

EXPERIMENTAL STUDY OF THE INFLUENCE OF OPERATING CONDITIONS ON THE OVERALL PERFORMANCE OF A SOLAR PHOTOVOLTAIC POWER PLANT : THE CASE OF THE ZAGTOULI POWER PLANT.

ABSTRACT

Solar photovoltaic power plants connected to the electricity grids suffer production losses due, on the one hand, to grid instability and, on the other, to the quality of the installation. The general objective of this work is to improve the performance of a photovoltaic power plant by reducing losses between production and energy injection into the grid. To achieve this, production was estimated using two calculation methods, in order to compare the prediction made by the operating company. The plant's annual performance ratio was calculated, with an estimated value of 88.21%. This translates into good performance.

Keywords: Optimization, Performance ratio, Production, Injection, Solar power plant.

1. INTRODUCTION

Energy is an essential factor in a country's socio-economic development. Fossil energy, long the preferred source of energy production, has proved to be limited by a number of factors, including the depletion of fossil resources and environmental pollution (pollutant emissions). Added to this is the destruction of the ozone layer (greenhouse gas emissions), and the upkeep and maintenance of generating plants. To remedy these shortcomings, renewable energy sources appear to be an appropriate solution. They are inexhaustible on a human scale, require very little maintenance and are environmentally friendly. Among these sources, solar energy occupies a prominent place. A distinction is made between solar thermal energy and solar photovoltaic energy.

As part of its energy mix policy, Burkina Faso has built a photovoltaic solar power plant at Zagtoui, enabling it to reduce part of its energy deficit. The plant is a godsend in terms of diversifying sources of electricity production, as it contributes around 5% of national output. This is in line with the government's policy of supplying over 100 MW of solar energy to the national grid, or around 30% of national production by 2020 [1]. With its large solar energy potential (5.5 kWh/m²), Burkina Faso has a commodity whose exploitation will enable it to boost its development [1].

For this plant to reduce the cost per kilowatt-hour of electricity, it must be profitable. However, its production is hampered by factors such as the instability of the electricity grid and the untimely shutdown of certain inverters, in addition to natural factors such as intermittent sunshine and rising temperatures. These factors contributed to a reduction in the plant's performance.

Research has been carried out on grid-connected solar photovoltaic power plants.

Daha Hassan DAHER et al. worked on experimental performance monitoring of a solar photovoltaic power plant in Djibouti (2018). They evaluated the performance of a

300 kWp photovoltaic plant over two years and obtained an average value of 85%. This enabled them to produce a linear regression diagram to monitor this plant.

Michaël BRESSAN et al. worked on the development of a supervision and control tool for a solar photovoltaic installation (2014). They developed a monitoring system for photovoltaic installations. This enabled them to model these photovoltaic systems in normal and faulty operation, so they were able to develop different models of the I-V characteristic.

Aminata Pignon TRAORE et al. studied the development of an energy management and conversion unit for a PV/GE hybrid power plant based on a new product architecture (2015). They developed a new architecture for hybrid power plant cabinets using Off-Grid inverters.

Stéphane VIGHETTI et al. studied grid-connected photovoltaic systems: Selection and sizing of converter stages (2010). They experimentally developed two photovoltaic field topologies and improved them by inserting balancers.

The overall aim of this paper is to assess the impact of the Zagtouli power plant's operating conditions on energy production and grid injection, in order to improve the plant's performance. This will involve estimating and evaluating energy production, assessing the influence of the grid on the plant and calculating its performance.

2. MATERIALS AND METHOD

2.1. Zagtouli solar power plant

The Zagtouli solar photovoltaic power plant is located approximately 14 km west of Ouagadougou (latitude $12^{\circ} 18' 22''$ north, longitude $13^{\circ} 8' 15''$ west) along the Nationale N°1 in the direction of Bobo-Dioulasso.

It covers an area of 60 hectares (ha), with an installed capacity of 33.7 MW. The solar field comprises 129,600 260-Wp polycrystalline silicon photovoltaic modules, 1,800 structures of 72 modules in parallel, 5,400 strings of 24 modules in series, 466 DC combiner boxes and 16 CPI (Integrated Photovoltaic Center).



