Evaluating the Performance of Harmonic Neutral Blocking Filter in ECG Electric Power Distribution System

George Eduful *Member, IAENG*, Kingsford J.A. Atanga

Abstract— **Triplen harmonic currents are becoming major concern in the Electricity Company of Ghana (ECG) distribution system. Significant levels of triplen harmonic currents generate heats, increase system losses and reduce the economic life spans of distribution transformers. In this paper, the performance of three harmonic suppressors in the control of harmonic emission levels in three ECG's distribution transformer substations have been investigated. Harmonic parameters monitored include, harmonic currents, Total Harmonic Distortions (THD) and harmonic energy losses. Results show that the neutral blocking harmonic filters can reduce harmonic current in neutral conductors by 88% and consequently decrease harmonic energy loss by 97%. The estimated annual energy savings from the harmonic reduction for each transformer amounted to *10, 707.86 kWh***

Index Terms— Triplen Harmonics, Neutral Blocking Filter, Harmonic Suppressor, Total Harmonic Distortions

I. Introduction

IN our previous study [1], technical loss evaluation of distribution transformers in the Electricity Company of Ghana (ECG) distribution system was conducted. It was shown that harmonic currents can increase losses in distribution transformer to more than 100%. The study identified triplen harmonics as the main components responsible for the harmonic losses, and by way of solution, recommended deployment of either harmonic neutral blocking filters or active harmonic filters. To help take an informed decision, investigation into the performance of types of filters was considered necessary. However, in this study, the focus is on performance evaluation of the neutral blocking filter.

Three neutral blocking filters have been obtained and installed to control harmonic levels at three distribution transformer substations. Harmonic quantities were monitored at the secondary side of the transformers. The parameters monitored include, harmonic currents, Total Harmonic Distortions (THD) and harmonic energy losses. Results show that the neutral blocking harmonic filters can reduce harmonic current in neutral conductors by 88% and consequently decrease harmonic energy loss by 97%.

Manuscript received February, 03, 2017; revised February, 21, 2017 This work was supported in part by the Electricity Company of Ghana.

George Eduful is with the Electricity Company of Ghana, Research and Development Division, P.O. Box AN 5278, Accra-North, Ghana, Tel: +233246132735, email: eduful@ieee.org

Kingsford. J.A Atanga is with the Electricity Company of Ghana, Research and Development Division, P.O. Box AN 5278, Accra-North, Ghana, Tel: +233249560723, email: kantaga23@gmail.com

A. *Effects and Mitigation of Triplen Harmonics*

High harmonic neutral currents generate heat and reduce the capacity of neutral conductor. In worst case, the high current may lead to burn out of the neutral conductor creating an open neutral environment with very serious consequences. Also, high levels of neutral current can also generate potential difference between neutral and earth and cause potential to float at the neutral terminal. The neutral potentials result in erratic behavior and unpredictable performance of electric equipment. A neutral-to-ground voltage above 0.5 Volts has been identified as a possible source of disturbances [2, 3].

Generally passive and active filters are the two main methods used to reduce harmonic emission levels in power system. The choice of which filters to use in a particular case depends on harmonic measurements and the contents of the harmonic spectrum. The choice can also be influenced by economic issues.

Passive harmonic filters are the largest group of filters available. They consist of capacitors, inductors and resistors tuned to damp harmonics. It provides a low impedance path for the tuned harmonic frequency and consequently trap and damp it [4]. On the other hand, active filters inject current that is opposite in phase with the fundamental current. This way, they eliminate the harmonic components from the fundamental current [5]. They have the advantage of being able to be programmed to block several orders of harmonics instead of just one harmonic component [5].

In situations where triplen harmonics are dominant, a neutral blocking filters are used. These are essentially passive filters made of capacitor and reactor connected in series with a neutral conductor. The components allow 50 Hz (normal load) current to flow but provide extremely high impedance for triplen harmonic currents [6]. Application of this filter to a distribution transformer blocks all downstream loads from generating triplen harmonics [7].

Our motivation for this study was therefore to investigate the performance of the neutral blocking filter and possibly deploy them in ECG's distribution system especially, in areas where triplen harmonic currents are of major concern.

II. METHODOLOGY

Three neutral blocking filters also known as harmonic suppressors were obtained and each installed in series with the neutral conductors of three (3) 500kVA transformers in ECG's distribution system in Kumasi, Ghana. The transformers are delta-wye configured. The drawing of the set out is shown in Fig 1.

