Evaluating The Financial Implication of Power Harmonics on Electricity Corporation of Ghana (ECG)'s Distribution Networks and Customers

Felix Akpagloh, Stephen E Armah, Osei-Owusu Alexander

Abstract- The survival and sustainability of businesses, especially in volatile developing country markets, require that businesses frugally manage input cost such as the cost of electric power. However, Power Harmonics (PH) that cause excessive dissipation of energy as heat can raise the cost of electric power for companies and for the power suppliers as well. Unknown to them, many businesses in Ghana may have been exposed to serious financial losses as a result of the presence of power harmonics in the distribution network. Such PH is essentially a negative externality caused by the users of PH producing gadgets and visited on other unsuspecting users of electric power who are essentially bystanders: a classic case of a negative externality. PH is a major contributor to the poor state of power quality internationally and have been in existence since the first alternating current generator went online more than 100 years ago. This paper presents an analysis of the financial implication of power harmonics in the distribution network of the Electricity Company of Ghana (ECG) and on customers of the company using a mixed methodology of qualitative and quantitative approaches.

The results from the power system monitoring carried out confirm the presence and deleterious effects of power harmonics in the distribution network. Unfortunately, most customers are not aware of the negative effects of power harmonics. Differentiating the effect of PH from other poor power quality issues has cost consequences for most customers. Analysed results from the power system monitoring carried out shows that more than Gh¢2,396,814.00 ($1,261, 481.00 at an exchange rate ($/Ghc) of 1.9 in 2012) per annum is wasted as heat in the distribution network. There is therefore the need to introduce punitive measures against the generation of harmonics into the distribution system in order to incentivise the promulgators of PH to internalize the externality. This will ensure the survival and sustainability of businesses in Ghana's volatile and under-resourced industrial sector.

Keywords- (ECG), PH.

I. INTRODUCTION

Electrical power harmonics in the power system are integer multiples of the fundamental frequency of the power system (Hamilton, 2005). Such integer multiples of the fundamental frequency come about as a result of the drawing of non-linear current from the power system by non-linear loads leading to the distortion of the sinusoidal voltage waveform.
Electrical power harmonics have been in existence since the first alternating current (AC) generator went online several decades ago. However, the levels of electrical power harmonics at that time were minor. This was so, because all the loads in those days were linear loads and therefore had no detrimental effects on the distribution networks or the customers of the utility companies. A linear load is a type of electrical load that causes the current drawn by the said load to be proportional in waveform to the voltage and impedance. The waveform of the current follows the envelope of the voltage waveform in a sinusoidal form. In other words, according to Rice (1986), the voltage and current follow one another without any distortion to their pure sine waves. Examples of linear loads are resistive heaters, incandescent lamps, and constant speed induction and synchronous motors.
Electrical power harmonics distortion is not due to the operation of the power system, and was largely absent before the 1960's (Hamilton, 2005). However, the harmonic distortion is largely dependent on the type of load being connected to the distribution networks. Since the 1960s a different type of customer load has emerged gradually and almost totally replaced the type of load that existed before the 1960s. These new type of loads are run mostly with electronic power supplies are called non-linear loads.
The 50-Hz waveform, which is the fundamental frequency in Ghana, typically has numerous additional waveforms which are integer multiples of the fundamental frequency superimposed upon it when PH is present, thus creating multiple frequencies within the normal 50-Hz sine wave, (Rice 1986). The multiple frequencies are harmonics of the fundamental frequency. Power harmonics are present in the distribution network because they are generated by customer's load connected to these distribution networks not by the utility companies. Therefore, as more customers use more non-linear load, the cumulative negative effects of harmonics on electrical appliances in the distribution network will be a common feature. The non-linear loads usually export harmonics into the distribution network whiles the linear loads import harmonics from the distribution network. Whiles some customers do their best to reduce the negative effects their non-linear loads have on the power distribution system and on other customers, others do not care at all. In this sense Power harmonics constitute a negative externality of nonlinear load using consumers on power companies and users of linear loads.
The main negative effects according to IEEE Task Force (1985), suffered by both domestic and industrial customers because of other few customers who are generating voltage and current harmonics into the power system include: Plant mal-operation; Malfunctioning and early failure of electronic equipment; Overheating and early failure of electric motors; Torsional oscillations of motor shaft; as well as Overloading, overheating and failure of power factor correction capacitors. Resonance may also

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occur due to interaction of capacitors with harmonics. Other negative effects include Overloading and overheating of distribution transformers and neutral conductors and Reduction of efficiency of power generation, transmission, and utilization to mention but a few.

Most of the poor power quality problems experienced by customers connected to the distribution network are likely power harmonic related. This situation is certain to generate dissatisfaction from both the industrial and domestic customers. The presence and the effect of power harmonics is a pure negative externality and must be addressed with standard economic prescription for a negative externality such as a corrective tax to reduce the amount of the negative externality.

According to Kasmas et al (2007) and Gabriel et al (2009), as a consequence of power harmonics, the utility companies themselves suffer a lot of technical loss due to the presence of the power harmonics. A power distribution company like Electricity Company of Ghana (ECG) is probably losing thousands (if not millions) of Ghana Cedis because of the presence of high levels of power harmonics in the distribution network. It is a fact that most of the transformer manufacturers test their equipment only under ideal (linear) conditions. Hence, a substantial gap exists between published loss data and actual losses incurred after installation due to non-linear (distorting) loads as it is in ECG's case. In fact, according to De Lima (1996), a test result published in an IEEE Transaction paper documented an almost tripling of transformer losses when feeding 60kW of computer load rather than linear load.

