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Relationships between Harmonic Characteristics and Different Types of Voltage Source

Risnidar C[1,2*], I. Daut[3], Syafruddin H[1,2], Yusniati[4]
[1]Electrical Engineering Department, Universitas Sumatera Utara, Medan, Indonesia
F.T. USU, Kampus USU, Medan, Indonesia, Tel: +62 61 8213246, Fax: +62 6I 8213250
[2]Faculty of Electrical Engineering University Malaysia Perlis, (UniMAP), Kuala Perlis, Malaysia
02000 Kuala Perlis, Tel: +604-9791526 Fax: +604-9791431
[3]Faculty of Electrical Engineering University Malaysia Perlis, (UniMAP), Kuala Perlis, Malaysia
[4]Faculty of Engineering University of Islam Sumatera Utara, Medan, Indonesia
E-mail: risnidar@unimap.edu.my*, ismail.daut@unimap.edu.my, yusniati_27@ymail.com

Abstrak

Makalah ini mendiskusikan tentang karakteristik harmonik yang disebabkan oleh perbedaan tipe dari sumber tegangan. Sumber tegangan ideal adalah sinusoidal, namun dalam kondisi yang sebenarnya beban menerima sumber tegangan melalui elemen-elemen yang mengeluarkan tegangan tidak murni sinusoidal dan tegangan ini menjadi tegangan masukan ke beban. Sebagai contoh kasus adalah sumber tegangan pada titik hubung bersama (PCC) antara transformator dan beban linier dan non linier. Riset ini dilakukan mempergunakan alat Schhafner Power Quality Analyzer dan PM300 Power Quality Analyzer yang difokuskan untuk mengetahui semua karakteristik yang terkait dengan harmonik seperti daya, tegangan, arus, factor kerja (f.k), pergeseran harmonik, dan biaya rugi-rugi harmonik. Beban dalam riset ini adalah motor induksi dengan penggerak kecepatan yang bisa diatur (adjustable speed drive), beban ini dipilih karena merupakan salah satu dari beberapa alat elektronik yang menghasilkan harmonik. Sumber-sumber tegangan yang dipakai pada riset ini adalah: gelombang sinusoidal, gelombang segiempat, dan gelombang yang merupakan kombinasi dari harmonik order 3, 5 dan 7 yang bisa dihasilkan dari Schhafner Power Quality Analyzer.

Kata kunci: *biaya rugi-rugi energi, faktor kerja,harmonik, tipe sumber tegangan*

Abstract

This paper discusses about harmonic characteristics due to different types of voltage sources. Ideal voltage source is sinusoid, unfortunately in actual condition load receives voltage sources from elements which produce the non sinusoidal output voltage, and consequently, the load has non pure sinusoid waveform as an input voltage. Voltage source at power of common coupling (PCC) between transformer and linear load and nonlinear load has become an example of the case. This research has been conducted by using Schhafner Power Quality Analyzer and PM300 Power Quality Analyzer, which was focused to figure out all characteristics related to harmonics such as power, voltage, current, power factor (p.f.), Harmonic Distortion, and harmonic energy losses cost. The selected load is induction motor with Adjustable Speed Drive (ASD) because this typical load is one of electronic device that causes harmonics. The voltage sources in this research are sine wave, square wave and harmonic order combinations of 3rd, 5th and 7th which can create from Schhafner Power Quality Analyzer.

Keywords: *harmonic characteristic, power factor, type of voltage source, total harmonic distortion*

1. Introduction

Generally, voltage sources used to serve the load is sine wave. The improvement of voltage source is to increase the quality of voltage sources and as a result the characteristics of harmonic will better. For example, methods of cascaded multilevel inverter (CMLI), can improve power quality and a new DC voltage progression where the progression based on sine quantization method (SQM), which improve the amplitude of CMLI output voltage, this paper proposes to determine a sequence of DC voltages from discrete amplitudes of sine wave function. The method also collaborates with step equal residual area method (SERAM) to minimized total harmonics distortions (THD) [1]. And a simple method for selecting the best conductive angle based on power factor of load in three phase six-switch inverters is proposed. Conductive angle from 120º to 180º, and power factor from 0 to 1 are changed for lead and lag

