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Analysis of Power Disturbances and Voltage Imbalances in A City in Nigeria

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Abstract:
Investigation of power quality and the impact is necessary for source mitigation and effect attenuation. An analytical study of the electric power system, including data collection and processing on power disturbances and voltage imbalances at various household end-user points, was carried out in Wukari, Nigeria. The range of power disturbances and voltage imbalances at various end-user points were all factored into the experimental design. Subjective and objective approaches were adopted in the data collection using reliable and validated standard devices. The quantitative data analyzed showed power disturbances through abnormal voltage signals and outages. The technical implications resulted in residences' adoption of phase-to-phase connections to the national grid to meet voltage problems at peak load hours, which raised the voltage to an unusable intensity with a high tendency for electrical/electronic gadget damage. This effect challenges sourcing an alternative means of power supply in the metropolis. This study concluded that mitigation techniques are imperative from the national grid supply source and the household users' points.

Keywords: power quality, voltage, electricity, phase, unbalance.

INTRODUCTION

In Nigeria, electricity which is one of the prominent infrastructures essential for proficient successful disposition in modern life suffers a tremendous deficit in terms of power quality disturbances and voltage interruptions. The nexus between the electricity source, distribution system, and the end users supposes an increasingly crucial role in the reliability and efficiency of the power operation cycle [1]. Reliability and efficient maintenance of electrical power performance are very significant for the continuity of the electricity supply. Typically, electricity distribution networks serve a large number of nodes spanning over large geographical areas. Considering the complex structure of power grid connections, the probability that the system will operate to a standard performance level for a specific period, contingent on specified environmental conditions cannot be guaranteed due to various problems including fault occurrences. Fault in power systems due to inefficient and unreliable distribution networks poses a great threat to consumers in different sectors of the nation's economy. The most obvious effect is the series of power outages experienced in every nook and cranny of the country affecting different activities at residential, commercial and industrial levels. While erratic electricity supplies disrupt electric power-based activities, fluctuation of voltages negatively affects the service life of associated electrical/electronic equipment. Better electricity-related infrastructure can, thus, stabilize the efficiency and durability of returns/incomes.

In an electric power distribution system, a steady-state voltage does not exist. The end-users' characteristic demands from the feeding systems or the loading from the distribution points continually change, and so do the power system adjustment to these changes [2]. The changes and adjustments due to continual load alterations result in voltage variations which may be for a long duration. It can manifest either as over-voltage or under-voltage, depending on specified conditions for which source path for which the electrical current flow [2]. Significant voltage fluctuations, unbalanced phases, and poor power quality seriously impact performance and useful lives of electric equipment. Some electrical/electronic gadgets are adapted with one form of coil windings or another, which, efficient service delivery of these devices dependent, among other things is the supplied voltage balance status.

Power quality as expressed by [2] is given as

$$\text{Power quality} = \text{Reliability} \tag{1}$$

This simply implies that the availability of electrical networks or the grid is always within voltage and frequency tolerances. Imbalance or unbalance in supplied voltage is defined as the maximum deviation from the average of the three-phase voltages, divided by the average of the three-phase voltages and represented as percentage points [3]. The mathematical relationship for voltage imbalance or unbalance without the phase or line angles is given by National Equipment Manufacturer's Association (NEMA) [4].

$$\text{VL\% unbalance rate} = \frac{\mathrm{D_{max}VL_{3ave}}}{\mathrm{VL_{3ave}}} \times \frac{100}{1} \tag{2}$$

Where,
VL% unbalance rate = percentage line voltage unbalance rate
D_{max} = Maximum deviation
VL_{3ave} = Average voltage of the 3-line voltages
Similarly, Institute of Electrical and Electronics Engineers (IEEE) used phase instead of line for the description of the grid connection [4] thus:

$$\text{VP\% unbalance rate} = \frac{\mathrm{VP_{3ave}}}{\mathrm{VP_{3ave}}} \times \frac{100}{1} \tag{3}$$

Where,
VP% unbalance rate = percentage phase voltage unbalance rate
D_{max} = Maximum deviation
VP_{3ave} = Average voltage of the 3-phase voltages

$$\text{Average voltage } (V_{ave}) = \frac{V_{1R}+V_{2Y}+V_{3B}}{3} \tag{4}$$

Where,
V_{1R} = Grid line one coded red line
V_{2Y} = Grid line two coded yellow line
V_{3B} = Grid line three coded yellow line
The percentage imbalance can be expressed as the ratio of the negative or zero sequence components to the positive sequence component [3, 5]. Assuming there is no fault in the electric power system, the vector sum of the sequence voltages for the grids phases or lines must be zero.

