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Diagnosing Photovoltaic Power Plant Injection decoupling in Burkina Faso

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Abstract

This study focuses on the causes of the general protection triggering of the photovoltaic power plant of the Zagtouli site located in Ouagadougou in Burkina Faso, in West Africa. The objective of this work is to diagnose the causes of the photovoltaic power plant decoupling during the injection of PV electricity on the distribution grid. The methodology consists of collecting and analyzing data from the photovoltaic power plant in order to diagnose the causes of the injection decoupling of photovoltaic electricity. The results of this study show that the causes of decoupling of the Zagtouli solar power plant are mainly related to the voltage variation at the connection point outside the admissible range. However, a frequency fault leads to a voltage fault. It is then necessary to set up an automatic dynamic regulation of the voltage dedicated exclusively to the photovoltaic power plant.

Keywords: Photovoltaic power plant, injection, disruption, decoupling, diagnose

1 Introduction

The demand for electrical energy in developing countries is constantly growing, in particular due to the _demographic changes and the development of certain geographical areas. Thus, for a number of years, these countries have been plunged into a major energy crisis marked by power cut. In this context, it is essential to use decentralized production from renewable sources. Because of the large solar potential, the insertion of photovoltaic power plants is prioritized to deal with this energy crisis. Major project of photovoltaic electricity injection are planned to improve the access offer of electrical energy [1]. However, the injection of a photovoltaic power plant production on the distribution network can have impacts on the electricity network [2], [3]. In addition, the characteristics and disturbances of the distribution network can influence the operation of the photovoltaic power plant [4], [5].

The injection of photovoltaic electricity causes a local rise of the voltage at the injection point. This problem has been tested by Hadj Arab et al. [6]. Even with low injected power, they noticed that the voltage at the injection point was high. According to Thi Minh Chau Le [7], during a period of strong sunshine and low consumption, the injection of photovoltaic electricity creates an overvoltage at the injection points. The voltage of some nodes of the network can exceed the admissible threshold which causes the decoupling of the photovoltaic power plant [7], [8].

Another consequence of photovoltaic injection is the pollution of the electrical network by harmonics. It generates harmonics which disturb the voltage waveform. When this is not sinusoidal, there will be a malfunction and overheating of the receivers and equipment connected to the network [9].

The injection points of photovoltaic power plants are located at the level of the distribution network. However, the distribution network is designed to transport power flows from the source substation to the consumers. It happens that the production exceeds the consumption which creates an upward flow of active power [10]. If the injection rate of photovoltaic electricity is high enough, the energy flows transit from the distribution network to the transport network, which causes local congestion. According to Manzo, the multiplication of photovoltaic injections on the network is one of the reasons for the increase of the congestion number [11]. The injection of the photovoltaic causes the imbalance between phases. In the case of the use of single-phase inverters, an imbalance between phases appears, because the power produced is not correctly distributed between the three (3) phases of the same three-phase photovoltaic system [12]. This leads to an imbalance of the electrical network [13].

In West Africa, Maliki et al. investigate the impacts of increased penetration of photovoltaic generation on static performance as well as transient stability of PV power systems in Mali [14]. The obtained simulation results effectively identify the detrimental impacts of increased PV penetration for both steady state stability and transient stability performance.

In Cameroon, Amigue et al optimize integration of photovoltaic power into the electricity network, with the main constraint is to regulate the voltage at each injection point [15]. The results allowed to determine the optimal points of injection with less losses. Kitmo et al. studie the harmonic pollution of electrical grid [16]. They use active filters based on a cascaded multicellular inverter for three-phase PV systems connected to the North Cameroon interconnected grid. The results show that the system can reduce the harmonic distortion from 23.06% to 0.42% when the active

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power of the photovoltaic generators is injected into the electrical grids.

Burkina Faso aims to inject nearly 650 MW into its electricity network by 2030 [17]. But currently, the electricity production of three photovoltaic power stations is injected into the public electricity network, namely the production of the Zagtouli photovoltaic power station, with a peak power of 33 MW, of Ziga, with a peak power of 1.1 MW and Nagréongo with a peak power of 26 MW, that is a total power of 60.1 MW injected now, which represents only about 9% of the planned power.