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loads. Then RMS and THD values of the output voltage are studied. Simulation results show that a special conductive angle for each specific power factor has to be used to improve the mentioned indices and applying conventional conductive angles 120º, 180º and 150º in some power factors increases THD and RMS of output voltage.decreases [2].This is a novel Fuzzy Logic Controller (FLC) in conjunction with Phase Locked Loop (PLL) based shunt active filter for Power Line Conditioners (PLCs) to improve the power quality in the distribution system. The active filter is implemented with current controlled Voltage Source Inverter (VSI) for compensating current harmonics and reactive power at the point of common coupling. The VSI gate control switching pulses are derived from proposed Adaptive-Fuzzy-Hysteresis Current Controller (HCC) and this method calculates the hysteresis bandwidth effectively using fuzzy logic [3]. All of this method used sine wave as voltage sources.

Because this research discusses the kinds of voltage sources used to serve the load, such as sine wave, square wave and the combination of the harmonics order, so it is necessary to discuss about Fourier series. To analyse the harmonics, application of the Fourier series is appropriate. Actually, Fourier series is a periodic function can be written as sums of infinitely many sine and cosine functions of different frequencies [1] R.J. Beerends et al (2003), often expressed in terms of the angular frequency. Harmonic waveform distortion is one of the most important issues today. This paper discusses about investigation of harmonic effects due to harmonic types of voltage source, where voltage sources are a few types of harmonic waveforms. The meaning of voltage source as harmonic 3rd, 5th and 7th combinations is voltage that is created by Schhafner Power Quality Analyser. With Fourier series [2-4] the function of (*t)* can be expressed as:

$$\begin{aligned} f(t) &= a_0 + \sum_{h=1}^{\infty}\left[a_h \cos(h\omega_0 t) + b_h \sin(\omega_0 t)\right] \\ &= a_0 + \sum_{h=1}^{\infty}\left[a_h \cos\left(\frac{2\pi h t}{T}\right) + b_h \sin\left(\frac{2\pi h t}{T}\right)\right] \end{aligned} \tag{1}$$

where:

$f(t)$ = periodic function
a_0 = DC component
h = harmonic order
a_h = coefficient of cosine in Fourier series
b_h = coefficient of sine in Fourier series
t = time in second
T = periodic in 1/f
f = frequency fundamental in 50/60 Hz
$\omega_0 = 2\pi / T$ = angular velocity in rad/sec

$$a_0 = \frac{1}{2\pi}\int_{-\pi}^{\pi} f(\omega t) d(\omega t) \tag{2}$$

$$a_h = \frac{1}{\pi}\int_{-\pi}^{\pi} f(\omega t)\cos(h\,\omega t) d(\omega t) \tag{3}$$

$$b_h = \frac{1}{\pi}\int_{-\pi}^{\pi} f(\omega t)\sin(h\,\omega t) d(\omega t) \tag{4}$$

So, the non sinusoidal voltage sources are the voltage sources from the Schhaffner Power Quality are:

Square wave:

$$V_s = V_{sq} = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{1}{h}\sin(h\pi t) \qquad h = k-1 \tag{5}$$

Harmonic 35:

$$V_s = V_{h35} = V_{max}\left[\sin(2\pi ft) + \sin(3x2\pi ft) + \sin(5x2\pi ft)\right] \tag{6}$$

Harmonic 37:

$$V_s = V_{h37} = V_{max}\left[\sin(2\pi ft) + \sin(3x2\pi ft) + \sin(7x2\pi ft)\right] \tag{7}$$

. This case is a part of the system, where if a Point of Common Coupling (PCC) of one compontent nonlinear load become voltage source to another nonlinear load. In this research, the load is Induction Motor with Adjustable Speed Drive (ASD) which is supplied with Sine waveform, Square wave and Harmonic 3rd, 5th, and 7th combination waveform. The presence of harmonic distortion in the applied voltage to a motor will both increase electrical losses and decrease efficiency. These losses will increase motor temperature, resulting in even further losses [5] These currents passing through the system impedance cause voltage drops for each individual harmonic, resulting in distortion of the voltage's waveform. The effect of harmonic distortion of the voltage waveform due to impacts motor performance as p.f. IHD and THD for current and voltage, and energy losses due to harmonic [6-8]. This research is focused on harmonics problem because attention to the quality of electrical power is very important to the issue of voltage distortion- a major form of which is harmonic distortion [9].

