PERFORMANCE EVALUATION OF A 33.7 MW ZAGTOULI SOLAR PHOTOVOLTAIC POWER PLANT BY REDUCING LOSSES

ABSTRACT

Solar photovoltaic power plants connected to the electricitygridsuffer production losses due, on the one hand, to gridinstability and, on the other, to the quality of the installation. The general objective of thisworkis to improve the performance of a photovoltaic power plant by reducinglossesbetween production and energy injection into the grid. To achievethis, production wasestimatedusingtwocalculationmethods, in order to compare the prediction made by the operating company. The plant'sannual performance ratio wascalculated, with an estimated value of 88.21%. This value ischaracteristic of good performance according to the literature [5].

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

1. INTRODUCTION

Energy is an essential factor in a country'ssocio-economicdevelopment. Fossilenergy, long the preferred source of energy production, has proved to belimited by severalfactors, including the depletion of fossilresources and environmental pollution (pollutantemissions). Added to thisis the destruction of the ozone layer (greenhousegasemissions), and the upkeep and maintenance of generating plants. To remedytheseshortcomings, renewableenergy sources appear to be an appropriate solution. They are inexhaustible on a humanscale, requireverylittle maintenance and are environmentallyfriendly. Amongthese sources, solarenergyoccupies a prominent place. A distinction is made betweensolar thermal energy and solarphotovoltaicenergy.

As part of itsenergy mix policy, Burkina Faso has built a photovoltaicsolar power plant at Zagtouli, enablingit to reduce part of itsenergydeficit. The plant is a godsend in terms of diversifying sources of electricity production, as itcontributesaround 5% of national output. This is in line with the government'spolicy of supplying over 100 MW of solarenergy to the national grid, or around 30% of national production by 2020 [1]. Withits large solarenergypotential (5.5 kWh/m2), Burkina Faso has a commoditywhose exploitation will enable it to boost itsdevelopment [1].

For this plant to reduce the cost per kilowatt-hour of electricity, it must be profitable. However, its production ishampered by factorssuch as the instability of the electricitygrid and the untimelyshutdown of certain inverters, in addition to naturalfactorssuch as intermittent sunshine and risingtemperatures. Thesefactorscontributed to a reduction in the plant's performance.

Research has been carried out on grid-connectedsolarphotovoltaic power plants.

Youcef BOUMEHED et al worked on the experimentalevaluation of the performance of the 53 MW photovoltaicsolar power plant installed in the Djelfa region (2022). Theydemonstrated certain failures in the photovoltaic system and developedmathematicalmodels for calculating the operating characteristics of the Djelfa power plant by standard 61724 of the International Electrotechnical Commission (IEC).

Touahri TAHAR et al. worked on the study and sizing of an autonomousphotovoltaic system using the PVsyst software (22 March 2021). Theyworked on the sizing, simulation, evaluation and design of a stand-alonesolarphotovoltaic system in southwest Algeria.

IllatoufeghRhamar NASSER et al. worked on grid-connectedphotovoltaicsystemswith power regulation (2021). Theymodelled a photovoltaic system using Matlab simulink software and synchronisedthis model to the electricitygridusingwell-adapted power control.

Daha Hassan DAHER et al. worked on experimental performance monitoring of a solarphotovoltaic power plant in Djibouti (2018). Theyevaluated the performance of a 300 kWpphotovoltaic plant over twoyears and obtained an average value of 85%. This enabledthem to produce a linearregressiondiagram to monitor this plant.

Michaël BRESSAN et al. worked on the development of a supervision and control tool for a solarphotovoltaic installation (2014). Theydeveloped a monitoring system for photovoltaic installations. This enabledthem to model thesephotovoltaicsystems in normal and faultyoperation, sotheywere able to developdifferentmodels 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). Theydeveloped a new architecture for hybrid power plant cabinets using Off-Gridinverters.

Stéphane VIGHETTI et al. studiedgrid-connectedphotovoltaicsystems: Selection and sizing of converter stages (2010). Theyexperimentallydevelopedtwophotovoltaicfield topologies and improvedthem by insertingbalancers.

The originality of thiswork lies in the empirical use of estimation modelsfrom the PVGIS software and the calculation of the overall performance ratio of a photovoltaic power plant usingexperimental data.

