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Experimental Study of the Voltage Quality of the Low Voltage Distribution Network: Application to the City of Bobo-Dioulasso

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Abstract

The electrical energy produced must be consumed at the same time, hence the need to achieve a balance between supply and demand. Therefore, the production, transport, and distribution systems together constitute an electricity network. The distribution networks are designed to deliver energy to consumers. Unacceptable voltage drops are observed in the distribution networks of developing countries such as Burkina Faso. A study was carried out on the distribution network of the city of Bobo-Dioulasso in Burkina Faso. It allowed for experimentation with the "Megger MPQ1000" network analyzer to evaluate the quality of the voltage supplied to households. To this end, tests were carried out in a public distribution station and at a few subscribers in the Sarfalao district of the city of Bobo-Dioulasso. These tests were used to assess the percentage of voltage drops. These values, which are higher than 8% of the nominal voltage, are not regulatory. The load curves of the consumers in the district were also drawn. Indeed, the period of the high load is between 19:00 and 23:00 Local Time (LT), while the period of the medium and low load is between 00:00 and 18:00 LT.

Keywords

Experimental, Voltage Drop, MV/LV Networks, Network Analyzer

1. Introduction

Electricity networks are large and complex structures whose role is to transport electricity from massive production centers to consumption locations, often over long distances, according to Nguewo, 2012 [1]. This results in voltage drops among subscribers.

In this context, the Distribution System Operators (DSOs) are committed to guaranteeing the quality of the electricity they supply to their users. Maintaining the voltage within certain legal and possibly contractually set limits is one of the commitments of these DSOs according to Cosson, 2016 [2]. Therefore, they must know the quality of the voltage supplied to households. In this logic, software such as that of M. Du *et al.*, 2017 [3] has been developed to allow knowing the voltage of the different nodes of the Low Voltage (LV) network in order to make better decisions at the right time. Guinguané, 2018 [4], in his thesis, had shown that the quality of electricity supply in Burkina Faso remains poor, but he had not studied the specific case of the voltage on the LV distribution network.

Thus, in this paper, an experimental study was made by conducting tests on the electrical network of the city of Bobo-Dioulasso to measure the quality of the voltage.

To carry out this work, we will first explain the methodology and tools used for the study. Then we will propose an experimental protocol to carry out tests on the distribution network. Finally, we will analyze and discuss the different results.

2. Materials and Methods

For the present study, we select the sample of a public distribution substation and customers to be used in the study. A "Megger MPQ1000" electrical network analyzer was used for the measurement of electrical parameters. The measured electrical parameters will be analyzed and interpreted.

2.1. Public Distribution Network

The medium voltage distribution network starts from the High Voltage Category B/High Voltage Category A (HV/HVB) source station, from which several HV outlets are located, consisting of a set of conductors and switchgear that supply the medium voltage loads or the HV/LV public distribution stations according to Hérault, 2009 [5].

The SONABEL network has substations with 160 kVA, 250 kVA, 400 kVA, and 630 kVA transformers… These transformers are installed in breezeblock houses, on pedestals and on poles…

We chose substation number 55 of the distribution network of the city of Bobo-Dioulasso, the second-largest city in Burkina Faso. Its transformer has an apparent power of 400 kVA and a load factor of 66%. It is located in a residential area, more precisely in the Sarfalao district of Bobo (section ZS, lot 32, plot 00) illustrated in **Figure 1**.

2.2. Selection of Subscribers

A sample of subscribers was selected, taking into account their distance from the public distribution substation. On this basis, the subscribers are selected according to the references in **Table 1**.

Table 1. Summary of tests carried out on subscribers supplied by substation N˚55.

