Energy and Power Engineering, 2024, 16, 345-357
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Stability Study of Low Voltage Electrical Distribution Network: Audit and Improvement of DJEGBE Mini Solar Photovoltaic Power Plant in the Commune of OUESSE (Benin)

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How to cite this paper: Tokpohozin, B.N., Osséni, S., Fannou, J.-L., Adigbé, V. and Akowanou, C.D. (2024) Stability Study of Low Voltage Electrical Distribution Network: Audit and Improvement of DJEGBE Mini Solar Photovoltaic Power Plant in the Commune of OUESSE (Benin). *Energy and Power Engineering*, **16**, 345-357.
https://doi.org/10.4236/epe.2024.1610017

Received: August 20, 2024
Accepted: October 18, 2024
Published: October 21, 2024

Abstract

The supply of quality energy is a major concern for distribution network managers. This is the case for the company ASEMI, whose subscribers on the DJEGBE mini-power station network are faced with problems of current instability, voltage drops, and repetitive outages. This work is part of the search for the stability of the electrical distribution network by focusing on the audit of the DJEGBE mini photovoltaic solar power plant electrical network in the commune of OUESSE (Benin). This aims to highlight malfunctions on the low-voltage network to propose solutions for improving current stability among subscribers. Irregularities were noted, notably the overloading of certain lines of the PV network, implying poor distribution of loads by phase, which is the main cause of voltage drops; repetitive outages linked to overvoltage caused by lightning and overcurrent due to overload; faulty meters, absence of earth connection at subscribers. Peaks in consumption were obtained at night, which shows that consumption is greater in the evening. We examined the existing situation and processed the data collected, then simulated the energy consumption profiles with the network analyzer "LANGLOIS 6830" and "Excel". The power factor value recorded is an average of 1, and the minimum value is 0.85. The daily output is 131.08 kWh, for a daily demand of 120 kWh and the average daily consumption is 109.92 kWh, or 83.86% of the energy produced per day. These results showed that the dysfunctions are linked to the distribution and the use of produced energy. Finally, we proposed possible solutions for improving the electrical distribution network. Thus, measures without investment and those requiring investment have been proposed.

Keywords

LV Distribution Network, Energy Audit, Mini PV Plant, Malfunctions, Corrective Measures

1. Introduction

"Sustainable energy" means energy produced and used in such a way as to promote human development in all its dimensions (social, economic, and environmental) [1]. Across the world, two billion people do not have access to electricity and continue to use traditional solid fuels for cooking. Many energy strategies can benefit the environment, the economy, and the quality of life. Over the next 20 years, the amount of primary energy for a given level of energy services could be cost-effectively reduced by 25% to 35% in industrialized countries. The evolution of technologies has exceeded all expectations [2]. Global demand for renewable energy has steadily increased, as has energy consumption, particularly in developing countries [3].

We need to talk about renewable energies because it is thanks to them that we can begin to take care of our beautiful planet. These are inexhaustible energies found in nature, and thanks to them [4], we can mitigate the effects of climate change while guaranteeing our energy needs. Renewable energy sources, as their name suggests, are renewable, that is to say, in a certain way, and unlike energies such as oil, gas, or coal, they are inexhaustible. Renewable energies make it possible to provide energy services with emissions of air pollutants and greenhouse gases equal to or close to zero. Without decisions in the coming decades, too many development opportunities will be lost [3]. This is one of the main reasons why it makes sense to start banking on renewable energy, such as solar and wind power, as it minimizes the risk that future generations will run out of energy. Energy resources have to face climate change even worse than what is currently occurring.

The benefits of using this energy source are enormous. According to data from the International Renewable Energy Agency (IRENA), doubling the share of renewable energy worldwide to reach 36% of consumption by 2030 would mean a substantial increase in employment in the sector, which would increase from 9.2 million employees (currently to 24 million), which would correspond to an increase in the global economy of 1.1%. In short, thanks to renewable energies, new businesses can be created, energy dependence on third parties is reduced, and they contribute to job creation up to 5 times more than with conventional energies.