The overallaim of thispaperis to assess the impact of the Zagtouli power plant's operating conditions on energy production and grid injection, to improve the plant's performance. This willinvolveestimating and evaluatingenergy production, assessing the influence of the grid on the plant and calculatingits performance.

2. MATERIALS AND METHOD

2.1. Zagtouli solar power plant

The Zagtouli solarphotovoltaic power plant islocatedapproximately 14 km west of Ouagadougou (latitude 12° 18' 22'' north, longitude 13° 8' 15'' west) along the Nationale Nº1 in the direction of Bobo-Dioulasso.

It covers an area of 60 hectares (ha), with an installedcapacity of 33.7 MW. The solarfield comprises 129,600 260-Wp polycrystallinesiliconphotovoltaic 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).

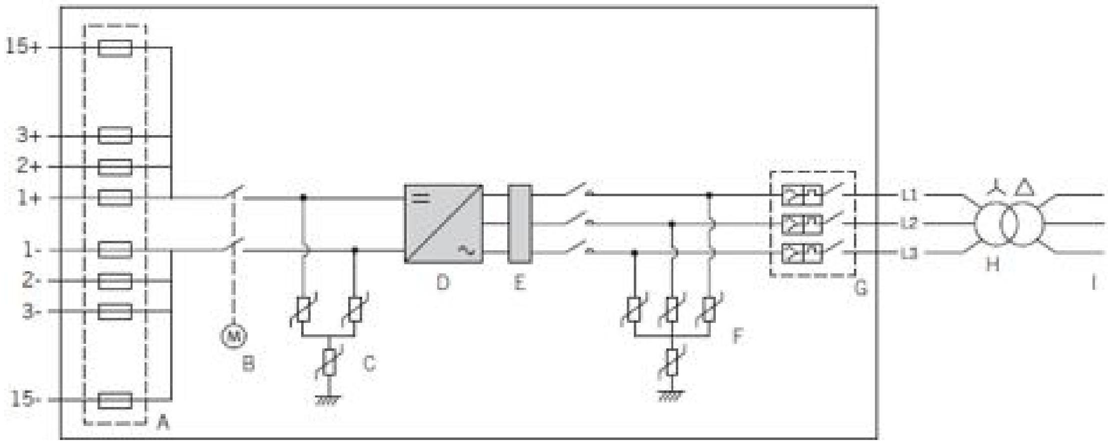
Figure 1 : Aerialview of the Zagtouli solar power plant.

2.2. Plant operation

From the solarfield, the DC (continuous) electrical output isrouted 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. Thesecellsform 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.



A. Optional DC fuses.
B. Motorised DC switch.
C. DC surgearresters.
D. Inverter.
E. Filter
F. AC surgearrester
G. AC thermal magnetic switch (optional)
H. Transformer
I. AC output for msainsconnection medium voltage

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:

$$E_{th_1} = S * r * H * C_P \qquad (1)$$

Where E_{th_1} isenergyproduced in Wh, *S*is the surface area of the photovoltaicfield, *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 isitspeak power (power under standard STC conditions). Under these conditions, the module willproduceelectrical power equal to thispeak power for Ne hours. The correspondingelectricalenergyisequal to the product of the peak power and the elapsed time, to the nearestloss coefficient :

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

With E_{th_2} theenergyproduced in Wh, P_c thepeak power of the field in MWc, N_e the number of equivalenthours of sunshine and C_p the loss coefficient.

2.3.2. Calculating the performance ratio

The Performance Ratio is the ratio of the actualyield to the theoreticalyield of a photovoltaic system. It indicates how muchenergyisactuallyavailable, afterdeductingenergylosses (thermal and conductivitylosses) and operating consumption for power supply. It is one of the most important values for assessing the efficiency of a photovoltaic system. Its value isindependent of the location measuring the quality of a photovoltaic system and isalsoknown as the quality factor.

The purpose of the performance ratio is to :

- Gather information on the energyyield and reliability of the photovoltaic system.
- Monitor the plant's condition over a long period.
- Compare the yields of differentsystems.

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

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

With E_{inj}, the energyinjectedinto the grid in one year (in MWh), E_{inj} the averageannualsolar radiation (in kWh/m2), S the generating area of the PV field (in m^2), r the yield of the photovoltaic module (in %).

