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Practical Analysis of Harmonics Effects on Transformer

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ABSTRACT

Harmonic currents or voltages are generated from a non-linear load when it is connected to the mains supply. The problems caused by harmonic include overheating of cables, especially the neutral conductor, overheating and vibration in induction motors and increased losses in transformers. In this paper, the details analysis of harmonics effect on a 1KVA transformer is analyzed. A frequency oscillator source is used for generating the harmonics signal on the transformer. The total harmonic distortion, crest factor and K-factor are analyzed by using a Fluke-435 power analyzer.

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Introduction

Harmonics and distortion in power system current and voltage waveforms have been present for decades. However, today the number of harmonic producing devices is increasing rapidly. These loads use diodes, silicon controlled rectifiers (SCR), power transistors, etc. Due to their tremendous advantages in efficiency and controllability, power electronic loads are expected to become significant in the future, and can be found at all power levels, from low-voltage appliances to high voltage converters. One result of this is a significant increase in the level of harmonics and distortion in power system networks [1].

Transformers are major components in power systems. The increased losses due to harmonic distortion can cause excessive losses and hence abnormal temperature rise. The measurement of iron losses and copper losses of single-phase transformers is important in particular for transformers feeding nonlinear loads. When the power factor capacitors are fitted, harmonic currents can damage them and care must be taken to avoid resonance with the supply inductance. Losses in transformers are due to stray magnetic losses in the core, and eddy current and resistive losses in the windings. Of these, eddy current losses are of most concern when harmonics are present, because they increase approximately with the square of the frequency. Before the excess losses can be determined, the harmonic spectrum of the load current must be known [2].

The usage of nonlinear loads on power systems increasingly the awareness of the potential reduction of a transformer’s operational life due to increase heat losses. The performance analysis of transformers in harmonic environment requires knowledge of the load mix, details of the load current harmonic content and total harmonic distortion (THD). The additional heating experienced by a transformer depends on the harmonic content of the load current and the design principles of the transformer [3].

Special transformers such as V–V, Scott and Le-Blanc transformers are used to convert a three-phase supply into one or two single-phase supplies. These transformers are commonly used in the electro locomotive traction systems. The authors in [4] investigated the harmonic cancellation characteristics of such transformers. The results showed that when two harmonic-producing loads are connected to each single-phase side of the transformers, the harmonics produced by the loads will cancel out at the primary sides of the transformers. The amount of cancellation is affected by transformer type and harmonic order.

A novel method for reducing harmonics in series-connected converters is proposed in [5]. The proposed method adopted an averaging inductor to the series-connected converters and thus simplified the pulse multiplication process. The principle of their method was demonstrated by a three-thyristor switching circuit scheme, which can make a 12-pulse double bridge converter to operate at 36 pulses. The simulation results reinforced the theoretical work. Only slight changes are needed for the proposed method to reach higher pulse operations. This made this method even more attractive when high-pulse operation is desired.

The use of companion harmonic circuit models for transient and harmonic analysis of electrical networks where an exact periodic steady state initialization method was proposed in [6]. The suggested companion harmonic circuit models are the result of applying the trapezoidal integration rule to the differential equations characterizing electric elements in the dynamic harmonic domain. The technique was applied to a simple network exhibiting harmonics due to transformer saturation. The models provided a direct means of calculating both the steady state and transient response of the harmonics in an electrical network.

Types of Harmonics

The harmonics can have an effect on current waveform (Current Harmonics) or voltage waveform (Voltage Harmonics). The current harmonics can be produced by a bridge rectifier circuits. Current harmonics have an effect on the electrical equipment supplying harmonic current to the device (transformers, conductors). Harmonic currents can cause excessive heating to transformers. For electrical systems feeding single phase loads the third harmonic has gained attention in design consideration and transformer selection for causing the neutral conductor to draw excessive current. Voltage harmonics