$$\bar{V}_{1R} + \bar{V}_{2Y} + \bar{V}_{3B} = 0 \quad (5)$$

The unequal distribution of single-phase loads in a three-phase circuit is the primary source of voltage imbalance (typically less than 2%). A voltage unbalances exceeding 2% in a three-phase system can cause excessive current imbalance, an increase in winding temperature or overheat that is detrimental to the windings. Blown fuses in one phase of a three-phase capacitor bank can potentially cause voltage imbalance. Single-phasing circumstances can cause severe voltage imbalances (more than 5%) [3, 5]. Motors and transformers overheat due to voltage imbalance caused by device induction current imbalance. It is the deviation from the standard value of 220 Volts between three-phase voltages [6]. The evaluation of power quality involves the analytical study of the power system, such as capturing and processing current and voltage strength values at various points of a distribution system [7]. There is scarcely any research on power disturbances and voltage unbalance from the national grid supplied to the residential sector of Nigeria's economy. It is against this background, that this survey was conducted on power disturbances and voltage imbalance in the Nigeria households.

MATERIALS AND METHOD

Study Area

The survey and data collection took place in Wukari town, Taraba state, Nigeria. Wukari town is located between latitude 7°51'N and 8°15'N of the equator and between longitude 9°47'E and 14'E of the Greenwich meridian. It has an area of 4,308 km (1,663 sq. m) and a population of 241,546 at the 2006 census (Figure 1). The neighboring town includes Ibi town, Gindin, Dorowa, and Jootar. Electricity distribution in Wukari town is done by Yola Electricity Distribution Company (YEDC) Wukari business unit.

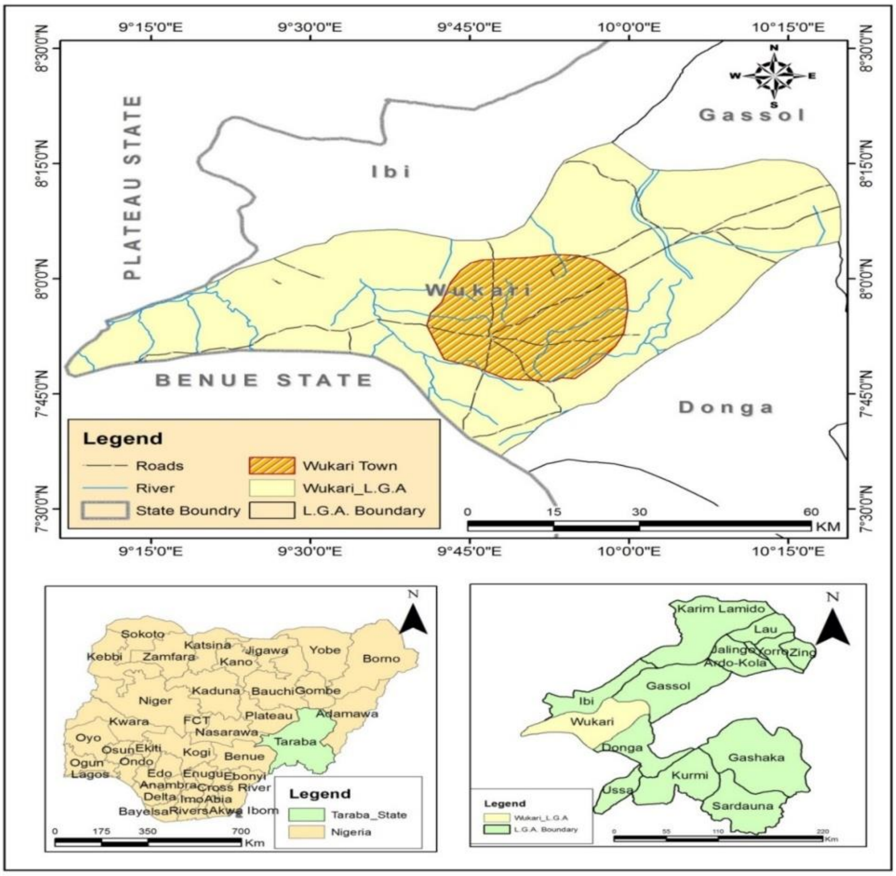

Fig. 3. Map of Nigeria and Taraba State showing the study area (Wukari).