This calculationrequires the following information :

- The observation period:thisis optimal for one (1) year.
- Generating surface area:thisisknown.
- Module efficiency:thisisshown on the panel datasheet.
- Energy injectedinto the grid in one year:thisisread on the meter.
- Averagesolar 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

Data	Values
Surface area S (m^2)	189.236,736
Efficiency$r$ (%)	15,51
Irradiance (kWh/m^2)	2140,06
Loss factor C_p (%)	90

Table 2: Data for the second method

Data	Values
Peak power P_c (MWc)	33.696
Loss coefficient C_p (%)	90
Sunshine hours N_e (h)	2007,5

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

Table 3 : Theoretical and actual values of Zagtouli'sannualsolar production.

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

The values obtained by thesetwomethods are comparedwith the annualestimate 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, alarmsystems, etc.) [3]. This shows a better approximation than the first method. Figure 3 shows the comparative evolutionbetween the two estimation methods and the plant'sactual production.

As production started on February 16, 2018, the months of February 2018 and 2019 areaddedtogether to avoidshowinghalfmonths.

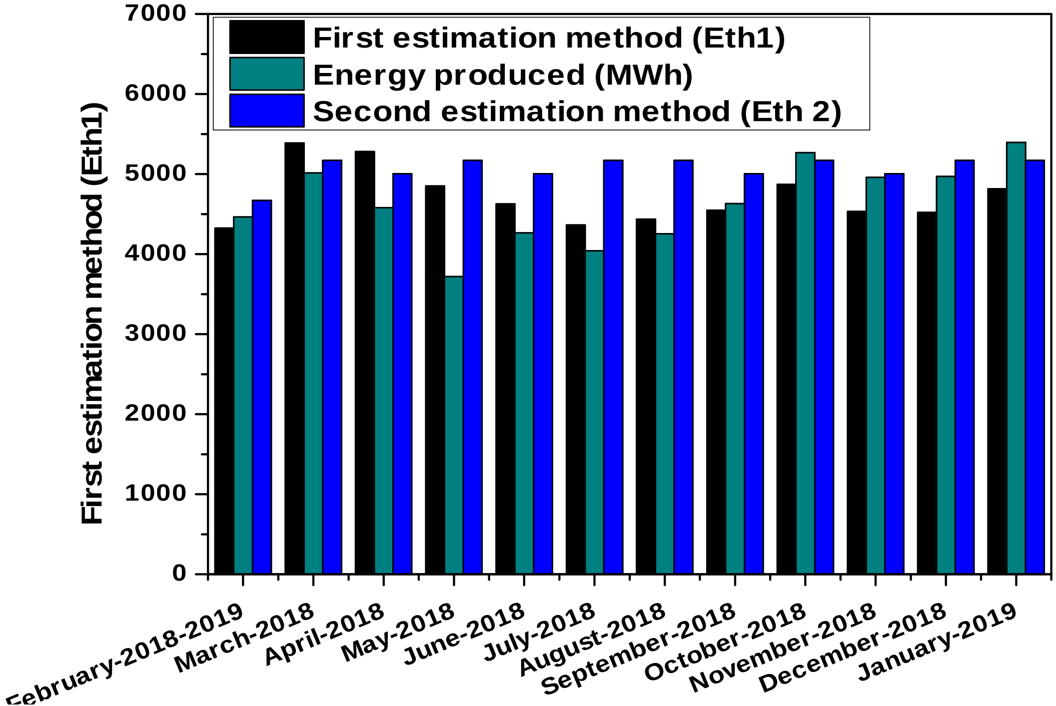


Figure 3: Comparative diagram of the two estimation methods and actual production.

3.2. Evaluation of production

Figure 4 shows the evolution of production as a function of insolation. It illustratesthatthere are otherfactorsimpacting the plant's production. Looking at May and June, weseethat May has more sunshinethan June, yetits output islower. The sameapplies to May - July, August, September, November, December and January. There'salso a peak in sunshine in March (whenit'svery hot) and a peak in production in January (whenit's cool). July and August are the least sunnymonths (cloudyperiod). The months of March, April and May should have seen the highest production, as theybenefitedfrom more sunshine. However, itwasJanuary and Octoberthatrecorded the highestyields. Of course, we can alsoconsider the influence of temperature, whichiscertainly high in March, April and May, but does not entirelyjustifythis drop in production (April, May).