However, the injection of photovoltaic electricity on the national electricity distribution company (SONABEL) causes problems that affect the quality of the energy supplied. Since the commissioning of the 33 MW photovoltaic power plant in Zagtouli, frequent untimely decouplings have been observed. These decouplings have a negative impact on electrical production, as well as the lifespan of components. Our study focuses on the causes of triggering of the general (external) protection. For an operating period of less than four years, the circuit breaker displays 1588 operations out of the 2000 planned, i.e. nearly 80% [17]. In order to find a solution to the untimely decoupling of the injection of the Zagtouli plant and to anticipate any inconveniences of the planned plants, it is important to question the causes of the decoupling of the injection from the production of this plant, with a view to consider appropriate solutions.

The objective of this work is to diagnose the causes of decoupling of the photovoltaic power plant of the Zagtouli site located in Ouagadougou in Burkina Faso, in West Africa. This work is organized in five (5) sections: the second section talks about the presentation of the studied photovoltaic power plant, the third section discusses the material and methodology used, fourth section is devoted to the results and discussions and finally section 5 presents the conclusion and perspectives.

2. Presentation of the studied plant

The 33 MW Zagtouli photovoltaic power plant is located in the suburbs of Ouagadougou in Burkina Faso. The site, owned by the national electricity distribution company (SONABEL) is at 14 km west of Ouagadougou and 1 km south of National Road number 1. The Figure 1 shows the location of the Zagtouli power plant.

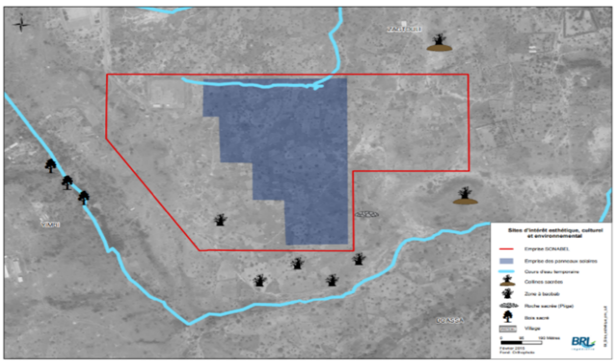

Fig. 1. Location of the Zagtouli photovoltaic power plant [18].

The Figure 2 presents the spatial occupation of the Zagtouli power plant.

Fig. 2. Spatial occupation of the photovoltaic field of the PV plant [19].

The plant has 129,600 PV modules of 260 Wp each in polycrystalline silicon, mounted on 1800 structures inclined at 15° and oriented to the south, over an area of 60 hectares. The total peak power of the power plant is 33 MW.

2.1 Injection point

The plant injects without storage at the Zagtouli substation to the 33 kV busbar [20]. Figure 3 shows the injection point of the 33 MW Zagtouli photovoltaic power plant.

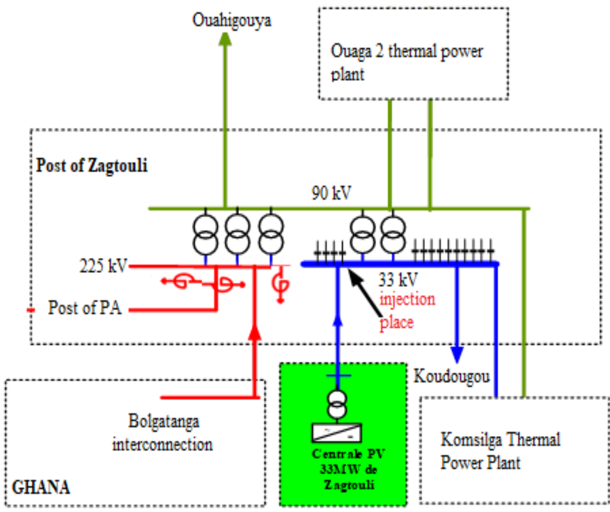

Fig. 3. Injection point of the Zagtouli power plant.

The regulation of the voltage at the injection node is carried out by the set of switchings of the two reactances of 15 MVAR and 30 MVAR locally from the station or remotely from the dispatching in a manual or automatic way.

2.2 Technical structure

The technical structure is as shown in Figure 4.