Source: Ministry of land and analysis, Jalingo

The Study Population

The total population of electricity consumers in Yola Electricity Distribution Company (YEDC) Wukari business unit is obtained by summing the total number of consumers in the currently working strata, referred to as k-books, in Wukari; business units (Table 1).

Table 1: Customer Population

K-BOOKS	CUSTOMERS POPULATION
04/14	201
27/35	223
09	60
16/33	422
12	126
08	135
10/11	234
13	112
01/02/03	252
05/06	158
L (Churches and Mosques)	23
M (Commercial areas)	87

(Source: Yola Electricity Distribution Company Wukari Business Unit, 2017)

The total number of customers (population of consumers) is denoted N. The total number of customers in the strata is denoted N*i*.

Where *i* =1, 2, 3, 4, 5, …, 11

$$N = \sum_{i=1}^{n} Ni$$

$$N=N1+N2+N3+\ldots+N11$$

N=201+223+60+422+126+135+234+112+252+158+87

N=2038

This is the total population of customers in Wukari business unit besides the churches and mosques. Hence the targeted population was 2038 units.

The study sample for this research was calculated by using Taro Yamane's formula at 95% confidence level (Yamane, 1973). The calculation formula of Taro Yamane is presented as follows.

$$\text{n} = \frac{N}{1 + N(e)^2}$$

Where,
n= sample size required
N = number of people in the population
e = allowable error (%)

Application of Taro Yamane's formula (Yamane, 1973) in study sample determination gave

$$n = \frac{2038}{1 + 2038(0.05)^2}$$

$$= \frac{2038}{5.82}$$

= 350.17 ≈ 350 end users'

Study Design

The study focused on the national grid customer population in the Wukari. Subjective and objective approaches were adopted in the data collection for power disturbances originating from consumers' networks, a technicality in national grid connections and implication of power disturbances using a self-developed, pre-tested and validated questionnaire and handheld digital multimeter model M226C. The questionnaire was made up of two main sections, each focusing on a specific aspect. These include location information and power outages. The objective approach focused on electric energy supplied measurement at the end-user point and consumers' networks and devices, which included three-phase loads, unbalanced connections, a lack of adequate neutral wire, no earthing system, and a low circuit breaker rating.

Data Analysis

The data was analysed using a computer software package (Statistical Package for Social Sciences version 16.0) in the form of frequency, percentage, mean, and standard deviation (SD).

RESULTS AND DISCUSSIONS

A representation of the end-users of the national electricity grid revealed that of the three hundred and fifty (350) end-users of electricity targeted by this study, two hundred and nine (209) customers participated, representing a response rate of 59.71%. The outcome of interference emanating from end-user networks and devices was evaluated. These mainly include disturbances due to phase loads, connection imbalances and the lack of a suitable neutral conductor (low circuit breaker rating or grounding system).

There are typically four network lines distributed across the transmission towers. The first above was coded as a red line, the second as a yellow line, the third as a blue line, and the fourth as a neutral line. Due to the three-phase mains connection of three life wires and a neutral conductor, a total of four cables are required from the public power grid to the meter panel on the house wall (Figure 1a). The two-phase grid connection consists of two life wires and a neutral line, i.e. a total of three cables from the utility grid to the meter panel on the house wall (however, no classified connection by the YEDC Wukari business unit). Single-phase, consisting of a live wire and a neutral wire, for a total of two wires connected to the meter board (Figure 1b). The phase-to-phase mains connection is a combination of two lifelines to the meter board with no neutral (safety) wire (Figure 1c).

Figure 1(a) Three-phase connection (b) Single-phase connection (c) Phase-to-phase Connection

The result showed that 86 end-users representing 41.1% of participants, had a single-phase, 53 end-users representing 25.4% of participants, had a three-phase, 45 end-users representing 21.5% of participants, had a phase-to-phase wire connection, with 25(12.0%) unspecified others.