Figure 1 :Aerialview of the Zagtouli solar power plant.

2.2. Plant operation

From the solarfield, the DC (continuous) electrical output is routed to the junction boxes via 6 mm² conductors. In the junction boxes, each of the conductors passes through a fuse holder terminal block, then arrives at a terminal block wherethey are connected to a lightningconductorbeforecontinuing to a switch-disconnector.

From the junction boxes, thiscollectedenergy exits on two 185 mm² cables (positive, negative), and isthen sent to the CPI inverter via a set of busbars. The invertertransforms the direct current (DC) delivered by the PV modules intoalternatingcurrent (AC) from the power blocks. Its AC output (420 V) isconnected to the primary input of the 420 V/33 KV transformer. Eachinverterisfed by 14 or 15 junction boxes.

The energy at the HTA output on the secondaryside of the power transformer passes throughthree (3) cellsintegratedinto the CPI. These cellsform a system of three (3) loopswiththose of the otherCPIs. This energyisthentransmitted to the “outgoing” cells of the solarsubstation via “loopoutgoing” cells. All production is sent to the “Zagtouli substation” for injection into the power grid.

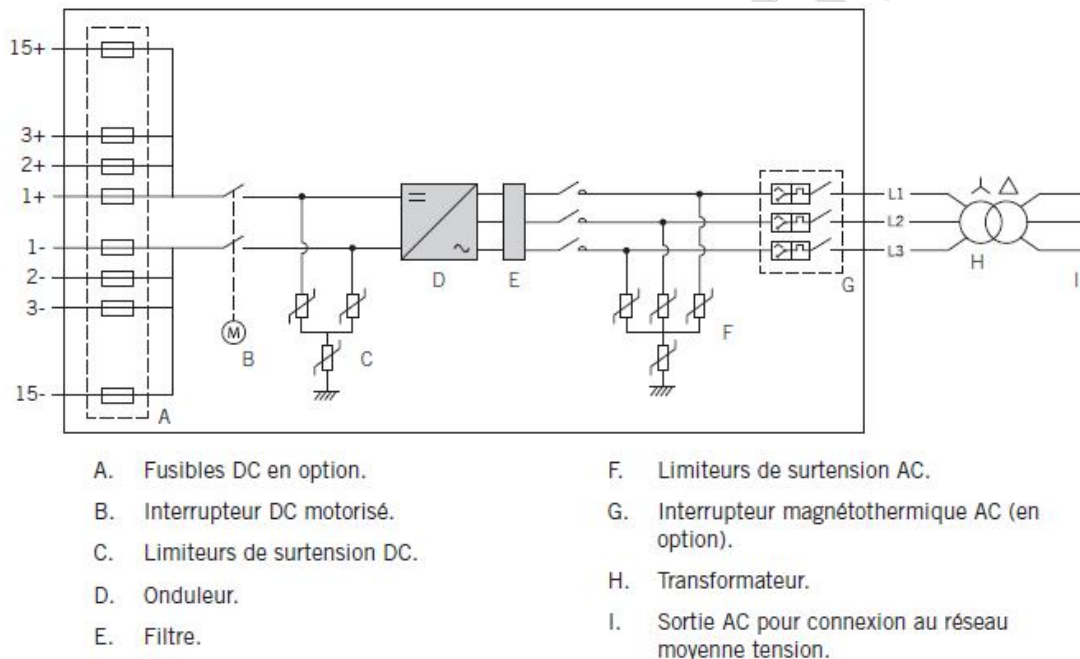


Figure 2: Electricaldiagram of the solarfield at the transformer outlet.

2.3. Determining performance

2.3.1. Estimating production

This is a production estimateprovided by PVGIS, a photovoltaic simulation software package. The software offerstwomethods for estimating the output of a photovoltaic installation. This method uses the following formula:

$$E_{th_1} = S * r * H * C_p \quad (1)$$

Where E_{th_1} is energy produced in Wh, S is the surface area of the photovoltaic field, r the module efficiency, H the radiation on the inclined surface in kWh/m², C_p loss coefficient (minimum 10% loss).

