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Power Quality and Voltage Interruptions in Electric Power Utilisation, Model Cost and Technical Implication: The Case of SMEs in Wukari, Nigeria

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Abstract
Power quality issues are usually consumer-caused or end-user point-of-care issues that are manifested as current, voltage, or frequency abnormalities that result in consumer device failure or utility failure. This study was conducted to examine power quality and voltage interruptions, their costs and technical implications for SMEs whose most important resource for business operations is electricity. The research methodology employed for this study involved the collection, analysis and integration of quantitative data on power quality disturbances that sensitive SMEs that tolerate electric/electronic utilities can tolerate. The results obtained showed a high proportion of electricity deficits and voltage fluctuations deviating from the nominal 220-volt standard prescribed for household purposes in the country. The impact of the power problem on operational costs was represented in a modelled relationship constructed for induced cost and voltage disturbance variables. The multiple damaging effects of voltage disturbances on SMEs require urgent regulation on the part of the distribution network and the consumer side.

Keywords: *Voltage, voltage fluctuation, power quality, SME, end-user*

1. Introduction

An uninterrupted and reliable electricity supply network is assuredly one of the cardinal imperatives for any nation’s growth and development. Electric power distribution to the end users which is the final phase in the electricity service delivery chain of electric power systems incorporates all electricity utility entities from the point of power generation to the service entrance of individual consumers’ equipment (Hadow *et al.*, 2011). Any power distribution network aims to deliver electrical power produced from the power plants to consumers at the desired voltage level and with a high degree of reliability. Thus, the link between the sources of electric power, the distribution systems, and the consumers assumes an ever more critical role and must be as reliable as possible (Adejumobi and Olamipekun, 2009).

Currently, the Nigerian electricity sector is facing many challenges. The national power grid normally serves to power the country but is backed by various alternative backups by individuals. The grid is designed to transmit electrical energy at full load up to a certain capacity. However, due to inadequacies, the intended capacity is usually exceeded. Electrical power systems are susceptible to various power quality disturbance problems. The power quality described by Fathi (2012) is the electrical energy performance that under normal conditions is mainly affected by disturbances in feed-in systems or load problems. The simple power quality definition equation is:

$$\text{Power quality} = \text{Reliability} \qquad (1)$$

Problems associated with power quality are usually consumer-driven or end-user point issues evidentially manifested in current, voltage or frequency deviations, which contribute to end-user equipment failure or utility defaulted operation (Kennedy, 2000). Another problem of poor power quality is damage to the cable, and cable replacement is so costly. The cable life is an exponential

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function of the number of impulses of a certain magnitude that it receives (Hopkinson,1984). The damage to the cable is related by:

$$D = NV^{c} \tag{2}$$

where

D is a constant, representing damage to the cable,
N is the number of impulses
V is the magnitude of impulses and
c is an empirical constant ranging from 10 to 15.

Therefore, anything that will decrease the magnitude of the impulses only slightly has the potential to extend cable life a great deal.

These days, the widespread use of highly advanced technology or devices which have become more sensitive and as well interconnected in extensive networks and processes has complicated all aspects of the electric power system (Fathi, 2012). These devices not only have a greater sensitivity to the effects of power quality, but they also have the potential to negatively affect the devices (Fathi, 2012; Ogunyemi *et al.*, 2012). This makes the power quality system the end users' concern, likewise the supply authorities' concern (Fathi, 2012). The contemporary implication of power quality fluctuations is very expensive, which often manifests in shut-downs of systems and equipment malfunctions or outright damage (Fathi, 2012; Ogunyemi *et al.*, 2012). This, according to studies, has also led to less productivity, loss of money and labour, lost and corrupt data, and poor power efficiency (Fathi, 2012; Ogunyemi *et al.*, 2012).