The prospect of a world where we use renewable energies could well become a reality. An effective strategy for meeting the energy needs of rural populations consists of promoting their progression on the "energy ladder" [3]. Whether it is wind, solar, or biomass energy, renewable energy has become a viable energy supply option around the world, and in North America. The 2007 report from the Renewable Energy Action Network for the 21st Century (REN21) reveals that in that year, renewable energy accounted for 5% of global energy production capacity and 3.4% of global electricity production [5] [6]. Excluding large hydropower plants (which account for 15% of global electricity generation), RE generation capacity is estimated to have reached 240 gigawatts (GW) globally in 2007, or 50% more than in 2004. The current path of energy development is not compatible with the objectives of sustainable development [7].

The fastest growing energy production technology in the world is solar energy produced by grid-connected photovoltaic (PV) systems; the cumulative installed capacity of these systems increased by 50% in 2006 and 2007, which has undergone a marked improvement today. We, therefore [5], had a total installed power of nearly 7.7 GW at the end of 2007. This means that 1.5 million houses in the world are equipped with PV panels on their roofs connected to the network [8]. The United States Department of Energy estimates that net generation in 2007 was 32.1 billion kilowatt-hours (kWh), up 21 percent from a year earlier and nearly five times more than at the beginning of the 21st century [8].

Technological innovation in developing countries could be profitable on an economic, environmental, and human level. Energy can be a powerful tool for sustainable development [9]. Then, distribution network managers (DNM) are used to guarantee the quality of the supplied electricity [10]. It is for this reason that many management companies are involved in the process of seeking to improve the stability of their network through electrical audit missions. Electrical auditing is considered an expertise that enables the evaluation of the operating quality of a system [11]. It makes it possible to identify the weaknesses and points of non-compliance of an electrical network and subsequently propose avenues for improvement.

After analyzing the energy consumption profiles, we found voltage imbalances and power factors, which led to poor load distribution and equipment malfunctions. Hence, the non-compliance of subscriber installations is identified as a key factor of network instability.

2. Materials and Methods

2.1. Presentation of the Study Site

Photo 1. Site of the mini-power station in DJEGBE.

2.1.1. Geographical Location of the Site

Located in the North-East of Benin in the Collines department, the commune of Ouèssè (**Figure 1**) is limited to the North by the commune of Tchaourou, to the South by the communes of Savè and Glazoué, and to the West by those of Bantè and Bassila and to the East by the Federal Republic of Nigeria. It has nine (09) districts, including DJEGBE, which has three (03) villages, namely Adjaha, Wla, and Lokossa, sheltering the mini power plant site (**Photo 1**) [12]. The geographical data of DJEGBE are summarized in **Table 1** [4].