Subscriber number	Type of connection	Subscription	Distance to the post (m)	Test period
Extension N˚55 (ZS 32 00)	Three-phase	-	starting point	27/05/2019 to 30/05/2019
ZK 41 03 001	Single-phase	5 A	1038	17/05/2019 to 27/05/2019
ZS 48 14 002	Three-phase	30 A	574	19/06/2019 to 25/06/2019
ZS 15 17 001 to 003	Three-phase	Two (2) 5 A subscriptions and one 3 A subscription	1075	25/06/2019 to 27/06/2019

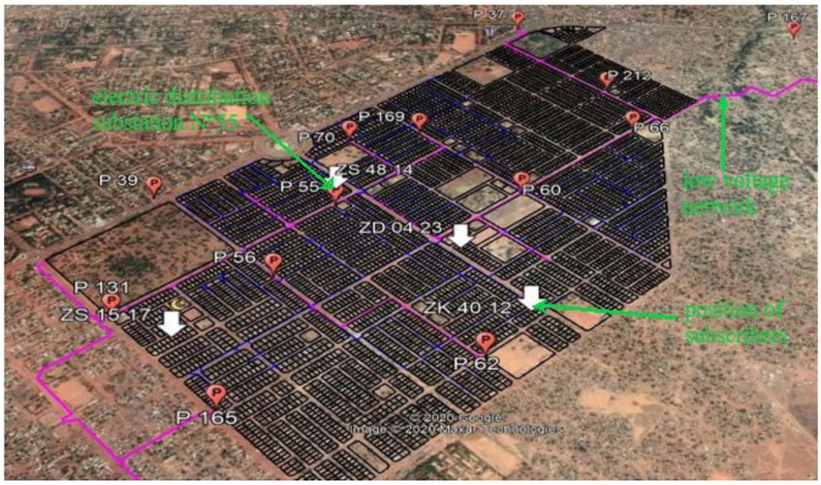

Figure 1. Map of the test area.

3. Measurement of Electrical Parameters

3.1. Description and Operation of the Network Analyzer

The network analyzer is a device for evaluating the quality of an electrical network. It provides a snapshot of the main characteristics of the network such as current, voltage, frequency, active and reactive powers, harmonics… Voltages up to 1000 V can be measured with the device according to Megger, 2016 [6]. **Figure 2** is a picture of the network analyzer installed at customer ZS 41 03 001. In this picture, the analyzer is on the left and the SONABEL subscriber's panel is on the right.

3.2. Measurement of Electrical Parameters

The measurements are performed with the network analyzer "Megger M PQ1000". The experimental protocol used for this work consists of an MV/LV transformer, an LV feeder, the connections of SONABEL subscribers, and a network analyzer. The experimentation consisted in installing the network analyzer at the public distribution station and the subscribers' homes. The recording lasted a minimum of 24 hours during the hot and winter periods. The measurements are processed with "Megger PQ" software. It is purchased with the device. It is software that allows the configuration, processing and analysis of data. When installed on a computer, it allows data such as voltage, current, transited

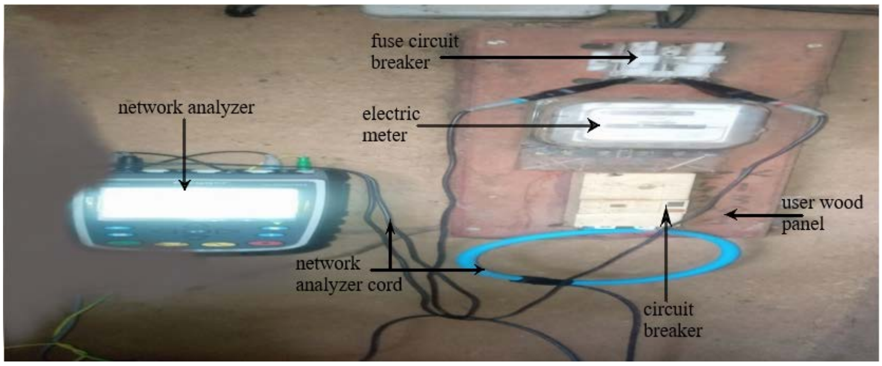

Figure 2. Megger MPQ1000 analyzer installed at a single-phase customer.

energy, power factor, harmonics, etc. to be imported and analysed. It is also used to draw curves to facilitate the interpretation of these electrical parameters. The following Figure 3 shows the principle of the experimental protocol for the different tests.

