hours of operation at full power for T1 is minimum in October of 153.27 hours and maximum in December of 465.59 hours which implies that T1 gives a good production in December as shown in Table 2. The total number of operating hours for T1 is 7444 hours, the minimum number of hours of production was recorded in October of 358 hours which is due to maintenance of the machine during that month and the maximum number of hours of production is 731 hours in January and 706 hours in March as shown in Table 3.

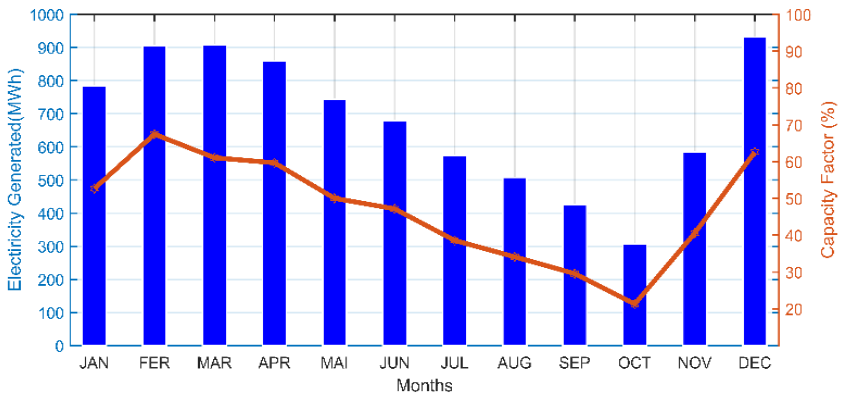

Figure 2. Energy capacity factor for T1

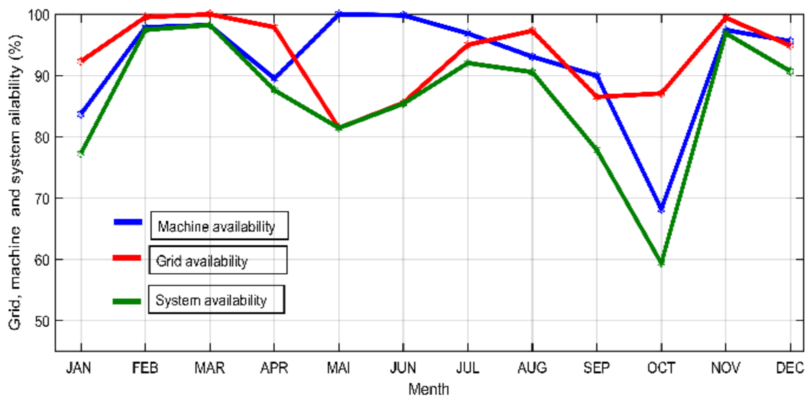

Figure 3. Turbine T1 operation analysis

Table 4. The annual energy production for 2016

	Energy (kWh)	CF (%)	DM (%)	DR (%)	DS (%)
T1	7 853 816	44,71	92,76	90.84	83.57
T2	8 226 029	46,82	98,34	91.41	89.89
T3	8 231 949	46,86	99,06	91.24	90.38
T4	7 957 330	45,29	98,54	91.29	89.95
T5	7 954 115	45,28	98,53	90.78	89.44
T6	7 805 439	44,43	98,88	90.60	89.58
T7	7 822 298	44,53	99,15	91.26	90.48
T8	7 628 456	43,42	97,56	91.02	88.80
T9	7 696 883	43,81	99,03	90.28	89.40
T10	7 687 646	43,76	97,70	91.28	89.80
T11	7 570 310	43,09	95,92	90.95	87.24
T12	6 718 986	38,25	89,59	88.32	79.12
T13	7 335 601	41,76	97,15	91.24	88.63
T14	7 883 897	44,88	99,14	91.29	90.50
T15	7 531 775	42,87	94,60	90.58	85.68

Table 5. The annual energy production for 2017

	Energy (kWh)	CF (%)	DM (%)	DR (%)	DS (%)
T1	8208622	46.85	91.69	94.33	86.49
T2	8658314	49.37	94.93	94.20	89.42
T3	8438052	48.16	97.03	93.17	90.40
T4	8020116	45.78	93.02	94.86	88.23
T5	6606640	37.71	84.46	88.97	75.14
T6	7967698	45.48	94.67	93.97	88.96
T7	7330330	41.84	88.82	93.10	83.06
T8	7665216	43.75	93.38	94.81	88.54
T9	8265884	47.18	97.83	94.55	92.50
T10	8065948	46.04	95.47	96.00	91.65
T11	6982052	39.85	85.71	91.75	78.64
T12	5709474	32.59	86.25	81.88	70.62
T13	7997026	45.65	95.81	95.78	91.77
T14	8231916	46.99	96.12	95.61	91.90
T15	8402528	47.96	97.29	94.37	91.81