The three-phase supply should be distributed evenly and reasonably across the three-phases. Single-phase loads connection of different demand capacities and characteristics, as well as power consumption to a three-phase electric power supply system, will cause unbalanced voltages distribution of phase or gridline voltages at the point of the power supply and unequal currents flow in the three-phase power circuits [9].

In addition, unbalanced phase voltage distribution in the three-phase supply voltages can create negative sequence components, thereby inducing extra power losses with undesirable currents and voltage drop in neutral conductors [9].

The power quality relies on the electric power availability from the national grid within voltage and frequency tolerances. Unbalanced distortion is one of the power qualities factors in determining the energy efficiency of the power distribution system.

Measuring transformer load from single-phase loads has shown that all single-phase loads are potential sources of unbalanced distortion [9] with adverse effects on the electric power distribution system, such as unbalanced 3-phase voltages.

From the analysis of the voltage unbalance in the three-phase grid connections using the formula stipulated by the National Equipment Manufacturer's Association (NEMA) and the maximum allowable unbalance tolerance of 2.0%, there were several unsatisfactory grid connections unbalanced in the metropolis (Table 2). The absence of proper neutral lines was also observed in several participant households. These contributed to the witnessed voltage fluctuations.

Table 2. Voltage strength values at various points of power distribution system

Districts	Voltage strength values		Remarks	
	Off-peak hour	Peak hour	Off-peak hour	Peak hour
N1	1.61%	4.34%	Satisfactory	Unsatisfactory
N2	14.40%	6.23%	Unsatisfactory	Unsatisfactory
N3	2.80%	1.00%	Unsatisfactory	Satisfactory
N4	6.40%	2.30%	Unsatisfactory	Unsatisfactory
N5	1.46%	3.21%	Satisfactory	Unsatisfactory
N6	4.10%	3.65%	Unsatisfactory	Unsatisfactory
N7	8.00%	3.37%	Unsatisfactory	Unsatisfactory
N8	3.30%	2.29%	Unsatisfactory	Unsatisfactory
N9	4.61%	3.48%	Unsatisfactory	Unsatisfactory
N10	4.15%	1.57%	Unsatisfactory	Satisfactory

Also, from the analysis, welders were found near many households. This intermix in the land use development planning in the metropolis results in a fluctuation in the power supply since the most prevalent causes of voltage fluctuation are electric arc furnaces and welders. Comparing the intensity of a voltage flicker to the sensitivity of human visual perception revealed that a high response (95.2 per cent) might generate voltage fluctuations or lamp flickers by exhibiting continuous, rapid variations in the load current magnitude [5]. Continual unpredictable voltage sags and swells can cause sensitive equipment to malfunction, overheat the equipment, and shorten its life [5]. Under voltage is defined as a drop in RMS ac voltage below 90% at the power frequency [5]. The power supplied by the national grid does not satisfy the electric power need of 86.8% of participant households. The reason ranges from high voltage (3.8%), low voltage (27.3%), power outages (29.7%) and unspecified others (39.2%). High voltage is predominantly observed in the night seasons (55.5%), whereas low voltage becomes the issue in the daytime (63.2%). Validation of the participants' observation was the physical measurement obtained at each household unit. Analysis conducted regarding the nominal standard value of 220 Volts stipulated for electrical/electronic gadgets in Nigeria, and values considered as under and over-voltage as decrease or increase beyond 10% in the RMS ac voltage from the nominal value [5], Figure 3 showed that at off-peak periods, the voltages were overvoltage for the three grid lines over 198 – 242 volts range which make them prone to the destruction of tools used by the households. At peak load hour, the residences have the options of switching to a grid with nominal voltage, but districts N2, N3 and N6 that have all the grid voltages not more than the standard value.