Figure 5 shows the evolution of power generated and injectedinto the grid. The PDL (Point De Livraison) metermeasures power generated in megawatt-hours, while the CM (Centrale deMesure) measures power injectedinto the grid in megawatt-hours. The twocurves are verysimilar, showingthatverylittleenergywaslostbetweengeneration and grid injection. On average, 99.73% of the energyproducedwasinjectedinto the grid.

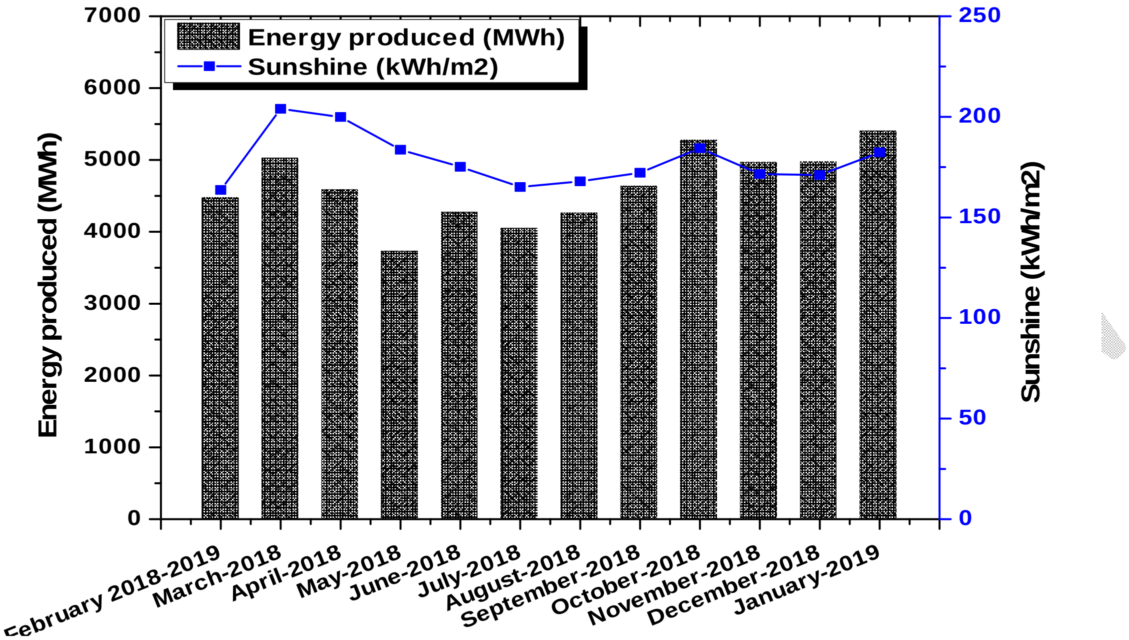


Figure 4: Production and solar radiation diagram.