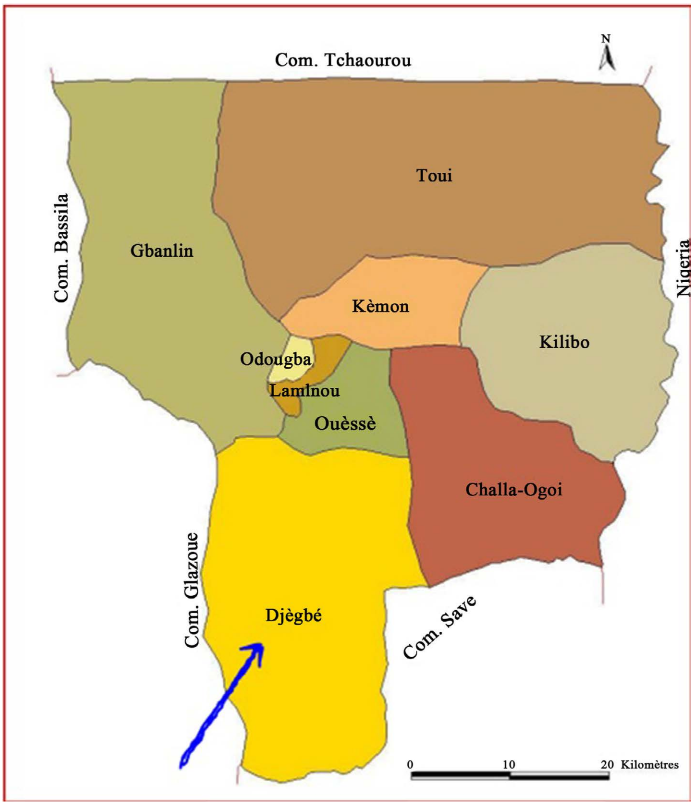

Figure 1. Map of Ouèssè commune showing DJEGBE [12].

Table 1. Geographical data of DJEGBE [4].

Latitude	8˚18'0"N
Longitude	2˚24'0"E
Altitude	168 m

2.1.2. Weather Conditions in Djègbe

The district of Djègbé has a savannah climate, like all the localities in the region, such as Ouèssè. In this village, the average annual temperature is 27.1˚C with precipitation of 907.6 mm. In February, the average temperature is 29.5˚C. Therefore, February is the hottest month of the year. August is the coldest month of the year, with an average temperature of 24.7˚C [13]. The average precipitation of 11.4 mm makes December the driest month. In September, precipitation is the heaviest of the year with an average of 135.5 mm [4].

2.1.3. Network Analyzer and Tellurometer

To take and analyze the measurements, we used the LANGLOIS 6830 model power and harmonic analyzer. A power and harmonic analyzer, commonly called a network analyzer (Photo 2(A)), makes it possible to display the characteristics and disturbances linked to an electrical network and is part of an electrical audit. Indeed, this network analyzer is an ideal tool for recording and analyzing all the fundamental electrical parameters of an electrical installation. It makes it possible to measure voltage, current, power, and energy parameters useful for a complete diagnosis of an electrical installation in order to locate, anticipate, prevent, and resolve network quality problems in power distribution systems [14]. It thus allows the study of load in a single-phase network, the visualization of current and voltage waveforms when commissioning electrical equipment, the measurement and monitoring of harmonic distortion caused by electronic loads and, above all, the storage of all these events or data in a single device. To use the software of this network analyzer, you will need to connect the RS-232 cable from the analyzer to the PC and then carry out the various operations. This software allowed us to have different profiles of power consumption, power factor, and harmonic rate on the electrical network. A tellurometer (Photo 2(B)) is an instrument for measuring the resistivity of the ground as well as the resistance of the earth connections of an electrical network. It determines the distance by measuring the round-trip travel time of the reflected microwaves.

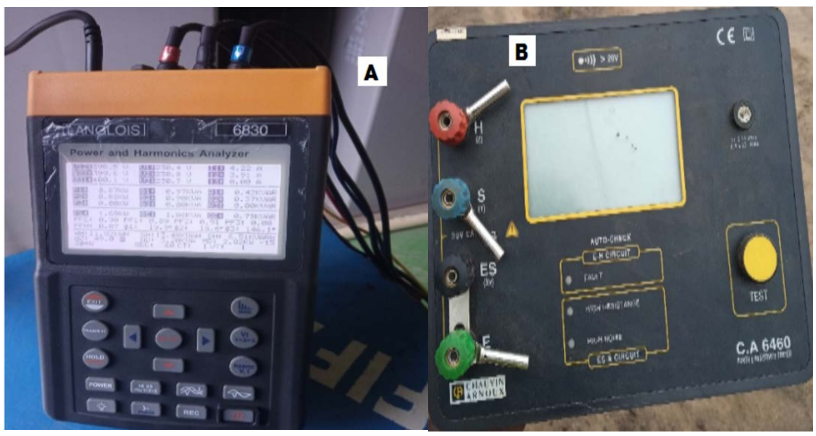

Photo 2. (A) network analyzer and (B) tellurometer.

