Advances in Electrical and Telecommunication Engineering 1 (2018), 9-16
ISSN: 2636-7416

Advances in Electrical and Telecommunication Engineering (AETE)

AETE is a peer review journal of the Department of Electrical & Electronics Engineering, Ambrose Alli University, Nigeria

Electrical Energy Losses Reduction using Power Factor Correction Technique

[1] Osahenvemwen, O. A., [2] Okhumeode, M. E. & [3]Omatahunde, B. E.

[1,3]Department of Electrical and Electronics Engineering, Ambrose Alli University, Ekpoma, Nigeria
[2]Commercial Department, Metering and Energy Audit Section, Benin Electricity Distribution Company, Benin City, Nigeria
osahenvemwenaustin@ymail.com

ARTICLE INFO

Article history:
Received 17 January 2018
Accepted 16 February 2018
Published 31 May 2018

Keywords:
Active Energy
Capacitance Bank
Reactive Energy
Reactive Power

ABSTRACT

This research work presents the use of power factor correction method in reducing electrical energy losses in a power distribution network. Data were collected for the actual (active) energy (MW), the reactive energy (MVAR), the apparent energy (MVA) and the measured power factor for a period of seven months (July 2016 to January 2017) from the Yongxing Steel Factory distribution network. Based on the data analysis, it was observed that active power and the reactive power have close value while the corresponding apparent power values are different. The power drawn from the power distribution system are non-linear in nature throughout the month of July. The power system possesses different phase load, measured in amperes, such are phase A, phase B and phase C. The various phase loads followed the same pattern and the variation between the measured and calculated power factor values are presented. The percentage error correction coefficient was used to determine error and relationship between these two parameters measured and calculated power factor. The low power factors witnessed were less than 0.85. Low power factor result in higher reactive power (MVAR) usage in power consumption, leading to increases in electricity costs or increases billed demand. Deployment of power factor correction (capacitance bank) can eliminate higher billing rate related to reactive power consumption. The economic important and other benefits are highlighted in this study.

1. Introduction

The deployment of constant electrical power serves as a life wire of any country robust economic, leading to high level of living standard. The electricity sector especially the distribution sector has accommodated a lot of investors saddled to supply the consumer with quality of service. In view of this quality of service, the issue of power factor must be considered. Ideal power factor must be of unity value or very close to unity value, while low power factor leads to higher apparent power demand, drawn from the power distribution (Pabla, 2003; Solomon *et al.*, 2012).

Based on higher power drawn, the distribution network required larger size transmission lines cable and transformers leading to higher operating cost of power supply to the end users. This high cost associated with power supply, due to higher apparent from low power factor, are systemically billed on to the consumers through higher tariff rates, such huge operating costs led to an investigation by Odiase & Onohaebi (2010).

Please, cite this article as: Osahenvemwen, O. A., Okhuomeode, M. E. & Omatahunde, B. E. (2018). Electrical Energy Losses Reduction using Power Factor Correction Technique, *Advances in Electrical and Telecommunication Engineering, 1*(1), 9-16. Retrieved from: https://www.sciengtexopen.org/index.php/aete/article/view/14

The power sector has the responsibility to distribute power to individual premise and to ensure that power customers pay for their services. The methodology deployed by the distribution power sector are estimating billing method and metering billing method, both methods are used to determine the amount of power energy consumed by power customers.

The types of power consumed by customers are classified as residential, commercial and industrial customers. The various electrical appliances are fans, television, radio, lighting bulb, air-conditioner, electric motor, refrigerator etc. The powers consumed by these customers in these areas are of different electrical appliances and variation in power load consumption. The electrical appliances can be classified into two such as linear load (e.g. lighting bulb, radio system etc.) and non-linear or inductive load, often commonly generated by industrial equipment's process such as electric motors, fans, drive pumps and refrigeration plant (Kerszenbaurn *et al.*, 1991; Innocent *et al.*, 2002).

Non-linear loads are associated with voltage and current harmonics, which contribute to high impact of power losses and negative effects on electricity distribution sector (Osahenvemwen *et al.*, 2016). The non-linear loads generated by refrigerator, air conditional and electric motors introduce inefficiencies into the electricity supply network by drawing additional currents, called "inductive reactive currents". Inductive load draws more current, which does not produce any useful power; as such loads can increase the loading on the supplier's cable and switch over devices.