One of the main harmonic characteristics is power factor (p.f.). This is a measure of how effectively a specific load consumes electricity to produce work. The higher of power factor, the more work produced for a given voltage and current. The relationships vector between power and power factor to explain about power factor is shown in Figure 1.

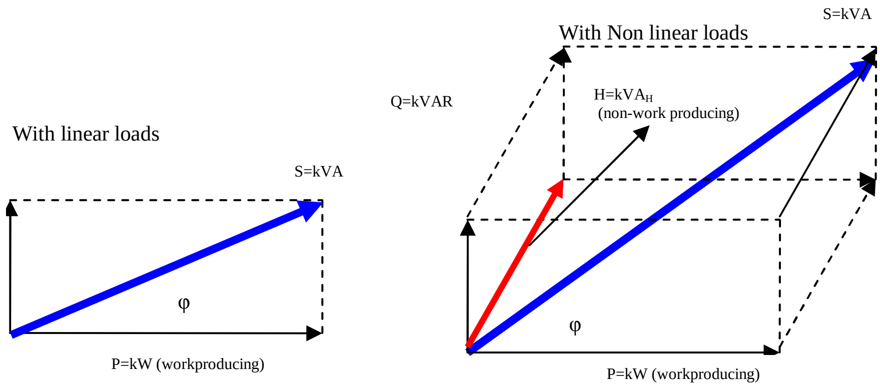

Figure 1. Power factor relationship for Linear and Non-Linear loads

From Figure 1, the relationships between power and power factor for Linear Loads and Non-Linear Loads are as follow:

a. Linear Loads

$$p.f. = \frac{P}{S} = \frac{kW}{kVA} = \cos\varphi \tag{8}$$

$$S = \sqrt{P^2 + Q^2} \tag{9}$$

$$kVA = \sqrt{kW^2 + kVAR^2} \tag{10}$$

b. Non-Linear Loads

$$p.f. = \frac{P}{S} = \frac{kW}{kVA} = \cos\varphi \tag{11}$$

$$S = \sqrt{P^2 + Q^2} \tag{12}$$

$$kVA = \sqrt{kW^2 + kVAR^2 + kVAR_H^2} \tag{13}$$

True power factor = (Displacement p.f) x (Distortion p.f.)

The others characteristic of harmonic are: The values of V_{rms} $I_{rms,}$ Power (P), were calculated directly from the harmonic components obtained with a Fast Fourier Transform of the sampled data of the voltage and current waveforms of the Induction Motor under tests. These quantities were calculated as:[5][6][7][9][10]

$$V_{rms} = \sqrt{\sum_{h=1}^{\infty} V_h^2} \text{ and } I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_h^2} \tag{14}$$

$$P = \sum_{h=1}^{\infty} V_h I_h \cos\varphi_h \text{ and } S = V_{rms} I_{rms} \tag{15}$$

where V_h, I_h φ_h are magnitudes and phase shift of the voltage and current, *h* order harmonic.

The factor that measures the distortion in the non sinusoidal wave is Total Harmonic Distortion (THD) where this factor is defined for both voltage and current as below:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \text{ and } THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{16}$$

2. Research Method

From the measurement of Induction Motor with Shaffner [10], where the voltage source to load is variable, the models are: sinusoidal, square and a few harmonics waveforms. And the load is a three phase induction motor. These experiments are done, because to investigated the effect of voltage source types of harmonic to serve load, because at any PCC in power system, the load maybe find the source not pure sinusoidal, for example from secondary of transformer.

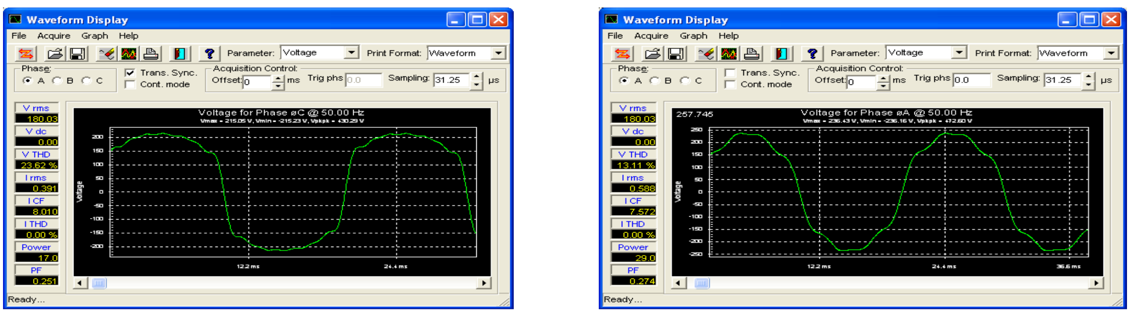

Figure 2. Type of voltage source from 3rd, 5th and 7th harmonic order combinations