2.2. Methodology

To carry out a good diagnostic study of the low voltage electrical distribution network of the DJEGBE mini power plant, it is important to follow a rigorous method. Our study will therefore be carried out in three main phases: examination of the existing situation; the exploitation and processing of data. The success of these steps determines the reliability of the diagnosis.

2.2.1. Examining the Existing

To successfully complete this step, it is important that the analyst has tools and information collection frameworks that can enable him to carry out his study successfully and efficiently. The higher the level of diagnosis sought, the more precise the information must be. The different phases are meeting with the company managers, visiting the installations, and collecting data. To succeed in this first step, it is imperative to have a framework for collecting information or intelligence, which will be very useful later. At this stage, it will be necessary to:

- Meet a decision-maker: this is a meeting that must take place with company personnel with decision-making power. It is important that the person is one of the responsible managers of the mini-power plant or mini-grid capable of making decisions.
- Determine the needs: this involves finding out beforehand the situation in which the company finds itself, and on this occasion also providing essential and relevant information to the manager for a better assessment of its situation. The auditor must also inform himself of the objectives and means that will be available to him to carry out the study.
- Visit the field: this is an essential step since it is based on this information that all the work will be done. This step consists of visiting the installations of the mini power plant and the mini-grid, then taking the necessary measures. Also, it is important to visit subscriber households, check their installations, and collect data and irregularities. Thus, to take measures to properly audit the electrical network of the DJEGBE mini power plant, we carried out a one-week mission from 07/07/2022 to 07/14/2022 on the site at DJEGBE. This allowed us to better appreciate the realities on the ground in terms of electricity network instability. The strategy used to achieve our data collection objectives is essentially based on measuring using a network analyzer: voltages between phase-neutral (single voltages) and between phase-phase (compound voltages); the current of each line of the electrical network; active powers consumed and power factors. After taking the measurements, we went over the electricity network and visited subscriber households to check their installations in order to identify irregularities at their level. It is essentially that all future work will be based on this data.

2.2.2. Data Exploitation and Processing

The measurements taken or data collected during the previous step will be the subject of an in-depth study. It is from this study that avenues for improving the electrical distribution network of the mini power plant will emerge. Thus, we used the *Power & Harmonics Analyzer and Excel Software* for data analysis and graph development. At this level, we will have to focus on the analysis of power consumption profiles, power factors, current stability among subscribers, network protection measures, and establish the daily energy balance of the site in order to better understand the causes of the instability of the electricity network. Therefore, we will be able to compare the capacity of the mini power plant to the real consumption needs of subscribers.

3. Results, Analysis and Discussion

3.1. Presentation of Results

- The visit to the mini-power plant installations allowed us to note that these various pieces of equipment are in good condition, and well installed in the technical building. However, we note some broken modules: Broken PV modules, Cobwebs, unsuitable cables, obsolete installation, and meters destroyed by lightning. Concerning the protection devices, we note the presence of a lightning arrester, rod lightning, danger warning signs, fire extinguisher, and earthing with a resistance value of 10-ohm, TT neutral regime is used.
- Visiting subscribers, household by household allowed us to identify several irregularities in their installations. We mainly note the presence of cobwebs, unsuitable cables, meters destroyed by lightning, and obsolete installation. Regarding the protection devices, we note the presence of a divisional circuit breaker, the absence of earthing, and the absence of differential devices.

3.1.1. Conditions and Evaluation of Voltage Imbalance

Transmission networks are equipped with voltage adjustment solutions to guarantee stability. When a voltage variation is detected, the first setting engaged is the primary setting. This acts on the alternator: it sets the reactive power supplied as a function of the voltage. This setting is triggered automatically on the alternators present in the disturbance zone (Primary setting). Secondary control occurs in the face of large but slow national voltage fluctuations (which primary control cannot correct). It will determine the level of participation of the alternators according to their real voltage and the so-called "pilot" voltage. It is also automated (Secondary adjustment). Tertiary adjustment occurs as a last resort: it is triggered manually to ensure the restoration and/or maintenance of the voltage plan (Tertiary adjustment). Voltage imbalance occurs when the supplied voltages are not equal. A quick way to assess a voltage imbalance is to calculate the difference between the highest and lowest voltages across the three supply voltages. The value found should not exceed 4% of the lowest supply voltage [15]. The table below shows the highest and lowest values of the supply voltages recorded on each phase.