Two scenarios were considered: transformer without suppressor and transformer with suppressor. A single-pole switch was installed to create a path to bypass the suppressor when the transformers are isolated from the suppressors.

To determine the effectiveness of the suppressors, each distribution transformer was operated for seven days continuously with a suppressor and then without a suppressor for another seven days. This method was repeated for two months.

Three phase energy meters (EM) with automatic remote reading functionality were installed for the performance monitoring. In addition to the installed energy meters, Fluke 435 Series II power quality and energy analyzers were also used throughout the period as backup measuring devices.

Parameters measured include fundamental currents, harmonic currents, Total Harmonic Distortions (THD) and harmonic energy loss. For comparative analysis, the recorded parameters were compared with both measuring devices.

III. RESULTS AND DISCUSSION

A. Analysis of Current in the Neutral Conductors

Currents measured in the neutral conductors of the transformers are shown in Fig.1. The figure compares graph of neutral current without the harmonic suppressor to a graph of current when the suppressor was in circuit. In all the three locations where the filters were installed, currents reduction in the neutral conductors were quite significant. The margin of reduction increased with loads.

Load variations and imbalance on the transformers were quite pronounced. The load varied from 35 to about 60% capacity of the transformers. From Fig. 1(C), it can be observed that at one instance, the current in the neutral conductor got reduced from 350 to 200 A, representing 45% reduction in the neutral current. This was a case when the load on one of the transformers was maximum (at 60% capacity of the transformer). Interestingly, it was the same instance where the maximum reduction in current occurred. Ideally, it was expected that the current in the neutral would be very low or near zero after the suppression. However, we were not surprised to see the 200 A as the load on the transformers were highly unbalanced. Also, it will be shown later that the current is still high in the neutral because the suppressor could not block all the triplen harmonics.

The relation (1) given below is generally used to estimate power loss in three phase 4-wire system, especially under unbalanced condition.

$$P_{loss} = \left(I_1^2 + I_2^2 + I_3^2\right) \times R_{phase} + I_N^2 \times R_N$$

It is therefore obvious that to minimize power losses in three phase 4-wire distribution system, either the loads should be balanced across the phases or the I^2 RN term in (1) be reduced. Mathematically, we can also say that for minimum power losses, the differential of (1) with respect to the neutral current (I_N) should be equal to zero, thus