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can effect sensitive equipment throughout your facility. Voltage harmonics arise when current harmonics are able to create sags in the voltage supply. When any device draws current it creates a voltage dip which is required for current to flow. This voltage dip is visible with larger loads when turning on a hair dryer or a table saw and seeing the lights dim down. The amount of sag depends on many factors like transformer impedance and wire size. Current harmonics create voltage harmonics, but the magnitude of the voltage harmonics depends on the “Stiffness” of electrical distribution’s “System Impedance”. An example to help understand current distortion verse voltage distortion is the common light bulb. This low cost light bulb may have a 75% current THD (Total Harmonic Distortion). This means that 75% of the current drawn by the bulb is considered “Harmonic Current”. These light bulbs usually do not affect other devices in your home because even though the current drawn by the bridge circuit is rich in harmonic current it creates very little sag in home’s voltage supply and if there is a voltage analyzer , then it can be seen the THD voltage, which will be less than 1 percent.

Figure (1) shows the harmonics effect on the waveform shape. The upper row (left and right) shows the fundamental frequency consists of two circle waves ($4\pi\ f_0$). The third subplot in this figure (at row two-left side) represents the second harmonics ($2f_0$), while the right one represents the third harmonics ($3f_0$). The effect of these harmonics on the main waveform is shown in the last subplots (subplot 5 and 6). From these subplots (5 and 6) it can be seen that the third harmonics can have more effect on the signal waveform shape. The third harmonics can make the signal shape to be more fluctuated than the effect of second harmonics. Figure (2) presents the fourth and fifth harmonics effect on the waveform. From this figure, the odd harmonics is still has more effect on the complex waveform shape. So the odd harmonics (5, 7, 9, etc.) have more effects on the waveform than even harmonics (2, 4, 6, etc.).

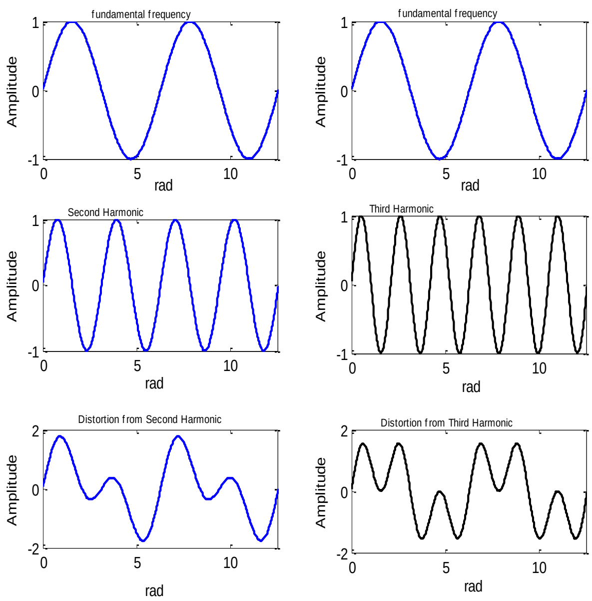

Figure (1): Second and third harmonic waveforms effect

Harmonics Reduction

The harmonics can be reduced by selecting equipments with low THD currents, and the result will reduce the THD voltage. If is difficult to use such equipment with a low THD current there are other options available, such as adding line chokes or isolations transformers to reduce the harmonic currents.

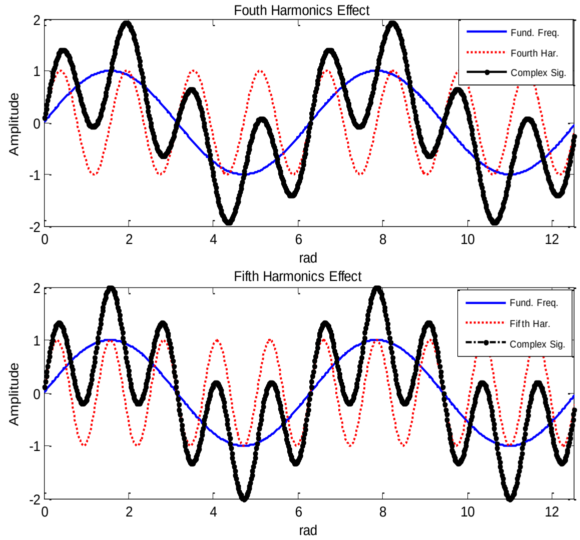

Figure (2): Fourth and fifth harmonic waveforms effect

The current distortions that can have an effect on voltage waveform can be reduced by using a tuned capacitor. Also it can be redesigning the systems distribution to reduce system impedance. Many solutions are used for reducing the effects of harmonics, some of them are:

Harmonics Current Reduction

- By adding line chokes to the equipment producing harmonics
- By adding isolation transformer to the equipment producing harmonics
- By using a 12- Pulse or 18 pulse rectifying circuits instead of 6 pulses

Harmonics Voltage Reduction

- By adding a tuned capacitor banks to the source of current harmonics
- By changing the transformer size and impedance

The other method by using phase-shifting transformers, which are cost-effective, energy efficient, highly reliable passive devices that are always on the job, treating harmonics regardless of the level of load they are serving at a given point in time.

Harmonic Effect on Transformer Losses

Transformer manufactures usually try to design transformer in a way that their minimum losses occur in rated voltage and sinusoidal current. However, by increasing the number of non-linear load in recent years, the load current is no longer sinusoidal. This non-sinusoidal current causes extra loss and temperature in transformer [7]. Several methods of estimating the harmonic load content are available which are:

1)Crest- Factor

2)Percent of THD (%THD)

3)The third method is the K-Factor which can be used to estimate the additional heat created by non sinusoidal loads

The crest factor is a measure of the peak value of the waveform compared to the true RMS value [4, 5].

$$CF = \frac{I_{\max}}{I_{rms}} \qquad (1)$$

where I_{max} is the peak magnitude of the current waveform and I_{rms} is the true RMS of the current.

The %THD is a ratio of the root-mean-square (RMS) value of the harmonic current to the RMS value of the fundamental frequency [7, 8].

$$\%THD = \frac{\sqrt{\sum_{h=2}^{\infty}(I_h)^2}}{I_1} \qquad (2)$$

The last equation is used for measuring the additional harmonic current to the total RMS value.

In the third method, the K-factor is used and it is defined as the sum of the squares of the per unit harmonic current times the harmonic number squared.

$$K = \sum_{h=1}^{\infty}\left(I_{h(pu)}\right)^2 h^2 \qquad (3)$$

where $I_{h(pu)}$ is the harmonic current expressed in per unit based upon the magnitude of the fundamental current and h is the harmonic number [8].

Simulation Results

In this section, a practical experiment is used for calculating the THD for a single phase transformer of 1KVA. The practical experiment is done by using the list of devices given in table (1). The details components are shown in figure (3). The variable frequency supplier (i.e. N700E) is used for generating the 3^{rd}, 5^{th}, and 7^{th} harmonic frequency on the transformer. While the variable resistors of 600W are used for controlling the supplied voltage at different frequency on the transformer.

Table (1): List of used components in the experiment

Item	Model Number
Variable frequency supplier	N700E
Transformer	1KVA
Power quality analyzer	Fluke-435B
Storage oscilloscope	SFRAM
Variable resistors	600W

Figure (3): Practical experimental components

Harmonics Effect at Different Frequencies

In this section, a practical experiment is used for calculating the THD for a single phase transformer of 1KVA. Figure (4) gives the harmonics effects in table forms. The upper figures represents the harmonics in Ampere, Volt, and Watt from left to right respectively. The first table show that the THD_f =266 for line (L1) and equal to 157.9 for neutral (N) decreases as the harmonics increases to 250Hz and 350Hz (figures (5) and (6). The corresponding values of $THD_f(250Hz)=202.6$ and $THD_f(350)=195.5$. The values of THD_f were also decreased for neutral lines at the same tables (i.e. $THD_f=157.9$ (at 150Hz), $THD_f=117.7$ (at 250Hz), and $THD_f=116.2$ (at 350Hz). The other values at the same tables represent the values of odd harmonics from H3 to H15. The other values of harmonics percentages in terms of Volt and Watt are also given in the same figures. The other subplots lie in the below-right sides illustrates the harmonics effect as a function of Volts/Amps/Herts. The harmonic percentage decreases as the applied frequency increases. (figure (4) to figure (6). From the same subplots, the crest factor is constant at 1.4 due to using the variable resistors for controlling the applied currents and voltages on transformer, which means the currents I_{max} and I_{rms} are constant in equation (1), so the values are constant.