The power factor concept is based on the utilisation of the total current drawn from the power distribution network. In addition, power factor is a determent factor to know the amount of load current that converted to useful work in power system (Sun *et al.*, 1980). The power factor expression is given as (Chem *et al.*, 1991):

$$Powerfactor = \frac{\text{total active power input (w)}}{\text{total apparent power input (VA)}} \tag{1}$$

Evaluation of transmission losses and efficiency has become imperative to improve the power sector and losses associated with the transformer design such are copper wire and magnetic loss (Harpuneet & Harjeet, 2012; Ubi & Effiom, 2013). In addition, losses are experienced in the distribution cables due to undersized distribution power cable, corona losses, dielectric, radiation losses and skin effect losses (Theraja & Theraja, 2004). Another aspect that introduced losses is the electric inductive load.

Power factor technique can deployed to eliminate the losses associated with inductive load and improve the operation of electric grids system. Also, eliminating losses at customer end has become imperative, hereby increasing the power factor to unity value. This can be achieved by the following methods; such as the static capacitors, synchronous motors and phase advancers (Solomon *et al.*, 2012; Okundamiya, 2016). Tsinkovich (2013), focused on non-linear load in industrial plant, deploying capacitor bank to improve the power factor, with emphases that current harmonic spectrum determined the choice of capacitor bank deployed.

2. Methods and Materials

The use of capacitor bank analysis in eliminating poor power factor is very important, lower capacitance can enhance the poor power factor, while higher capacitance can lead to undesirable effects. A properly analysed value of capacitance can eliminate inductance and lead to unity power factor. Power factor correction is normally for three phase load at source of inductive motor. However, due to economic reason, is advisable to deployed power factor correction at the meter end. The capacitor's bank is most efficient in power factor correction technique with high economic benefits. Therefore, the power correction is deployed in this study, to the power supplied to the Yongxing from Benin Transmission substation switch yard. The power factor correction technique based on capacitors can increase the power factor low value to high power factor.

The power factor correction analysis was based on (1) using the following parameters: active or actual power (measured kilowatt), apparent power (measured in kilo Volt-Amperes), and reactive power (measured in kilovolt ampere- reactance). Yongxing Factory took its electrical power supply from Benin Transmission substation switch yard 132/33kV, 60MVA step down transformers, with metering equipment and circuit breaker for energy accountability and the transformer protection respectively. A 33kV dual circuit lines from the Benin Transmission substation with each of the lines designed to accommodate about 30MW feeders as shown in Figure 1. Detailed description of the transformer is given in Table 1.

Table 1: The specifications of the substation transformer

Transformer Ratings	Quantity	Total Capacity (MVA)
2 MVA, 33/6kV	3	6
5.4 MVA, 33/0.66kV	2	10.8
8.5 MVA, 33/1kV	4	34
Total	**9**	**50.8**

Figure 1: Substation for Yongxing Steel Factory

Clamp on power factor was used for measurement, connecting the power factor meter. The voltage leads wire is connected first to the power factor meter and thereafter clipped to the load wire. The clamp on current transformer is then clamped on to the phase supplying the load. Data capturing in Yongxing Factory was quite easy and effective since there are already existing smart metering system, which has the ability to store and transit data to the utility. Hence, data were downloaded from the meter using computer software called "ACE PILOT" connected via an optical port. The major components of the Yongxing Steel Factory 33kV Distribution Network include the metering unit, BEDC 33kV sub-stations and the switching sub-stations. Table 2 shows values of the mean parameters obtained from Yongxing Steel Factory.

Table 2: Mean parameters values obtained from Yongxing Steel Factory

Active Energy (MWh)	Reactive Energy (MVARh)	Measure Power factor	Calculated Power factor
198	115	0.704	0.864

3. Results and Discussion

Assuming the Bill Multiple Factor (BMF) is 2000, if the average value of active or actual energy is 198MWH and the apparent energy is 231 MVAH. Therefore, the peak active and apparent demands can be calculated respectively as follow:

$$\text{Peak active demand} = \frac{198\ x\ 2000}{1000} = 396kW \tag{2}$$

$$\text{Peak apparent demand} = \frac{231\ x\ 2000}{1000} = 462\text{kVA} \tag{3}$$

$$\text{Power factor } = \frac{396kw}{462kVA} x100\% = 0.857\% \tag{4}$$

The peak readings for the seven months, the bill will be based on 86 per cent power factor.