As a result, power quality assessment has become a critical concern for nearly every power utility around the world. This is a requirement for maintaining and sustaining the reliable operation of sensitive equipment with minimal energy losses in an energy system for targeted gains (Fathi, 2012). In Nigeria, despite daily data collection by the competent authority on major power reliability issues, there is little discernible power quality data. This is because data on power quality in the distribution system is not uniformly defined and recorded (Ogunyemi *et al.*, 2012). The challenges Nigerian power systems face range from generation to distribution systems, evident in reliability far below expectations (Popoola *et al.*, 2011; Ogunyemi *et al.*, 2012). Businesses in Nigeria typically experience power disruptions, blackouts or voltage fluctuations. This results in huge costs for these companies due to damaged equipment, spoiled materials, wasted manpower, machinery and materials, and lost production. The overall impact of power quality issues and voltage fluctuations is that business uncertainty increases and return on investment decreases. It has also seriously sabotaged the country's growth potential and attractiveness to foreign investors (Adenikinju, 2005).

Power quality evaluation requires the proper recognition of any anomalous performance on a power system, which adversely affects electrical/electronic equipment conventional operation or causes outright damage through the collection of data resources and analysis regarding power quality standards and recommendation of applicable mitigation techniques to the power quality problems in a particular sector or region (Fathi, 2012). Studies in this area of research adopted diverse approaches in investigating power outage effects on firms which include costs analysis from production or output loss associated with electricity outages and economic effects of power outages on firms' activities (Bernstein and Heaney, 1988; Steel and Webster, 1991; Caves *et al*. 1992; Lee and Anas, 1992; Uchendu, 1993; Matsukawa and Fuji 1994; Beenstock *et al.*, 1997; Adenikinju, 2005; Cissokho and Seck, 2013). The predominant approach in data collection in these studies has been a subjective research technique with little or no attention to the objective assessment of power disturbances in terms of power quality and voltage fluctuations. It is against this background that this study was conducted to investigate the power quality and voltage interruptions, the cost and technical implications on small and medium enterprises that use electricity as their source power for operation.

2. Materials and Methods

The research methodology used for this study involved the collection, analysis and integration of quantitative data on power quality disturbances from the national grid for small and medium-sized enterprises (SMEs) whose core resource for their business operations is electricity. A total of 74 SMEs took part in the study. A multi-stage sampling approach was used in the recruitment of the participants in this study. The study area was evaluated following the District Divisions of the Wukari Business Unit of Yola Electricity Distribution Company (YEDC). The ten (10) operational districts had the numbers N1 to N10. A small group was selected using a variation of targeted sampling representing each district. A portable AC digital clamp multimeter (Mastech M266 model) was used to measure power quality. The voltage fluctuations and interruptions in the use of electrical energy; costs, and technical implications were evaluated using a self-developed questionnaire. The questionnaire used for data collection was developed based on current electricity supply issues, which were determined during a preliminary survey. This has been pre-tested for simplicity and clarity of content. In addition, the questionnaire underwent a content assessment and analysis for suitability for the study purpose, approval and acceptance of the final copy for this study. The questionnaire was interview-administered to the participants. The phase voltages of the grid feeders and the type of grid connection were measured and recorded by each participant's business unit. The measurement was carried out at peak and off-peak times following the business hours of the participants. A relationship between induced costs (dependent variable) and performance impairment variables (independent variables) was established using multiple linear regression analysis in SPSS software version 16.0. The representation of the created multiple regression model has the following format:

$$Y = m_0 + m_1x_1 + m_2x_2 + m_3x_3 + \cdots + m_qx_q + c$$

Where:
Y is the dependent variable or response,
$q$represents the regressor variables or number of independent,
x_i is the regressor or independent variables
i is the range from 0, 1, 2, 3, …, q,
m_j is the coefficient of regression,
i = 0, 1, 2, 3, …, q, and
c is the un-modeled source effects term that affects dependent variable unevenness (Agha and Alnahhal, 2012). Illustrations of results obtained weredone in tabular and graphical formats.