The different elements of the protocol are described as follows:

- The load: these are customers connected to the SONABEL network for whom the electrical parameters of the installations have been recorded and analyzed. The subscriptions of these customers are of the single-phase or three-phase type;
- The transformer: this is a static converter that lowers the voltage from 15,000 V to 230/400 V to adapt it to the needs of users. The transformer used in this study is 15/0.4 kV with a power of 400 kVA. It supplies customers in Sector 17 of Bobo-Dioulasso, Sarfalao district;
- The network analyzer: As described above, it measures and records the electrical parameters of the network in normal and transient operation. It compares the data with the standard and detects those that are not regulatory. It also provides curves to facilitate interpretation. I_a, I_b, I_c, V_a, V_b, and V_c represent respectively the currents and voltages of phases a, b, and c;
- LV lines: These provide single or three-phase low voltage to SONABEL customers. The main feeder is made of twisted Retylene cable 3 * 70 + 1 * 54.6 + 16 mm^2 aluminum and the customer connection cables are made of twisted Retylene aluminum cable 2 * 16 mm^2 or 4 * 16 mm^2 depending on whether it is a three-phase or single-phase connection. The maximum currents that these cables can carry without exceeding the thermal constraints (admissible current) are 83 A, 74 A, and 180 A respectively for twisted Retylene aluminum cables 2 * 16 mm^2, 4 * 16 mm^2, and 3 * 70 + 1 * 54.6 + 16 mm^2 according to NFC 15 100, 2002 [7].

4. Results and Discussion

4.1. Results

The analyzer was installed at transformer station N˚55 and three (3) subscribers of the Bobo-Dioulasso electricity network. Its illustrative diagram is in Figure 3 and Figure 4.

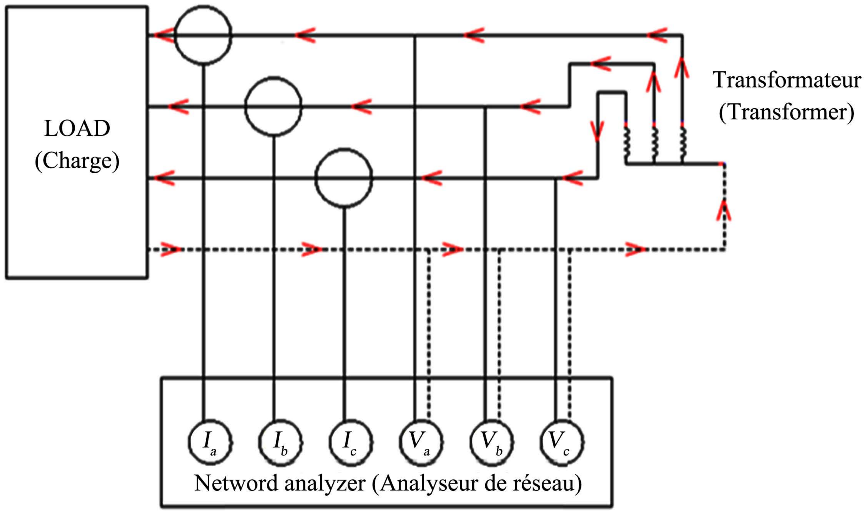

Figure 3. Schematic diagram of the experimental protocol.