The main characteristic of harmonics are Individual Harmonic Distortion (IHD) for 3rd ,5th and 7th, Total Harmonic Distortion (THD) for voltage and current, Power losses due to harmonics, power factor, Cress factor for each harmonics, I_{rms}, V_{rms}. The measurements are done with voltage sources variable from 160 V until 240 V. The types of voltage source from the combination of harmonic order 3rd, 5th and 7th as Figure 2.

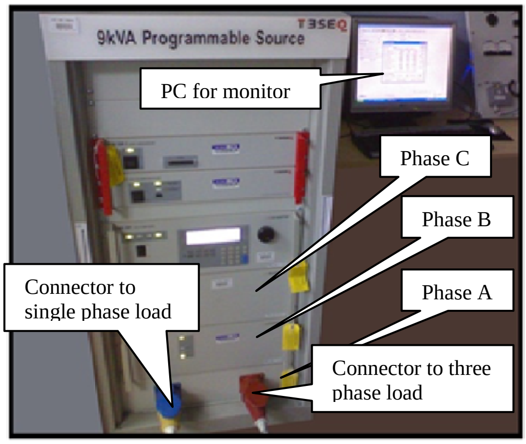

Figure 3.Power quality schaffner eqiupment

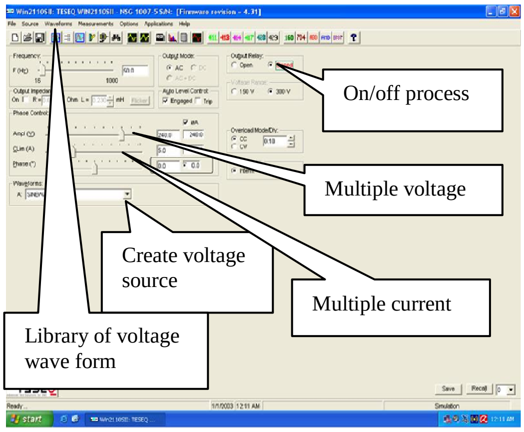

Figure 4. Create process of voltage sources

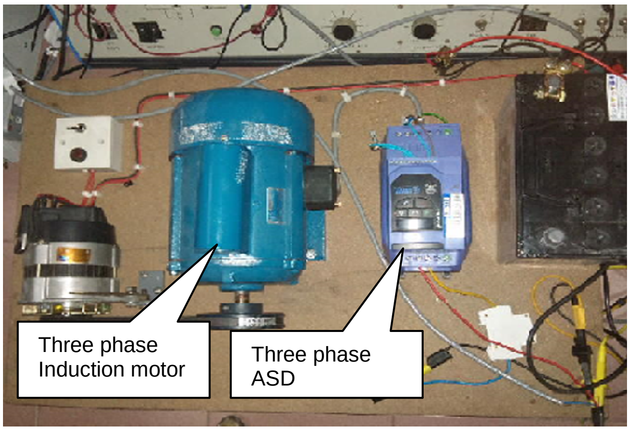

Figure 5. Induction motor measurement

The Induction motor specifications are: 3 phase, 1.5 Hp, 50 Hz, 1370 rpm, 4 poles. The measurements have been done with ASD. In this research, the main characteristics of the induction motor were measured related to harmonic due to variable voltage source.

3. Results and Discussion

In this experiment, the analysis is focused of influence the voltage source type on harmonic characteristics as follow:

3.1. 3rd harmonic voltage

The 3rd harmonic with voltage square waveform is the largest voltage (about 33.432%), because for this waveform the distortion is high where the smallest distortion is sinusoidal waveform (about 0.126%), because this waveform is a fundamental waveform. Hence, for harmonic waveform source, the harmonic 313 is large (about 20.114%) harmonic 357 (about 10.036%) is small. All of these due to harmonic 5th are dominant.