Why care about the amount of power affected by harmonics? The economical reason is: we've generated and paid for it, but can't use it. For example, if 50 kilowatts come into a house and a portion of that power is made unusable by poor power quality due to the presence of power harmonics, the house will be paying for 50 kW, but can only use 50 kW minus the wasted portion. If one could quantify the waste and multiply it by the utility rate charged per unit, it would be clear whether the amount of waste were substantial enough to merit fixing the harmonic issue. One of the most recognized effects of harmonics in electrical systems is the excess heat they create in the conductors carrying them. That heat is a form of unintentional power consumption. Overheating of electrical appliances drastically reduce their life span.

Considering how bad the effects of harmonics could be on customers electrical appliances and the level of electrical energy loss associated with harmonics, it is clear that as more customers get educated on what is responsible for most of their troubles in terms of quality power supply, the utility companies will be facing a lot of law suits in the near future. The regulatory authorities should therefore act now by introducing punitive measures against any customer found to generating and exporting harmonics into the distribution network.

A reduction in harmonics in the distribution network will greatly reduce technical loss in the system. Therefore, once power harmonics have been confirmed in the power system, policies aimed at reducing the level of power harmonics in the distribution systems must be strongly pursued by all utility companies in order to reduce technical loss associated with PH and improve their financial position. This is especially pertinent in developing countries where governments are not likely to encourage full cost recovery in the energy sector. In light of the background information provided, this paper evaluated the financial implication of Power Harmonics on Electricity Corporation of Ghana (ECG)'s Distribution Networks and Customers. This was done not only to highlight the problem and educate the unsuspecting and uninformed customers but also so that a viable solution can be offered to curtail the wastage of power as a result of power harmonics, it resultant destruction of electrical appliances and more importantly its financial implications.

II. LITERATURE REVIEW

The principal effect of power harmonics is that it undermines power quality so we begin this section be reviewing the literature on the definition of power quality

Definition of power quality

The distinction of power quality from power generation, power transmission, sub-transmission and distribution has been addressed in the literature by several researchers but there is still no consensus definition for the term "power quality". Often the underlying reason for the definition depends on the angle from which the power quality issue is being considered. According to El-Saadany (1998), the term "power quality" is sometimes used loosely to express different meanings: "service quality", "supply availability", "supply reliability", "voltage quality", and "current quality". The flexibility of defining power quality from different angles, accounts for the multiple meanings of power quality. Hence different aspects of quality are looked at different levels of the power system from generation level to the distribution level. At the generation level, power quality issues are concerned about the ability to generate electric power with very little variation in the specific generation frequency, 50 or 60 Hz (in Ghana the frequency of generation is 50Hz).

Voltage quality is the major determinant at the transmission level whiles at the sub-transmission and the distribution levels, aspects of both voltage quality and current quality are considered. Rens et al (2001) is of the opinion that from the marketing point of view, electricity is a product and the power quality is the index of the product quality from generation level down to distribution level. According to IEEE standard 1159-1995 published by the Institute of Electrical and Electronics Engineers (IEEE) in 1995, power quality is defined as " the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment". However, this definition failed to define power quality for the whole power system. By limiting the term power quality to only sensitive equipment, it failed to relate how the impact of harmonic current affects the whole power system and not only the equipment.

A new version of IEEE standard (IEEE Std 1159.3 2003) redefined power quality as "set of parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude and waveform)". This definition also only defines power quality from the system voltage perspective. However, power quality issues goes beyond system voltage alone. According to the International Standard IEC 61000-4-30, 2003 of the International Electro-technical

Commission (IEC), power quality is defined as "Characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters." This definition considered power quality as relating to how and the number of times it is measured from a power system point of view.

Heydt (1991) defines power quality as "the measure, analysis, and improvement of bus voltage, usually a load bus voltage, to maintain that voltage to be a sinusoid at rated voltage and frequency." From this, it is clear that the definition Heydt gave is from the point of view of the utility and specifically on quality voltage. In the early days, the electrical utility companies were the only authority taking care of power quality issues before deregulation of the power industry. The focus of most of these utilities, were only on the system voltage and frequency, In other words, power quality problems were handled as voltage quality problems in those days. The advancement in technology which led to the proliferation of the use of nonlinear and sensitive loads in the distribution network is a major cause of rise in current deviation that causes voltage distortion which results in power quality disturbances. In this modern era the causes of power quality disturbances are no longer limited to the quality of the system voltage. Dugan et al (2003), define power quality problems as "any power problem manifested in voltage, current, or frequency deviations that results in failure or wrong operation of customer equipment." The possible causes of power quality disturbances are covered by this definition. Notwithstanding this definition, there are other factors/sources which are responsible for the poor power quality.

According to Bollen (2000), power quality is "the combination of voltage quality and current quality. Thus power quality is concerned with deviations of voltage and/or current from the ideal." From the statement above, power quality problem is said to occur as long as there is a deviation from the ideal waveform of either or both the voltage and the current. It is to be noted that due to the close relationship between the voltage and the current, it is very difficult to easily draw the line between voltage disturbances and current disturbances. Moreover, there is no common reference point that the disturbance can be examined from. For example, the neighboring loads of a large induction motor will suffer from a voltage dip any time this induction motor is switched on due to its large starting current. To the neighboring loads this is considered a voltage disturbance but the cause of this is the sudden demand of a large starting current by the induction motor. The event of starting the induction motor has caused a disturbance in the power system. This disturbance could be considered as a voltage disturbance from one angle and a current disturbance from another perspective. Due to the difficult nature of distinguishing between voltage disturbance and a current disturbance, it has become preferable to use the term power quality disturbance. Notwithstanding this, the underpinning cause of a disturbance in the power system is still either a deviation in the waveform of either the voltage or the current (Bollen, 2000).

