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Performance Metrics of a Grid Connected Photovoltaic Plant: A Practical Case of the 1.3MW Phakalane Plant in Gaborone, Botswana

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Abstract

The performance of a solar photovoltaic plant can be analyzed using various key performance indicators such as performance ratio, capacity utilization factor, system efficiency, system availability etc. This paper is a presentation of the performance of a 1.3MW grid connected photovoltaic system in Gaborone, Botswana. The methodology utilizes the energy generated and supplied to the grid from January to December 2020 to compute the quality ratios: performance ratio, capacity utilization factor and the technical availability of the plant. During the period of study, the grid connected plant injected 2,245,505.00 kWh of energy to the national grid with the final yield, reference yield, performance ratio and the capacity utilization factor of: 1 724 peak sun hours; 2 196 peak sun hours; 78.5%; and 19.66% respectively. Comparing it with other plants this system's performance is very good. However, the technical availability of the plant was only 57.4% with Mean Time Before Failure (MTBF) of 129 hours and Mean Time To Repair (MTTR) of 96 hours. Therefore, this paper reveals the impact of grid interference and prolonged downtime on the performance of grid tied PV systems. The study gives insight to engineers, researchers, decision makers and other stakeholders in this field so that focus must be directed to ensure the availability of such power plants especially in Africa where most grids experience frequent tripping.

Keywords: Photovoltaic (PV) plant; Grid connected; Performance Ratio (PR); Capacity utilization factor (CUF); Technical Availability; Mean Time Before Failure (MTBF); Mean Time To Repair (MTTR).

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1. Introduction

Solar energy has gained popularity due to global promotions on the implementation of Renewable Energy Sources (RES) towards the green and sustainable energy drives and policies. Electric utilities are expected to increase the PV plant portfolios from their current insignificant levels and such is the case with Botswana as well. Through independent power producer (IPP) projects, the country has embarked on expanding its renewable energy and natural gas power generation portfolio. As a result, in September 2016, Botswana's Ministry of Energy was renamed as "Ministry of Mineral Resources, Green Technology, and Energy Security" to reflect the country's new commitment to incorporating renewable energy into its energy production mix. Currently the peak energy demand of Botswana is approximately 690MW, however, the country’s two coal-based power stations, Morupule A and B, have been facing technical problems that impact negatively on electricity production. The plants have capacities of 120 MW and 600MW but they always perform below the capacity factor target of 70%. Shortfalls are supplemented through back up diesel plants, load shedding, and imports from neighbouring countries. There are also two Botswana Power Cooperation (BPC) owned back-up plants namely, Matshelagabedi and Orapa with capacities of 70MW and 90MW, respectively. The South African utility Eskom is a major supplier of energy consumed in the country, with further Southern African Power Pool (SAPP) inflows from the neighbouring countries like Mozambique, Namibia, and Zambia. The energy situation in Botswana is contrary to the high levels of irradiation it receives of approximately 3200 sunshine hours, which is a prerequisite of electricity production through PV systems.

Currently, in Botswana there are three grid-connected PV systems, the plant understudy i.e 1.3 MW solar power plant in Phakalane, near Gaborone (capital city), a 20 kW system located in Mokolodi village which was funded by the European Union and a 34 kW system owned by a private operator [1]. There are also a number of small-scale grid connected roof top installations which use the grid as back up [1]. The 1.3MW solar power project was implemented in 2012 through a Japanese grant as part of a strategy called “Cool Earth Partnership” which Japan announced in 2008 to address environmental issues. The purpose of such a project was to showcase the technology and for the country to learn issues of installation and maintenance of such systems. The experience gained would be transferred to similar projects for instance the 100MW and the 35MW solar plants which were in the procurement stage in 2023 [2]. So the performance of this plant must be closely monitored, as accurate and constant performance monitoring of existing PV systems on the field is one of the most important strategies to ensure success of this technology [3].