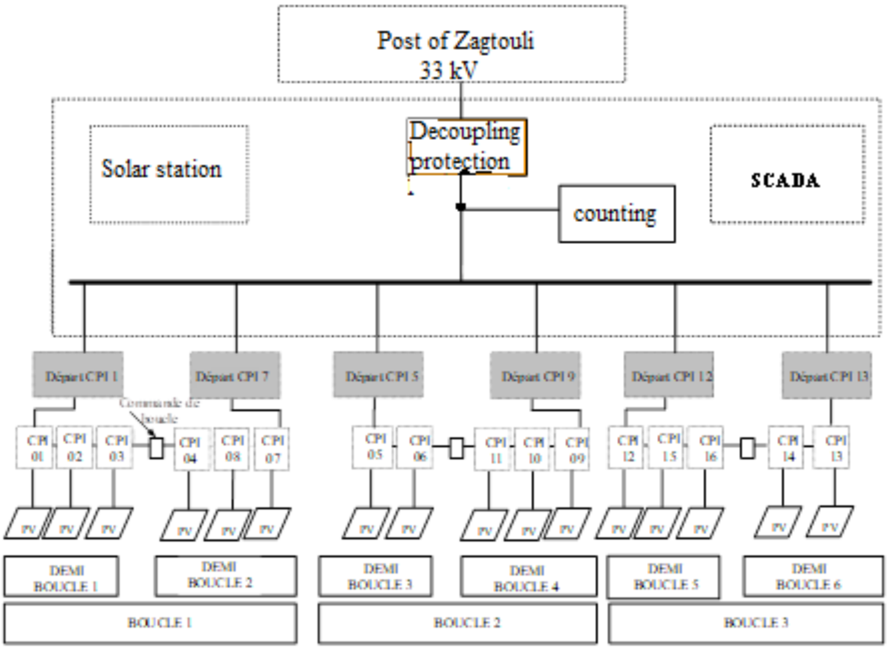

Fig. 4. Configuration of the Zagtouli photovoltaic power plant.

The figure 4 shows the technical structure of the Zagtouli photovoltaic power plant. This plant is of modular configuration and comprises sixteen transformer stations. Each substation includes one transformer (420 V / 33 kV) and two inverters (270 VDC / 420 VAC). All the elements of each station are housed in a building called the Integrated Photovoltaic Center (CPI). The service life of the plant is at least 30 years. The Zagtouli photovoltaic power plant has two types of decoupling protection: internal protection and external or general protection. The internal protection is integrated in each inverter and controls the coupling conditions of each inverter while the external one supervises the whole production. The decoupling protection remains closed when the coupling conditions are met. When the conditions are not met, the circuit breaker opens or remains open to protect the inverters.

3. Materials and method

The methodology consists of collecting and analyzing data on voltage, ground connection and frequency faults to diagnose the causes of decoupling of the injection of photovoltaic electricity into the national electricity grid.

3.1 Data collection

The data collection consists of extracting from the register the data related to all the decouplings of the plant during the period 2020 to 2022. The data to be collected are the causes of insulation, voltage and frequency faults at the injection point, which cause the decoupling of the injection of the electricity produced on the electrical network. The data for this study are statements extracted from the registers recorded in the database of the Supervisory Control and Data Acquisition (SCADA).

The SCADA is a supervision, control and data acquisition system comprising a set of industrial programmable logic controllers (PLC) as well as remote terminal units (RTU). The data stored in the inverters and at the level of the solar station pass through optical fibers to the control room. The SCADA equipment is grouped together in the control room. This system acquires data through sensors installed throughout the Zagtouli site. SCADA enables on-site or remote monitoring of the production process and reporting. Real-time data of powers, intensities, voltages, frequency, dates, times and causes of decouplings, as well as meteorological data are archived in the database.

Voltage, frequency, power and intensity data taken from the photovoltaic plant using sensors are recorded in the SCADA. It is the data regarding high or low voltage faults, frequency values outside the normal range, and ground fault, are extracted from the SCADA register which are used in this study. Table 1 gives the SCADA data recording format.