History of the effects of power harmonics studies

The severe consequences of power harmonics have been researched in many countries to determine the financial cost of power harmonics to the consumer and the economy. The existence of poor power quality in the power system does not only affect the financial performance of industries and businesses dependent on the use of electrical energy.

Power Quality Issues in India

In India, Malleswara et al (2011) undertook a research to determine the economic aspects of power quality disturbances in India. The research analyzed the power supply system to determine if there is any technical and negative economical effect from the presence/occurrence of power quality issues. The study revealed that there are currently no standards for poor power quality in relation to customer's point of connection (POC). This is a big predicament to the power utility companies, electrical equipment manufacturers and the customers. Electrical equipment manufacturers may want to take advantage of the absence of such benchmarks in other to make maximum profit. The power utility operators also cannot hold the customers liable for the level of power harmonics generated in the power system. This situation makes it very difficult to identify who is responsible for the power harmonics in the power system at the POC. This results in a huge financial drain on the utility companies and the customers. The equipment manufacturers are therefore left off the hook.

According to Malleswara et al (2011), poor power quality in the power system in India is a big disincentive and is hurting the country's industrial competitiveness. This situation negatively affects India's efforts to become the world leader in the supply of industrial goods. In this era, computers are used in industries, commerce, business, trade, finance, healthcare, etc to facilitate and automate work process. The report has stated that, the India's State Electricity Board is unable to meet the power needed for these computerize processes. The demand for clean power by the informatics infrastructure is a reality of today's electronic age in India. The electromechanical electrical equipment of the previous generation was found to be far less vulnerable to disturbances in the power system than the electrical equipment of today. For example Variable speed drives, programmable logic controllers, automated CNC machine tools, computers, and their peripherals

According to the report by Malleswara et al (2011), poor power quality in the electrical distribution network can have significant financial consequences. The extent of these financial consequences is industry or equipment dependent. They established how poor power quality can cause significant amount of direct and indirect financial losses. Their report established the difficulty associated in the determination of the exact amount of losses when power quality event occurs. Malleswara et al (2011) state that, in order to accurately determine the associated financial cost of poor power quality, three main factors are often considered. These are: customer load susceptibility, disturbance profile at the bus bars involved and the calculation of losses induced by damage or malfunction of equipment or process interruption. These costs may be classified into two groups-direct and indirect costs.

Direct costs: This is a cost incurred by the business entity as a result of lack of production, salary costs during non-productive hours, damaged product, loss of raw material, damaged equipment, extra maintenance, waste of electrical energy etc.

Indirect costs: Costs of lost sales, costs associated with poor reputation for late delivery or non-delivery, cost of untimely equipment failure, costs of out-of specification product or services etc.

Notwithstanding the above it is difficult to place value on the inconveniences associated to the power quality disturbances in the distribution network. In addition, two methods were identified for the determination of the financial impact of poor power quality. The first is to consider the probabilities and impacts of the events by means of an analytical approach. The difficulty with this method is that it is difficult to get the correct inputs values for the analysis, even though this method is more precise in the determination of the cost of power quality disturbance.

The second method, according to Targosz et al (2007), is dependent on the customer's willingness to bear the cost of resolving the power quality issues and the use of historical data in the analysis to determine the economic cost. In all, a total of 325 industries or businesses were covered across six centers (Calcutta, Delhi, Bangalore, Mumbai, Hyderabad, and Chennai) in India during the power quality disturbance study. One of the major outcomes of the study was that most of the power quality disturbances issues were emanating from the customers' premises. This is a confirmation of the notion that the power utility companies are typically not responsible for the generation of the poor power quality in the power system, but rather almost all the factors responsible for the poor power quality in the power system is caused by the customers as a result of the type of loads they connect to the power system.

Malleswara et al (2011) confirmed that due to lack of specified power quality disturbance standards at the POC, the stakeholders of the power system in India are not aware of their respective responsibilities concerning power quality issues. This situation is responsible for the increase in disputes related to power quality issues at the POC among the power utility companies, customers and the equipment manufacturers. The study confirmed that the financial impact of power quality issues in India is currently estimated at a staggering amount of Rs. 20000.00 cr/p.a (which is 3.86billion US dollar per annum at a rate of Rs52.00 on the 10th October, 2012. cr stand for crore and is a multiplying factor of 10,000,000.00).

Power Quality Issues in United States of America

A research carried out in 2001 by the Electric Power Research Institute (EPRI) of the United States of America shown that the advancement in technology has created a situation that call for the continuous availability and good quality of electrical power. In the United States, power transmission is made available through the nationwide grids, which are connected by several power generation stations.

The advancement in technology has drastically changed the way we interact with the rest of the world and the world cannot function properly without electrical power. Most of the today's load are non-linear loads and demand that the power supply be of a very high quality. The rate of growth of non-linear loads is presented in figure 1. It is evident that the rate of growth of the non-linear loads from the 1990s to 2000s has been very drastic compare to the rate of growth from the 1930s to the 1990s.

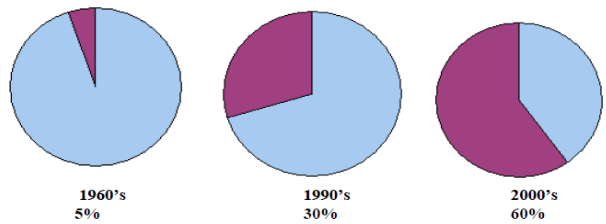

Figure 1 Non Linear Load Growth in USA

Source: Hamilton, 2005

From this it is evident that the rate of growth of the non-linear loads from the 1990s to 2000s has been very drastic compare to the rate of growth from the 1930s to the 1990s.

