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RESEARCH ARTICLE

ANALYSIS OF ELECTRICAL DISTURBANCES ON THE OPERATION OF THE 7 MW PHOTOVOLTAIC SOLAR POWER PLANT CONNECTED TO THE MALBAZA ELECTRICITY GRID (NIGER)

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Abstract

To increase the country's energy production, the State of Niger has built a 7MW photovoltaic solar power plant connected to the grid of the Nigerien electricity company in the department of Malbaza, Tahoua region (13^0 58'3.54 "North and $5^0$31'11.95 " East). In order to optimize the energy production of this plant, a study of electrical disturbances on the operation of the photovoltaic system has been conducted in this article. This was based on data on energy production as a function of irradiation and temperature, and electrical disturbances that caused a malfunction of the plant from January 1, 2019 to December 31, 2019. This analysis showed that, for an expected annual operating time of 4300.47hours, the solar plant operated normally at 95.37%. The remaining 4.43% comes from a disturbed regime linked to the grid (3.93%) and the solar power plant (0.7%). It has also been shown that the grid disturbances that caused the malfunction of the solar power plant are outages (83.02%), voltage fluctuations (8.03%), voltage dips (7.9%) and overvoltages (1.05%). At the solar power plant, two types of disturbances were recorded, including power failures (99.49%) and earth faults following current leaks (0.51%). Thus, the average annual availability of the grid is 95.58% and that of the power plant is 99.26%. The various results finally showed that apart from irradiation and temperature, grid availability is also a very important parameter to take into account in the energy production of a grid-connected photovoltaic system.

Introduction:-

In a rapidly changing global energy context marked by a decrease in conventional fossil fuel resources and constantly growing greenhouse gas emissions, the use of renewable energies remains among the essential solutions to limit the effects of the activity human rights on global warming.

Of all the renewable energies, solar photovoltaic (PV) is of particular interest to Africa, since it has a significant solar source [1]. Nowadays, solar photovoltaic plants are developing at a rapid pace and have reached a technical maturity that allows them to become an important segment of industry and energy.

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Niger, a vast landlocked country in the Sahel, has an important solar resource. Sunshine is indeed characterized by an average duration of 8.5 hours per day and an average estimated level in the range 5 - 7 kW / m^2 / day.

Thus, to improve the country's energy production, the Nigerien authorities have thought about developing photovoltaic solar power plants. It is in this context that comes the construction project of a 7MW photovoltaic solar power plant connected to the electricity grid in Malbaza, which was commissioned in November 2018.

On the one hand, the connection of PV systems to the public electricity grid can have some impacts on: the change in power flows (bidirectional), the voltage plan, the protection plan, the quality of the energy, the planning of the network…
And on the other hand, the characteristics, operation and disturbances on the utility grid can influence the operation of PV systems [2].

This article aims to analyze the phenomena that disrupt the operation of this solar power plant. To do this, we will first review the literature on the electrical disturbances of a PV system connected to the grid and secondly present the materials and the method used to assess these disturbances on the 7MWp solar power plant of Malbazal; and finally present the results and discuss them.

Background :
Disruptions to the operation of grid-connected solar photovoltaic plants originate on the one hand from the electricity grid and on the other hand from the PV plants themselves.

Influence of the grid on PV plants: Disturbances on the grid strongly influence the operation of solar photovoltaic power plants. The phenomena at the origin of these disturbances are numerous and multifaceted. They generally come either from the intrinsic characteristics of distribution networks, or from the quality of the voltage degraded by other network users (consumers or producers), or from a combination of these two causes. These effects generally lead to unjustified decoupling of the inverters [3]. The most common disturbances are:

1. Voltage variations and slow voltage fluctuations: Voltage variations are variations in the peak value of amplitude less than 10% of the nominal voltage and voltage fluctuations are a series of voltage variations or cyclical or random variations of the envelope voltage whose characteristics are the frequency of the variation and the amplitude. The voltage is amplitude modulated by an envelope whose frequency is between 0.5 and 25 Hz[4] [5].Slow voltage variations are caused by the slow variation of the loads connected to the grid. Voltage fluctuations are mainly due to rapidly varying industrial loads such as welding machines, arc furnaces,… [4] [5].Their influences on the operation of the PV plant depend on the initial level of grid voltage, the operation of the inverter and the type of decoupling protection;
2. Voltage dips and blackouts: A voltage dip is a sudden drop in voltage at a point in an electrical power network, to a value between 10% and 90% followed by a recovery of the voltage after a short period of time ranging from 10 ms within seconds. The blackouts represent a particular case of voltage dips greater than 90% of the nominal voltage or total disappearance for a period generally between 10 ms and one minute for short cuts and greater than one minute for long blackouts. Voltage dips are associated with faults occurring on the grid, such as lightning strike of a grid structure or the contact of a tree with the line. However, they can be caused by sudden variations in the loads connected to the network as well as by inrush currents when transformers are energized and when motors are started [4] [7] [8]. A brief blackouts can usually be caused by a short circuit occurring in the network. This type of anomaly is characterized by its duration, which depends on the operating time of the protection devices. Interruptions are sometimes preceded by a voltage dip in the event of a fault occurring on the power source [4] [7] [8].Voltage dips are considered the most serious disturbances to quality of service due to their effects on sensitive processes. Their depth and duration vary depending on the characteristics of the network and the production groups connected to it [3]. The ≪ DIN VDE 0126 ≫ standard requires inverters to disconnect in less than 200 ms if the voltage drops below the threshold of 80% of the nominal voltage Un [3]. However, tests to determine the sensitivity of inverters to voltage dips, carried out within the framework of the European DISPOWER project on 12 PV inverters conforming to DIN VDE 0126, have shown that several inverters decouple for U = 85% Un and in all cases for times much less than 200 ms[3] [10]. This shows the great sensitivity of these inverters to voltage dips. Voltage dips are therefore one of the main causes of tripping of PV systems. Disconnecting a large number of PV systems could generally have local and global impacts on grid operation, especially on weak grids [3];

3. Overvoltages: Overvoltages are increases in the voltage amplitude from 1.1 pu to 1.8 pu. they are less frequent compared to voltage dips and are generally due to short circuits in isolated neutral systems [56] [75].In the event of a single-phase short-circuit in such a system, the two phases not affected by the fault can take a value up to 1.73 pu, ie the line voltage. In the event of a two-phase short-circuit, the phase not affected by the fault is characterized by an overvoltage that can go up to 1.5 pu [56] [75].The consequences of overvoltages are very diverse depending on the application time, the repetitiveness of the amplitude, the mode (common or differential), the stiffness of the rising edge and the frequency [56] [138]. They most often lead to a decoupling of the inverters from the network.
4. Influence of photovoltaic systems on the distribution network: In the past, distribution networks behaved like passive elements in which the power flows flow unidirectionally from the source substation to the end consumers. Due to the inclusion of decentralized production, power flows and voltages are impacted not only by loads but also by sources. In view of these technical specificities of photovoltaic installations, the connection of PV systems to the grid can have significant impacts on its operation [3] [4] [11]. The most significant influences of PV systems on the distribution grid are:
5. Influence on the voltage plane: The presence of PV generators has an influence on the voltage plan and on the grid control devices. The voltage generally varies according to the injections of active and reactive power on the network [3] [4] [11] [12]. In particular during a period of strong sunshine and low consumption, the voltage of certain nodes of the network may exceed the admissible threshold [3] [4].In addition, varying solar irradiance causes fluctuation of PV power, thus implying fluctuation of local voltage [13].A study conducted by the Tokyo University of Agriculture and Technology on some 550 PV installations in the locality of Ota City, showed that the injection of energy into the grid increases the voltage to a threshold causing the decoupling of certain systems; especially at the end of the week when consumption is low [3] [12];
6. Influence on the protection plan: The contribution of PV systems to the fault current in the distribution network has low consequences on the protection level. However, the selectivity and the sensitivity of the network protections can be affected and cause unwanted tripping of the healthy feeder or blindness of the faulty feeder protection.Withtransformerless type inverters connected to the grid in neutral mode, a leakage current can be created and flow between the capacitance (of the PV panel and filter) and the earth. If the value of this leakage current reaches the differential protection threshold, a PV cut could occur [13] [14].Also, in the event of a short-circuit on the network, the current from the latter supplied by the PV system can interfere with the detection of the fault by the protection devices provided on the network. Therefore, it is necessary to propose coordination strategies for the different protections - network, PV and consumption to ensure the correct operation of the short-circuit protections [13];
7. Influence on the quality of Energy: Grid-connected PV systems can cause harmonic current injection, direct current injection into the grid, or phase imbalance. The presence of an electronic power interface can inject chopping harmonics into the network if the inverters are not equipped with effective filters. The consequences of these harmonics can be instantaneous on certain electronic devices: functional disturbances (synchronization, switching), untimely tripping, measurement errors on energy meters [3] [4]. A study carried out in Spain shows that current inverters (with high frequency transformer and with or without low frequency transformer) on the European market inject a DC component into the network [3] [15]. The presence of DC currents in distribution networks can affect the correct operation of differential switching devices, create errors on energy meters, affect the service life of network components, in particular through an increase in their corrosion and finally, contribute to the saturation of transformers [3]. The insertion of PV systems can also cause phase imbalance when using single phase inverters. If the power produced is not properly distributed between the 3 phases of the same three-phase PV system, then this system will contribute to unbalance the LV network. This phenomenon has been demonstrated in several studies [3] [16] [17].