Table 1. Example of SCADA data logging table

Dates	Beginning hour	End time	Reason code
03/02/2021	13h07	13h19	27
03/02/2021	08h48	08h53	59
10/02/2021	14h20	14h28	59
16/02/2021	14h11	14h14	59
23/02/2021	13h07	13h19	27
23/02/2021	08h48	08h53	59
28/02/2021	06h32	06h38	59
28/02/2021	12h18	12h38	59
04/03/2021	17h20	17h31	59
04/03/2021	14h16	14h19	64
04/03/2021	15h31	15h33	64
05/03/2021	13h40	13h45	59
06/03/2021	12h59	13h00	
07/03/2021	12h36	12h42	59
07/03/2021	13h40	13h50	81
09/03/2021	15h09	15h20	27

A SCADA system includes hardware, controllers, communication networks, a database, input-output management software and a human-machine interface (HMI). It is a large-scale remote management system allowing a large number of telemetry measurements to be processed in real time and technical installations to be controlled remotely. Informations are collected automatically throughout the photovoltaic plant operation, using sensors.

3.2 Data processing

To comply with the present study, the data was preprocessed to remove erroneous data such as parameter values that do not match the error code, etc. We then used statistical methods and the graphics option of Excel software to find the curves and mathematical equations reflecting the evolution of each type of defects [21]. The data processing consists in decoding the causes of decoupling by using the codes of the various causes of decoupling. Code 59 indicates high voltage, code 27 indicates low voltage, code 64 means an ground or insulation fault and code 81 is the cause of an abnormal frequency variation. Then the erroneous values were eliminated. The coupling of photovoltaic power plants to public networks is governed by standards relating to the limits of variation of the voltage and frequency of the network on the one hand and on the other hand by the requirements submitted to producers. Standard NF EN 50-160, used in Burkina Faso, defines an allowable voltage variation of ± 5% and a frequency variation of ± 1% [20]. In the case of this study, the voltages and frequencies that cause injection decoupling are off the page from 31.35 kV to 34.65 kV and 49.5 Hz to 50.5 Hz, respectively. The high voltage is that which is greater than 34.65 kV and the low voltage is that which is less than 31.35 kV.

3.3 Proportion of different causes

Based on the identified causes of decoupling, the percentages by cause of decoupling are calculated for the three (3) years. The percentage of high voltage faults is given by Equation 1:

$$P_{Umax} = \frac{N_{Umax}}{N} \times 100 \quad (1)$$

where:
- P_{Umax} represents the percentage of high voltage faults;
- N represents the total number of specified faults;
- N_{Umax} the number of high voltage value.

The percentage of low voltage faults is given by Equation 2:

$$P_{Umini} = \frac{N_{Umini}}{N} \times 100 \quad (2)$$

where:
- P_{Umini} is the percentage of low voltage faults;
- N is the total number of specified faults;
- N_{Umini}, the number of low voltage values.

The percentage of frequency faults is given by Equation 3:

$$P_f = \frac{N_f}{N} \times 100 \quad (3)$$

where:
- P_f represents the frequency fault percentage;
- N is the total number of faults specified;
- N_f, the number of frequency faults.

The percentage of ground faults is given by Equation 4:

$$P_t = \frac{N_t}{N} \times 100 \quad (4)$$

where:
- P_t represents the earth fault percentage;
- N represents the total number of faults specified;
- N_t the number of ground faults.

3.4 Calculation of undistributed energy

From 2022, the power plant operators have included non-distributed energies (NDE) in the readings. The duration of the decouplings of each year and the NDEs of 2022 being known, the NDEs of 2020 and 2021 are calculated. The undistributed energies of the year 2020 are calculated according to the Equation 5:

$$NDE_{20} = \frac{NDE_{22}}{D_{22}} \times D_{20} \quad (5)$$

where:
- NDE_{20} represents the undistributed energy during the year 2020;
- NDE_{22} represents the undistributed energy during the year 2022;
- D_{20} represents the total duration of the decouplings for the year 2020;
- D_{22}, the total duration of the decouplings for the year 2022.

The undistributed energies of the year 2021 are calculated according to the Equation 6:

$$NDE_{21} = \frac{NDE_{22}}{D_{22}} \times D_{21} \quad (6)$$

where:
- NDE_{21} represents the undistributed energy during the year 2021;
- NDE_{22} represents the undistributed energy during the year 2022;
- D_{21} is the total duration of the decouplings for the year 2021;
- D_{22}, the total duration of the decouplings for the year 2022.