The main characteristic of a module is its peak power (power under standard STC conditions). Under these conditions, the module will produce electrical power equal to this peak power for N_e hours. The corresponding electrical energy is equal to the product of the peak power and the elapsed time, to the nearest loss coefficient :

$$E_{th_2} = P_c * C_p * N_e \quad (2)$$

With E_{th_2} the energy produced in Wh, P_c the peak power of the field in MW, N_e the number of equivalent hours of sunshine and C_p the loss coefficient.

2.3.2. Calculating the performance ratio

The Performance Ratio is the ratio of the actual yield to the theoretical yield of a photovoltaic system. It indicates how much energy is actually available, after deducting energy losses (thermal and conductivity losses) and operating consumption for power supply. It is one of the most important values for assessing the efficiency of a photovoltaic system. Its value is independent of the location measuring the quality of a photovoltaic system, and is also known as the quality factor.

The purpose of the performance ratio is to :

- Gather information on the energy yield and reliability of the photovoltaic system.
- Monitor the plant's condition over a long period.
- Compare the yields of different systems.

The formula for calculating the performance ratio is given in equation (2.1) [2] :

$$PR = \frac{E_{inj}}{E_{ray} * S * r} \quad (3)$$

With E_{inj} , the energy injected into the grid in one year (in MWh), E_{inj} the average annual solar radiation (in kWh/m²), S the generating area of the PV field (in m²), r the yield of the photovoltaic module (in %).

This calculation requires the following information :

- The observation period: this is optimal for one (1) year.
- Generating surface area: this is known.
- Module efficiency: this is shown on the panel data sheet.
- Energy injected into the grid in one year: this is read on the meter.
- Average solar radiation measured over one year.

3. RESULTS AND DISCUSSION

3.1. Estimated production

The data used for the first and second methods are shown in Tables 1 and 2 respectively.

Table 1: Data for the first method Table 2: Data for the second method

Data	Values	Data	Values
Surface area S (m ²)	189.236,736	Peak power P _c (MW _c)	33.696
Efficiency η_r (%)	15,51	Loss coefficient C _p (%)	90
Irradiance (kWh/m ²)	2140,06	Sunshine hours N _e (h)	2007,5
Loss factor C _p (%)	90		

These data have enabled us to obtain an annual estimate of the plant's production (Table 3).

Table 3 : Theoretical and actual values of Zagtouli's annual solar production.

Theoretical production (MWh)		Actual production (MWh)
First method (E _{th1})	Second method (E _{th2})	
56 531	60 892	55 560

The values obtained by these two methods are compared with the annual estimate made by the SCADA software used by CEGELEC. CEGELEC was the company in charge of the pilot operation of the Zagtouli plant, and planned to inject 55,600 MWh into the national grid, excluding local site consumption (lighting, video surveillance, alarm systems, etc.) [3]. This shows a better approximation with the first method. Figure 3 shows the comparative evolution between the two estimation methods and the plant's actual production.

As production started on February 16, 2018, the months of February 2018 and 2019 are added together to avoid showing half months.