Several performance indicators are used to evaluate the performance of PV systems, but the appropriate ones for grid tied systems are the final yield, reference yield and the performance ratio [4]. This paper analyses the aforesaid parameters and take a step further by quantifying the availability of the system. The performance ratio (PR) and the availability are key performance indicators that reflect on downtime and energy delivery. More-so, the effectiveness of a PV system is determined by the quantity of energy lost while a system is unavailable as well as how well the system functions when it is available. While accidental incidents and occasional component failures can cause grid-connected PV power systems to fail, resulting in considerable economic losses, these systems are also affected by grid-related perturbations beyond the PV system boundaries that results in inverters tripping to avoid islanding. Islanding occurs when the PV system continues to operate and supply power to the load while the grid is off. This exposes utility maintenance and repairs workers to danger so the inverter automatically disconnects the PV system when the grid is down. In Sub – Saharan Africa grid unreliability is a common phenomenon, yet on-grid systems are created to disconnect from the grid once it is offline [5]. Therefore, with these systems, although the sun is shining there will be no electricity generated. Hence, the frequency of grid induced system failures and the time taken to restore the PV system after the grid fault lower the system’s availability and reliability.

Therefore, this paper provides a presentation of the PR and technical availability of the 1.3MW PV plant in Botswana, Gaborone. The evaluation of these parameters was made possible by analyzing the energy generated by the plant in the year 2020 provided by the only BPC. PR is the best critical performance indicator for comparing the performance of different PV plants in different locations, regardless of weather and climate conditions. With respect to this, a comparison of the performance of this plant with other grid connected systems is carried out. The performance of PV Plants can be made better by ensuring that the plant is 100% available for operation and that the grid is also at 100% availability [6]. So, this paper also reveals the impact of grid unavailability and prolonged downtime on energy production and performance of the 1.3MW PV grid tied plant. The analyzed data contained daily energy fed to the grid recorded at 30 minutes intervals for one year (Jan–Dec 2020), however from the data it was not possible to get the information regarding other grid faults that might have occurred while the 1.3MW plant was down. Again, the data could not show the actual time taken to restore the grid for all the instances a grid fault was experienced. This information would assist in the estimation of the down time of the 1.3MW plant after grid restoration. Moreover the daily climatic and environmental conditions for the year 2020 were not factored in to determine their contribution especially in terms of energy losses.
However, the study gives insight to engineers, researchers, decision makers and other stakeholders in this field to ensure that the availability of such power plants is closely guarded especially in Africa where most grids experience frequent tripping.

The organization of the paper follows this structure: Section 2 presents literature review while section 3 describes the plant understudy, its layout together with any other relevant information. The methodology is provided in section 4. The results and discussion of the analyzed data is done in section 5. Lastly, the conclusion and the recommendations are given in section 6.

2. Literature Review

2.1 Grid tied systems performance analysis

Grid-tied systems are divided into two categories: with or without batteries. Systems without batteries do not supply any energy during power outages and have two main components: a solar PV array with a grid-connected inverter [7]. The DC/DC converter is merely included to step up the array DC voltage. Figure 1 demonstrates the general layout of the major components of a grid connected PV system without battery storage. In general, the grid connected photovoltaic (GCPV) system runs in a balanced state, with perfect load currents and voltages, while staying within the inverter's operational limits. The presence of a grid fault causes the GCPV system to be unbalanced. Natural interference, technical mistakes, or the connection of a high number of loads to the electricity grid all contribute to this imbalance. Most grids are highly unreliable mainly because of these four categories of factors; environmental, political, security, organizational and technical. These factors causes these plants to have low coverage, yet grid connected PV systems are proving to be a solution to energy challenges faced by most African countries. For high electrified countries grid unreliability and power outages have been identified as the main problems. Higher frequency of downtime and longer repair durations can cause a significant reduction in productivity [8].This suggests that the reliability can be increased by reducing the frequency or duration of interruptions [9]. So the performance measurement of grid connected PV systems is of criticality as this guides decision makers in identifying and mitigating against some deviations from the expected results, particularly due to grid interference.

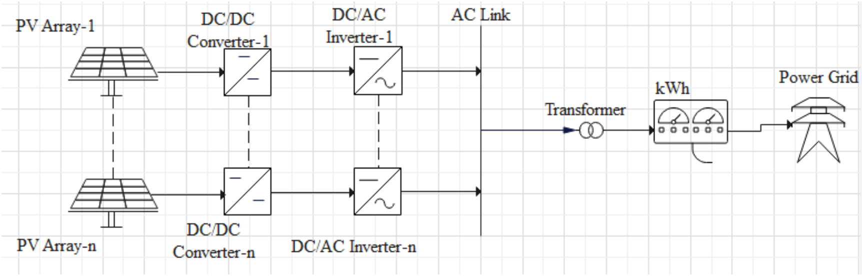

Figure 1: Grid Connected PV System [10]