Determining Billed Demand

The billed demand is the true kW or 90 percent of the kVA, whichever is greater. Based on the result obtained from (2) and (3), 90% of kVA (=418.5 kVA) is higher than 396 kW therefore billed demand is 418 kW. While the peak demand obtained is 396 kW, the billed demand is 418 kW. The difference of 23 kW is the power factor penalty. In this condition the power bill shown a higher kW value than the meter indicated value. Hence, the reactive power is deduced as follows:

$$\text{Reactive Power} = \sqrt{kVA^2 - kW^2}$$

$$= \sqrt{418^2 - 396^2}$$

$$\text{Reactive Power} = 134\text{kVAR}$$

The obtained value are used to determine the demand charging rate at 86 percent power factor deploying the recommended General Service Rate Structure (GSRS). The energy consumption charge (kWh) is negligible for this calculation as it is unaffected by the power factor. The billed demand (kW), which is 90 percent of the kVA is:

Billed Demand = 418 x 0.90 = 376.2 kW

Estimating kVAR for 90 Percent Power Factor

Installing capacitors bank will increase the power factor up to 90 percent. While kVA decreases, kW remain constant as indicated by the metering system. The numbers of required capacitors are determined by deploying Factor Improvement Table. From the power factor Table, therefore, 0.109 x kW will determine the estimated kVAR of capacitors needed to increase the power factor to 90 percent.

$$0.109\ x\ 396\ kW = 43.164kVAR$$

Installing 43.2 kVAR of capacitors will improve power factor to 90 percent using the Power factor correction Table analysis, the new demand charge and the resulting savings cost can be determined by the improving power factor to 90 percent reduces total kVAR to:

$$(115 - 42\ )kVAR\ = 73kVAR$$

The kVA is now:

$$= \frac{396}{0.90} = 440kVA$$

The obtained values on improvement analysis on power factor are presented in Table 3**.** In Nigeria, the cost of energy is 31.27 per KWh. Therefore, 396 kW x 31.27 x 60 x 60(kWh) = ₦44,578,512

Table 3: Obtain values based on improved power factor analysis

Active Power (kW)	Reactive Power (kVAR)	Apparent Power (kVA)	Required Power Factor
396	73	440	0.9

Power Factor Correction and Billing Calculations

The true kW and kVA can be determined by deploying the billing multiplier factor to each reading. Using a billing multiplier factor of 2000, with Watt meter reading of 900kW and the Volt-Ampere meter reading of 1125 VA, the peak demands can be calculated as follows:

$$\text{Peak active demand} = \frac{900\ x\ 2000}{1000} = 1800kW \qquad (5)$$

$$\text{Peak apparent demand} = \frac{1125\ x\ 2000}{1000} = 2250\text{kVA} \qquad (6)$$

$$\text{Power factor } = \frac{1800\ kW}{2250kVA}x100\% = 0.80\% \qquad (7)$$

Assuming these are the peak readings for the month, the bill will be based on 80 percent power factor. Based on the measured power factor is 0.7017, while the calculated power factor is 0.854, leading to 70 and 80 percent respectively, while the billed demand is the true kW or 90 per cent of the kVA is 2025 kVA. The 2025 kVA value is higher than 1800 kW; therefore the billed demand is giving as 2025 kW, leading to the peak demand of 1800 kW. Figure 2 presents the aggregate energy in power distribution system, while Figure 3 and Figure 4 show the phase loads and power factors for the month of July 2016 respectively.

As observed from the aggregate energy in power distribution system (Figure 2), the active power and reactive power have close value while the corresponding apparent power has a different values. Also, associated powers in the power distribution system are non-linear in nature throughout the month of July 2016. This phenomenon affects our electronics appliances. The Yongxing Steel Factory power system possess different phase load (Figure 3), measured in amperes, such are phase A, phase B and phase C. It was observed that the various phase loads followed the same pattern and the three phases are not linear throughout the month of July 2016.

Firstly, it was observed that the power factor witnessed was not unity in nature on the power system. In addition, a sharp drop in power factor at 12 July 2016, and 14 July 2016 was observed. Secondly, that the power factor witnessed was less than 0.85 and it does not exhibit linear characteristic. Low power factor results in higher than necessary reactive power (kVAR) usage in power consumption, leading to increases in electricity costs or increases billed demand. Deployment of power factor correction can eliminate higher charges related to reactive power consumption.