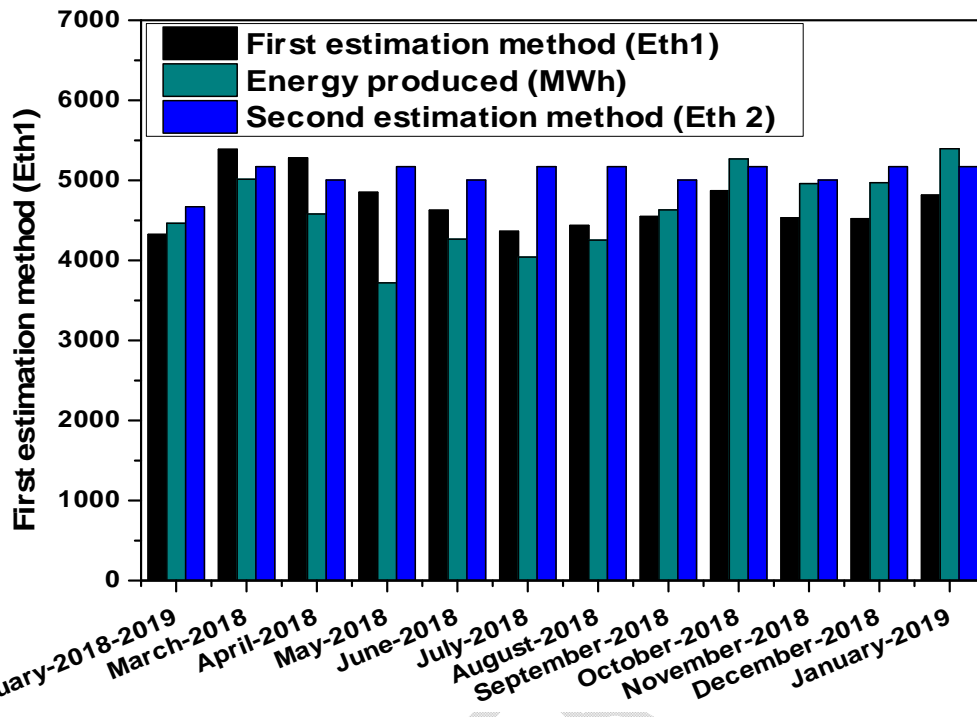


Figure 3: Comparative diagram of the two estimation methods and actual production.

3.2. Evaluation of production

Figure 4 shows the evolution of production as a function of insolation. It illustrates that there are other factors impacting the plant's production. Looking at the months of May and June, we see that May has more sunshine than June, yet its output is lower. The same applies to May - July, August, September, November, December and January. There's also a peak in sunshine in March (when it's very hot) and a peak in production in January (when it's cool). July and August are the least sunny months (cloudy period). The months of March, April and May should have seen the highest production, as they benefited from more sunshine. However, it was January and October that recorded the highest yields. Of course, we can also consider the influence of temperature, which is certainly high in March, April and May, but does not entirely justify this drop in production (April, May).

Figure 5 shows the evolution of power generated and injected into the grid. The PDL (Point De Livraison) meter measures power generated in megawatt-hours, while the CM (Centrale de Mesure) measures power injected into the grid in megawatt-hours. The two curves are very similar, showing that very little energy was lost between generation and grid injection. On average, 99.73% of the energy produced was injected into the grid.