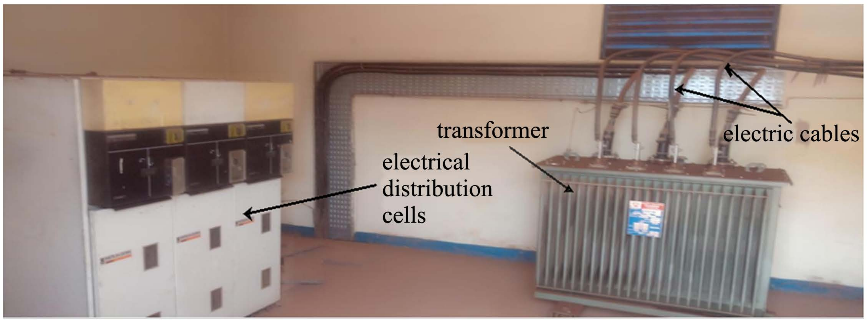

Figure 4. Cells and MV/LV transformer at Bobo-Dioulasso substation N˚55.

This enabled several data to be collected through four (04) tests carried out at different times.

4.1.1. Test 1

Test 1 carried out at substation N˚55 (0.4/15kV/400kVA transformer) concerns the period from 27/05 to 30/05/2019. The characteristic data are presented in Figure 5.

This test 1 carried out at the public distribution substation N˚55 provided data to evaluate voltage drops and to construct load curves for the different subscribers. It is noticeable that the demand for electrical energy is high between 19:00 and 23:00 Local Time (LT), and it starts to decrease from 23:00 LT. The period of low and medium current demand is between 00:00 LT and 19:00 LT (Figure 5).

For the following, the period of high power demand being observed between 18:00 and 23:00, we will present only the data of this period for tests 2, 3 and 4. In each test, we will give the following parameters:

V_{tr} = voltage at the transformer terminals in Volts (V);

I_{tr} = LV feeder current at substation N˚55 in Amperes (A);

V_{abo} = voltage at the customer in Volts (V);

I_{abo} = current at the customer in Amperes (A);

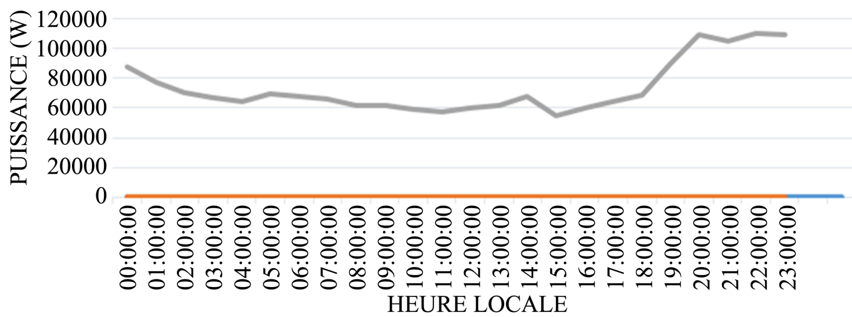

Figure 5. Load curve of customers supplied by substation N˚55 (readings on 28/05/2019).

P = transited power from the LV feeder (kW);

u_{ex} = the relative voltage drop resulting from the experiment in percentage (%).

4.1.2. Tests 2, 3, 4

Tests 2, 3, and 4 were carried out respectively at subscribers ZK 41 03 001, ZS 48 14 002 ZS 15 17 001 to 003. The distances of these DSO subscribers from substation N˚55 and the periods in local time of the measurements are as follows:

- Test 2, subscriber ZK 41 03 001, located at 1038 m from substation N˚55, and the measurements were carried out from 19/06/2019 at 16:35 to 25/06/2019 at 16:03, 5 A single-phase subscription;
- Test 3, subscriber ZS 48 14 002, located 574 m from substation N˚55, and the data were recorded from 25/06/2019 at 17 h 40 mn to 28/06/2019 at 14 h 30 mn, 30 A three-phase subscription;
- Test 4, subscribers ZS 15 17 001 to 003, located at 1075 m from substation N˚55 and the recording took place from 25/06/2019 at 17 h 40 mn to 28/06/2019 at 14 h 30 mn. This family has the particularity to have 2 connections of 3 A (3 A subscription) and a connection of 5/15 A (5 A subscription). The measurements concern all these subscribers.