The below-middle subplots in the same figures represent the main signal of 230V (source voltage) in addition to the applied harmonics voltage of 23V in neutral line. From this figure it is clear that the signal shape is fluctuated due to the effect of applied harmonic signal on transformer. The other subplots (below-middle) at same figures represent the effect of harmonics on signal shape (5^{th} and 7^{th} harmonics).

Finally, the last subplots (below-left) represent the harmonics effect on the current waveform. From these subplots, the fluctuation is higher at the 3^{rd} harmonics than the other values at 5^{th} and 7^{th} harmonics. This case is considered to be normal, because the amplitude of harmonics decreases as the order increases.

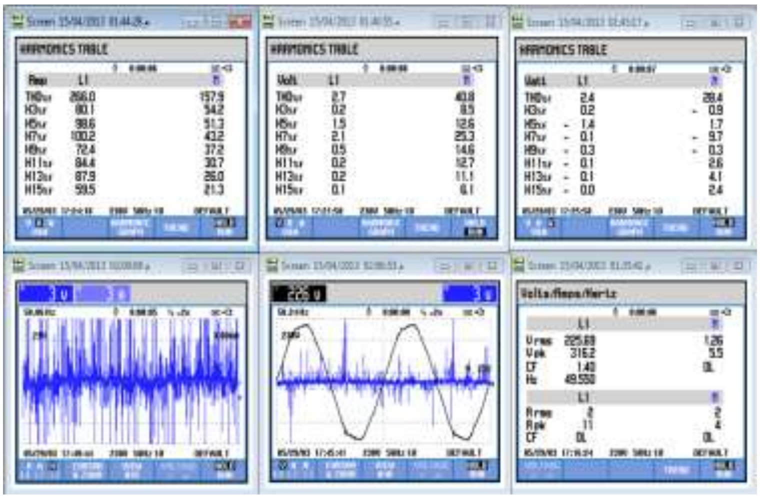

Figure (4): Harmonic Effects at 150Hz

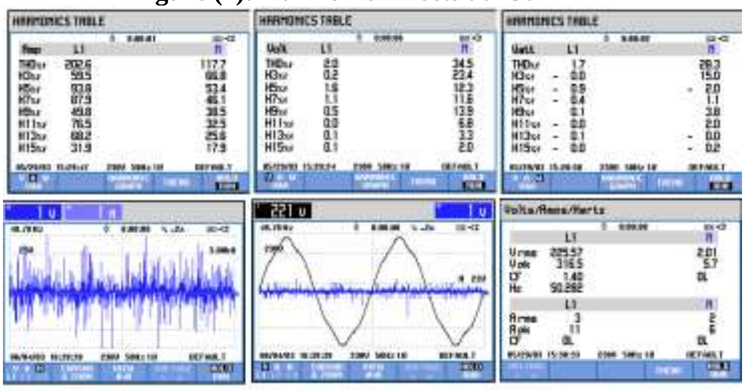

Figure (5): Harmonic Effects at 250Hz

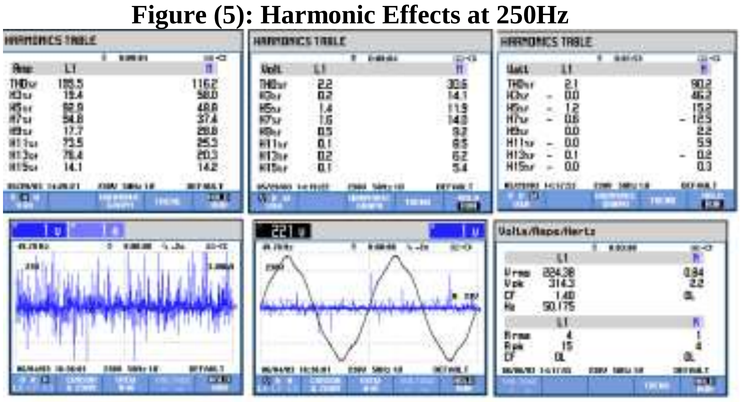

Figure (6): Harmonic Effects at 350Hz

Total Harmonics Distortion and K-Factor

The THD and K-factor can also be extracted by using the power quality analyzer (Fluke-435B). The next three figures (1.e. figure (7), (8) and (9)) show the amplitude of harmonics in neutral line for current waveform. From the first two figures the THD and K-factor decrease as the frequency of simulated harmonics increase. The THD decreases from 110.2% to 79.5%, while the K-factor decreases from 42.2 to 