Nonlinear loads are very sensitive to poor power quality. When the power supply is of poor quality, it contributes to high power losses in the distribution systems. According to EPRI (2001), the financial effect of power quality issues in the United States is $15 billion to $24 billion per year.

Power Quality Issues in Ghana

In Ghana, there are two regulatory institutions created under the ministry of Energy by an act of Parliament. The Public Utilities Regulatory Commission (PURC) was established under the Public Utilities Regulatory Commission Act 538 in 1997 and the Energy Commission (EC) also was established under the Energy Commission Act 541 in same year, 1997. Thus, EC was created to be responsible for indicative national planning, technical standards and licensing of electricity utilities at any voltage level. Whiles the PURC was created to regulate and be responsible for economic issues such as monitoring quality of service and ensuring fair competition among the stakeholders of the power industry. Acts 538 and 541 which established the PURC and EC respectively provide the regulatory frame work for the electricity industry in Ghana as categorized below:

PURC's regulatory mandates are:

- protecting the interests of consumers and providers of utility services
- monitoring the standard of performance of the utilities
- promoting fair competition among the stake holders
- providing guidelines on rates chargeable for electricity services
- examine and approve electricity tariff

EC's regulatory mandates are:

- receive and assess applications and grant licenses to public utilities for the generation, transmission, wholesale supply and distribution of electricity;
- Promote and ensure uniform rules of practice for the generation, transmission, wholesale supply and distribution of electricity.
- establish and enforce, in consultation with PURC, standards of performance for the relevant public utilities;

It is reasonable to argue that issues of power quality problems have not fully been addressed by these two institutions. In particular poor power quality due to PH has been totally ignored. Most of the time, issues of frequent power interruptions and availability of power are considered to be the most important factors affecting power quality. There is hardly any focus on power harmonics as being a major remote factor to so many poor power quality issues. This confirmed the reason why there is no power harmonics standard in the power industry

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in the country from these regulatory institutions and hence no punitive measure against power harmonics. The absence of power harmonics standard from these two institutions does not mean that power harmonics are absent in the power distribution network in the country. Unfortunately, there is no documentation on the negative financial effect of power harmonics in the distribution network in Ghana currently. The results of this research will thus provide the first documented evidence of the adverse effects of PH on the distribution network and in consumers.

Estimation of the cost of power harmonics energy

The presence of power harmonics in the distribution network cause significant loss in supply networks as well as at the customer end. The increasing number of modern electronics devices is responsible for the increasing level of power harmonics in the distribution system. The total estimated harmonic costs consist of costs related to: harmonic energy losses, premature aging of electrical equipment and de-rating of equipment. According to Baggini (2008), the harmonics power of the n^{th} harmonics can be calculated by equations (1.1 and 1.2) below:

$$P(n) = U(n) * I(n) * Cos(\theta U(n) - \theta I(n)) \quad \ldots\ldots (1.1)$$

$$Ph = \sum_{k=2}^{n} P(n) \quad \ldots\ldots (1.2)$$

Where

$P_{(n)}$ is the active power of the n^{th} harmonic order

$U_{(n)}$ is the harmonic voltage of the n^{th} harmonic order

$I_{(n)}$ is the harmonic current of the n^{th} harmonic order

$\Theta_{U(n)}$ is the phase angle of the harmonic voltage of the n^{th} harmonic order

$\Theta_{I(n)}$ is the phase angle of the harmonic current of the n^{th} harmonic order

The total number of hours in the year is 8760 hours. However the researcher assumed that the customer loads were connected to the power system for a total of 8200 hours during the year.

According to Emanuel et al (1991), the total annual power harmonics energy lost is therefore presented in equation (1.3) below

$$Eh = Ph * 8200 \quad \ldots\ldots (1.3)$$

As at December, 2011 the cost of a kWatt hour of electricity, for the medium special load tariff (SLT) customer was Gh¢0.203889 per kWh (PURC, 2011).

The total cost of energy lost due to the presence of power harmonics is therefore:

$$Energy\ Lost(h) = Ph * 8200 * 0.20889$$

$$Energy\ Lost(h) = Ph * 1{,}712.898$$

III. METHODOLOGY

The primary objective of this research was to "establish the existence of power harmonics in the distribution networks and whether it contributes to technical losses. In particular the research tried to verify whether Power Harmonics decrease revenue generation in ECG in Ghana". For this study the author used a combination of exploratory and descriptive types of design with a mixture of qualitative and quantitative research methods.

These choices of design were to give a vivid picture and discover the essence of the phenomena being investigated by the researcher before the data collection procedure was carried out. The primary respondents in this research were selected from the industrial and commercial customers of the Electricity Company of Ghana as well as from the Energy Commission and the PURC both of who have a regulatory mandate for the energy sector. The actual fieldwork was conducted in 2012 in the Tema operational area of the ECG. The main data was collected by the setting up of a PA power analyzer in the customers' premise. The PA power analyzer is a world-class recognized test equipment used in monitoring power system disturbances in the power distribution system.