The daily variations of voltage, voltage drop, current, and power according to the test have been represented through the curves in **Figure 6**.

With regard to the relative voltage drop curves, we notice a significant voltage loss between 19:00 and 23:00 LT at the users. For the three power lines, the maximum values of the voltage drop are obtained between 20:00 and 21:00 LT, which often reach 20% of the nominal voltage. Furthermore, the average values of the curves in **Figure 4** are contained in **Table 1**.

The average values of the curves in **Figure 6** are contained in **Table 2**.

The experiment consisted in collecting data on the LV network in the Sarfalao district of Bobo-Dioulasso. They will be analyzed and discussed and will also allow us to conclude this work.

4.2. Discussions

The results of test 1 at the public distribution substation N˚55 showed that the period of high power demand is between 19:00 and 23:00 LT. During this time

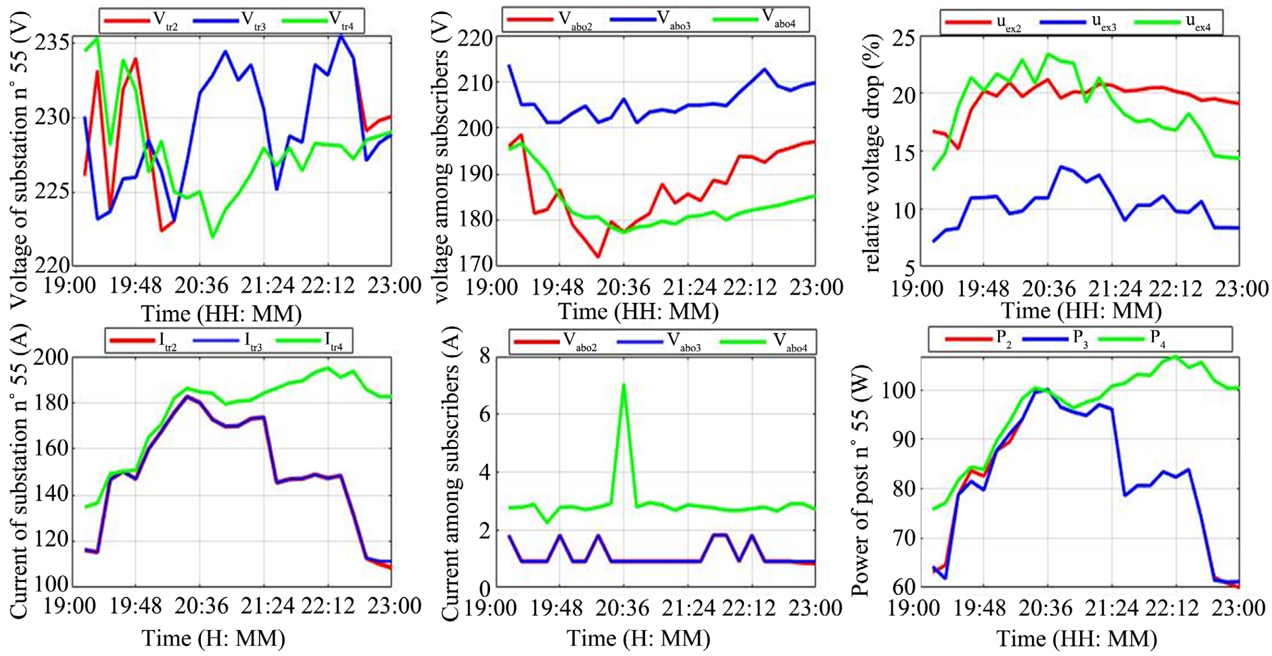

Figure 6. Daily variations of voltage, voltage drop, current, and power. With: V_{tr2}, V_{tr3}, V_{tr4}: voltages at the transformer terminals in Volts (V) during tests 2, 3, and 4 respectively; I_{tr2}, I_{tr3}, I_{tr4}: LV feeder currents of substation N˚55 in Amperes (A) during tests 2, 3, 4; V_{abo2}, V_{abo3}, V_{abo4}: subscriber voltages in Volts (V) during tests 2, 3, and 4 respectively; I_{abo2}, I_{abo3}, I_{abo4}: subscriber currents in Amperes (A) during tests 2, 3, and 4 respectively; P_2, P_3, P_4: Transmitted power of LV feeder (kW) during tests 2, 3, and 4 respectively; u_{ex2}, u_{ex3}, u_{ex4}: relative voltage drops from the experiment in % during tests 2, 3, and 4 respectively.

Table 2. Average values of the electrical parameters of tests 2, 3, 4.

Test n˚	V_{tr} (V)	I_{tr} (A)	V_{abo} (V)	I_{abo} (A)	P (kW)	u_{ex} (%)
2	230.10	149.91	186.89	1.11	82.78	18.77
3	229.27	150.07	205.68	1.12	82.62	10.27
4	227.8	175.76	183.18	2.947	95.99	19.6

interval, the voltage collapses and is sometimes at a lower value than during the period of low and medium power demand. This period is observed between 00:00 and 18:00 LT and we see that the voltage is generally higher. (Figure 5)

At family ZK 41 03 001, which is located at 1038 m from substation N˚55, the daily variation of the voltage drop was presented in Figure 6. The test gave an average relative voltage drop of 18.77% for a power of 82.78 kW (Table 2). This voltage drop is not permissible as the permissible voltage drop for households is 8%, *i.e.*, a voltage of 211.6 V for a nominal voltage of 230 V.