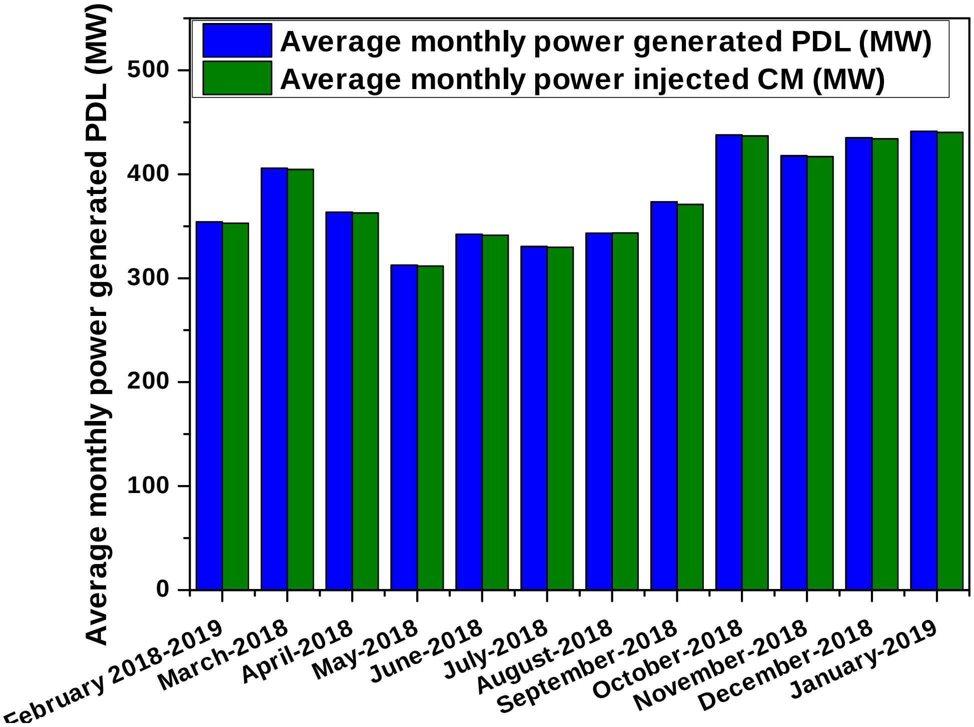


Figure 5: Diagram of average power generated and fedinto the grid.

3.3. Influences of grid voltage and frequency

The integration of solar power plants into the electricalgridpresentsseveralconstraints, such as voltage dips, to whichinverters are sensitive, and upstreamgrid voltage lossescaused by loadshedding. Thesephenomena have a direct impact on the plant'sproductivity, reducingits output. In Burkina Faso, the permissible voltage marginis 33 KV +/- 10%, makingit possible to couple solar power plants to the national grid.

For solar power plants, the frequency range to berespected to enable inverters to feedinto the gridis 50Hz +/- 5%. Due to the intermittent nature of irradiation during the day, there are times when the gridmay lose 10% to 40% of the power comingfromsolar power plants, which can lead to a drop in frequency. Duringperiods of high sunshine and lowconsumption, 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 duringloadshedding. The followingdiagram shows the impact of tripping on production (Figure 6). A trip is the opening of the contacts of a circuit breaker to interrupt the electricalcurrent 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, thisoccurswhen 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, whichshut down automatically in the event of a "gridfailure".

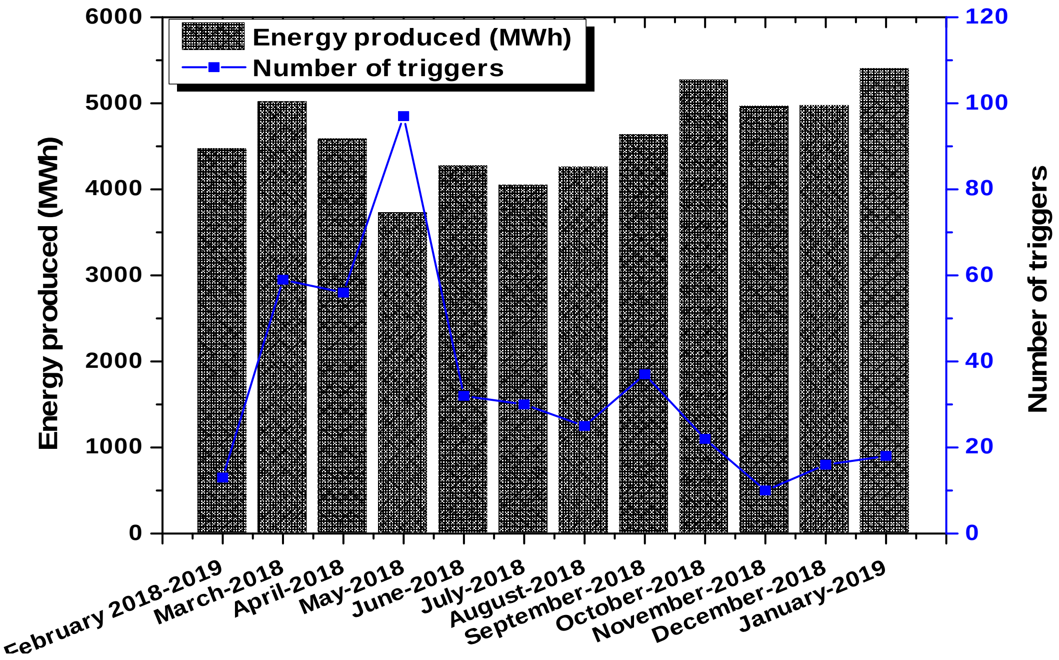


Figure 6: Production and trippingdiagram.