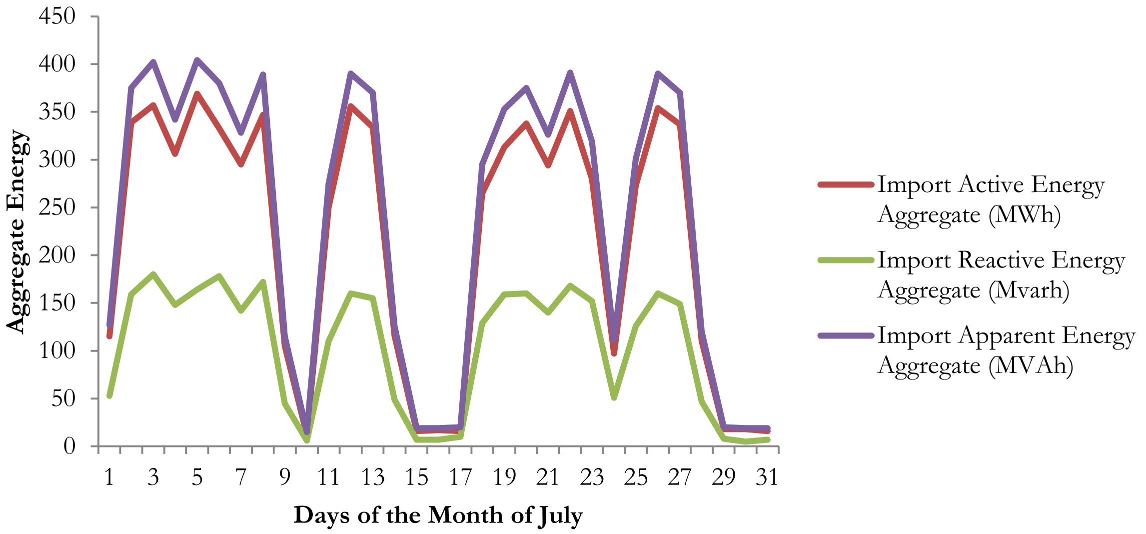

Figure 2: Aggregate energy in the Yongxing Steel Factory power system

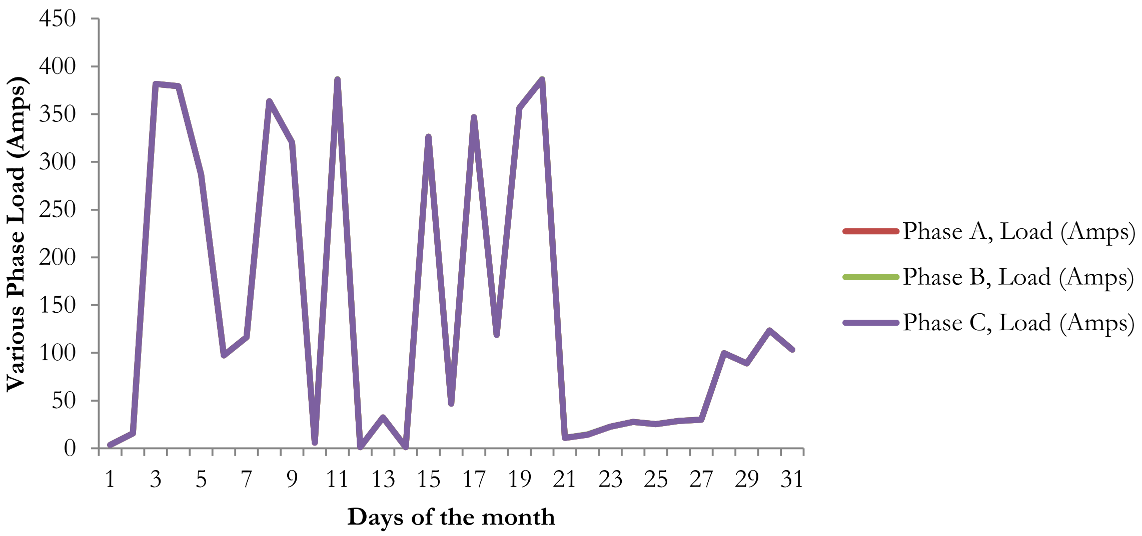

Figure 3: Various phase loads (A) for the month of July, 2016

Figure 5 shows the aggregate power such as active, reactive and apparent power of the Yongxing Steel Factory from July 2016 to January 2017. It was observed that power demand or transmitted power to Yongxing Steel Factory was in variant from July 2016 to January 2017. This also led to non-linear power factor witnessed in power distribution network shown in Figure 6.