Table 2. Power supply voltages are higher and lower in each phase.

	Supply voltages (simple voltages in Volts)		
Quality	L1	L2	L3
Highest	234.7	232.1	231
Lowest	227.7	228	14.1

Highest supply voltage: 234.7; lowest supply voltage: 14.1 4% of 14.1 = 0.564 V (**Table 2**). Calculation of the difference between the highest and lowest voltage. Let Ud this difference. Ud = 234.7 − 14.1 = 220.6 V, we have: 220.6 > 0.564.

3.1.2. Observation of Power Stability Among Subscribers

During observations and analyses of the various measures, we noted that subscribers who are on:

- **Line 1:** From 7 a.m. to 12 a.m. and from 12 a.m. to 6 a.m., repetitive outages are rare, and when they occur, they only last approximately 15 to 30 minutes. For the rest of the time, subscribers have power until early morning.
- **Line 2:** From 7 a.m. to 12 a.m. and from 12 a.m. to 6 a.m., no outages are recorded; only frequent cases of voltage drops are notified. The current is more or less stable on this line.
- **Line 3:** From 7 a.m. to 12 a.m. and 12 a.m. to 6 a.m., the current is not at all stable. There are repetitive outages that last for hours, and for the rest of the time, subscribers remain in total darkness until early morning.

3.1.3. Analysis of Energy Consumption Profiles by the LV Network

The analysis of the electrical network of the DJEGBE mini power plant was carried out using a device called a power and harmonic analyzer (Photo 2(A)) model 6830. The measurements were taken for a week according to different time settings.

1) Profile of power consumed by the BT network.

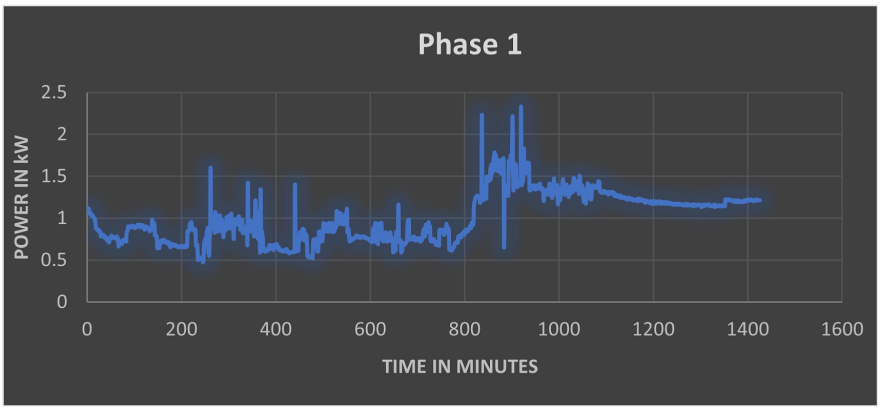

Figure 2. Power profile of phase 1. (L1)