A sample selection of fifteen (15) industries was monitored based on convenience sampling as their selection was based on customer complaints relating to issues on power quality. These sampling strategy were used due to lack of access to the premises of some industrial customers. The researcher gained easy access to industrial customers who had problems associated to power quality issues. For the researcher to obtain a general representation of some stakeholders about this research, a total number of 150 questionnaires were giving out to 80 employees of industries in Tema, 60 employees (Engineering and Operations department) of Electricity Company of Ghana and Ten (10) Members of both Energy Commission and PURC as the regulatory authorities of power in Ghana. The researcher utilized a range of statistical methods to analyze survey data. The researcher used graphical and descriptive analysis with the help of some computer software programs such as Microsoft Excel was used in the analysis of the data gathered.

Results and Analysis

Here we answer-the research questions by analyzing the data from the test equipment–as well as collated results from respondents

Research Question 1: Does power harmonic exist in the distribution networks of the Electricity Company of Ghana?

Discussion

The power monitoring test performed confirmed the existence of power harmonics in the power distribution system of ECG. In Figures 2, 3 and 4 below, both the voltage and the current waveforms of three different factories are presented. The current waveforms of all these factories showed clear evidence of the existence of power harmonics in the distribution networks.

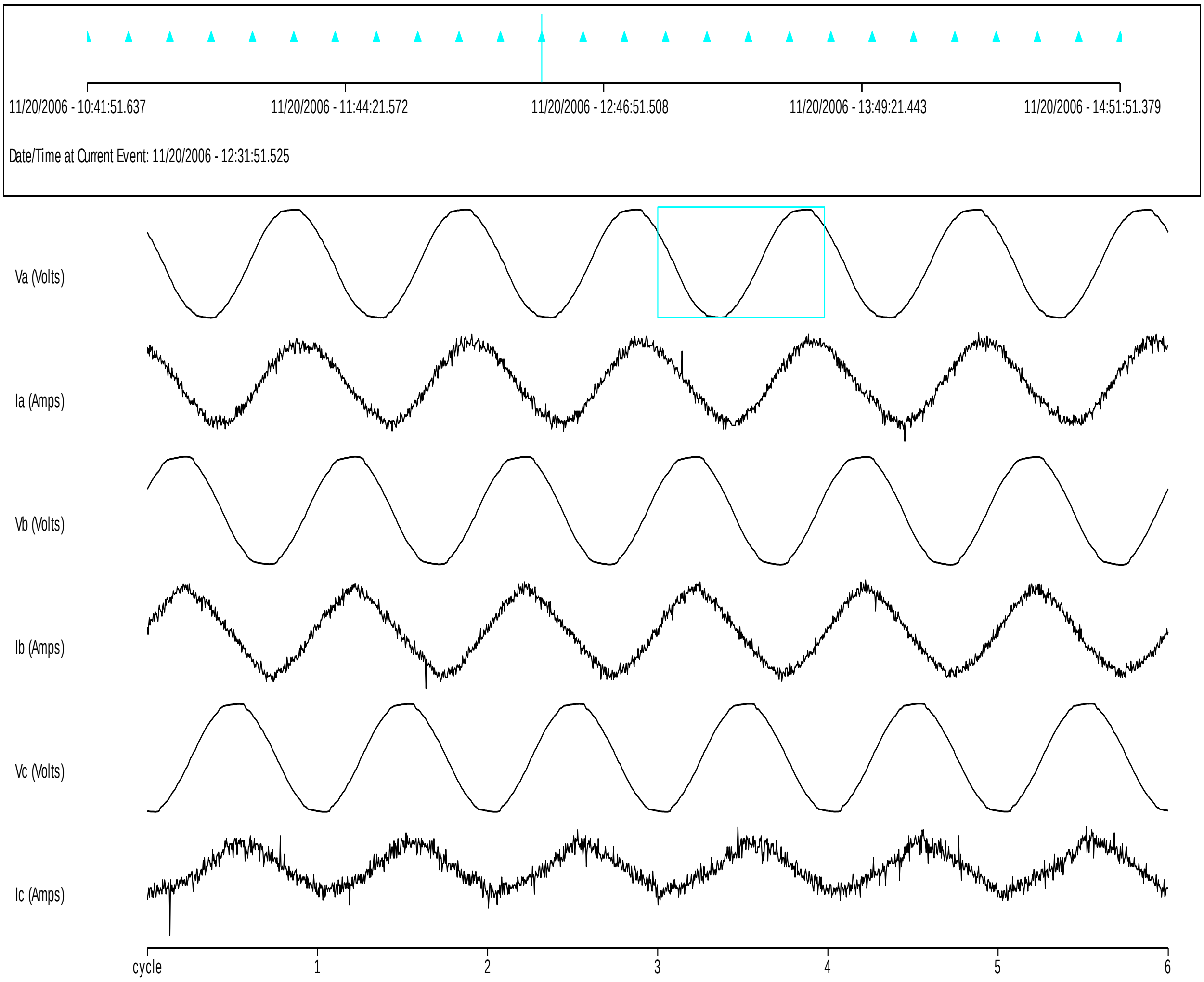


Figure 2 Three phase sinusoidal waveform for voltage and current at Glotech

Source: From field monitoring data of the researcher, 2013

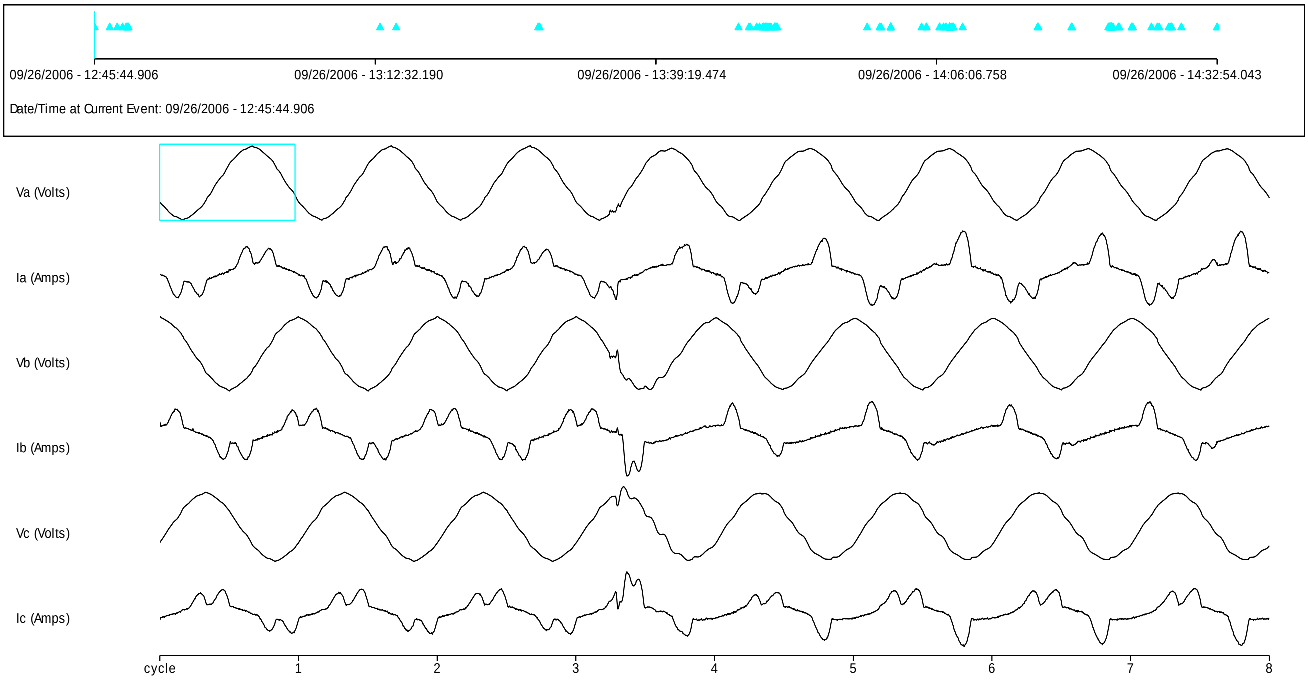


Figure 3 Three phase sinusoidal waveform for voltage and current at Bloplast

Source: From field monitoring data of the researcher, 2013

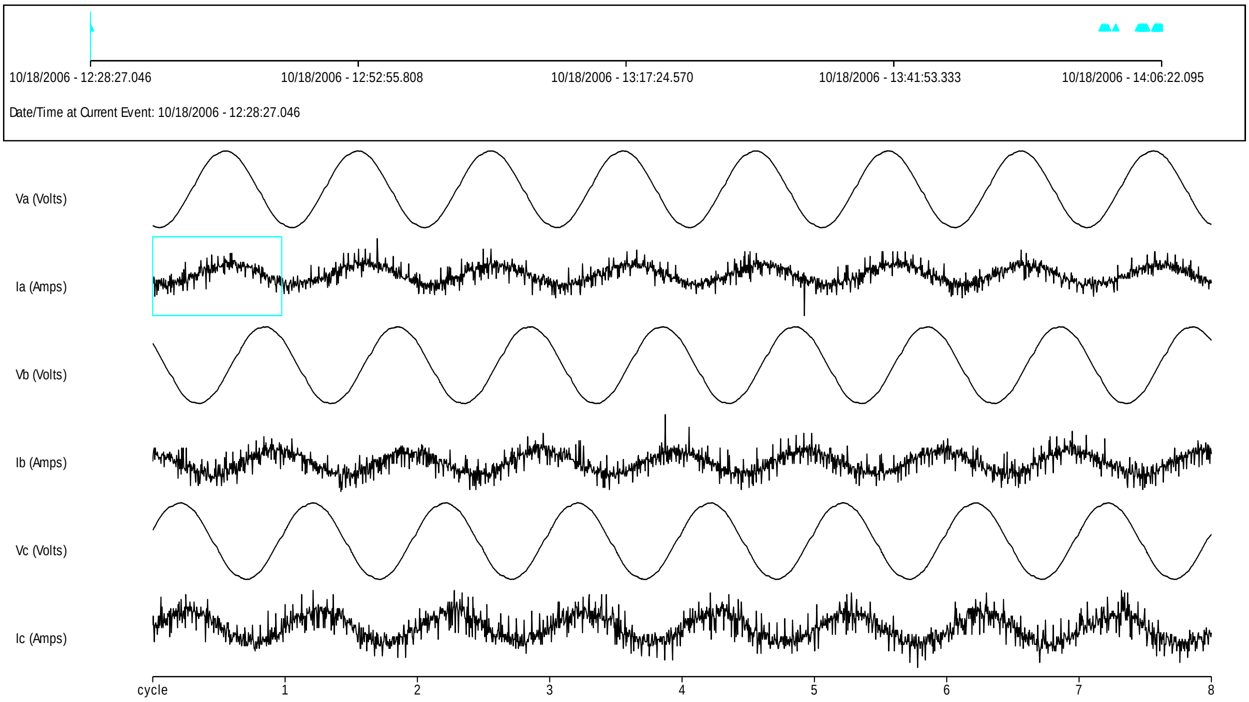


Figure 4 Three phase sinusoidal waveform for voltage and current at Tema Steel Work I

Source: From field monitoring data of the researcher

Occurrence of Power Quality Issues

This question was design to determine stakeholders' level of understanding of issues concerning power quality in the distribution network. From table 1 below, majority of the respondents (90.4%) indicated the occurrence of power quality issues at their workplaces. It is however interesting to note that whiles 6.1% do not agree that there is power quality issues, a whole 3.5% of the respondents do not have any idea whether there is poor power quality or not at their work place. Though 3.5% is small compare to the total number of respondents however, these are people with at least a minimum technical level of education so their answer is strange.