Materials and Methods:-

Location of the Malbazaphotovoltaicsolar power plant site :Locatedat a latitude of 130 58'3.54"North and a longitude 5^{0}31'11.95" East, the photovoltaicsolar power plant islocated in the department of Malbaza (Tahoua region), about 455 km from Niamey, capital of Niger. The elevation of the site is 325 meters and thereis no significantdifference in the level of the groundacross the area. It is a 7MW photovoltaicsolar power plant connected to the public electricitygrid. The studied site covers an area of 11 ha and islocatedata distance of 1.4 km from the connection station. The installation area of the power plant is as defined in figure 1 below.

Figure 1:- Location of the Malbaza solar power plant.

Presentation of the Malbazasolar power plant : The control unit is made up of 21,231 identical modules which have the followingcharacteristics:

1. Maximum nominal power (Nominal Maximum Power): 330Wc;
2. Open Circuit Voltage: 45.6V;
3. Short Circuit Current: 9.65A;
4. Voltage at nominal power (Voltage at Maximum Power): 36V;
5. Currentat Maximum Power: 9.17A.

These modules are groupedtogether in series of 21 modules to form a " string" (row). These strings are distributed in junction boxes called "String Conbiner Box (SCB)". 1MW unit capacity central inverters (see figure above) are used to convert direct currentfromSCBs to alternatingcurrents. Eachinverter has a mini step-down chopperconverterwith a controller to extract the Maximum Power and to adapt the output voltage of the strings to the input of the inverter. The inverterssupply an alternating voltage of 400V AC. The inverters are installed in conditionedcentenarians. Transformers are used to increase the voltage from 400V AC to 20,000V AC. A total of four (4) transformersincludingthree of 2.2 MVA and one of 1.1 are used. The 2.2 MVA transformerseach have two 400V inputs and one 20000V output and are eachpowered by twoinverters and the 1.1MVA one has a single input and a single output and ispowered by a single inverter. These four transformers are thencoupled in paralleltwo by two by Ring Main Unit (RMU). The output of theseRMUsisthencoupled in parallel on a 20kV busbar to injectenergyinto the network througha 20kV line of 2km long provided for thispurpose. As the 400V busbars are not accessible, a 20kV / 0.4 250kVA auxiliary transformer isused to supply the auxiliaryloads.

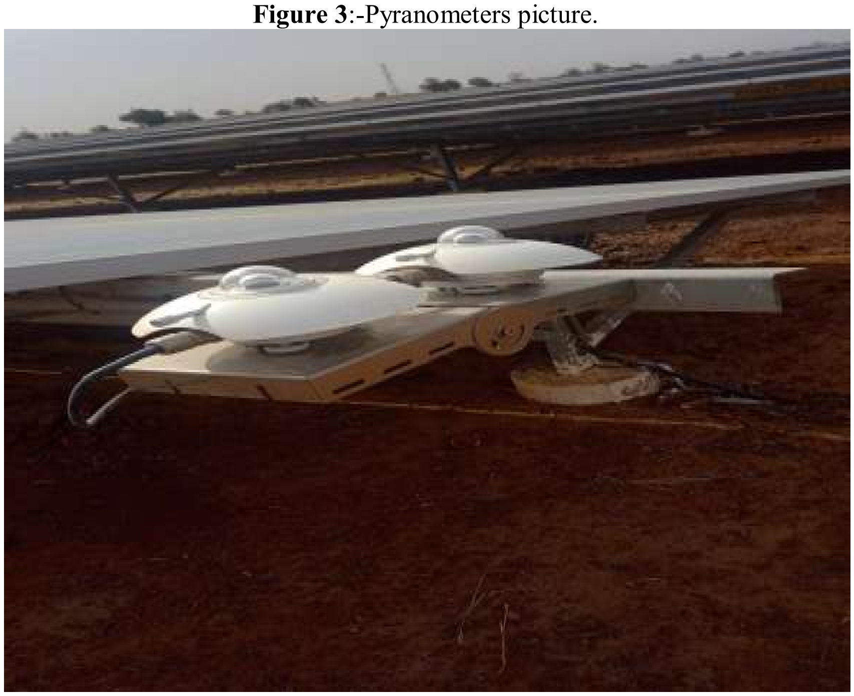
Measuringequipment: Notwithstanding the current and voltage transformers for current and voltage measurements, the site has a measuring station made up of:

1. twopyrometers: one for measuring the global radiation on the inclined plane of the modules and the other for measuring the global radiation on the horizontal plane;
2. twothermometers for measuring the ambienttemperature and the temperature of the modules;
3. ahygrometer for measuringhumidity;
4. aHeliometer for measuringwind speed;
5. apluviometer for measuringrainfall.

The photos of the measurement site are shown in Figures 2 and 3.

Figure 2:- Measuring station.

Figure 3:-Pyranometers picture.



These measuring and control devices allow all parameters of the solar power plant to be monitored from the control room. All of these parameters (electrical and metrological) are recorded by SCADA (Supervisory Control and Data Acquisition) and are accessible from the control room server. The method used to analyze the electrical disturbances on the power plant consists first of all in recording, through the SCADA, the various disturbances that have caused the disconnection of the inverters from the grid or the shutdown of the system, as well as their durations from January 1, 2019 to December 31, 2019. These disturbances will then be classified according to their origin whether they come from the grid or from the solar power plant itself. Finally, we calculate the technical availability of the plant and the network. Technical Availability is the parameter that represents the time during which the plant operates out of the total possible time during which it is able to operate, without taking into account the exclusion factors. The total possible time is considered to be the moment when the plant is exposed to irradiation levels above the Minimum Irradiance Threshold of the generator. It is raised through the SCADA. The Technical Availability is thus defined and calculated as follows [18]:

$$A_t = \frac{T_u - T_{down}}{T_u}.100$$

with:

A_t = Technical availability (Uptime) in percentage;

T_u = Period of time with irradiation in the plane of the modules above the Minimum irradiance Threshold in hours;

T_{down} = Period from T_{utile} when the system is down (no production) in hours.

Results and Interpretations:-

Table 1:- Electrical disturbances at the power plant for the year 2019.

The electrical disturbances that caused a malfunction of the solar power plant from January 1 to December 31 are summarized in table 1 below:

Table 2:- Monthly technical availability and energy production in 2019.

Month	Duration of disturbances from the grid				grid downtime	Disturbance from the plant		Duration of plant unavailability
	Total duration of cuts	Total duration of abnormal fluctuations	Total duration of overvoltage	Total duration of undervoltage		Total duration of earth faults	Total duration of power outages	
january-19	6h07mn00s	00h00mn00s	00h00mn00s	00h00mn00s	6h07mn00s	00h00mn00s	00h7mn12s	00h07mn12s
february-19	2h47mn00s	1h12mn00s	00h00mn00s	00h00mn00s	3h59mn00s	00h00mn00s	00h00mn00s	00h00mn00s
March-19	50h30mn00s	00h49mn00s	10mn00s	00h10mn00s	51h39mn00s	00h00mn00s	00h00mn00s	00h00mn00s
april-19	23h14mn00s	00h12mn00s	00h16mn00s	00h36mn00s	24h18mn00s	00h4mn09s	00h00mn00s	00h04mn09s
May-19	9h19mn00s	00h46mn00s	00h10mn00s	12h10mn00s	22h25mn00s	00h00mn00s	00h00mn00s	00h00mn00s
june-19	8h25mn00s	1h23mn00s	00h00mn00s	00h20mn00s	10h08mn00s	00h00mn00s	00h00mn00s	00h00mn00s
july-19	5h01mn00s	00h25mn00s	00h00mn00s	00h05mn00s	5h31mn00s	00h5mn08s	00h00mn00s	00h5mn08s
August-19	7h40mn00s	1h05mn00s	00h00mn00s	00h00mn00s	8h45mn00s	00h00mn00s	00h00mn00s	0h00mn00s
september-19	04h37mn00s	02h16mn00s	00h44mn00s	00h00mn00s	**07h37mn00s**	00h00mn00s	00h00mn00s	**0h00mn00s**
October-19	06h24mn00s	03h19mn00s	00h16mn00s	00h00mn00s	**9h59mn00s**	00h00mn00s	00h00mn00s	**0h00mn00s**
november-19	03h14mn00s	01h07mn00s	00h00mn00s	00h00mn00s	04h21mn00s	00h00mn00s	00h00mn00s	**0h00mn00s**
december-19	12h54mn00s	01h00mn00s	00h10mn00s	00h00mn00s	14h04mn00s	00h00mn00s	29h57mn12s	29h57mn12s
annual values	140h12mn00s	13h34mn00s	1h46mn00s	13h21mn00s	168h53mn00s	00h09mn17s	30h04mn24s	30h13mn41s