$$\frac{d\left(P_{loss}\right)}{dI_N} = 0$$

$$0 + 2I_N \times R_N = 0$$

Therefore, for minimum Power loss,

$$I_N = 0$$

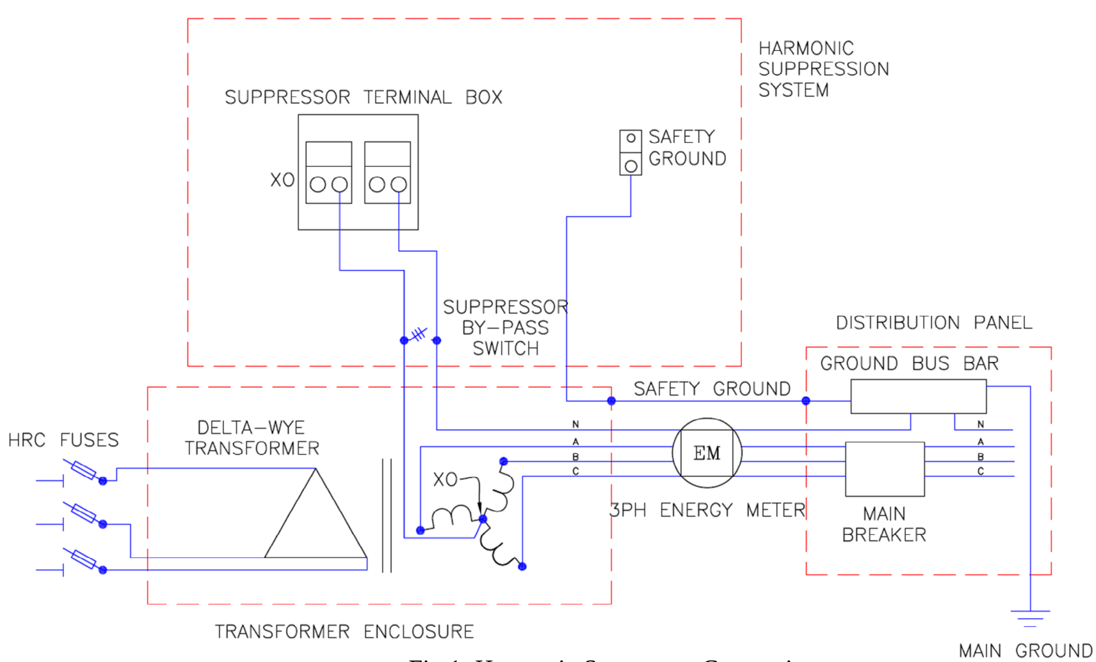
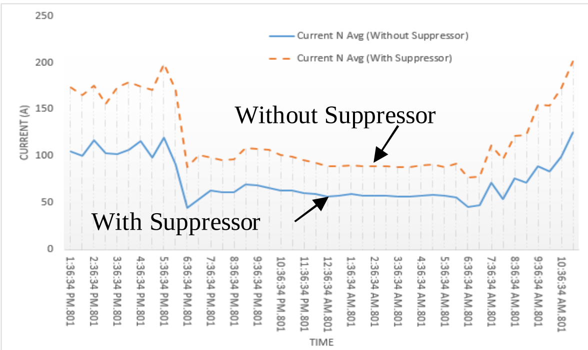
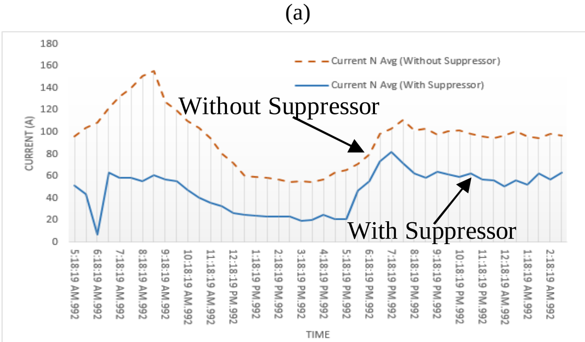


Fig.1: Harmonic Suppressor Connection

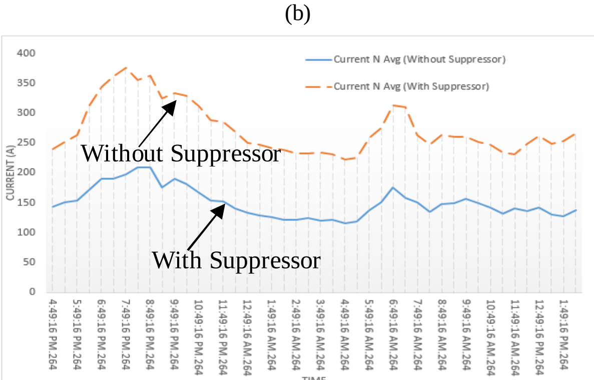
In theory, I_N can only be zero if loads on the three phase 4-wire distribution system are equally distributed. However, in the presence of 3rd harmonics, I_N cannot be zero. This is because the triplen harmonics are zero sequence components that are additive at the neutral. It is important to note that the application of the of the suppressor and the load balancing technique will still not bring the I_N to zero as the suppressor was limited in terms of blocking all the triplen harmonics. It however expected that the two methods will work together to reduce the current in the neutral conductor drastically.



(a)



(b)

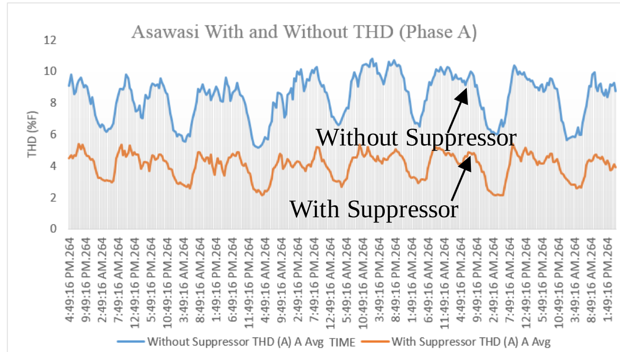


(c)