Table 6. The annual energy production for 2018

	Energy (kWh)	CF (%)	DM (%)	DR (%)	DS (%)
T1	8 189 136	46,74	91,49	96. 34	88.14
T2	8 096 318	46,21	95,66	94.34	90.24
T3	7 549 970	43,09	94,38	87.84	82.90
T4	7 093 032	40,49	93,70	89.57	83.92
T5	7 965 232	45,46	96,12	94.35	90.96
T6	8 097 544	46,22	96,68	96.64	93.43
T7	7 697 500	43,94	92,91	94.38	87.68
T8	7 724 140	44,09	93,26	94.65	88.27
T9	8 154 664	46,54	95,67	96.84	92.64
T10	8 093 718	46,20	95,41	96.57	92.13
T11	6 357 166	36,29	90,28	75.60	68.25
T12	7 936 130	45,30	94,32	96.96	91.45
T13	8 156 392	46,55	96,43	96.10	92.67
T14	7 743 220	44,20	92,16	96.07	88.54
T15	7 913 770	45,17	94,86	94.41	89.55

Table 7. The annual energy production for 2019

	Energy (kWh)	CF (%)	DM (%)	DR (%)	DS (%)
T1	8 260 342	47,15	97,65	92.07	89.91
T2	7 341 590	41,90	95,82	88.58	84.88
T3	7 205 664	41,13	95,17	83.60	79.56
T4	7 595 552	43,35	93,08	90.76	84.48
T5	7 274 572	41,52	96,78	88.20	85.35
T6	7 648 800	43,66	96,27	90.35	86.98
T7	7 854 030	44,83	96,24	92.59	89.09
T8	7 854 872	44,83	95,77	92.57	88.65
T9	7 892 098	45,05	96,89	92.62	89.74
T10	7 823 134	44,65	96,75	92.13	89.13
T11	7 200 380	41,10	93,29	90.61	84.53
T12	7 613 600	43,46	97,62	90.02	87.88
T13	7 957 832	45,42	98,24	92.13	90.51
T14	7 555 606	43,13	95,90	90.38	86.67
T15	8 216 672	46,90	97,96	91.45	89.58

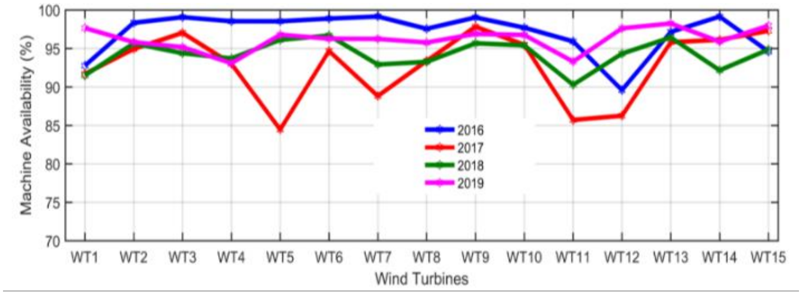

Figure 4. Machine availability

The best production year is 2018 with an energy of approximately 116.76 GWh. The best annual production recorded is 8658314 KWh marked by the T2 in 2017. T1 produces the maximum total amount of electrical energy among the fifteen turbines in this park during these years. Figure 5 shows the energy produced by the machines over the four years 2016 to 2019.