The calculations of the monthly availability of the network and the solar power plant for the year 2019 as well as the energy production according to the irradiation and the temperature are summarized in Table 2 below:

1. analysis of the operation of the solar power plant: The analysis of the power plant's electrical disturbances for the year 2019 made it possible to draw the functional graph of the plant shown in Figure 5 below:

Month	Normal operating time	Duration of grid unavailability	Duration of plant unavailability	Grid availability	Plant availability	production (MWh)	Irradiation on the modules (KWh/m^2)	Average ambient temperature (° C)
january-19	347h00mn00s	6h07mn00s	00h07mn12s	98.38 %	99.97 %	1101.7	196.29	26.93
february-19	320h49mn00s	3h59mn00s	00h00mn00s	98.76 %	100.00%	1064.4	187.54	28.3
March-19	364h52mn12s	51h39mn00s	00h00mn00s	85.85 %	100.00%	993.6	179.58	45.42
april-19	364h46mn00s	24h18mn00s	00h04mn09s	92.89 %	99.98 %	998	184.47	37.72
May-19	385h9mn00s	22h25mn00s	00h00mn00s	87.91 %	100.00%	888.1	161.77	46.67
june-19	373h16mn48s	10h08mn00s	00h00mn00s	97.30 %	100.00%	1007.7	181.74	33.1
july-19	383h51mn00s	5h31mn00s	00h5mn08s	98.56 %	99.98 %	987.9	180.75	30.82
August-19	374h19mn48s	8h45mn00s	0h00mn00s	97.64 %	100.00%	861.7	153.94	28.7
september-19	354h27mn00s	07h37mn00s	0h00mn00s	97.85 %	100.00%	1011.1	184.46	31.28
October-19	355h10mn48s	9h59mn00s	0h00mn00s	97.17 %	100.00%	1015.20	183.50	31.79
november-19	332h09mn00s	04h21mn00s	0h00mn00s	98.71 %	100.00%	1081	196.69	33.44
december-19	344h37mn48	14h04mn00s	29h57mn12s	95.88 %	91.25 %	989	195.52	37.87
annual values	4300h28mn12s	168h53mn00s	30h13mn41s	95.58 %	99.26 %	11998.8	2186.2453	34.3365

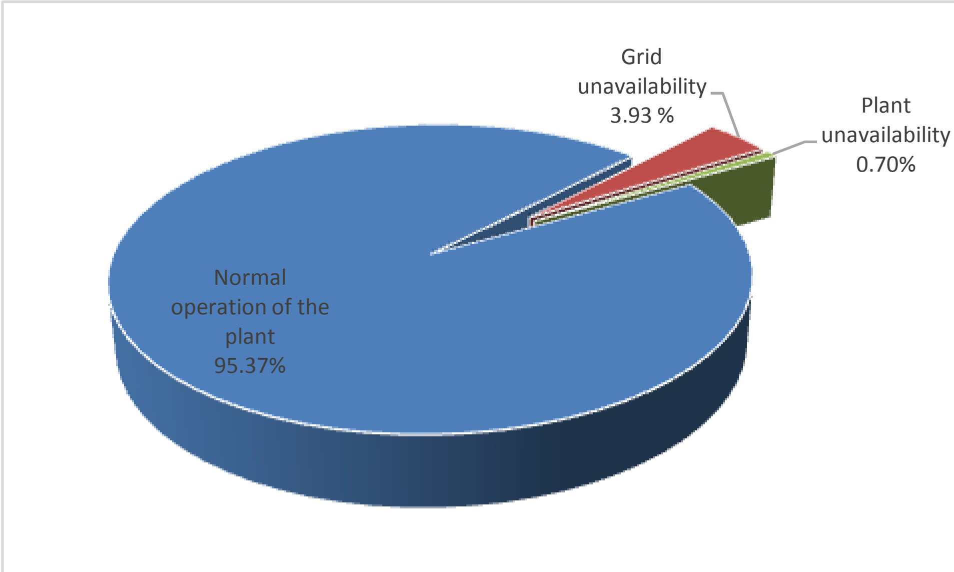


Figure 5:- Functional graph of the solar power plant.