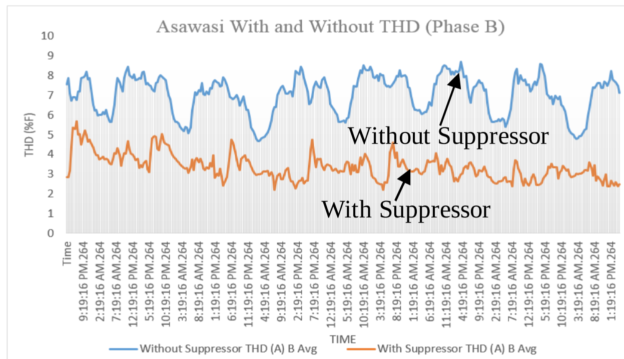
Fig.2: (a)-Rawlings Park Substation, (b)-Ayigya Zongo – Substation and (c) - Asawase Renault Substations

B. Analysis of Total Harmonic Distortions

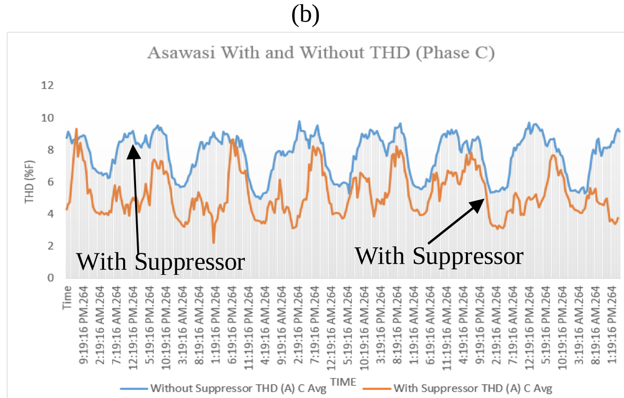
Analysis in the phases: Levels of harmonic currents in the phases of the transformers compared with the fundamental load currents were found to be too low for analysis. Total Harmonic Distortion (THD) readings however presented a useful information. Figure 2 compares current THDs on the phases of the transformers (with and without the harmonic suppressors). Here the performances of the suppressors are very clear. The THDs in the phases dropped from about 9 to 4% showing suppressor's performance of around 55%. It can be seen that there is still some level of distortion in the current after the harmonic suppression. These distortions were result of residual harmonic currents that escaped the suppressing action of the suppressors.



(a)



(b)



(c)

Fig.3: Current THD with and without suppressor in (a) – Phase A, (b) – Phase B and (c) – Phase C

C. Analysis of THDs in the Neutral Conductor

The performance of the suppressors in the neutral conductors were quite remarkable. As can be seen in Fig 4, current THD in the neutral conductors reduced from about 80 to10%, confirming the supremacy of the suppressor at the neutral point. In general, the suppressors displayed a performance of about 88%. However, an interesting results were observed in the voltage THDs. A drop in the current THD resulted in an increase in the voltage THD. This phenomenon initially appeared to have violated the basic principles that suggest that low levels of current harmonics

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

should result in low current THD and automatically lead to low levels of voltage THDs. Subsequently, it was found that the impedance of the suppressor, through which the harmonic current flowed, accounted for the higher harmonic voltage distortions. This was a major disadvantage found with the suppressors as high voltage THDs result in erratic behavior of equipment.

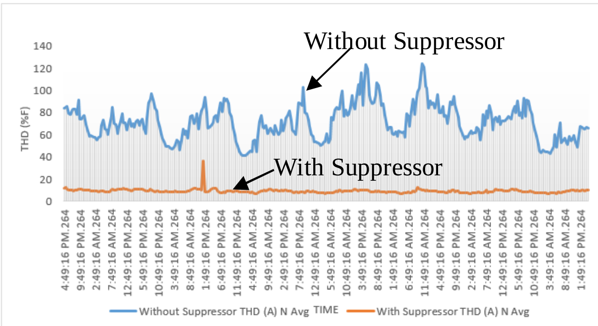


Fig.4: Current THD in Neutral Conductor (with and without suppressor)

D. Harmonic Energy Loss Analysis

Plot of measured data for the harmonic energy losses in one of the transformer substations is shown in Fig 3. Using curves of bestfit, harmonic energy consumed over a period of 22 hours was described by the following functions:

$$f(E_{with}) = 5.196t^{0.6601} \quad (2)$$

$$f(E_{without}) = 6.6244\ln(t) - 5.6625 \quad (3)$$

Where $f(E_{with})$*, the function of harmonic energy consumed with the suppressor in circuit,* $f(E_{without})$ *is the function of harmonic energy consumed without the suppressor in circuit and* t *is the time of energy consumed in hours.*