18.2 in figure (9), the THD increases relative to the corresponding value in figure (8), and this due to taking the reading in high harmonics existing in the lab during the testing time in addition to the injected harmonics by the variable frequency supplier (N700E). from figure (7) it can be seen that the amplitude of harmonics decreases as the frequency on x-axis increases. The amplitude of harmonics above 30% as the order of harmonics less than 13th. The amplitude of THD less than 20% as the harmonics order be above 17th.

Figures (10), (11) and (12) illustrate the harmonics effect in neutral line for voltage waveform. From these figures, the THD and K-factor decrease as the frequency increases from 150Hz to 350Hz. Also it is clear that the maximum amplitude of harmonics lie at the odd integer of the fundamental frequency. The THD percent in figure (10) has an amplitude above 20% when the order of harmonics below 31th. Note that the values of harmonics is very high in figure (10) for line voltage.

The last three figures (13), (14) and (15) present the THD for voltage waveform in neutral line. The THD decreases from 40.9% at 150Hz to 35.3% at 250Hz and then to 31.2% at 350Hz.

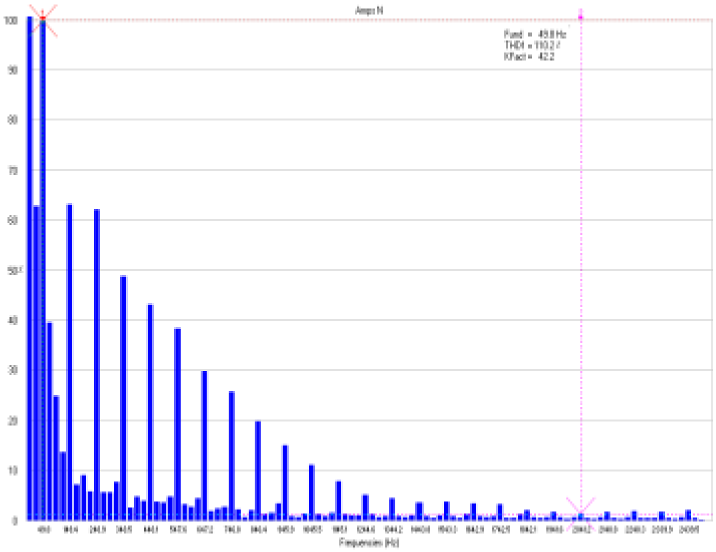

Figure (7): Amplitude of Harmonics at 150Hz (neutral line for current waveform)

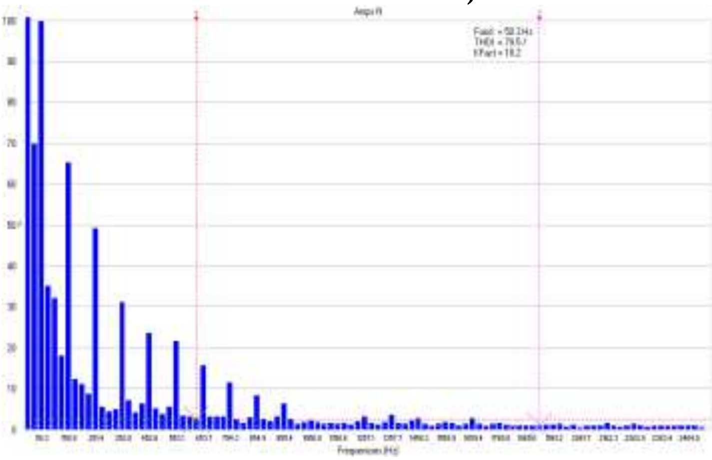

Figure (8): Amplitude of Harmonics at 250Hz (neutral line for current waveform)