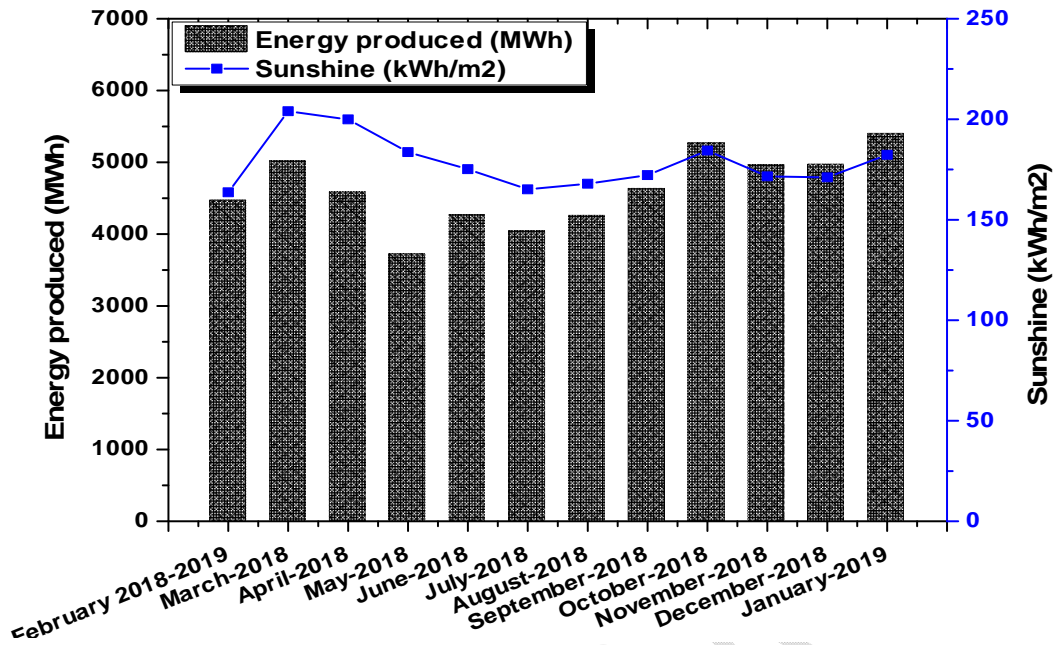


Figure 4: Production and solar radiation diagram.

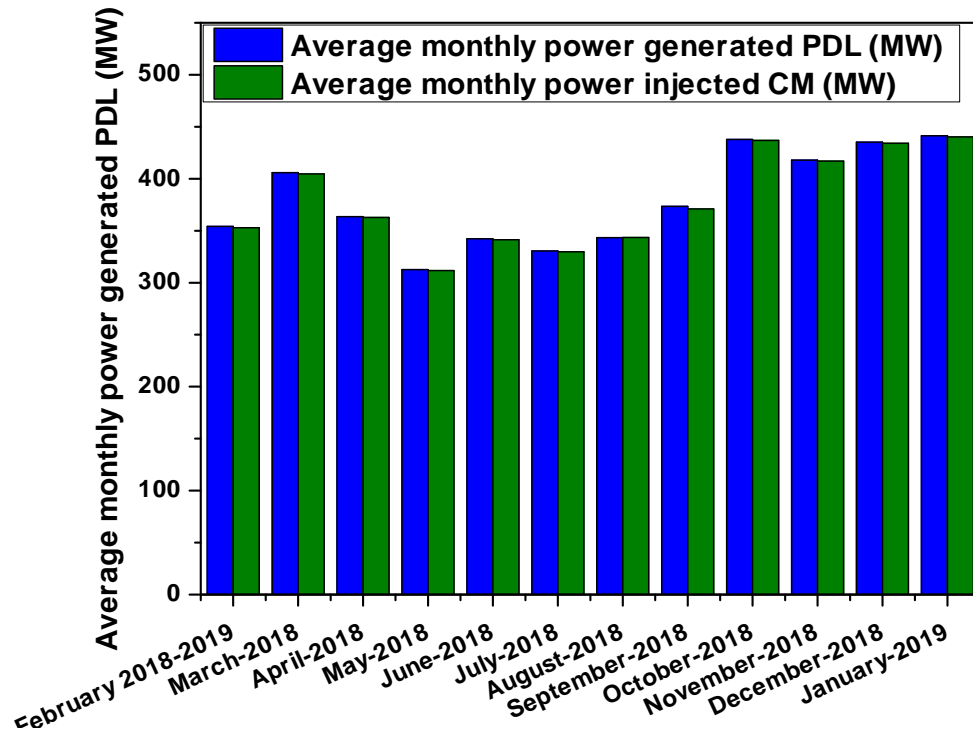


Figure 5: Diagram of average power generated and fed into the grid.

3.3. Influences of grid voltage and frequency

The integration of solar power plants into the electrical grid presents a number of constraints, such as voltage dips, to which inverters are sensitive, and upstream grid voltage losses caused by load shedding. These phenomena have a direct impact on the plant's productivity, reducing its output. In Burkina Faso, the permissible voltage margin is 33 KV +/- 10%, making it possible to couple solar power plants to the national grid.