3.4. Performance evaluation of the Zagtouli power plant

Figure 7 shows the evolution of the plant's performance. We can seethat the best performances wereachievedduringNovember, December and January. The drop in performance observed in

March, April and May can bepartlyexplained by tripping due to fluctuations in the grid (heatwaveperiod). Apart from the amount of sunshine, tripping has a considerable impact on the power plant becauseit causes production to stop immediately. The performance ratio after one (1) year of operationis 88.21%. This value ischaracteristic of good performance under STC (Standard Test Condition) conditions. In fact, for ratio values above 80%, performance issaid to be good, and for values below 70%, itissaid to bepoor [5].

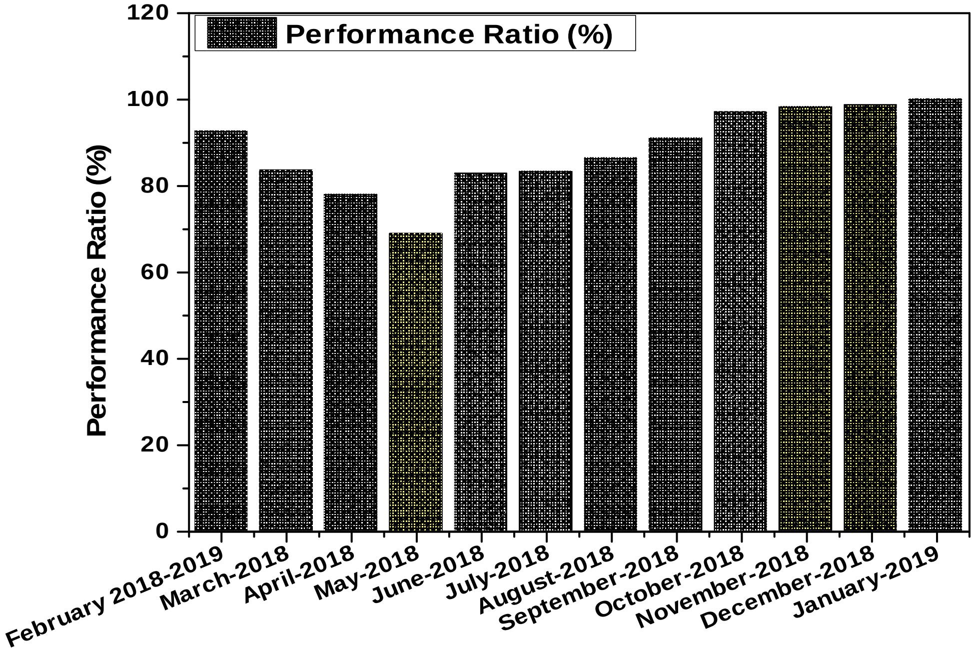


Figure 7: Performance diagram for the Zagtouli power plant.

CONCLUSION

Afterestimating and determining the energy production of the Zagtouli power plant, iassessed the impact of the electricity network. Ithencalculated the plant's performance ratios. As an annual performance ratio, iobtained a value of 88.21%. i can thereforeconcludethat the performance of the Zagtouli plant is close to ideal. Gridinstabilitywasalsoidentified as the factor thathad the greatest impact on the performance of the Zagtouli solar power plant, as itwas the source of the majority of tripping. In the plant's first year of operation, therewere a total of 415 trippingevents. The monthsmostaffected by these disruptions were March (59), April (56) and May (97). Most of these trips were due to the instability of the national interconnectedelectricity network. Nevertheless, the Zagtouli power plant made a considerable contribution to national production. At 55.4 GWh, itcontributedaround 5% of national output.

This work enables SONABEL to see the impact of the conditions underwhich the Zagtouli powerstation'senergy production isused, enablingthem to reduce power losses by taking palliative measures. The scientific contribution of thisworkis not only the empirical use of the estimation modelsprovided by the PVgis software but also the calculation of the overall performance ratio of a 33 MWpsolarphotovoltaic power plant, usingexperimental data.

Table 4: Averagemonthly power generated and injectedinto the grid.

Month	Monthly insolation (h)	Averagedaily power output PDL (MW)	Averagemonthly power generated PDL (MW)	Averagedaily power injected CM (MW)	Averagemonthly power injected CM (MW)
February 2018-2019	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 recordedfrom 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

Authors’ contributions

Thiswascarried out in collaboration among all authors. All authorsreed and approved the final manuscript

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declaredthat no competinginterestsexist.

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