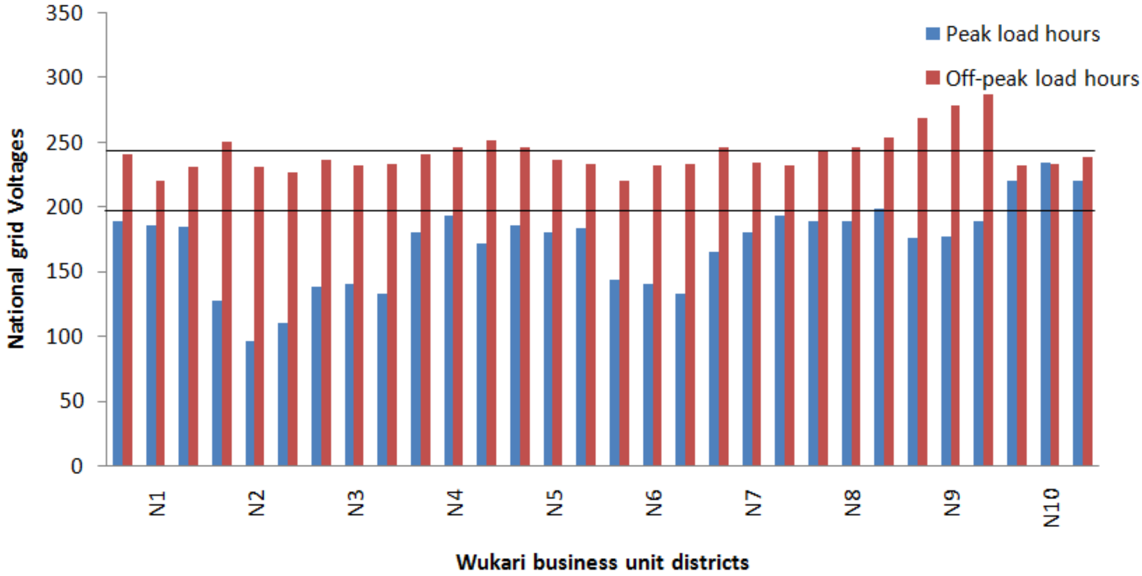

Figure 3. Average voltage status on three-phase grid connection

Single-phase connection showed under-voltage at peak load hours, which affects the users. However, at off-peak hours, it was found that the voltage increased to a range of nominal usable voltage with slight overvoltage in district N4 and overvoltage in district N9 (Figure 4). To enhance the supplied voltage during the off-peak period, some households adopted a phase-to-phase connection that increased the available voltages to a non-useable level (overvoltage) (Figure 5). Higher or lower than nominal voltage or current can cause certain types of equipment to malfunction or be damaged, as is well known. [7]. 80.4% uses electric power stabilizer in their utility connections, while 19.1% of participants do not use a stabilizer. 51.4% used a stabilizer in connection. While 48.6 did not use a stabilizer in the grids.