For solar power plants, the frequency range to be respected to enable inverters to feed into the grid is 50Hz +/- 5%. Due to the intermittent nature of irradiation during the day, there are times when the grid may lose 10% to 40% of the power coming from solar power plants, which can lead to a drop in frequency. During periods of high sunshine and low consumption, solar power plants tend to increase the frequency of the grid, resulting in production instability. In short, with the insertion of solar power plants into the grid, frequency fluctuations are a common occurrence during load shedding. The following diagram shows the impact of tripping on production (Figure 6). A trip is the opening of the contacts of a circuit breaker to interrupt the electrical current in the event of an incident (overload, leakage of current to earth, or short-circuit) on an electrical circuit. In the case of the Zagtouli power plant, this occurs when the circuit-breaker on the "Zagtouli substation" side opens, bringing production to a halt due to the "absence of the grid". In fact, the power plant uses network inverters, which shut down automatically in the event of a "grid failure".

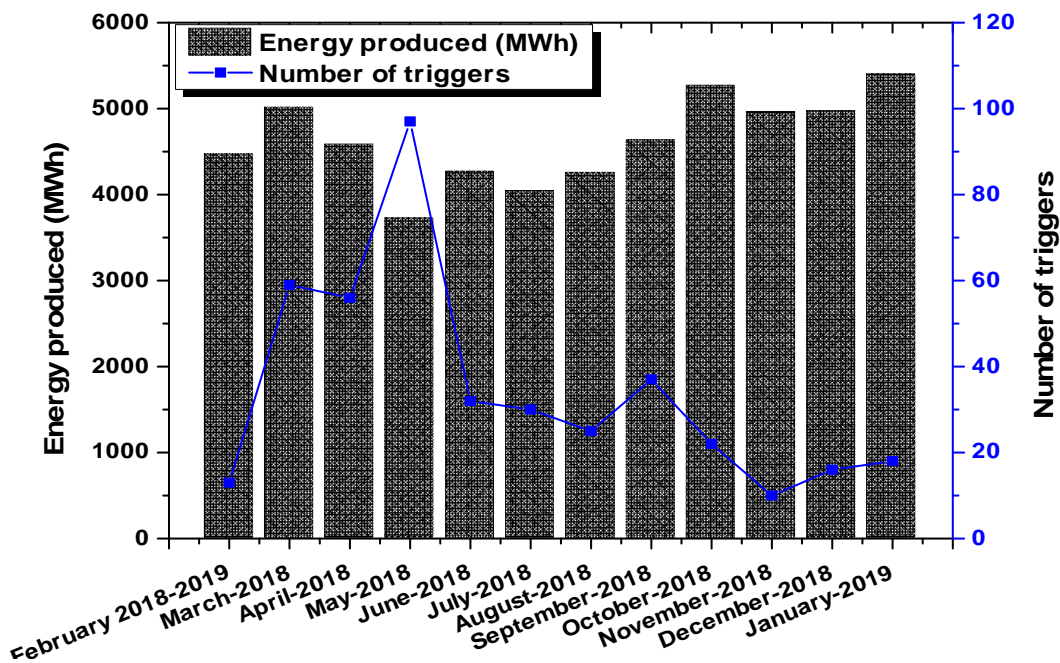


Figure 6: Production and tripping diagram.

3.4. Performance evaluation of the Zagtouli power plant

Figure 7 shows the evolution of the plant's performance. We can see that the best performances were achieved during the months of November, December and January. The drop in performance observed in March, April and May can be partly explained by tripping due to fluctuations in the grid (heat wave period). Apart from the amount of sunshine, tripping has a considerable impact on the power plant because it causes production to stop immediately. The performance ratio after one (1) year of operation is 88.21%. This value is characteristic of good performance under STC (Standard Test Condition) conditions. In fact, for ratio values above 80%, performance is said to be good, and for values below 70%, it is said to be poor [5].