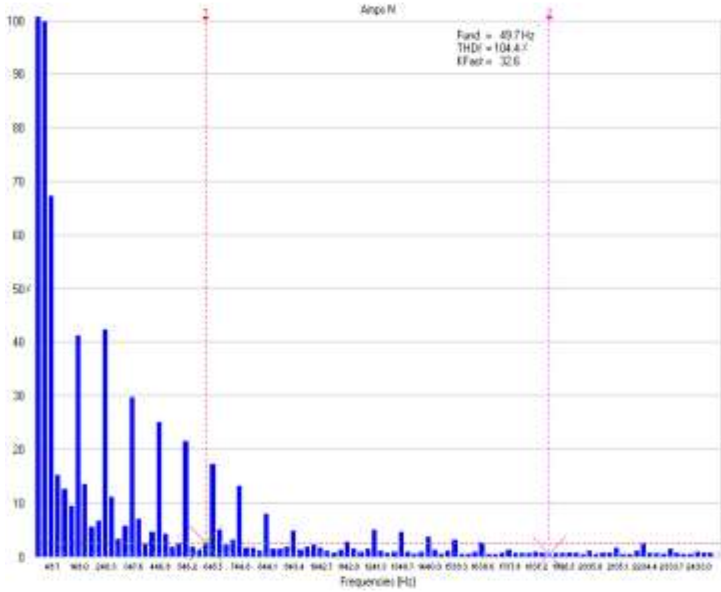

Figure (9): Amplitude of Harmonics at 350Hz (neutral line for current waveform)

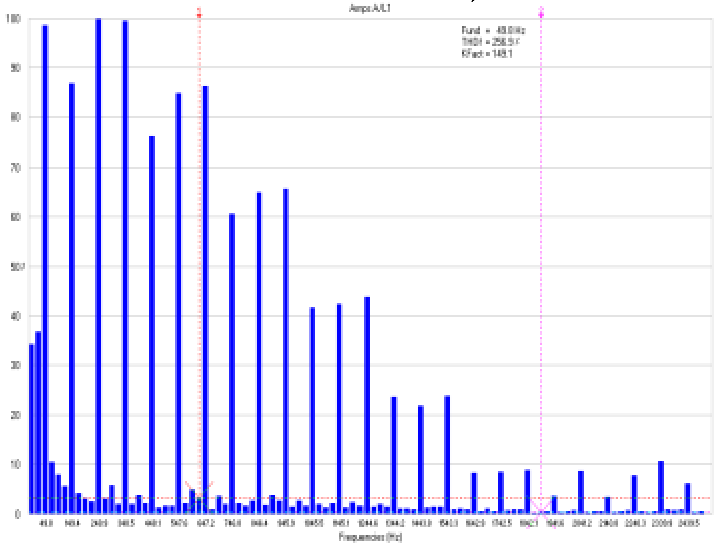

Figure (10): Amplitude of Harmonics at 150Hz (Line-harmonics for current waveform)

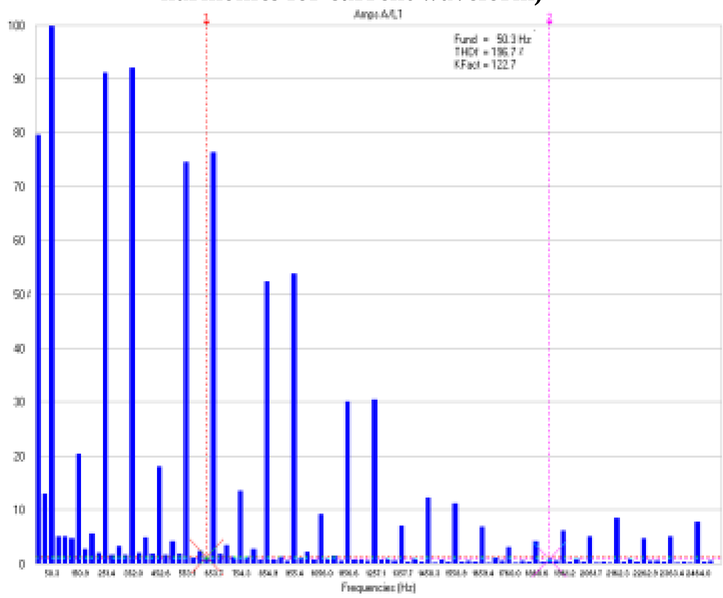

Figure (11): Amplitude of Harmonics at 250Hz (Line-harmonics for current waveform)