Many research have been performed on the analysis of the performance of Grid connected PV systems located in different places using the same metrics for system performance analysis outlined by The International Electro-technical Agency (IEC). [11] Presented the techno-economic assessment of an on-grid solar PV system in Palestine based on the capacity utilization factor and performance ratio. The author demonstrates the usefulness of these metrics in providing feedback to designers and other decision makers. The study compared the results of the energy generated from the simulation software program (PVsyst) with the actual energy generated and supplied to the grid for three consecutive years 2016-2018.The simulation results provides yearly average of 76 718.51kWh while the measured values of energy were slightly lower at 67 820.76 , 66 325.17 and 65 568.74kWh respectively. The PRs of this plant within this period was 0.88, 0.86 and 0.85 with the capacity utilization factor of 18.5%. Both the energy fed to the grid and the PR of this plant decreased each year. A study on the Performance and Optimization of Commercial Solar PV plants provides a detailed annual performance and the technical aspects of these plants is carried out in [12]. In this paper, the optimum size was designed using PVsyst and SAM software, and, the yearly energy production was 161 198MWh at 74,8% PR. Some of the parameters evaluated in this research which are relevant to the current study are the reference and the final yield. Authors in [13] evaluated the energy installation of a mini grid connected PV system at Algiers on a typical year, energy losses and the most significant performance parameters of the system were quantified. The PR of this PV plant ranged between 62% and 77% which is within the accepted International standards. [14] described and displayed approaches together with methods of analysing the performance of PV systems so that the results can be used to improve the operational behaviour of PV systems. The author in [15] provided the Comparative Performance Analysis of Grid-Connected PV Power Systems with Different PV Technologies in the Hot Summer and Cold Winter Zone. The findings of this study revealed that the performance of grid-connected PV power systems is influenced by factors such as geographical location, PV module type, and climate conditions such as solar radiation and ambient temperature. However this research takes a step further in showing that grid interferences renders grid tied PV system redundant as such systems only operates when the national grid is in normal operation.

It is worth noting that the performance of a PV system and its components can be determined by calculating several parameters that describe energy amounts and comparing them to the IEC standard 61724 [11, 13]. The main parameters that are usually used are the final PV yield, reference yield and the performance ratio. The above studies did not relate the performance parameters of PV systems with the technical availability of these plants of which this current study attempts to find the relationship between them. The application of these parameters in analyzing the performance of grid connected PV systems can typically be seen in [4, 12, 16-19]. According to [4], the PR of PV systems installed between 1983 and 1985 ranged between 0.65 and 0.7 while those installed from 1996 to 2002 the PR was 0.75-0.8 indicating an increase in PR as new technologies and designs emerge. The system in [16] was monitored within a period of one year and these results were obtained: final yield of between 43.85 h and 105.27h, reference yield of 103.3h- 156.2 h with PR ranging from 34% to 70% and capacity factor of 10.09%. In [17], the effect of degradation on the PV system's PR are studied, and the results show that the degradation is more in summer due to high temperatures which occur from April to June in India. The average PR for the studied period was 88.06%, with the lowest of 81.03% recorded in May and the highest being 93.85% recorded in January 2015.The study in [18] revealed that tripping of inverters affects the availability of the plant. The plant studied was monitored for 5 consecutive years and the availability ranged between 92.44%and 95.69%. Evaluation of the PV systems availability is critical in order to find ways of keeping it high [18]. Authors in [19] demonstrate the contribution of solar PV system in reducing the demand on the grid. The descriptions and related formulas are outlined in section 2.2, notably; a value of 72% PR at 98% availability is achievable [4].

2.2 Performance Metrics

The following performance metrics created by International Energy Agency (IEA) were identified and used to evaluate the performance of the plant understudy.

2.2.1 Annual average insolation

Botswana receives over 3,200 hours of sunshine per year, with an average insolation on a flat surface of 21MJ/m^2. Botswana has abundant countrywide irradiation presenting the lowest average values of irradiation in a range of about 2,000 kWh/m²/annum (~5,5 kWh/m²/day) direct normal irradiance (DNI) and global horizontal irradiance (GHI). This amount of insolation is among the highest in the world, making solar energy a promising renewable energy resource for Botswana [20].

At a peak sun value of 1000 W/ m^2, the average annual insolation value is determined as:

$$I_A = H_p \times D \times I_F \qquad (1)$$

where; I_A is the annual insolation, H_P is daily average peak hours, D is the number of days in a year and I_F is the fixed irradiance.