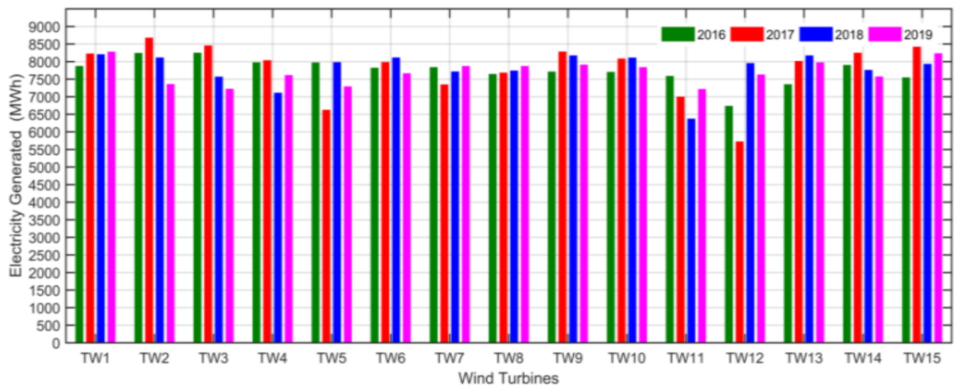

Figure 5. Annual energy produced by the turbine for the period 2016-2019

The availability of the system (machine-network) is unstable and needs improvement. It presents an annual average of 88.16% in 2016, 86.6% in 2017, 88.05% in 2018 and 87.12% in 2019. Figure 6 shows the fleet (machine-grid) system available for the four years 2016 to 2019.

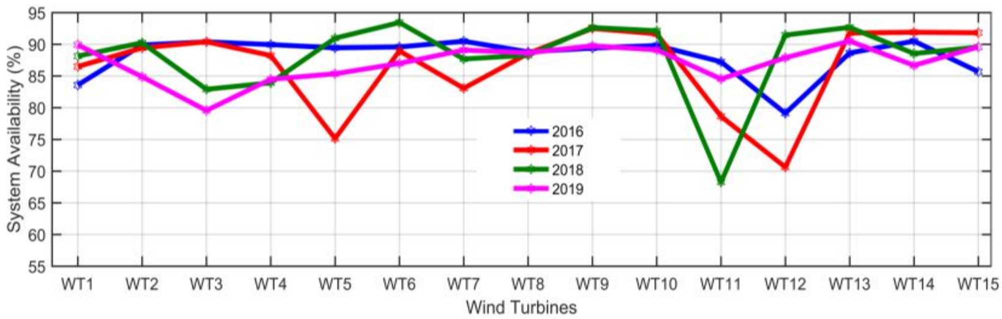

Figure 6. System availability 2016-2019

The capacity factor during these four years is 43.98% in 2016, 44.35% in 2017, 44.43% in 2018, and 2019 the average capacity factor of 43.87%. Figure 7 shows the fleet factors for the four years 2016 to 2019.

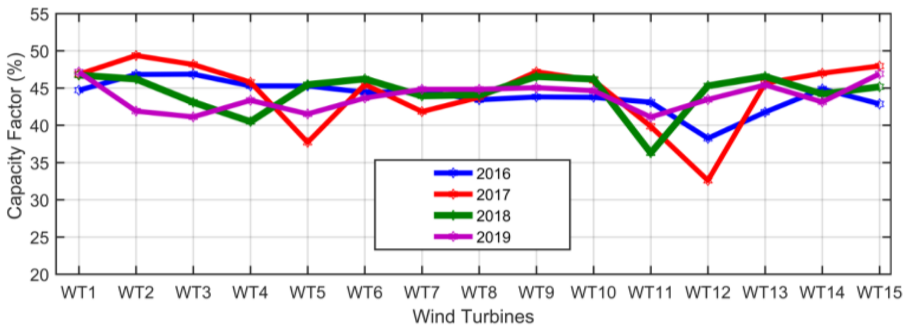

Figure 7. Capacity factor 2016-2019

Comparing all turbines in the 30MW fleet in operating mode, from 1 July 2015 to 31 December 2019, Figure 8 represents the energy-capacity factor curve for each machine, while Figure 9 illustrates the energy versus machine operating time curve during this period.