4. Results and discussions

The site studied is that of the 33 MW photovoltaic solar power plant of Zagtouli located in Ouagadougou in Burkina Faso, in West Africa. From the data collected on this site, an analysis is carried out to diagnose the causes of decoupling of the injection of photovoltaic electricity. From the data recording tables, the decouplings were categorized by nature of cause, taking into account unspecified decouplings (USD), decoupling during the production period (DDP) of the plant, from 7 a.m. to 5 p.m. and decoupling outside production period (DOP) of the plant, from 5 p.m. to 7 a.m. The recordings include the date, the start and end time, as well as the cause of the decoupling.

The Ttable 2 gives summary of the decouplings is carried out by adding up the decouplings by cause over the three years.

Table 2. Summary of decouplings by cause from 2020 to 2022

Year	Causes de découplage				Nomber USD	Total DDP Decouplings (-)	Total DOP Decouplings (-)	Total (-)
	Low voltage	High voltage	Non-standard frequency	Ground fault				
2020	12	14	0	2	74	51	51	102
2021	64	193	9	16	20	150	152	302
2022	22	101	3	0	0	52	74	126

The number of decouplings by type of cause (low voltage, high voltage, out-of-standard frequency and ground fault) for the year 2020 is recorded. One hundred and two (102) decouplings were listed including 12% low voltage, 14% high voltage and 2% earth fault. This constitutes 28% of the causes identified. On the other hand, 72% of the causes of decoupling could not be identified, these are causes of unspecified decoupling (USD).

During the year 2021, three hundred and two (302) decouplings were listed, including 21% low voltage, 64% high voltage, 3% out-of-range frequency variation and 5% ground fault. That is 93% of the causes identified. On the other hand, 7% of the causes of decoupling could not be specified.

Concerning the year 2022, one hundred and two twenty-six (126) decouplings have been listed, including 17% low voltage, 80% high voltage and 3% out-of-range frequency variation. Here, we have 100% of the causes specified.

From 2020 to 2022, five hundred and thirty (530) decouplings were recorded in the operation of the power plant, including 19% of minimum voltage, 58% of maximum voltage, 2% of frequency variation out of range and 3% of problems of isolation. The Figure 5 presents the distribution of all decouplings according to their cause.

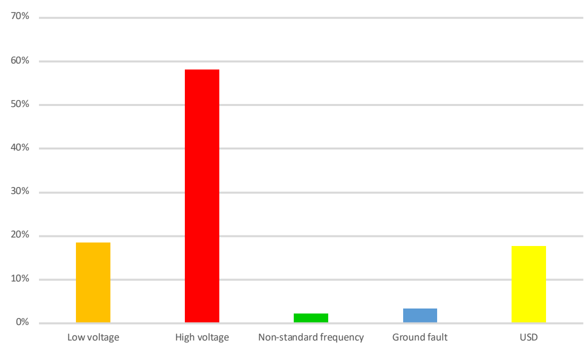

Fig. 5. Breakdown of decouplings by cause over the study period.

The figure 6 represents the percentage of the different causes of decoupling.

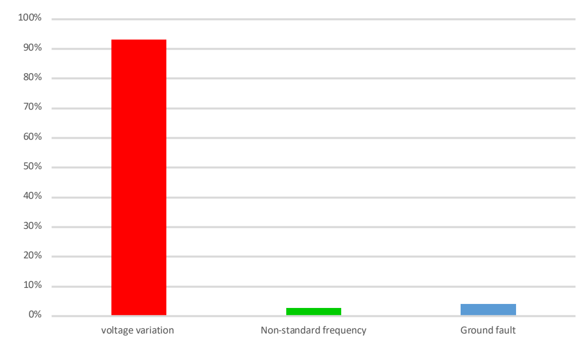

Fig. 6. Breakdown of decouplings by causes identified.

Figure 6 indicates that 71% of the causes are due to the variation of the voltage beyond the admissible limits against 22% for low voltages. . Frequency and ground faults are very minimal at 4% and 3% respectively.

The major cause of power plant uncouplings is the variation of the voltage beyond the admissible limits, 93% compared to the specified causes (Fig. 7).