2.2.2 Final yield

The final yield, Y_f can be defined as the net energy output (E) divided by the rated PV array DC power (P_O). It compares the performance of different PV systems as it normalizes the energy produced by each system with respect to capacity [13].

$$Y_f = \frac{E}{P_0}\ , (kWh/kW) \qquad (2)$$

2.2.3 Reference Yield

The reference yield (Y_r) is the ratio of total in-plane solar radiation kWh/m2 (S_r) to the reference irradiation (H_r) at standard test conditions (STC) (1 kW/m^2).). It provides the total in-plane solar radiation or an equivalent number of hours at the reference irradiance.

$$Y_r = \frac{S_r}{H_r}\ , (kWh/kWp) \qquad (3)$$

2.2.4 Performance ratio (PR)

The PR calculates the overall impact of equipment breakdowns and efficiency on a plant's rated potential output and it is the ratio of (2) and (3).

$$PR = \frac{Y_f}{Y_r} \qquad (4)$$

2.2.5 Capacity Utilization factor

This is the ratio of real annual energy output by the PV system (E_A) to the amount of energy the PV system would generate if it is operated at full rated power for full day for a year [21] and is given as

$$C_f = \frac{E_{AC}}{P_{PV\,rated} \times 366 \times 24}\ , \qquad (5)$$

E_{AC} is the annual energy yield and $P_{PV\ rated}$ is the rated power output of the installed PV array.

2.2.6 Availability

This measures productivity losses resulting from downtime and it is determined as;

$$A = \frac{Uptime}{Uptime + Downtime} \qquad (6)$$

Technical availability is the parameter that represents the time during which the plant is operating over the total possible time it can operate, without considering any exclusion factors. It is calculated as:

$$A_t = \frac{T_{useful} - T_{down}}{T_{useful}} \times 100 \qquad (7)$$

A_t = Technical Availability (uptime) (%)

T_{useful}= period within plane irradiation above MIT(h)

T_{down} = The period of T_{useful} when the system is down (h) (Anon n.d.)

Availability can also be determined by using the Mean Time To Repair (MTTR) [22].

$$MTTR = \frac{Total\ duration\ of\ outages}{Frequency\ of\ outages} \qquad (8)$$

And Mean Time Between Failures (MTBF)

$$MTBF = \frac{Total\ system\ operating\ hours}{Number\ of\ failures} \qquad (9)$$

$$Availability \quad A = \frac{MTBF}{MTBF + MTTR} \qquad (10)$$

3. The Plant Description and System Data

The 1.3MW photovoltaic plant is located in Botswana, Africa (24°34’59”S, 25°59’17”E). The nominal power of this fixed tilt PV system is 1300kW, oriented with azimuth and tilt angle of 177° and 28°, respectively. It consists of 6032 monocrystalline PV modules, rated at 220-W DC, with a peak voltage of 470VDC. Six strings of 16 series connected modules are combined in parallel and fed into 4 junction boxes. The fifth junction box consists of 5 strings parallel connected, each string having 16 series connected panels. The system consists A set of 5 junction boxes feed the connection boxes. There is a total of 65 junction boxes, 13 connection boxes and 13 inverters. A typical connection box for the plant understudy is illustrated by Figure 2.

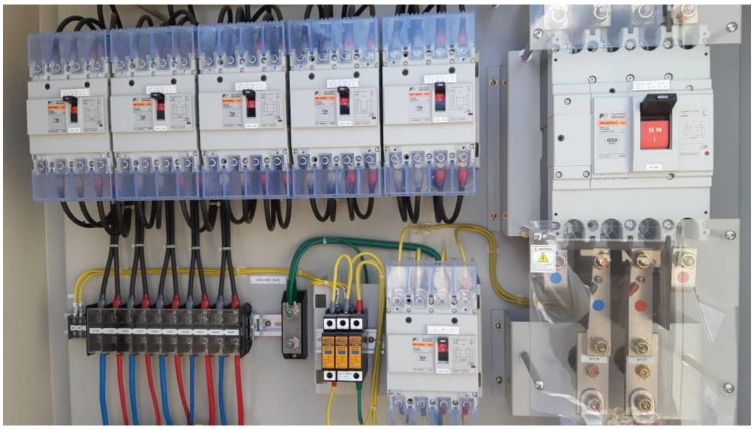

Figure 2: Typical Connection box

All the 13 inverters are rated at 380 V AC output voltages and this is a grid following system. The system is subjected to an average peak sun value for Gaborone area of 6hours and average monthly irradiation levels of 161 kWh/m^2 [23]. Figure 3 presents the layout of the 1.3MW grid connected PV plant.