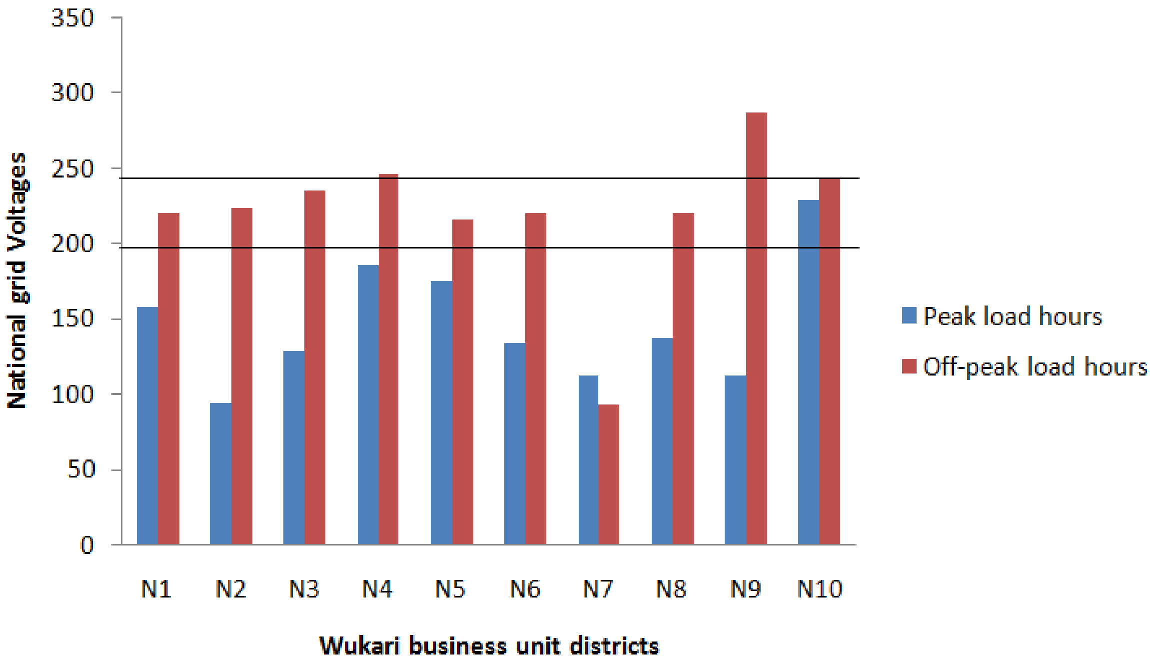

Fig. 4. Average voltage status on single-phase grid connection

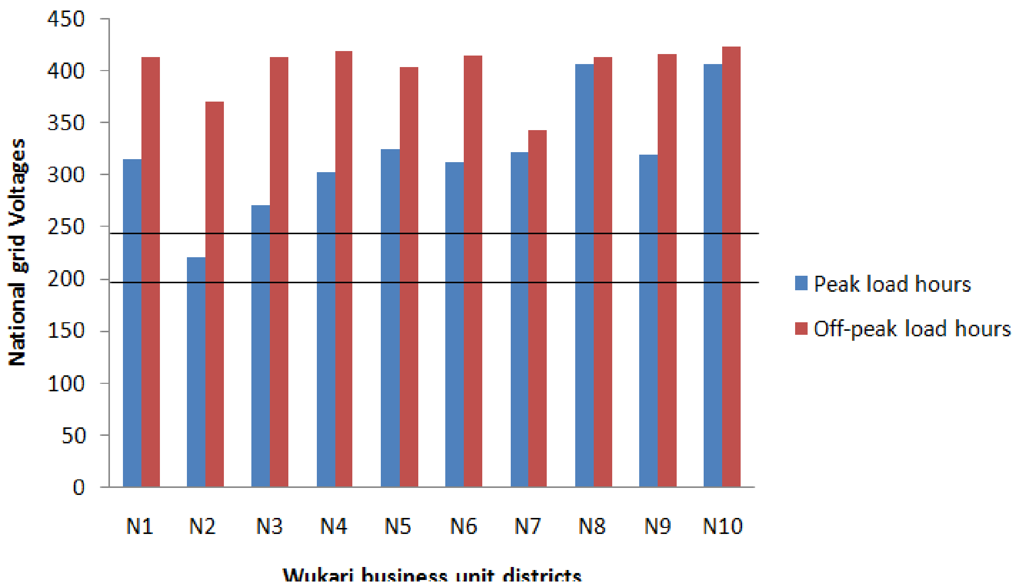

Fig. 5. Average voltage status on phase-to-phase grid lines connection

Power quality has a direct impact on electrical equipment and diverse systems because power interruptions cause equipment damage and poor system performance. Power quality testing should be done frequently with high-sensitivity equipment to maintain optimal performance. It is established that higher or lower than nominal voltage or current can cause equipment to malfunction or be damaged [7]. The electricity supply in Nigeria is not only unreliable but also of poor quality. There is no information on the state of the Nigerian power system's power quality [7].

A power outage is a complete power loss caused by faults and accidents [5]. Mitigation to power outage problems is to seek an alternative means of power supply such as a standby electric power generator. One hundred and thirty-one (131) participant households have alternative power supply means, out of which 97.1% are predominantly generators. This proportion of the participants adds to 81% (130/160) million Nigerians who generated their electricity through alternative sources to make up for irregular power supply [10]. Consequently, the result agreed with the observation made by Azodo [11] in a southwestern city in Nigeria.

CONCLUSION

Electric power distribution from the national grid within the acceptable voltage and frequency tolerances to the end-user is achievable. The power disturbances and voltage imbalance sources analysis in this study showed that end-users' characteristic demands from the feeding systems or the loading from the distribution points, type of grid connection and presence of high-power demand equipment such as welding process contribute to the witnessed voltage fluctuations in the metropolis. Inadequate power quality through under-voltages from the feeding systems was predominantly observed at peak load hours but changed to over-voltage during off-peak hours. The role of the end-users in the power quality demands the engagement of the local electric utility company or a highly skilled electrician for appropriate grid connection and notification of relevant authorities on power issues perceived concerning the supplied power. But, then, a substantial supply system can significantly reduce the severity of voltage fluctuation, which concerns the electric utility company in the area.

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