Two other tests were carried out from 19/06/2019 at 16:35 LT to 25/06/2019 at 16:03 LT at the subscriber ZS 48 14 002 and from 25/06/2019 at 17:40 to 28/06/2019 at 14:30 LT at the family ZS 15 17 001 to 003 (Figure 6). The evaluation also shows respective average relative voltage drops of 10.27%, corresponding to an average power of 82.62 kW and 19.6% for an average power of 95.97 kW for tests 3 and 4 respectively. They are not equally regulatory.

Generally speaking, the lowest voltages are observed during the peak period (19:00 LT to 23:00 LT): 171.9 V at 20:30 LT, 201.1 V at 20:40 LT, and 177.4 V at 20:30 LT for tests 2, 3, and 4 respectively. Comparing these results with other research works, we note that Bagré, 2014 [8] also demonstrated that the voltage drop along the feeder is higher at peak than at minimum load due to the higher load demand (Ohm's law) and higher losses.

5. Conclusions

We have carried out an experimental study with the "Megger MPQ1000" electrical network analyzer. It allows having an instantaneous image of the main characteristics of the network (current, voltage, frequency, active and reactive powers, harmonics). For this purpose, an experimental protocol has been designed. Data recordings at the public distribution substation N˚55, 15/0.4 kV - 400 kVA, and some subscribers in the Sarfalao district of Bobo-Dioulasso were carried out.

The tests carried out made it possible to plot the load curve of the subscribers. We note that the maximum demand is observed between 19:00 LT and 23:00 LT, and it becomes medium and low between 00:00 LT and 18:00 LT. The highest voltage drops are observed during this peak period. The average values of the relative voltage drops obtained, which are higher than 8% of the nominal voltage, are not regulatory. They call on the distributor to make urgent corrections. For this, they need to implement new planning frameworks incorporating innovative concepts and considering the future process to optimize the operation of the network according to Sindi, 2016 [9]. Therefore, in further work, we will propose modeling that will allow Distribution System Operators (DSOs) to assess the critical length of LV lines to provide regulatory voltages to their subscribers.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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