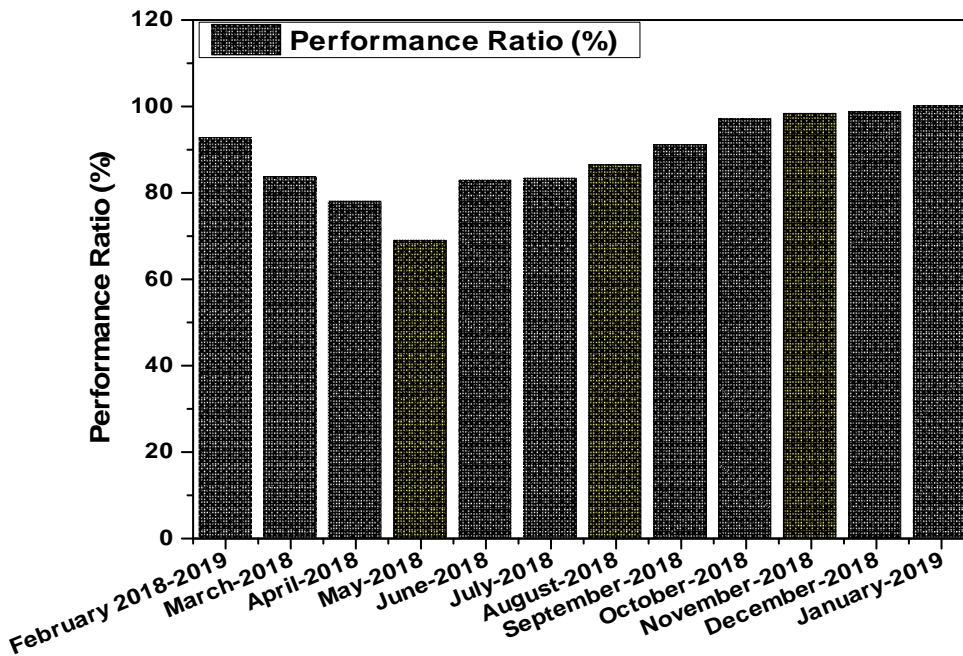


Figure 7: Performance diagram for the Zagtouli power plant.

CONCLUSION

After estimating and determining the energy production of the Zagtouli power plant, we assessed the impact of the electricity network.

We then calculated the plant's performance ratios. As an annual performance ratio, we obtained a value of 88.21%. We can therefore conclude that the performance of the Zagtouli plant is close to ideal. Grid instability was also identified as the factor that had the greatest impact on the performance of the Zagtouli solar power plant, as it was the source of the majority of tripping. In the plant's first year of operation, there were a total of 415 tripping events. The months most affected by these disruptions were March (59), April (56) and May (97). Most of these trips were due to the instability of the national interconnected electricity network. Nevertheless, the Zagtouli power plant made a considerable contribution to national production. At 55.4 GWh, it contributed around 5% of national output.

Table 4: Averagemonthly power generated and injected into the grid.

Month	Monthly insolation (h)	Averagedaily power output (MW)	PDL generated (MW)	Averagemonthly power generatedPDL (MW)	Averagedaily power injectedCM (MW)	Averagemonthly power injectedCM (MW)
February2018-2019	353	12,65	354,09	12,60	352,90	
March 2018	383	13,09	405,83	13,05	404,62	
April 2018	378	12,12	363,49	12,09	362,70	
May 2018	369	10,08	312,52	10,05	311,60	
June 2018	374	11,41	342,19	11,37	341,23	
July 2018	379	10,66	330,53	10,64	329,79	
August 2018	384	11,08	343,34	11,08	343,42	
September 2018	372	12,45	373,39	12,37	370,97	
October2018	373	14,12	437,82	14,09	436,83	
November 2018	356	13,93	417,89	13,90	416,88	
December 2018	354	14,04	435,23	14,00	434,00	
January 2019	379	14,23	441,28	14,20	440,22	
Total	4454	12,47	4553,08	12,44	4540,62	

Table 5: Triggers recorded from 16 February 2018 to 15 February 2019.

Period	Number of triggers
February 2018-2019	13
March 2018	59
April 2018	56
May 2018	97
June 2018	32
July 2018	30
August 2018	25
September 2018	37
October 2018	22
November 2018	10

December 2018	16
January 2019	18
Total	415

REFERENCES

[1]: Zagtouli photovoltaicsolar power plant: thisgigantic contribution presented to the populations of the Northernregion.