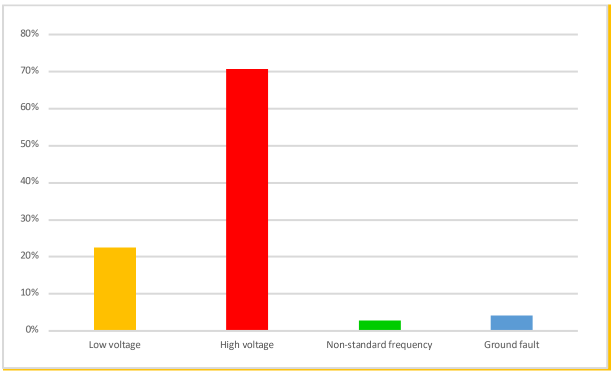

Fig. 7. Breakdown of decouplings by causes identified.

4.2 Impact of decoupling on production

A period of operation of the photovoltaic plant between 7 a.m. and 5 p.m. is considered. Table 3 gives the evolution of non distributed energies (NDE) during the production period, over the three years.

Table 3. Evaluation of ENDs from 2020 to 2022

Year	Duration of decouplings (h)	Non distributed Energy (MWh)
2020	20	36
2021	34	62
2022	26	47
Total	80	145

The evaluation of the NDE shows that the decouplings create a shortfall of 145 MWh, i.e. nearly 0.6 MWh per decoupling.

4.3 Analysis of decoupling causes

In figure 7, the observation is that 93% of the identified causes of decoupling are due to the voltage variation. That means 71% for a high voltage level and 22% for the low level. Since the plant is connected to an interconnection station, the voltage level remains always high to allow the various regional lines to have good voltage at the end of the line.

Voltage regulation at Zagtouli substation is carried out through capacitors or inductors locally or from dispatching when the dispatchers notice an abnormal variation of voltage or at the request of the solar power plant operators. On the other hand, in the event of a strong variation in the voltage, the inductors open or close automatically to compensate the imbalance. This regulation lacks flexibility and responsiveness. Figure 8 illustrates the limits of regulation at the zagtouli post.

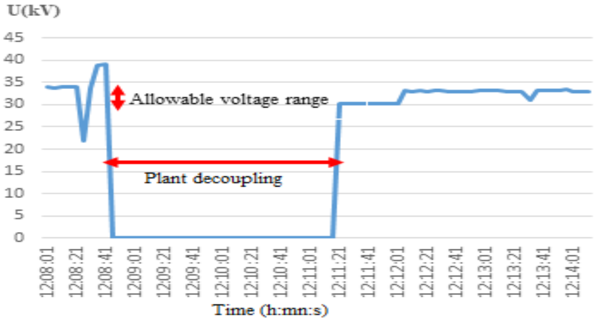

Fig. 8. Illustration of the regulation limit.

The statement carried out at the SCADA on all the decouplings allowed to pay particular attention to the triggering of the plant. The voltage variations reached extreme thresholds, –34% and +18% of the nominal voltage (33 kV). The information received from dispatching notes an incident on the Ghana line causing the overvoltage. The inductors installed for this purpose lacked the promptness to deal with the damage.

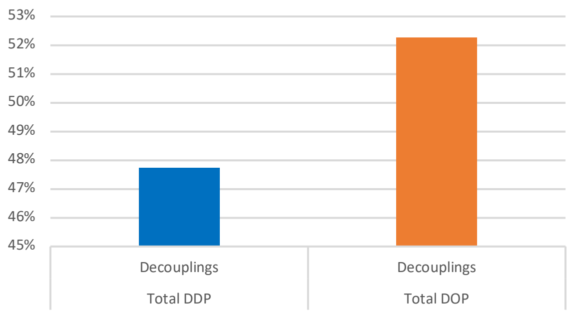

Fig. 9. Breakdown of decouplings.

Figure 9 shows that 52% of decouplings take place outside of production, i.e. at night between 6 p.m. and 7 a.m. This means that the major part of the decouplings takes place while the plant is not supplying any energy to the network. Thus, it can be deduced that the voltage variations at the injection point of the plant are due to instability of the network itself. The grid voltage varies so much that coupling attempts for the injection of PV electricity are most often unsuccessful.

4.4 Impact of voltage default on frequency

Figure 10 shows the evolution curves of the network voltage and frequency following tripping caused by network voltage higher than the maximum voltage.