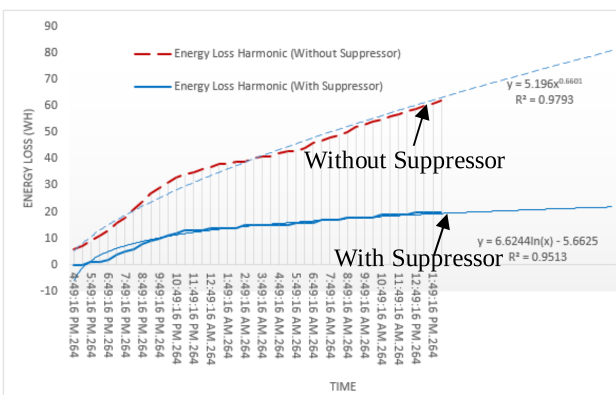


Fig.4: Harmonic Energy Losses (with and without suppressor)

To find harmonic energy saved by the suppressor over a period of 1 year, an area under (3) was substracted from an area under (2) for *t=1 hr to t=8760 hr* as follows:

$$E_{energy\_saved} = \int_{t_{1\_without}}^{t_{2\_without}} f(E_{without})dt - \int_{t_{1\_with}}^{t_{2\_with}} f(E_{with})dt \quad (4)$$

Harmonic energy consumed from the two scenarios are given below:

Harmonic energy consumed without the suppressor =10977 kWh

Harmonic energy consumed with the suppressor = 270.2 kWh

Therefore, harmonic energy saved as given by (4) is *10, 707.86 kWh*. This represents reduction of 97.5% harmonic energy loss in the system. It is important to note that this reduction is limited to only one of the 500 kVA transformer substations. In monetary terms, a total of *GhC 7, 173.59* is expected to be saved every year in relation to harmonic system losses per transformer substation. ECG has a total of 20, 000 transformer substations and therefore has the potential to save close to about *GhC 143,471,800* from harmonic suppression only.

IV. Conclusions

Triplen harmonic current are the main components responsible for the harmonic power losses in electric power distribution system. It has been shown that neutral blocking filters or harmonic suppressors are effective in controlling harmonic emission levels in power systems, and are more superior in reducing triplen harmonic current in neutral conductors. The suppressors can reduce harmonic distortions in phase currents and neutral conductors by 55% and 88% respectively. Even though the harmonic suppressors have demonstrated strong ability in the reduction of harmonic energy losses, they have been found to increase harmonic voltage distortion levels. This is a major disadvantage with the suppressors as high voltage THDs can lead to erratic behavior of electronic equipment. Further studies are therefore being recommended to find methods of addressing this disadvantage with the harmonic neutral blocking filters.

References

[1] George Eduful and Kingsford J.A. Atanga, 2016: Analysis of High Neutral Currents and Harmonic Impacts on Losses and Capacities of Distribution Transformers. Proceedings of the World Congress on Engineering 2016 Vol I WCE 2016, June 29 - July 1, 2016, London, U.K.

[2] Lukas Motta and Nicolás Faúndes, 2016: Active / Passive Harmonic Filters: Applications, Challenges & Trends. 17th International Conference on Harmonics and Quality of Power (ICHQP). IEEE Xplore Electronic ISSN: 2164-0610.

[3] Nandita Dey and A.K.Chakrabort, 2013: Neutral Current and Neutral Voltage in a Three Phase Four Wire Distribution System of a Technical Institution International Journal of Computer Applications (0975 – 8887)

[4] Waite, M. J., Zhang, L. and Chong, B., 2011: Active Power Filtering for a Three-Phase Four-Wire Network with Unidentifiable Harmonic loads. Manchester: IEEE, Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference. Pp. 1-8.

[5] Rauma, K. , 2012: Electrical Resonances and Harmonics in a Wind Power Plant. Master's Thesis, Aalto University, Espoo, Finland.

[6] Kazem, H. A., 2013: Harmonic Mitigation Techniques Applied to Power Distribution Networks. Advances in Power Electronics. Published by Hindawi Publishing Corporation. Pp. 1-10.

[7] Kolar, J. W. (2012). "The Essence of Three-Phase PFC Rectifier Systems Part I". IEEE Transactions on Power Electronics, 1-22.

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)