[2]:Technical information. SMA. Performance index. Quality factor for the photovoltaic installation.

[3]:Ingeteam (CEGELEC) TechnicalSheet.

[4]: ESPRIT. Connection of photovoltaic installations to the public low-voltage electricity distribution network. Regulatoryframework, impacts and recommendations. Page 45. April 2010.

[5]:Daha HASSAN DAHER. Experimental monitoring of the performance of a photovoltaicsolar power plant in Djibouti. Page 4. May 06, 2018. CIFEM2014-ART-17-67.

[6]: Thomas MAMBRINI. Characterization of photovoltaicsolar panels in real installation conditions and according to different technologies. Thesisdefended on 16/12/2014. Paris-sud University.

[7]: GHADA Bel Hadj Ali. Financingmethods for solarprojects in Tunisia. Grid-connectedphotovoltaic installations. Tunis, October 27, 2014.

[8]: Stéphane VIGHETTI. Grid-connectedphotovoltaicsystems:Choice and sizing of conversion stages. Engineering sciences [physics]. National Polytechnic Institute of Grenoble - INPG, 2010. French. Tel-00525110

[9]:Technical Application Document No. 10. Photovoltaic installations.

[10]:Dariga MEEKHUN. Realization of a system for converting and managing the energy of a system for poweringautonomouswireless sensor networks for aeronautical applications. University of Toulouse.

[11]: Zagtouli photovoltaicsolar power plant: thisgigantic contribution presented to the populations of the Northernregion.

[12]:Electricity production: Photovoltaicsolarenergy.

[13]:Statisticalyearbook 2016 of the Ministry of Energy. December 2017

[14]: SONABEL documents: Turnkey construction of the Zagtouli photovoltaic plant.

[15]: Michaël BRESSAN. Development of a supervision and control tool for a photovoltaicsolar installation. Electronics. University of Perpignan, 2014. French. <tel-01068025>.

[1]: Zagtouli photovoltaicsolar plant: thisgigantic contribution presented to the populations of the Northernregion.

[2]:Technical information. SMA. Performance index. Quality factor for the photovoltaic installation.

[3]:Ingeteam (CEGELEC) technicalsheet.

[4]: ESPRIT. Connection of photovoltaic installations to the public low-voltage electricity distribution network. Regulatoryframework, impacts and recommendations. Page 45. April 2010.

[5]:Daha HASSAN DAHER. Experimental monitoring of the performance of a photovoltaicsolar power plant in Djibouti. Page 4. May 06, 2018. CIFEM2014-ART-17-67.

[6]: Thomas MAMBRINI. Characterization of photovoltaicsolar panels in real installation conditions and according to different technologies. Thesisdefended on 12/16/2014. Paris-sud University.

[7]: GHADA Bel Hadj Ali. Financingmethods for solarprojects in Tunisia. Photovoltaic installations connected to the grid. Tunis, October 27, 2014.

[8]: Stéphane VIGHETTI. Photovoltaicsystemsconnected to the grid:Choice and sizing of conversion stages. Engineering sciences [physics]. National Polytechnic Institute of Grenoble - INPG, 2010. French. Tel-00525110

[9]:Technical Application Document No. 10. Photovoltaic installations.

[10]:Dariga MEEKHUN. Realization of a system for converting and managing the energy of a system for poweringautonomouswireless sensor networks for aeronautical applications. University of Toulouse.

[11]: Zagtouli photovoltaicsolar power plant: thisgigantic contribution presented to the populations of the Northernregion.

[12]:Electricity production: Photovoltaic Solar Energy.

[13]:StatisticalYearbook 2016 of the Ministry of Energy. December 2017

[14]: SONABEL Documents: Turnkey Construction of the Zagtouli Photovoltaic Power Plant.

[15]: Michaël BRESSAN. Development of a supervision and control tool for a photovoltaicsolar installation. Electronics. University of Perpignan, 2014. French. <tel-01068025>.