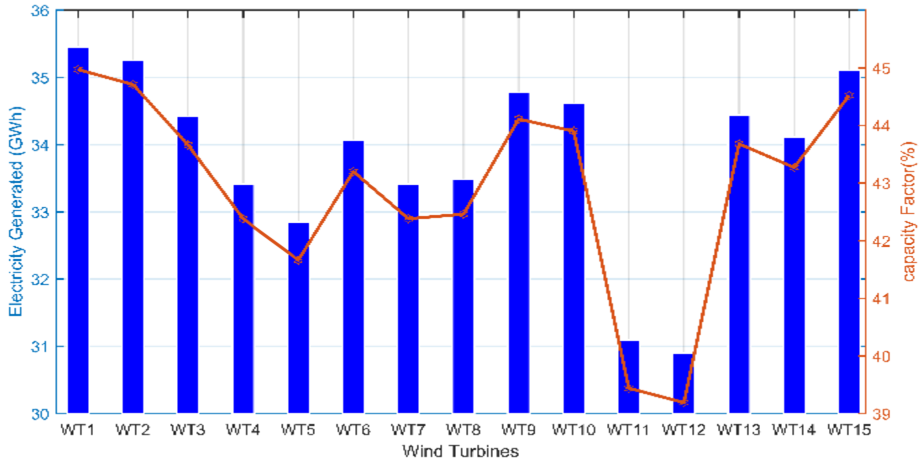

Figure 8. Total energy and capacity factor 15 July 2015- 31 December 2019

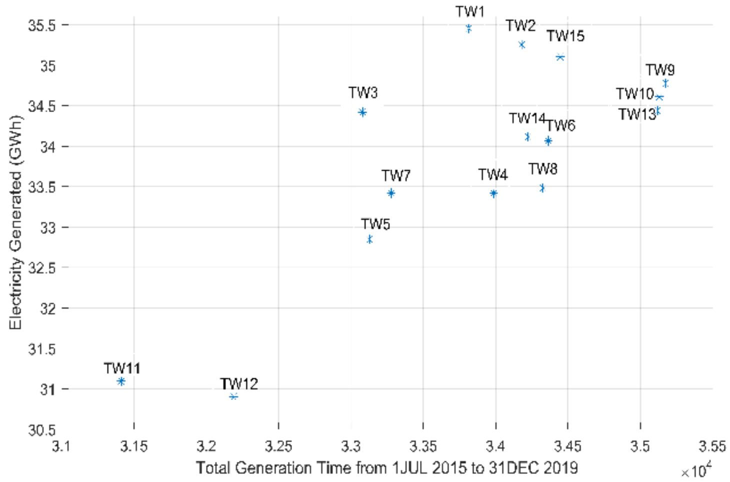

Figure 9. Total energy and number of hours of operation 15 July 2015- 31 December 2019

The above curves show that:

a. T1 produces the maximum amount of electrical energy among the fifteen wind turbines in this wind farm with a total energy output of 35.46 GWh, marking an average capacity factor of 44.97% based on the number of operating hours of 33,814 hours during the period from July 2015 to December 2019.
b. T12 produces the minimum energy in this period with a value of 30 GWh, marking a difference in energy for T1 of 4.563GWh, which is well explained by the low number of hours of operation during this period (32,189h), in this respect, we can also visualize in figures (8, 9) a similar behavior of T11 (energy produced 31.09 GWh) and a capacity factor of 39. 44% and operation hours 31,412h compared to the other Turbines, i.e. most of the time the Turbines were available, except for T11 and T12 which are more time out of service.
c. The total electricity supplied by the wind farm to the power grid from 1 July 2015 to 31 December 2019 is 507.39 GWh.
d. The average capacity factor is 42.55% from 1 July 2015 to 31 December 2019.

5. CONCLUSION

The objectives of this paper are related to the simplified evaluation of the performances through different parameters of a wind power plant implanted on a site in Nouakchott in operating mode connected to the national electricity grid. The second originality is related to the analysis of meteorological data to establish the conditions and parameters for which it is possible to give a score on the evaluation of the energy available on the site. Finally, the third originality is related to the presentation of the generation mode to compare the production balances of each wind turbine of the park for several years. This paper presents a performance analysis of a 30MW wind farm installed in the Sahelian area in Nouakchott, Mauritania. The results lead to the conclusion that most of the wind turbines are operating optimally with slight variations due to the seasonal wind variation of speed and direction. The capacity factor of the Nouakchott wind farm represents a high value of 42.58% shows that our power plant is among the most efficient in the world. This can be explained by geographical position and climatic conditions (high wind potential) in the farm site. It is recorded that T1 produces the highest amount of electricity during these years and has the highest average capacity factor because of its position in front of other turbines. On the other hand, grid availability is unstable and needs to be improved, varying between 90.86% in 2016 and 93.16% in 2018. In perspective, the future work will be monitoring the performance of other wind sites in Mauritania such as the 100MW wind farm in Boulaoir, 4.4MW wind farm in Noudhibou, small wind farms of 210KW in Mamghar and 270KW in Chami for the optimization of instantaneous production and conservation performance over time. Also, an analysis of performance degradation over time and development will follow.

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