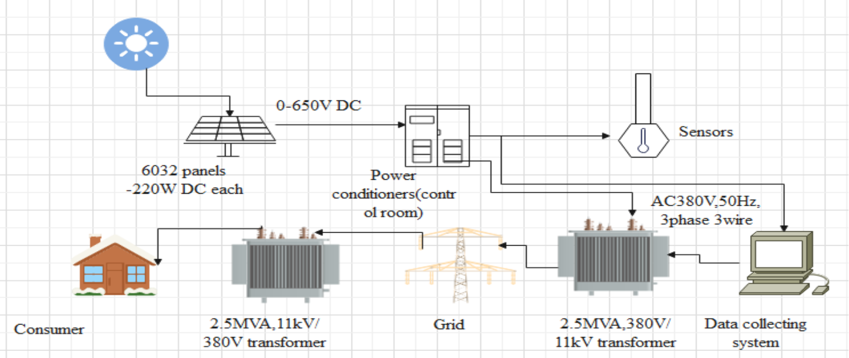

Figure 3: 1.3MW Grid connected PV plant layout

The energy generated by the plant was obtained from BPC database and summarized in Table 1. This data is then analysed in the next section to establish key performance parameters of the plant. According to the data, in January there was no energy supplied to the grid. For the period of May to July it is worth noting that the plant supplied more energy compared to the rest of the months with the highest yield of 318,057.00kWh recorded in May. We observe a high yield in winter months of May to July while extreme summer months of November to April the country experiences very high temperatures that impede the performance of solar panels.

Table 1: Monthly Energy Supplied by the plant for 2020 [24]

Month	Energy Supplied (kWh)
January	
February	69,899.00
March	12,036.00
April	113,541.00
May	318,057.00
June	306,258.00
July	280,993.00
August	268,670.00
September	261,006.00
October	250,014.00
November	197,363.00
December	167,668.00
Total	2,245,505.00

4. Performance Metrics Computations

The formulations and data presented above are used to compute PR, technical availability and capacity utilization factor. These parameters are then used to evaluate the performance of the plant under study.

The performance ratio is calculated by using (2) as follows

$$\mathrm{Y_f} = \frac{E}{\mathrm{P_0}} = \frac{2245505(kWh)}{0.220 \times 5920(kW)} = 1724Hrs$$

E, the total energy supplied to the grid in the year 2020 (Table 1) and P_0 is the DC array yield calculated as the product of the number of panels and the DC output of each panel (220W). The reference yield Yr;

$$\mathrm{Y_r} = \frac{\mathrm{S_r}}{\mathrm{H_r}} = \frac{6hours \times 366days \times 1000W/m^2}{1000W/m^2} = 2196Hrs$$

It is the ratio of the total in plane irradiance, (the product of the average peak hours per day in a year, for Gaborone it is 6 hours/day) and the peak sun value of 1000W/m^2. H_r is the PV reference irradiance of 1000W/m^2.

$$PR = \frac{Y_f}{Y_r} = \frac{1724hours}{2196hours} \times 100 = 78.5\%$$

The capacity utilization factor that shows the fraction of the maximum output the 1.3MW plant produces.

$$C_f = \frac{E_{AC}}{P_{PV\ rated} \times 366 \times 24} = \frac{2245505}{1300 \times 366 \times 24} = 19.66\%$$

To analyse the operating and non - operating times of the plant, the sunrise and sunset times are of significance, Table 2 shows these for Gaborone in 2020.

Table 2: 2020 sunrise and sunset times monthly averages

Source: https://www.worlddata.info/africa/botswana/sunset

Month	Sunrise	Sunset	Hours of daylight
January	05:39 am	07:11 pm	13:32 h
February	06:02 am	06:58 pm	12:57 h
March	06:16 am	06:33 pm	12:17 h
April	06:29 am	06:02 pm	11:33 h
May	06:43 am	05:41 pm	10:58 h
June	06:57 am	05:36 pm	10:39 h
July	06:58 am	05:46 pm	10:47 h
August	06:41 am	05:59 pm	11:18 h
September	06:11 am	06:11 pm	11:59 h
October	05:41 am	06:23 pm	12:42 h
November	05:20 am	06:41 pm	13:21 h
December	05:20 am	07:02 pm	13:42 h

The average hours of daylight per month in the year are a prerequisite to energy production by solar cells. Although the average peak hours for the horizontal plane array in Gaborone is 6 hours, longer daytime hours in Gaborone, Botswana are experienced between September to March ranging between 11.59 hours and 12.17 hours while from April to August the range is between 10.39 hours and 11.33 hours [25]. This corresponds with the average monthly insolation shown in Figure 3.