3. Results and Discussions

The characteristics of the business activities of the assessed SMEs are shown in Figure 1. Business functions and performance in these SMEs, as well as the achievement of the set goals in terms of time, cost and stress, highly require the reliability of the power supply. The type of grid connection and average values for the power quality and the status of voltage fluctuations at the SME subscriber point, are shown in Table 1. Faith (2012) guided the analysis of voltage levels by the following definition where voltage is a decrease in the root mean square value of alternating current (AC RMS) voltage to less than 90%, and overvoltage is an increase in the ac rms voltage of more than 110% at the power frequency. Analysis of the state of power quality revealed that the supplied voltages are below voltage (less than the authorized nominal 220 volts) during peak hours but predominantly over voltage during off-peak hours. The same observation was made by Ponnle (2015) that maximum voltage drop usually occurs at peak load times. In addition, the observation in this study agrees with that of Oluwole *et al*. match. (2014) reported that the operating voltage available to most electricity end-users on the national electricity grid is outside the prescribed deviation from the standard voltage values. This affects the use and operation of sensitive equipment during peak periods. The undervoltage condition at peak times prompted participants to boast about the rated voltage available. However, in the case of the phase-to-phase connection, over voltages occurred during off-peak and peak periods, while district N2 had normal voltage only during peak periods.

Power quality and associated electrical noise directly affect sensitive electrical/electronic equipment used in workplace applications such as commercial and industrial environments. Fathi (2012), referring to IEEE standard 1250-1995, stated that most of the newer user equipment available is not designed to withstand surges and faults of typical distribution systems. The effects are often expressed in property damage and loss of performance of a company. The impact of power quality on the business activities of the SMEs was assessed based on the damage to work equipment and the procurement of alternative power sources, which represents an additional cost impact for SMEs. The observed number of work tools/equipment lost due to power fluctuations over the last six months is shown in Figure 2, with most losses affecting 6 and 7 electrical/electronic tools. This observed outcome was substantiated by reports in the literature that, among other things, poor power quality leads to damaged devices (Fathi, 2012; Ogunyemi *et al*., 2012).