Table 1 Occurrence of power quality issues

	Yes	No	No Idea
Frequency	104	7	4
Percentage [%]	90.4	6.1	3.5
Total	115		

Source: field work by researcher, 2012

Type of Power Quality Issues

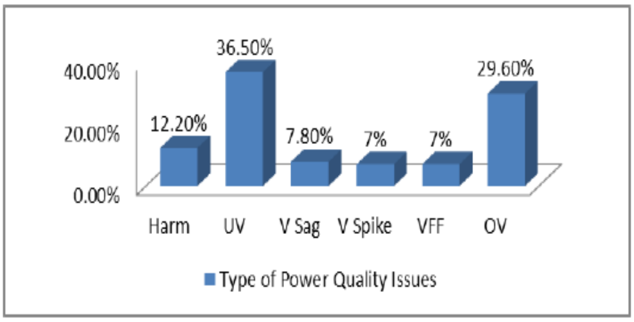
In a way it is difficult for most people to understand that there are several forms and causes of poor power quality issues. To most people it is either under voltage or over voltage occurrences that is responsible for poor power quality. From figure 5, majority of the respondents (36.5%) said their power quality issues were due to under voltage (UV) occurrences. The second highest (29.6%) cause of power quality issues, according to the respondents was over voltage occurrences (OV). Although from Figure 5, the third highest (12.2%) causes of power quality issues is by harmonics (harm), it is clear that most technical people especially in the industry are lacking understanding of some of the causes of their power quality issues.

A pictorial presentation of the causes of power quality issues is presented in Figure 5 below.

Figure 5 Graphical representations of power quality issues

Source: field work by researcher, 2012

(Harm = Harmonics, U V = Under Voltage, V Sag = Voltage Sag (Dip), O V = Over Voltage, V F F = Voltage Fluctuations and Flicker)



Research Question 2: Does the existence of power harmonics in the distribution networks have any contributing effect on the level of technical losses?

Discussion

The presence of power harmonics in the power system means the presence of heat. The presence of power harmonics also means that there are integer multiples of the fundamental frequency in the power distribution system. The electrical equipment connected to the power system is only able to consume power with the fundamental frequency. The rest of the frequencies made up with the integer multiples of the fundamental frequency are wasted. They are converted into heat. It should be noted that most of the electrical equipment are not meant to endure prolonged overheating. Prolong overheating reduces their fundamental insulation level. This is responsible for the premature aging of the electrical equipment and hence a drastic reduction in their life span.

An extract from power monitoring is presented in Table 2 below. From table 2 the total harmonics current I_{Harm} at TSWI at the time of carrying out the power system monitoring test, the current in

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the red phase was 80.64[A] and yellow phase was 372.2 [A] whiles the blue phase was 106.48[A]. This quantum of current is wasted in the power distribution system in the form of heat just by one steel company. It is worthy to note that, the red phase current alone is big enough to supply the electricity needs of 10 number three bedroom size houses with a medium size family.

	Red Phase			Yellow Phase			Blue Phase		
	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]
TSWI	123.97	204.61	80.64	108.49	480.69	372.20	113.97	220.45	106.48
Blowplast	306.88	333.13	26.25	343.51	370.81	27.30	239.13	264.68	25.55

Table 2 Power Harmonics Data, TSWI = Tema Steel Work I

Source: Field monitoring test carried out by the researcher, 2012

Table 3 Failure of Equipment

	Yes	**No**	**No Idea**
Frequency	78	25	12
Percentage [%]	67.8	21.7	10.4
Total	115		

Source: field work by researcher, 2012

Research question 2 was designed to determine the level of awareness of the respondents' knowledge about the relationship between frequent occurrences of power quality issues and the rate of equipment failure. From table 4.9, majority of the respondents, making 67.8% has confirmed that the frequent occurrences of power quality issues are responsible for the failure of equipment.

Notwithstanding this, from Table 3, 21.7% did not agree that the frequent occurrences of power quality issues are responsible for the failure of equipment. This group of respondent believes different factors are rather to be blamed than power quality issues. However, 10.4% of the respondents from **Table 3** actually do not have any idea of what is the level of failure of equipment in relation to power quality issues. This is very serious, because these are all technical staff expected to have enough experience about their job. Considering the level of competition and the difficult business environment that exist today, it is very important to frequently organize refresher courses for technical staff. This will enable them to be abreast with the latest development in their area of specialization and be a creditable human capital to their company.

Research Question 3: What is the level of awareness of power harmonics and how does its existence contribute to unreliability and poor power quality in power distribution?

Discussion

The presence of power harmonics in the power system means the presence of integer multiples of the fundamental frequency in the power distribution system. From the literature, one of the negative effects of power harmonics is the mal-operation of protection and control relays which most of the times result in unexplained switching off of electrical equipment. The heat resulting from the presence of power harmonics current give wrong impression to the protection system of the electrical equipment whose protection system is temperature dependent for overload conditions. This situation is a major contributing factor to some of the mysterious operation of circuit breakers.