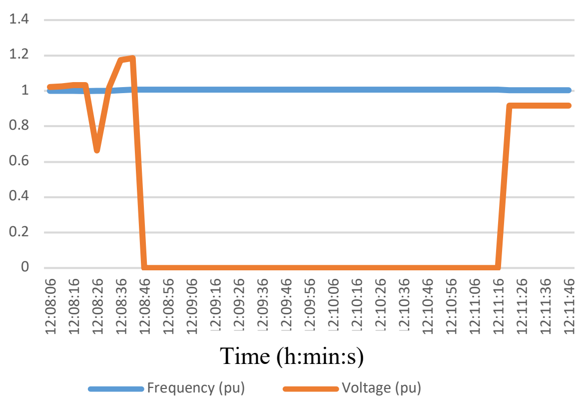

Fig. 10. Voltage and frequency variation for high voltage default.

The finding in Figure 10 is that exceeding the value of the voltage outside the upper admissible limits does not impact the frequency.

4.5 Impact of Frequency default on voltage

Figure 11 shows the evolution curves of the network voltage and frequency following tripping caused by a network frequency outside the admissible limits.

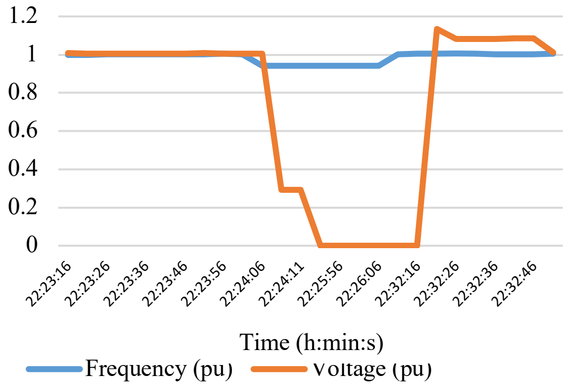

Fig. 11. Voltage and frequency variation following underfrequency tripping.

In figure 11, the observation is that the variation of the frequency outside the admissible limits leads to the collapse of the voltage.

This study made it possible to analyze the causes of decoupling of PV electricity injection into the electricity grid. The PV system generally influences: the source station power by reducing its call power; on voltage; on cosφ of the grid, already unstable. It turns out that the most significant and frequent causes of decoupling of PV electricity injection is the grid voltage variation outside the admissible limits. Our results are in good agreement with existing results in the literature [22], [23].

5 Conclusion

In this work, we made the diagnosis of the causes of decoupling of the photovoltaic power plant of the Zagtouli site located in Ouagadougou in Burkina Faso, in West Africa. First, data is collected on the operation of the photovoltaic solar power plant and on the parameters of the national electricity grid at the injection point, through the database. The analysis of the data gave results on the causes of untimely uncoupling of the injection. The causes of decoupling of the Zagtouli solar power plant are 93% linked to the variation of the voltage at the connection point outside the admissible range, 4% linked to the variation of the frequency and 3% linked to a fault in the ground connection. The causes of decoupling of the Zagtouli solar power plant are mainly related to the variation of the voltage at the connection point outside the admissible range.

In addition, a fault in the voltage does not cause a major variation in the frequency. However, a frequency fault leads to a voltage fault. The evaluation of undistributed energies showed that the decouplings generate 145 MWh of energy losses produced by the photovoltaic power plant and which should be injected, i.e. approximately 0.6 MWh per decoupling.

The main cause of decoupling of the PV injection on the electrical network is the fact of an inappropriate regulation of the voltage at the injection point. This is attributable to the lack of an appropriate voltage regulation system at the Zagtouli substation.

For the effective resolution of the Zagtouli power station decoupling problem, it is necessary to have an automatic dynamic regulation of the voltage dedicated exclusively to the power station.

In short, the photovoltaic electricity injection into the electrical grid causes an increase in voltage at the injection point and throughout the grid. The implementation of photovoltaic injection at the Zagtouli substation requires voltage regulation at the injection point. Until now, the intermittency of PV production is effectively modulated by the interconnection with Ghana.

For better injection of electricity from the Zagtouli photovoltaic power plant and for other PV injection projects into the interconnected electricity grid, reduction of the grid instability is necessary. We suggest the creation of a power plant dedicated to the automatic regulation of the national grid voltage.

The results of this study can be used to optimize the injection of electricity from photovoltaic plants into the national electricity grids of West African countries, which experience the same instability problems as the national grid. of Burkina Faso.

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