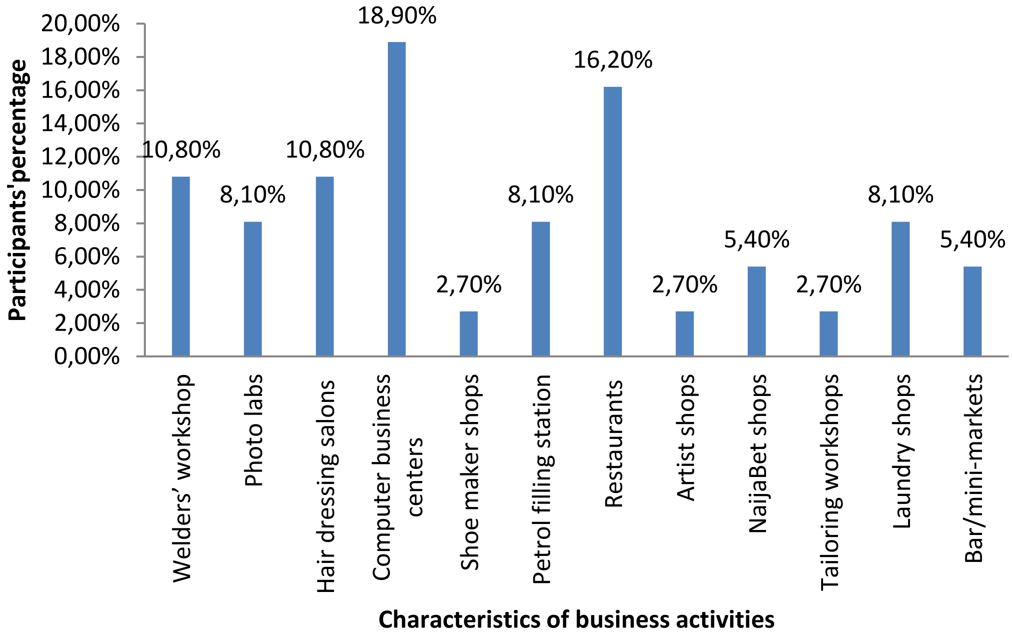

Figure 1. Characteristics of business activities in SME

Disruptions in the work process due to poor power quality and outages are a system efficiency problem, which usually translates into inactivity of resources (manpower, machinery and materials), repair or replacement of damaged tools/equipment, and additional costs for companies in finding Alternative energy sources express supply, such as generators (owned or rented) (Cissokho and Seck, 2013). Of the maximum duration participants needed for their business activities, only 1-5 and 6-10 hours of normal voltage electricity were available and could be used by 71.4% and 28.6% of participants, respectively, which is far below the required power the nominal standard voltage (Figure 3). power supply failures; High voltage, low voltage and outages contribute to power quality challenges in various sectors of the Nigerian economy. This is according to the World Bank report (2011), according to which all SME sizes in the country, regardless of their location or sector, experience average power outages of around eight hours per day. Power cuts/fluctuations were considered a more serious problem than any other predominant problem by 83% of all managers in Nigeria (World Bank, 2011). The cost analysis presented in this study looked at induced costs, i.e. the cost impact of alternative power sources due to power outages and voltage fluctuations (Figure 3). Values were derived from the number of litres of fuel consumed by SME participants multiplied by the average metropolitan fuel pump price of N195.00. According to estimates by the Manufacturers Association of Nigeria (MAN) and the National Association of Small-Scale Industries (NASSI), the induced costs from self-generated electricity amount to an average value of around N2 billion per week (Anyanrouh, 2013). Consequently, according to Cissokho and Seck (2013), the effects of poor power quality and outages result in increased production costs, uncertainty in meeting deadlines, idle capital, hiring fewer workers and poor service delivery.

Table 1. Summary of type of grid connection and average voltage status by the participants

Location	Phase	Voltage (V)		Remark	
		Peak hours	Off-peak hours	Peak hours	Off-peak hours
N1	Single-phase	157	220	Under	Normal
N1	Three-phase	R=189, Y=185, B=184	R=240, Y=220, B=230	Under Under Under	Normal Normal Normal
N1	Phase-to-phase	315	413	Over	Over
N2	Single-phase	94	223	Under	Normal
N2	Three-phase	R=127, Y=96, B=110	R=250, Y=230, B=226	Under Under Under	Over Normal Normal
N2	Phase-to-phase	220	370	Normal	Over
N3	Single-phase	128	236	Under	Normal
N3	Three-phase	R=138, Y=140, B=133	R=236, Y=232. B=233	Under Under Under	Normal Normal Normal
N3	Phase-to-phase	270	412	Over	Over
N4	Phase-to-phase	302	418	Over	Over
N4	Single-phase	185	246	Under	Normal
N4	Three-phase	R=180 Y=193 B=171	R=240 Y=246 B=251	Under Under Under	Normal Over Over
N5	Single-phase	174	215	Under	Normal
N5	Three-phase	R=185 Y=180 B=183	R=246 Y=236 B=233	Under Under Under	Normal Normal Normal
N5	Phase-to-phase	324	403	Over	Over
N6	Single-phase	134	220	Under	Normal
N6	Three-phase	143	220	Under	Normal
N6	Phase-to-phase	311	414	Over	Over
N7	Single-phase	112	93	Under	Under
N7	Three-phase	R=165 Y=180 B=193	R=245 Y=234 B=232	Under Under Under	Over Normal Normal
N7	Phase-to-phase	321	342	Over	Over
N8	Single-phase	137	220	Under	Normal
N8	Three-phase	R=188 Y=189 B=198	R=243 Y=246 B=253	Under Under Normal	Over Over Over
N8	Phase-to-phase	406	412	Over	Over
N9	Single-phase	112	287	Under	Over
N9	Three-phase	R=176 Y=177 B=189	R=268 Y=278 B=287	Under Under Under	Over Over Over
N9	Phase-to-phase	318	415	Over	Over
N10	Single-phase	229	243	Normal	Over
N10	Three-phase	R=220 Y=234 B=220	R=232 Y=233 B=238	Normal Normal Normal	Normal Normal Normal
N10	Phase-to-phase	406	423	Over	Over