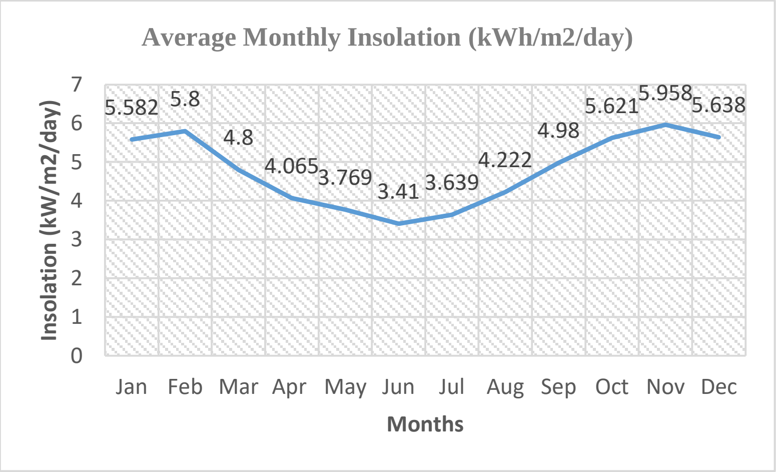

Figure 3: Monthly Average Insolation within the location of the 1.3MW plant

Figure 4 illustrates the monthly up and down times of the 1.3MW plant in 2020 calculated based on the data from the utility meter recordings in conjunction with the sunrise and sunset times.

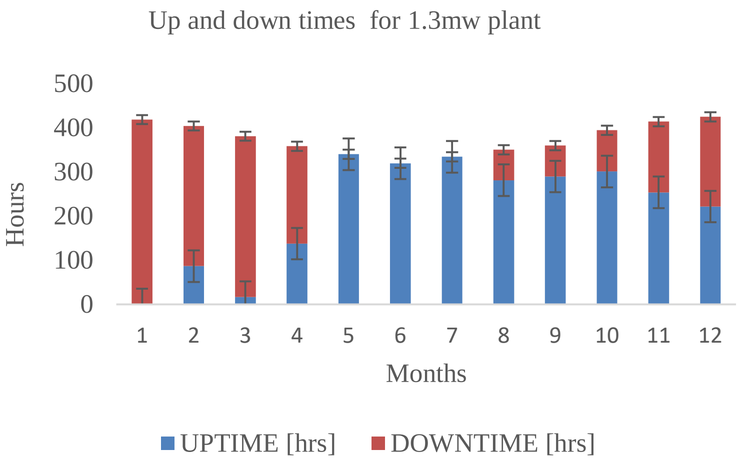

Figure 4: Monthly Useful times for the 1.3MW plant

The bar chart represents the total useful time for the PV system for each month from January (1) to December (12) in the year 2020, here the height of each bar indicates the total expected time of plant operation. In February- April the plant was in operation for approximately 21.4%, 4.3% and 38.4% respectively. 100% plant availability was realized in months of May-July. From August to December the plant was in operation for approximately, 80.3%, 80.56%, 76.4%, 61.3% and 52.15%. It was established from the energy supplied to the grid records that the plant experienced twenty (20) instances of grid failure and therefore this shall be used to compute reliability indices of the plant. The MTTR, MTBF and the technical availability of the plant is therefore computed basing on this information.

Determining the plant availability that measures productivity losses due to downtime and for the plant understudy was estimated using (7):

$$A_t = \frac{T_{useful} - T_{down}}{T_{useful}} \times 100 = \frac{4498-1917}{4498} \times 100 = 57.4\%$$

This obtained availability agrees with the computation methodology proposed by [22] where Mean Time To Repair (MTTR) is used.

$$MTTR = \frac{Total\ duration\ of\ outages}{Number\ of\ Failures} = \frac{1917}{20} = 96 hours$$

And Mean Time Between Failures (MTBF) as in (9) gives

$$MTBF = \frac{Total\ system\ operating\ hours}{Number\ of\ failures} = \frac{2581}{20} = 129 hours$$

And Availability (A) becomes $= \frac{MTBF}{MTBF+MTTR} = \frac{129}{129+96} = 57.33\%$

Both methods of [22] and [13, 14] provide the same solution of about 57% technical plant availability.