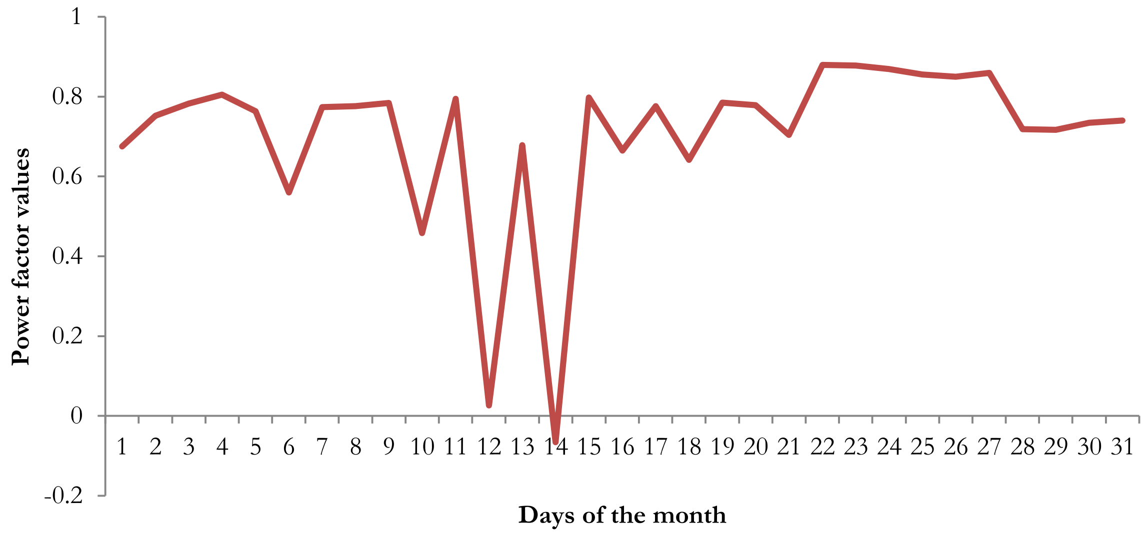

Figure 4: Various power factor values for the month of July, 2016

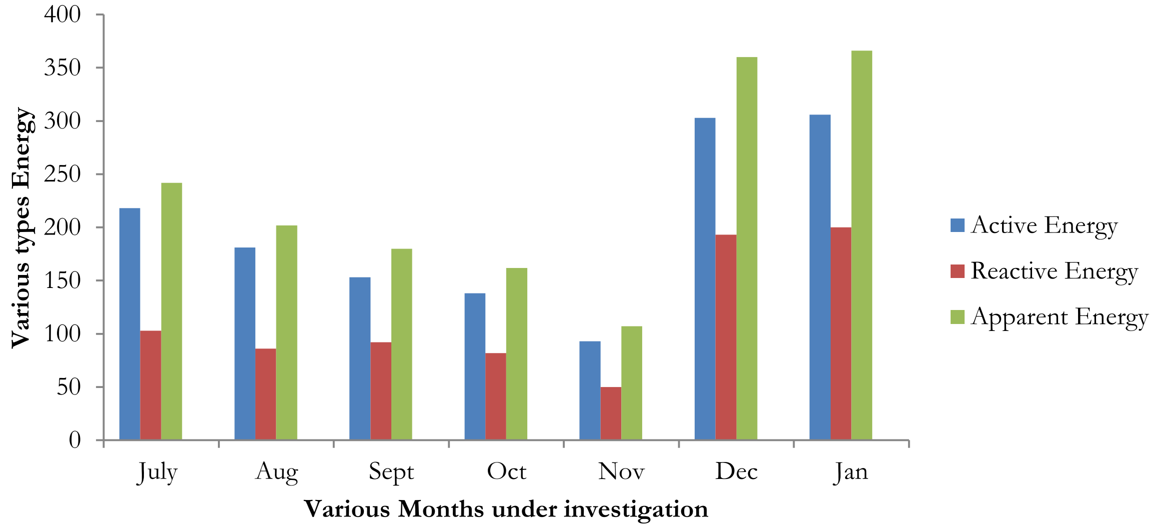

Figure 5: Various power distribution from July 2016 to January 2017

It was observed (Figure 6) that October 2016 witnessed the highest value of power factor followed by September and August 2016, while December 2016 witnessed the lowest value of power factor in power distribution system. Figure 7 shows the comparison of the measured and the calculated power factor distribution from July 2016 to January 2017.