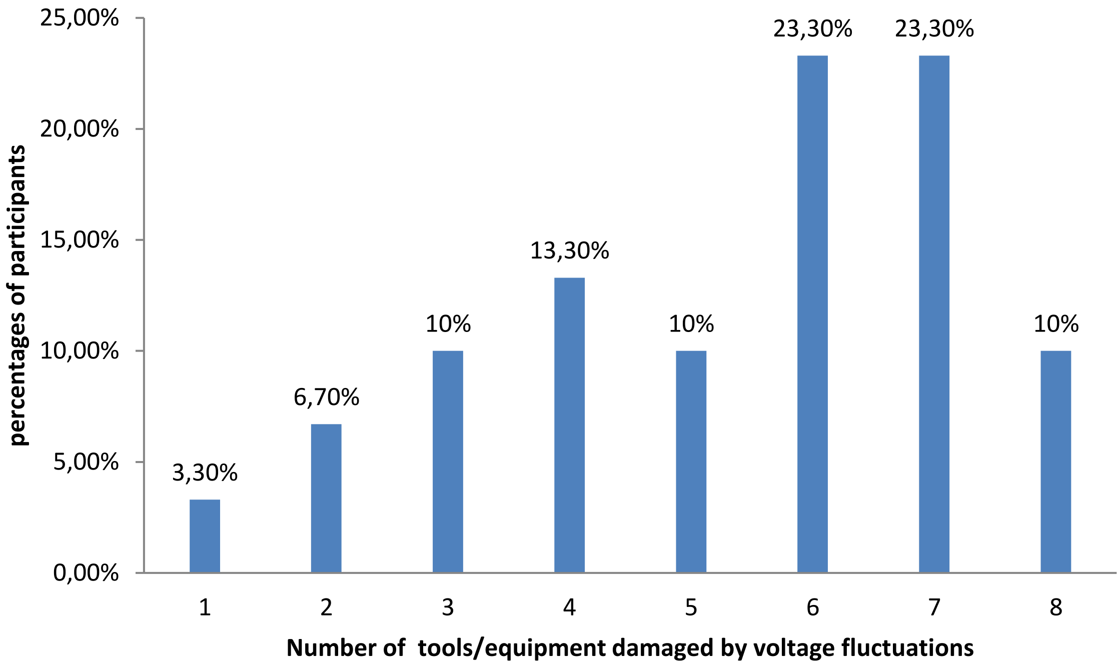

Figure 2. Number of items damaged by power fluctuations

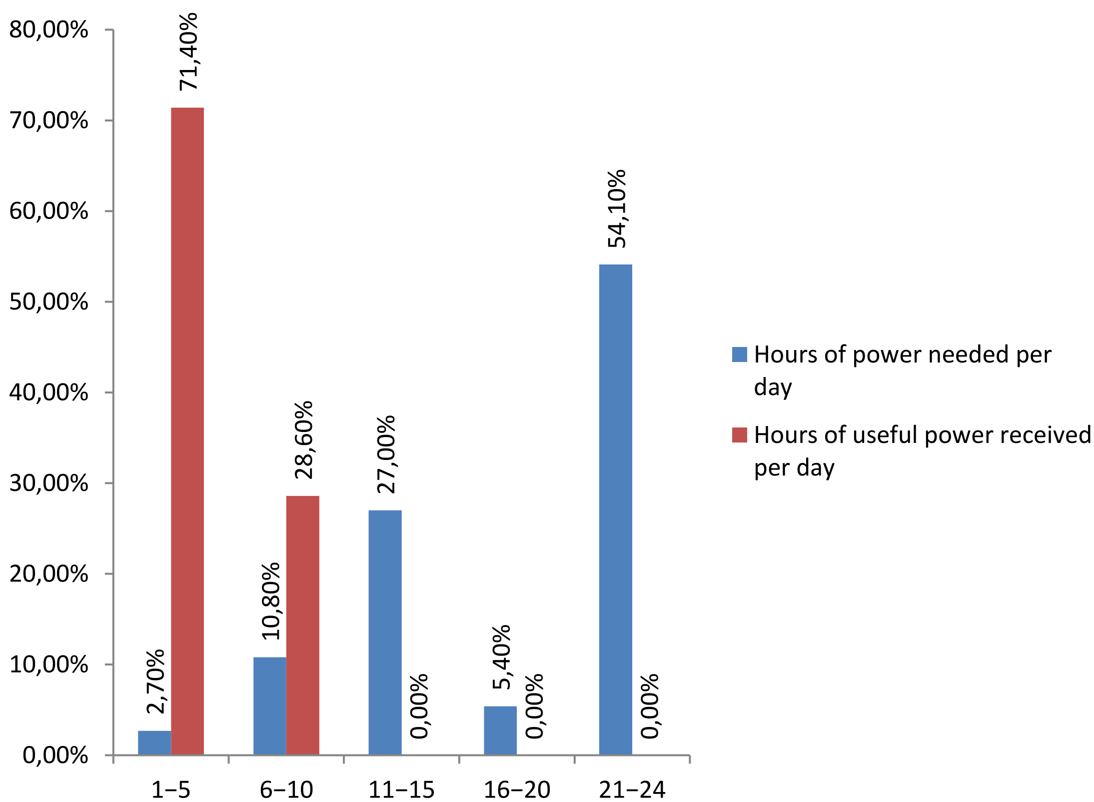

Figure 3. Variation between the available and needed quality electric power

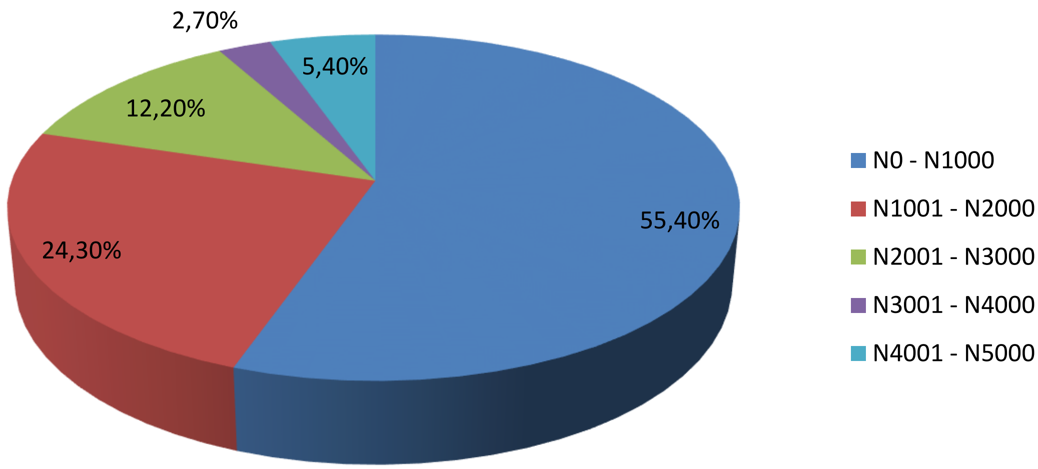

Figure 4. Daily induced cost of alternative source of power supply

The two categorical types of power disruption technically impeding trading or operation in power-dependent core power resources; poor quality and blackouts (Lineweber and McNulty, 2001) were assessed in this study. A thorough investigation or study of the association between the variables was performed using a regression statistical technique analysis. The regression model in this study included four regressor variables and therefore required a multiple regression model. The multiple regression model summarized the data and study relationships between the variables (Montgomery and Runger, 2007; Norusis, 1990). The multiple linear regression model was between daily costs and performance impairment variables, peak-hour voltages, off-peak hour voltages, and power outages. Table 2 shows the model that predicted the relationships between the daily induced costs using the power disturbance variables; peak-hour voltages, off-peak hour voltages, and power outages. Thus, the established model is given as follows:

$$Y = 4574.695 + 148.816x_1 - 778.898x_2 - 216.546x_3$$

Where: Y is the induced cost (dependent variable) and Independent variablesx_j: (constant), power outages, peak-hour voltages, off-peak hour voltages

Table 2. Relationship between power disturbances variables and induced cost

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Multiple regression	.066	1.656	3	70	.184	4574.695	148.816	-778.898	-216.546

4. Conclusion

A combination of subjective and objective research techniques was used to assess power quality and voltage interruptions in electricity usage at SMEs in Wukari city. Electrical energy performance in the study area is affected by disturbances in the utility systems, which have been shown to manifest themselves as voltage deviations at the consumer or end-user point. This has been shown to contribute to end-user equipment failure or operational failure. Containing the disturbances in the work process caused by the poor power quality among the SME participants, the introduction of phase-to-phase connections has increased the supply voltage above the nominal 220 volts for domestic use, making the equipment more vulnerable was for damage. Consequently, the search for an alternative power source caused cost implications for SMEs. The model established in this study can serve as a guide for determining the cost impact of power quality disturbances on SMEs.

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