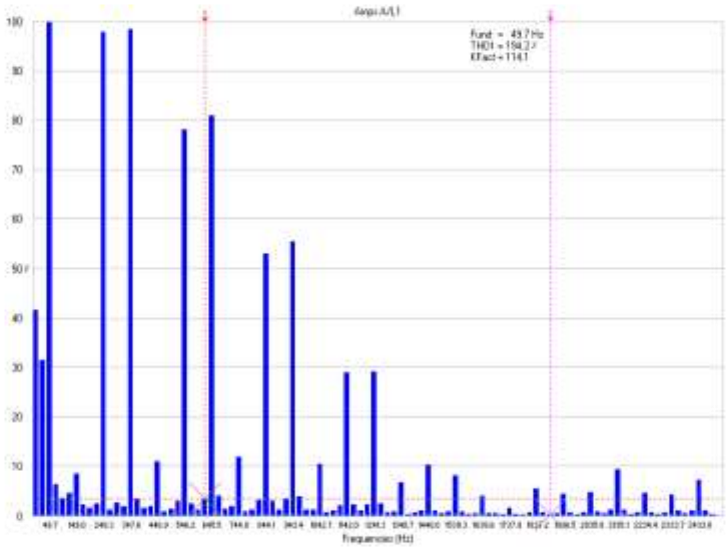

Figure (12): Amplitude of Harmonics at 350Hz (Line-harmonics for current waveform)

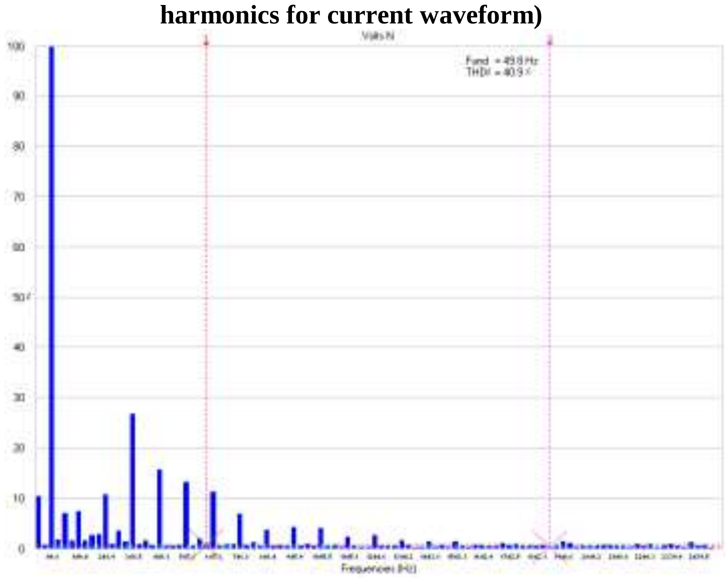

Figure (13): Amplitude of Harmonics at 150Hz (Neutral Line harmonics, volt)

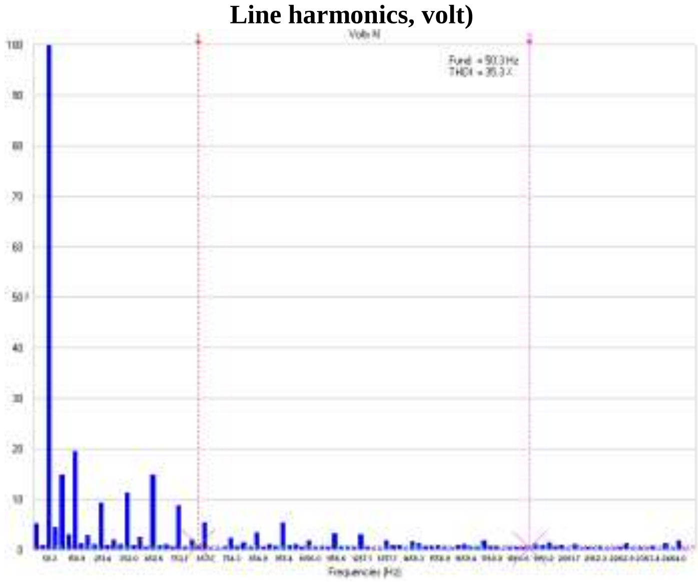

Figure (14): Amplitude of Harmonics at 250Hz (Neutral Line harmonics, volt)