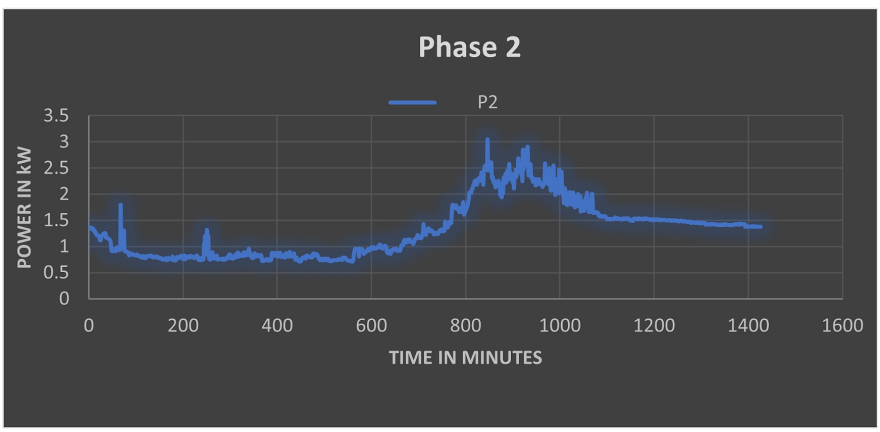

Figure 3. Power profile of phase 2. (L2)

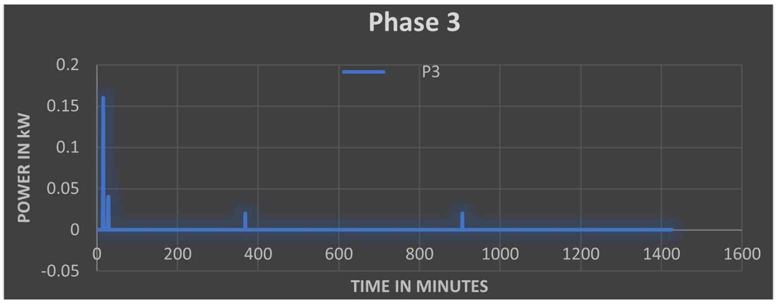

Figure 4. Power profile of phase 3. (L3)

Figure 5. Profile of the cumulative power of the three phases of the BT network.

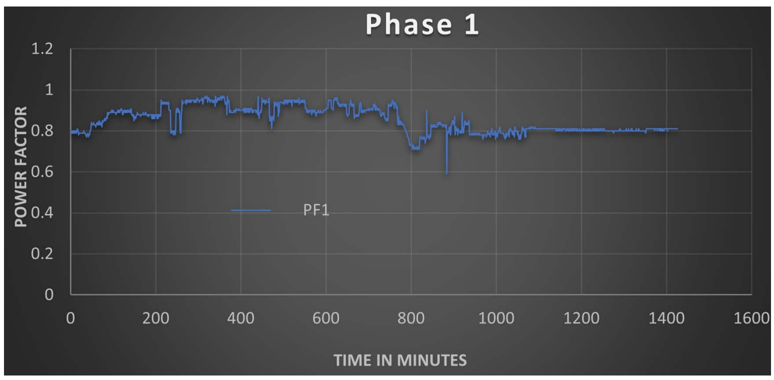

Figure 6. Phase 1 Power Factor Profile.

2) Profile of power factors consumed by the network.

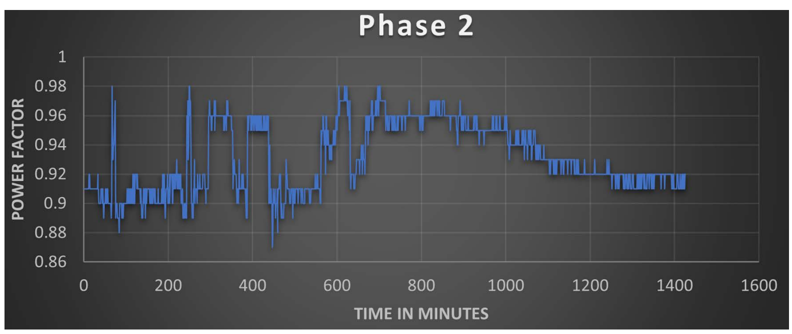

Figure 7. Phase 2 Power Factor Profile.