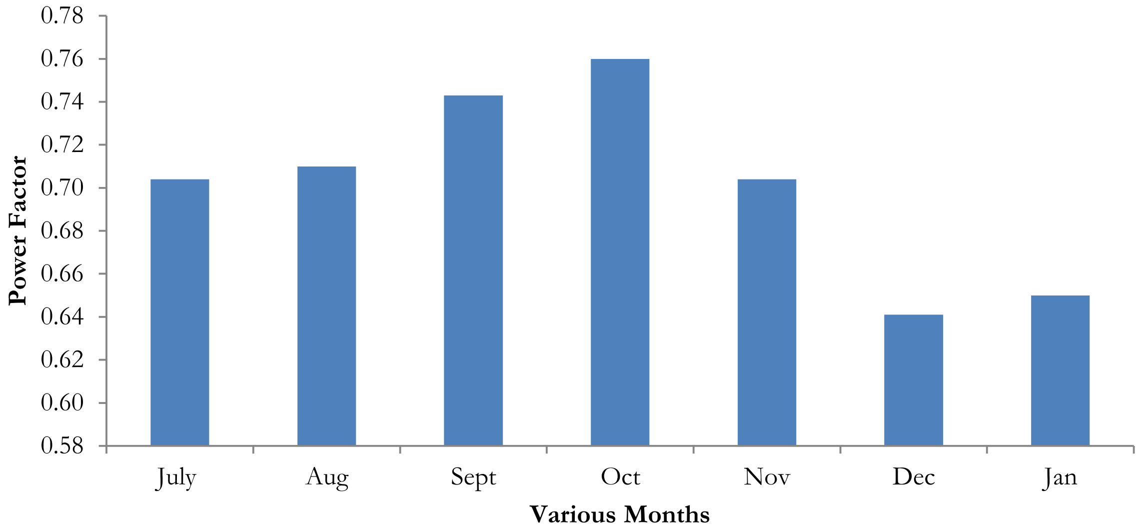

Figure 6: Various Powers factor from July 2016 to January 2017

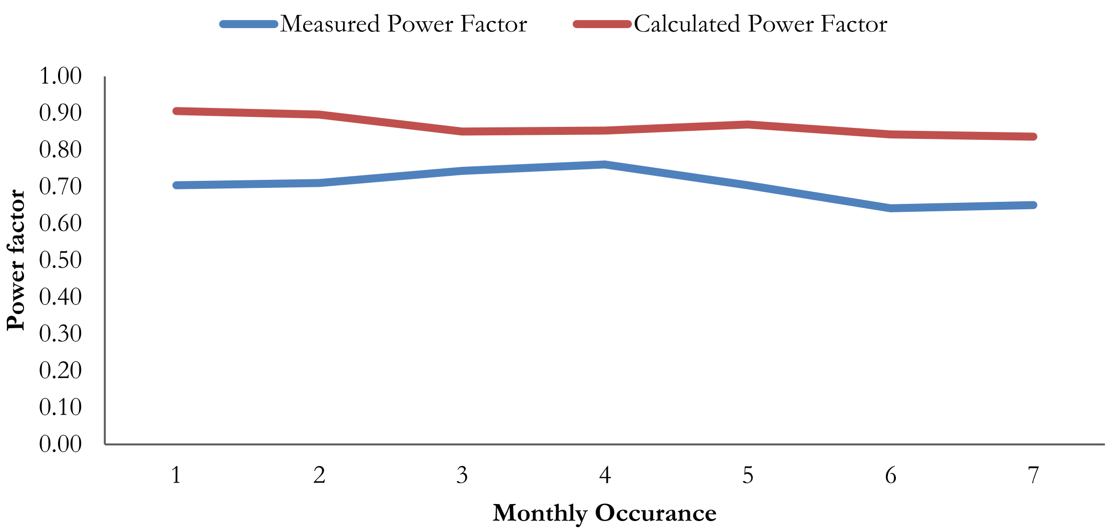

Figure 7: Comparison between measured and calculated power factors for Yongxing distribution network from July 2016 to January 2017

It was observed that there was variation between the measured and calculated power factor values obtained from Yongxing Steel Factory. The percentage error correction coefficient was used to determine error and relationship between these two parameters measured and calculated power factor.