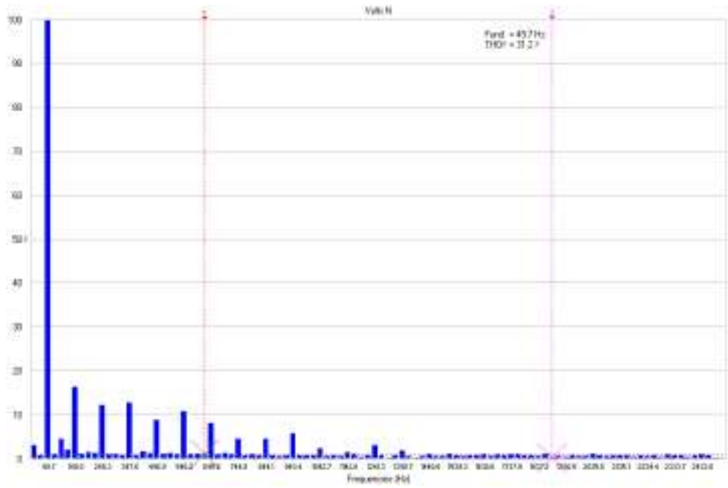

Figure (15): Amplitude of Harmonics at 350Hz (Neutral Line harmonics, volt)

Conclusions

The distortion of current and voltage waveform created by non-linear loads can cause many problems in an electrical distribution system. The harmonics signals at 3^{rd}, 5^{th}, and 7^{th} order are simulated via variable frequency supplier (N700E) by injecting the harmonics frequency on the load, which is a 1KVA transformer. The results show that the harmonics has high effect on the current and voltage waveform. The maximum harmonics percentage occurs at 3^{rd} order and decreases at high orders. The crest factor and K-factors decreases as the harmonics order increases.

Acknowledgments

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References

[1] Asaad A. Elmoudi, "Evaluation of Power System Harmonic Effects on Transformers", Doctoral Dissertation, Helsinki University of Technology, Department of Electrical and Communications Engineering, Power Systems and High Voltage Engineering, (2006).

[2] International Copper Association, Ltd and Codelco Services Ltd, "Harmonics, Transformers and K-Factors", CDA Publication 144, September (2000).

[3] I. Daut, H.S. Syafruddin, Rosnazri Ali, M. Samila and H. Haziah, "The Effects of Harmonic Components on Transformer Losses of Sinusoidal Source Supplying Non-Linear Loads", American Journal of Applied Sciences vol.3, issue 12, pp. 2131-2133, (2006).

[4] Hooman Erfanian Mazin, Wilsun Xu, "Harmonic cancellation characteristics of specially connected transformers", Electric Power Systems Research, Volume 79, Issue 12, pp. 1689–1697, December (2009).

[5] Kaili Xu, Kala Meah, A.H.M. Sadrul Ula, " A novel method for reducing harmonics in series-connected rectifiers", Electric Power Systems Research, Volume 78, Issue 7, pp. 1256–1264, July (2008).

[6] H. García, M. Madrigal, J.J. Rico, " The use of companion harmonic circuit models for transient analysis and periodic steady state initialization in electrical networks with nonlinearities", Electric Power Systems Research, volume 93, pp. 46–53, December (2012).

[7] S.B. Sadati, A.Tahani, B.Daraishi, M. Dargahi and H.Yousefi, "Comparation of Distribution Transformer Losses and Capacity Under Linear and Harmonic Loads " , Proceeding

of IEEE 2nd International Power and Energy Conference, pp. 1265-1269, (2008)
[8] Jian Zheng "Transformer ac winding resistance and derating when supplying harmonic-rich current" M.Sc. Thesis in electrical engineering in Michigan Technological University (2000).