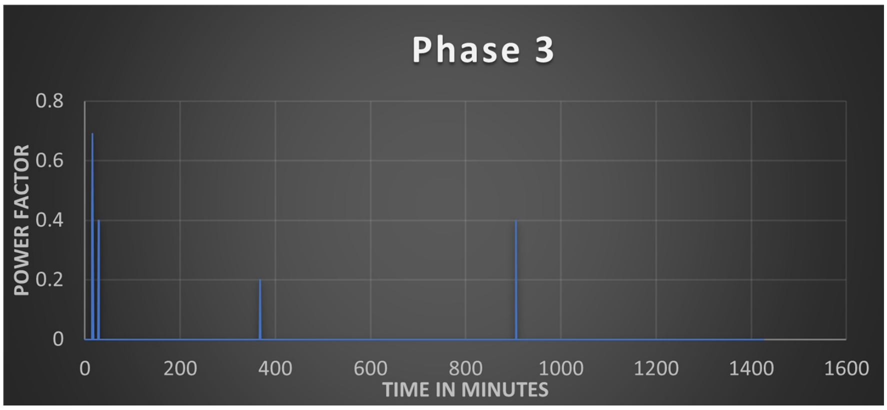

Figure 8. Power factor profile of phase 3.

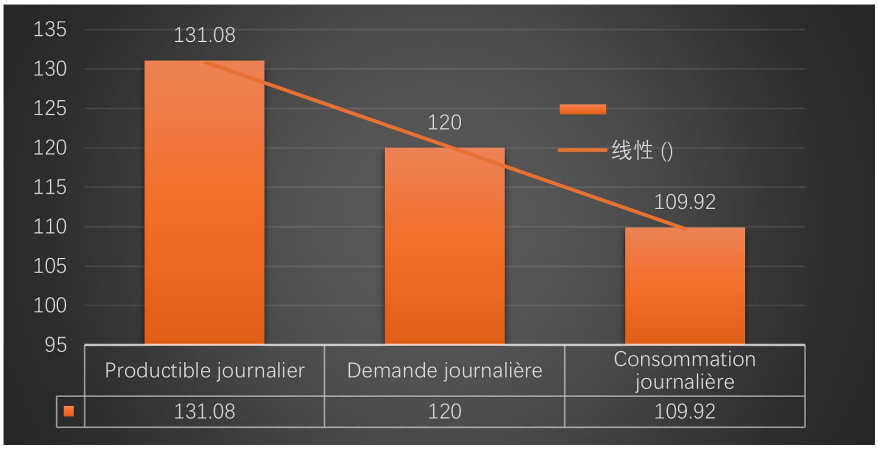

Figure 9. Daily energy balance.

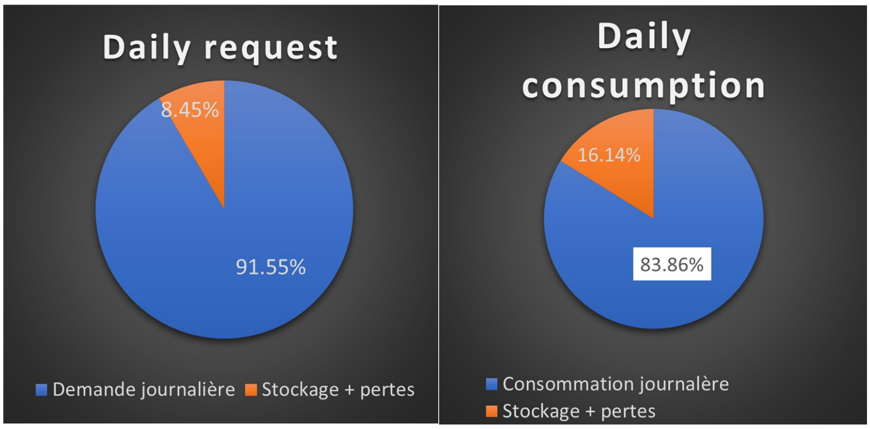

Figure 10. Daily Demand for Consumption with Storage + Losses.