Higher frequency of downtime and longer repair durations can cause a significant reduction in availability and hence productivity. Figure 5 depicts the relationship between the technical availability of the plant and the energy produced in each month of the year 2020.

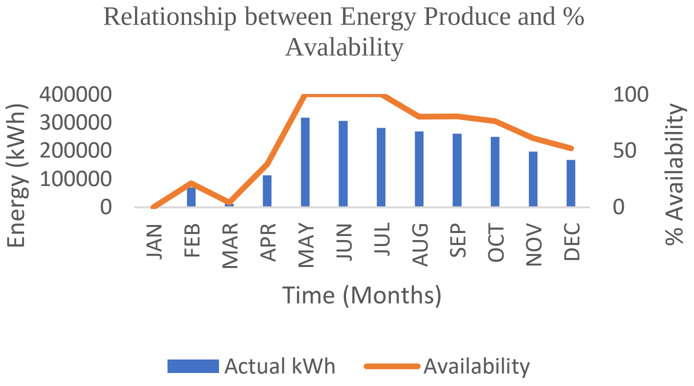

Figure 5: Relationship between Availability and Energy Production

The correlation between plant availability and the associated energy injected to the grid for each month shows that the plant operated at 100% availability in May, June and July, hence the energy supplied to the grid supersedes the other months. January being the worst affected at 0% availability and no energy transferred to grid. Second from the least is February, March and April operated at less than 30% availability and energy fed to the grid on each of these months is below 100 000kWh yet the average of all the months which is 187 125.4kWh. August, September, and October had availabilities that ranged between 75% and 80% with the corresponding energy transfer to the grid of 268 670kW, 261 000kWh and 250 014kWh which is above the monthly average energy feed. November and December were characterized by frequent outages which resulted in 61% and 52% availability with each supplying 197 363kWh and 167 668kWh respectively.

5. Discussion

In performance measurement of PV systems, special attention is given to the net energy. The 1.3MW plant under study is performing well at 78.5% PR, although this is a little less than the acceptable industry standard 80% [26]. However, it is evident from the data that at reduced or no grid induced faults the plant production was high. It was also established that the energy supplied to the grid per month is directly proportional to the technical availability of the plant. The final yield and the reference yield were found to be 1724 kWh/kWp and 2196 kWh/kWp respectively. Implying that on average the plant was expected to produce 1000W/m^2 for 2196 hours in the year 2020 but only did so for 1724 hours, resulting in a performance ratio of 78.5%. Although this falls within the range of the PRs of well performing plants, the record of the plant since inception in 2020 shows that the plant has never suffered any major malfunctions except for module theft. From the utility energy meter records, it was established that after grid unavailability the plant took long to be restored since such system is grid following. As a result, even during sunny days when the insolation is high the 1.3MW grid connected plant would produce no electricity thereby reducing its performance. Notably, the plant performed exceptionally well from May to October with the performance of above 100%. This is so because the reference energy or the expected energy was calculated using an average of 6 hours full load operation yet the plant is located where there is vast insolation which can operate 9 hours at full load.

Among the 20 instances of grid failure in the year 2020, January was the most affected, the plant remained in the off state throughout the month implying that the resources were idling with no production. Such scenarios impacted negatively on the overall energy and economic performance of the plant. The monthly energy yields transferred to the grid in the year 2020 summed up to 2 245 505 kWh. According to the geographical expectations in terms of solar irradiation, high energy must be realized during summer i.e. from September to March compared to winter as can be deduced from Figure 3, and as solar insolation decreases and daytime hours shorten in winter, the same should happen to the energy produced by the PV system. The monthly average insolation concurs with the year 2020 sunshine hours shown in Table 2. It is seen that the monthly average sunshine hours of the short and long days were 10.58 hrs, 10.39hrs, and 10.47hrs in May-July respectively and November, December and January experienced 13.21hrs, 13.42hrs and 13.32hrs. It can therefore be confirmed that summer months have longer sunshine hours compared to winter and higher rewards in solar energy must be realized.