	Red Phase			Yellow Phase			Blue Phase		
	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]	I_{rms} [A]	$I_{rms+Harm}$ [A]	I_{Harm} [A]
VRA_23	490.44	704.74	214.30	479.83	492.34	12.51	443.38	698.42	255.04

Table 3 Power Harmonics Data,

Source: Field monitoring test carried out by the researcher, 2012

VRA_23 is the name of the electrical panel number between ECG and Gridco at the New Tema bulk supply point at the time of undertaking the power monitoring test. A bulk supply point is the substation where Gridco supplies/sales power to ECG for onward distribution to customers.

From Table 3, the power harmonics current in the red phase was 214.30A, which is 30.4% of the total current. Whiles the harmonics current in the blue phase was 255.04A, which is 36.5% of the total. All these 214.30A in the red phase and 255.04A in the blue phase will be converted into heat in the power system since these currents are not usable by any electrical equipment. This situation will create a false impression of overload through the heat that is associated with the presence of the harmonics currents. This condition may lead to unexplained reasons of switching off of some circuit breakers in the power distribution network.

The presence of heat in electrical equipment like transformers, motors, generators and any other equipment with windings will have their life span reduced drastically. It increases the failure rate of these equipments. Thus the presence of power harmonics in the distribution network increases unreliability of power supply.

Familiarity with Power Harmonics

This question was designed to determine the level of the respondents' knowledge about the familiarity of the existence of power harmonics in the distribution system. From table 4, 36.5% of the respondents confirmed they are less familiar with the existence of power harmonic in the power distribution network; whiles 14.8% said they are not familiar with it at all. It is therefore not surprising that 33.9% of the respondents in Table 5 said they are not aware of the effect of power harmonics. This is confirmed by the strong positive Spearman Rank correlation coefficient between the answers of the respondents in Table 4 and that of Table 5. The Spearman Rank correlation coefficient is 0.88 which indicate a strong positive linear association between the familiarity of power harmonics and the level of awareness of the effects of power harmonics. A strong correlation between two variables would produce a value of Spearman Rank correlation coefficient ρ (rho) between 0.7 and 0.89.

Table 4 Familiarity of power harmonics

	Very Familiar	Familiar	Moderately Familiar	Less Familiar	Not Familiar
Frequency	14	23	19	42	17
Percentage [%]	12.2	20.0	16.5	36.5	14.8
Total	115				

Source: field work by researcher, 2012

Table 5 Level of awareness of the effect of power harmonics

	Very Aware	Aware	Moderately Aware	Less Aware	Not Aware
Frequency	16	20	24	39	16
Percentage [%]	13.9	17.4	20.9	33.9	13.9
Total	115				

Source: field work by researcher, 2012

Level of Awareness of the Sources of Power Harmonics

This question was designed to determine the respondents' level of awareness of the sources of power harmonics in the power distribution network. From table 6, 61.7% of the respondents confirmed that power harmonics is produced by some customers. Notwithstanding this, 27.8% attributed this to ECG. This is not a surprise, taking cognizant of the responses provided to the questions in table 4 and 5. This just demonstrated the level of understanding of even some of the professionals. Most of them seem not to be aware that there are several causes of poor power quality in the distribution network. NED had zero percent. The researcher strongly believed this was due to the fact that the respondents were not aware of what NED stood for. NED is the distributor of electricity in the Northern part of Ghana. The researcher was not expecting any of the respondents to tick any of the utility providers as the sources of power harmonics into the distribution network.

Table 6 Level of awareness of the sources of power harmonics

	Some Customers	ECG	VRA	Grid co	NED
Frequency	71	32	5	7	0
Percentage [%]	61.7	27.8	4.3	6.1	0
Total	115				

Source: field work by researcher, 2012

Research Question 4: What is the financial implication of the presence of the power harmonics in the distribution network?

Discussion and Conclusions

The presence of power harmonics in the power system lead to distortion of the current and the voltage waveform. The distorted waveforms end up producing heat which lead to energy losses in the distribution networks and to the end-user. It is a major factor in causing premature aging of electrical equipment. The presence of power harmonics in the distribution network, prevent making full use of the capacity of the electrical equipment.

By using equation numbers 1.1, 1.2 and 1.2 from Chapter 2 and data from field monitoring the annual energy loss in connection to the operations of Tema Steel Work II was computed as **Gh¢23,968.14**. This amount is just the energy lost in the power system due to the presence of the power harmonics mostly being produced into the distribution network by the Tema Steel Work Limited. However the cost of premature aging of the electrical equipment connected to the power system and the cost of the down time associated with the failure of these equipments could be much higher than **Gh¢23,968.14**.

The amount **Gh¢23,968.14** is just for one industry. Assuming there are just 100 of this type of company. It means in all there will be **Gh¢2,396,814.00** dissipated into the distribution system in the form of heat in addition to the un-estimated cost of the premature aging of the electrical equipment and cost of down time. The financial implication of the presence of power harmonics is that, it is a form of a very strong negative externality which will work against the profitability of either the power providers or the consumers.

There is no government in the developing world that will allow the market forces to determine electricity tariff because of political, societal and economic reasons. Power Distribution Company like ECG must strongly advocate for punitive measures that will help to drastically reduce the level of power harmonics in the distribution network. In particular since PH is an externality, the exporters of PH must be made to internalize the externality by paying a tax for each unit of PH exported. This will lead to a reduction of PH to socially efficient levels. A reduction in the level of power harmonics will translate into a reduction in technical losses. This is good for both the ECG and the customers, because it will reduce the amount of money spent on the purchase of electrical power. From the above, it is therefore concluded that power harmonics have a heavy financial burden on the distribution network.

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