We note that for a total operating time of 4300h28mn12s, the solar power plant operates in nominal mode disturbed at 95.37% against 4.63% of disturbed mode including 3.93% of disturbances coming from the network and 0.70% coming from the solar power plant itself;

1. Grid disturbance analysis: The distribution of the various disturbances coming from the grid and having caused a malfunction of the plant in 2019 are represented by the following figure 6:

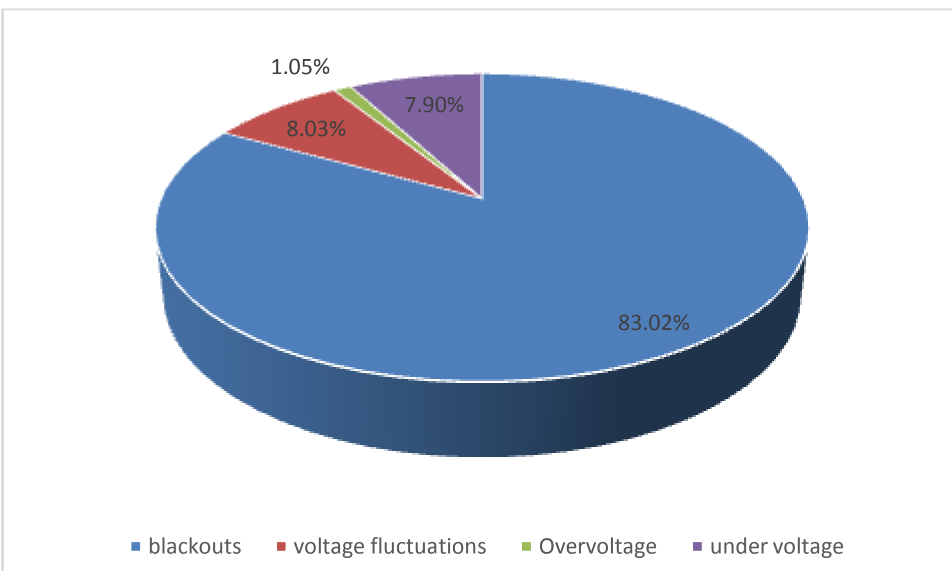


Figure 6:- Graph of grid disturbances.

We note that for a total downtime of 168h53mn, the network presents four types of disturbances that caused the plant to malfunction. Among these disturbances, outages represent the largest proportion with 83.02% of the total downtime, followed by fluctuations with 8.03%, voltage dips with 7.9%, and finally overvoltages with 1.05 % ;

1. Analysis of disturbances from the solar power plant: The disturbances coming from the power plant itself are represented in the following figure 7:

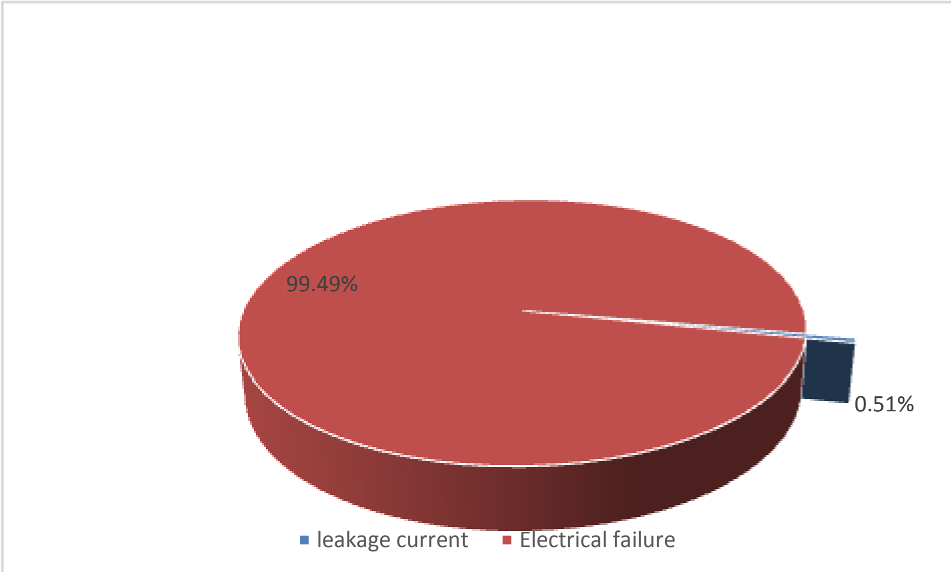


Figure 7:- Disturbances from the solar power plant.

Note that for a downtime of 30h13n41s, the power plant exhibits 99.49% of disturbances resulting from electrical failures and 0.51% of current leaks that have caused earth faults;

1. Analysis of the energy production of the solar power plant: Figure 8 below shows the variations in energy production as a function of temperature and site irradiation:

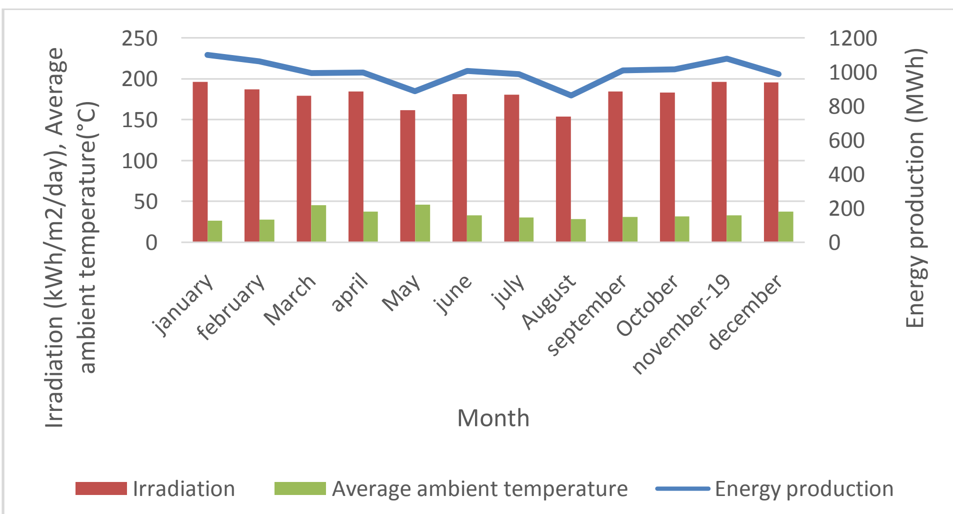


Figure 8:- Variations in energy production as a function of temperature and irradiation.

We observe that:

The monthly irradiation varies from 196.26KWh / m^2 for the month of January to 195.52KWh / m^2 for the month of December. The maximum irradiation is obtained in March with a value of 199.15KWh / m^2. The minimum irradiation is recorded in August with a value of 153.94KWh / m^2.

The monthly temperature of the modules varies from 37.57 ° C (minimum value) in January to 37.79 ° C in December. The maximum monthly temperature is recorded in April with a value of 49.34 ° C.

The monthly energy production varies from 1.118 GWh (maximum value) in January to 0. 9992 GWh in December. The minimum production is 0.904MWh obtained in May. The total annual energy is 12.19 GWh.

The evolution of energy production occurs in the same direction as that of irradiation, but the increase in temperature has a negative effect on energy production. The same conclusions were demonstrated by SebbaghToufik et al in their article entitled "the study of the impact of climatic factors (temperature, sunshine) on the power of photovoltaic cells" [19].

The analysis of Figure 8 also shows that the monthly irradiation values at the beginning of the year (January) and the end of the year (December) are respectively 196.29KWh / m^2 and 195.52Kwh / m^2. Those of the temperature are respectively 26.93 ° C and 37.87 ° C; This shows that the different irradiation and temperature values at the start and end of the year corresponding to the start and end of the annual cycle, respectively, coincide with a few differences ready. The same conclusions were proved by Michael S. Okundamiya et al in their article entitled "Evaluation of varions global solar radiation models for Nigeria" [20]. However, we note that the values of the monthly energy productions of January 2019 (1101.7MWh) and December 2019 (989 MWh) are clearly different with a productivity gap of 112.7MWh. This leads to the conclusion that there are other parameters which have an influence on the overall energy production of the plant apart from irradiation and temperature.