3.2. Analysis and Discussion of Results

The analysis of these profile curves of the consumed powers shows that phase 1 (**Figure 2**) reaches its peak at 8:38 p.m. with a consumption of 2.05 kW. Phase 2 (**Figure 3**) reaches its peak at 8:20 p.m. with a consumption of 3.05 kW. At phase 3, the peak power profile obtained is 0.17 kW with high malfunction at phase 3

(**Figure 4**). We have the same trend in terms of the accumulation of the three phases, where the peak is obtained at 9:34 p.m. with a consumption of 4.58 kW. The difference is at the level of phase 3 (**Figure 5**), where we only obtain at this level the peak at 6:30 a.m. with a consumption of 0.16 kW. This difference shows us that the three phases are not balanced, which is synonymous with poor load distribution per phase. It therefore emerges from this analysis that lines 1 and 2 are overloaded, which constitutes the main cause of the voltage drops among subscribers. The analysis of these power factor profile curves reveals that phases 1 (**Figure 6**) and phases 2 (**Figure 7**) respectively reach their power factor peak at 11:12 a.m. and 4:20 p.m. with a value of 0.97 kW. At phase 3, the peak power factor obtained is 0.69 kW, which occurred at 6:30 a.m. with a malfunction in places (**Figure 8**). These different values justify the imbalance between the phases. As for the cumulative power factor profile, it gives us a maximum value of 1 kW and a minimum value of 0.86 kW. These values are substantially good and acceptable and cannot cause a penalty. This assessment (**Figure 9**) allows us to know that the daily output is 131.08 kWh, for a current daily demand of 120 kWh, or 91.55% of the energy produced per day (**Figure 10**). Current consumption per day is 109.92 kWh or 83.86% of the daily production (**Figures 9** and **10**). Furthermore, this assessment reveals that a minimum energy of 21.16 kWh is likely to be stored per day, plus possibly losses. This report confirms that the problems of current instability observed among subscribers are not linked to PV production or the storage capacity of the batteries. So, the mini power plant has no problem; it works well, production is available and all that remains is to be used properly. The work of Joseph SEYMOUR and Terry HORSLEY is acceptable because the difference between the high and the lowest voltage obtained is much less than 4% of the lowest supply voltage. This confirms that there is an excessive voltage imbalance on the LV electrical distribution network of the DJEGBE mini-power plant. This implies a poor distribution of loads per phase. Furthermore, the various findings made at subscriber installations do not comply with the requirements of the French standard C15-100, which is the reference for electrical installations. On the other hand, the observations made in the mini-power station attest to compliance with the requirements of the French standard C15-100, which is the reference for electrical installations. This confirms that the problems of current instability observed among subscribers are not linked to PV production, nor to the storage capacity of the batteries, but rather to the distribution and use among subscribers whose installations do not comply with any standards.

4. Conclusion

In this work, we were interested in the impact of regulation on the stability of medium voltage feeders of the electrical distribution network. The audit carried out the existence of malfunctions on the LV network of the DJEGBE mini-PV power plant, in particular, a poor distribution of loads by phase with the overload of lines 1 and 2. Too great a voltage imbalance between the phases and the nonexistence of protection bodies at subscriber installations, which do not comply with the standard in force (NF C15-100). Faced with this, recommendations were given for the improvement of said network, this will allow the company to satisfy its customers and increase its turnover. Finally, our work made it possible to provide distribution network managers with methodologies for adjusting the parameters of local regulators at the producer level. The different approaches proposed present varied possibilities for best adapting to the needs and capacities of distribution network managers. Finally, we propose an adjustment of the speed of regulations for network codes, that is to say, which is valid regardless of the network and the producers it connects. The stability of a producer depends on its position on the network, its installed power and its measurement filter.

Authors' Contributions

This work was carried out in collaboration between all the authors. The "senior author" and the "first two co-authors" designed the study, performed the statistical analysis, and calculation, and wrote the study protocol for the manuscript. The "last co-author" supervised and coordinated the work. All authors have read and given final approval for publication of the manuscript.

Acknowledgements

The authors are indebted to the ASEMI Company based in DJEGBE (Benin) for the support and especially for the databases made available to us.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the authors at reasonable request.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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