4. Conclusion

This paper focused on the electrical energy losses reduction for the Yongxing Steel Factory power distribution network as case study, using power factor correction technique. Based on the data obtained from the steel factory, it was observed that the active power and reactive power have a close value while the corresponding apparent power value is entirely different. In addition, the associated powers in the power distribution system are non-linear in nature throughout the month of July 2016. The power system possess different phase load, measured in amperes, such are phase A, phase B and phase C. It was observed that the various phase loads followed the same pattern and the three phases are not linear throughout the month of July 2016. There was variation between the measured and calculated power factor values obtained from Yongxing Steel Factory. Firstly, it was observed that the power factor witnessed was not unity in nature. It has a sharp drop in power factor at 12 July 2016, and 14 July 2016. Secondly, that the power factor witnessed was less than 0.85 and it does not exhibit linear characteristic. Low power factor results in higher reactive power (kVAR) usage in power consumption, leading to increase in electricity costs or increase billed demand. Deployment of power factor correction can eliminate high charges related to reactive power-consumption.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Chem T. H., Chem, M. S., Inoue T, Kolas P. & Chebli E.A (1991). Three-phase generator and transformer models for distribution system analysis, *IEEE Transmission of Power Delivery*, 6, 18-21.

Harpuneet Singh, & Harjeet Singh Mangat, (2012). Impact of unreliable power on a paper mill: a case study of paper industry of Punjab, India, *proceeding of the International Multi-conference of Engineering and Scientists*, 92, 14-16.

Innocent E. D., Abimbola O., Michael O.K. & Brin M. (2002). Technical loss consumption and economic dispatch model for T & D system in a Deregulated ESI, *Power Engineering Journal*, 13-16.

Kerszenbaurn I, Mazur A., Mistry, M. & Frank J. (1991). Specifying dry-type distribution transformers for solid-state application, *IEEE Transactions on Industrial Application*, 27, 16-20.

Odiase O.F. & Onohaebi O. S. (2010). Empirical modelling of power losses as a function of line loadings and lengths in the Nigeria 330kV transmission lines, *International Journal of Academic Research Azerbaijan*, 2, 8-11.

Okundamiya, M. S. (2016). Power electronics for grid integration of wind power generation system, *Journal of Communications Technology, Electronics and Computer Science*, 9, 10-16.

Osahenvemwen, O.A., Enoma, O. C. & Aitanke, H. (2016). Evaluation of transmission losses and efficiency, *Ideal Journal of Engineering and Applied Sciences*, 1(1): 1-6.

Pabla, A. S. (2003). Electric Power Distribution, Fourth Edition, sixth reprint, Tata McGraw-Hill Pub.Com. Ltd New Delhi, 34-45.

Solomon Nunoo, Joseph C. Attachie, Frinklin N. D. (2012). An Investigation into the causes and effects of voltage drops on an 11kv Feeder, *Canadian Journal on Electrical and Electronics Engineering*, 3(1): 40-47.

Sun D. I. H., Abe, Shoults R. R., Chem M. S., Elchenberger, P., Farris D. (1980). Calculation of energy losses in a distribution System, *IEEE Transaction on Power Apparatus and System* V. PAS – 99 (4): 12-16.

Theraja B. I. & Theraja, A. K. (2004). Electrical Technology, publication division of Nirja construction and development co. ltd new delhi-110055, 1759-1782.

Tsinkovich O.I. (2013). Capacitor bank evaluation for power factor improvement of an industrial plant's distribution network with non-linear load, oil and gas business, *Electronic Scientific Journal*, 4, 282-290.

Ubi Peter Samuel & Effiom Lionel, (2013). The dynamic analysis of electricity supply and economic development, *Nigeria Journal of Sustainable Society* 2(1): 1-11.