1. Analysis of the technical availability of the electricity network and the solar power plant: The variations in energy production as a function of the monthly technical availability of the network and the power station are shown in Figure 9 below.

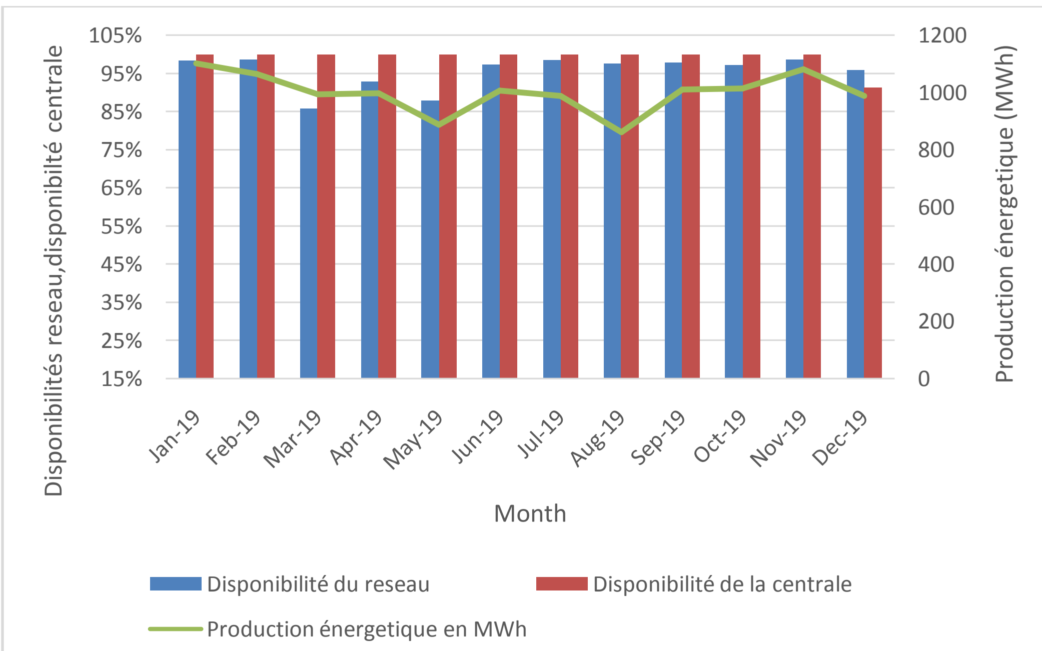


Figure 9:- Variation in energy production depending on the technical availability of the grid and the solar power plant.

Figure 9 shows that:

From January 2019 to November 2019 the monthly technical availability of the plant varies between 99.97% and 100%. But in December 2019, it was 91.25% following power outages lasting a total of 29h57mn12s. It was at 100% for eight months namely February, March, May, June, August, September, October and November. This led to an annual technical availability of 99.25%.

The monthly technical availability of the network varies between 85.85% and 98.71% with an annual technical availability of 95.58%. The most disturbed months are: March, April, May with monthly technical availability of 85.85% respectively; 92.89% and 87.91%.

The higher the technical availability of the network and the power station, the higher the energy production and vice versa. When one of the technical availability (of the network or the power plant) is low, energy production always remains low. This shows that energy production is strongly conditioned by the availability of the electricity grid and the solar power plant.

In January, the monthly technical availability of the network and the plant was 98.38% and 99.97% respectively, while it was respectively 95.88% and 91.25% in December. This is one of the reasons for the difference in energy productivity observed between these two months, which should logically coincide.

Conclusion:-

This study generally presents, on the one hand, the electrical disturbances of the grid that may cause a malfunction of the photovoltaic systems connected to the network and on the other hand the influence of an insertion of photovoltaic sources on the current protection plan of the electrical network. The real case of the 7MW solar photovoltaic plant in Malbaza was then dealt with. The study carried out on the analysis of data for one year (January 1, 2019 to December 31, 2019) showed that the solar power plant is much more destabilized by disturbances from the grid (blackout, fluctuations, voltage dips, overvoltages) than those coming from the solar power plant itself. It follows from this study that apart from irradiation and temperature, the availability of the electricity grid is also a very important factor to take into account in the energy production of a grid-connected photovoltaic solar system.

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