Contrary to this norm the 1.3MW grid connected PV system located in Gaborone Botswana in Southern Africa, in the year 2020, injected 318 057kWh, 306 258kWh, 280 993kWh,and 268 780kWh in May- August respectively compared to 197 363kWh, 167 668kWh,0kWh and 69 899kWh for November, December, January and February respectively. The up and down times of the plant were drawn from the data for the energy fed by the plant to the grid at 30 minute intervals and the average sunshine hours provided in Table 3 were used to estimate the total expected time of operation for the plant for each month factoring in that PV systems only produce energy during the day. Low plant availability (less than 50%) was experienced in January, February, March and April with 0%, 21.4%, 4.3% and 38%. From August to December the plant operated for more than 50% but below 100% with the following specific percentages: 80.3%, 80.56%, 76.4%, 61.3% and 52%.The plant clocked 100% availability in May, June and July. There was high level inconsistency in plant restoration time as deduced from the varying periods of downtime after a grid failure. Regarding reliability indices the MTBF of 129hours is too short a period for PV plants, it is an indication that the plant experiences a lot of grid interference which renders the plant offline due to the inherent characteristics of anti-islanding. Under these circumstances, with this system, although the sun is shining no electricity is supplied to the grid.

On the other hand the 94 hours MTTR is too long as the average response time for BPC in connection with High Voltage is 4hrs.This implies that the plant remains in the off state for prolonged periods after the grid has been restored.

So the overall plant availability stood at 57.4% in the year 2020 of which benchmarking with other PV grid connected plants this is fairly low. Hence, the frequency of grid induced system failures and the time taken to restore the PV system after the grid fault lowered the system's availability and reliability. Moreover, considering that PV systems can operate with minimum maintenance an improved availability would result in a corresponding increase in yearly energy production.

5.1 Comparison with other photovoltaic plants

Table 3 is a Comparison of the performance of the plant understudy with other plants. In terms of energy production, its performance is within the range of good performing plants. The performance ratios for some selected studied plants in given years were: Johannesburg, South Africa, 83.6;Durban,South Africa,87.1;KNUST,Ghana,74;Jungfraujoch,Switzerland,85.2. On the other hand a 57.4% availability is rather on the low side compared with other systems which have high availability like the ones given on the table located in: Tengana, India, 92.4%; Jungfraujoch, Switzerland, 100%.

Table 3: PV Plants Comparison Performance Ratio

Plant location	Installed capacity(kW)	Annual Energy output(kWh)	CUF	Availability (%)	PR	Reference
Gaborone Botswana2020	1300	2 245 505	19.66	57.4	78.5	Current study
Johannesburg South Africa 7/2019-6/2020	300				83.6	[27]
Kharipat, Bhaktapur, Nepal 2016	100	88 410	10.09		54	[16]
Telengana, India 2015-2016	1000			92.44		[28]
Durban, South Africa 01-12/2018	8	16 178			87.1	[29]
Jungfraujoch,Switzerland 3/97-2/98	1.152	1 541		100	85.2	[30]
KNUST, Ghana	1000	1 159 000	13.2		74.3	[29]
Algiers, Algeria		10 981			71	[13]
Mauritania	48	65 668	19		77.66	[30]

6. Conclusion

This research analyzed the effect of downtime on the performance of the 1.3MW grid connected plant from January to December 2020.The system injected 2 240 505 kWh of energy into the grid with final yield, reference yield, PR and capacity utilization factor of: 1 724 kWh/kWp, 2 196 kWh/kWp, 78.5% and 19.66% respectively. Attributing to MTTF of 124 hours and MTTR of 96 hours the plant availability is 57.4%, which is low compared with some similar selected PV systems. In winter the PV system was most efficient, notably because the plant was 100% technically available, although the expectation is for higher yields to be realized during summer owing to high insolation. This research established that after grid restoration the plant took long to be reset back online. It is therefore concluded that frequent grid disturbances and extensive repair times had a detrimental influence on availability, lowering it from 100% to 57.4 % there by translating to reduced PR. More-so, the research illustrated that availability and energy performance are directly related and therefore some effort must be directed towards improvement of plant uptime [31], particularly in Africa where grids experience high downtime thereby increasing the unreliability of these systems. The capacity utilization factor of 19.66% is within the acceptable range for PV systems. This paper contributes to research aimed at performance improvement and management of solar PV grid-connected systems to ensure that these are better utilized together with associated resources. Further research must be done to reduce the frequency or the duration of the system interruption.

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