3.2. 5th harmonic voltage

The 5th harmonic with voltage square waveform is the largest voltage (19.912%), because for this waveform the distortion is high. And the small distortion is sinusoidal waveform (0.024%), because this waveform is a fundamental waveform. For harmonic waveform source, the harmonic 313 (10.038%) is larger than harmonic 357 (7.02%) due to harmonic 3rd that dominant.

3.3. 7th harmonic voltage

The 7th harmonic with voltage square waveform is the largest voltage (13.964%), because the distortion of this waveform is high. And the small distortion is sinusoidal waveform (0.008%), because this waveform is a fundamental waveform. For harmonic waveform source, the harmonic 357 (4.958%) is smaller than harmonic 313 (6.986%). These are due to the dominant distortion of harmonic 7th.

3.4. THD harmonics voltage

The voltage square vs THD voltage harmonic experiment showed that the THD_V with voltage square waveform has the largest distortion (about 41.192%), because for this waveform the distortion is high, and the smallest distortion is sinusoidal waveform (0.21%).

3.5. 3rd harmonic current

The 3rd harmonic current with voltage square waveform is largest (2.90%), because for this waveform the distortion is high. And the small distortion for harmonic waveform source is harmonic 357 (0.842%), and sinusoidal (0.17%) is smaller than 313 (1.804%)

3.6. 5th harmonic current

The 5th harmonic current with voltage square waveform is largest (43.726%), because for this waveform the distortion is high. And the small distortion for harmonic waveform source is harmonic 357 (15.836%) than harmonic 313 (22.494%) And sinusoidal (0.616%) is smallest as fundamental.

3.7. 7th harmonic current

The 7th harmonic current with voltage square waveform is largest (22.084%), because for this waveform the distortion is high. And the small distortion for harmonic waveform source is harmonic 357 (0.378%) than harmonic 313 (10.792%). And sinusoidal (0.378%) is smallest as fundamental.

3.8. THD harmonic current

THD_i with the sinusoidal waveform is small distortion (1.178%), because for this waveform it is as fundamental waveform. The voltage square waveform is largest (44.92%), because for this waveform the distortion is high. For harmonic waveform source, the harmonic 313 is largest (24.6%) and then the harmonic 357 (17.372%).

3.9. Current peak

The I_{peak} with voltage square waveform is largest (2.2226A), because for this waveform the distortion is high. And the small distortion is sinusoidal waveform (1.495A), because for this waveform it is as fundamental waveform. For harmonic waveform source, the harmonic 313 is largest (1.8464A) and then the harmonic 57 (1.827A), and harmonic 357 (1.722A).

3.10. Power factor (p.f.)

The power factor (p.f) with voltage square waveform is largest (0.32), because for this waveform the distortion is high. And then is sinusoidal waveform (0.316). For harmonic waveform source, the harmonic 313 is largest (0.306) and then the harmonic 357 (0.304).

3.11. Active power

The active power with voltage square waveform is largest (0.0388kW), because for this waveform the distortion is high. And then is sinusoidal waveform (0.0362kW). For harmonic waveform source, the harmonic 357 (0.0354kW) is bigger than harmonic 313 (0.0348kW).

3.12. Apparent power

The apparent power with voltage square waveform is smallest (0.1696kVA), because for this waveform the distortion is high. And the sinusoidal waveform is (0.1816kVA). For harmonic waveform source, the harmonic 357 (0.1802kVA) and then the harmonic 313 (0.1754kVA) is the smallest.

3.13. Cress Factor (C.F.)

The C.F. with sine wave, is constant (1.528), while for harmonic 313 (1.894) is higher then harmonic 357 and square wave is highest (2.292). The harmonics and square wave are increase proportional with voltage source.

Table 1. Type of voltage source Vs, power active, Apparent Power, p.f

V_{source} A	P(kW)	S(kVA)	p.f.	C.F.
Harm 313	0.0348	0.1754	0.306	1.894
Harm 357	0.0354	0.1802	0.304	1.73
Sine	0.0362	0.1816	0.316	1.528
Square	0.0366	0.1696	0.32	2.292

Tabel 2. Type of voltage source Vs IHD and THD voltage

V_{source} A	3^{rd}V	5^{th}V	7^{th}V	THDv
Harm 313	20.114	10.038	6.986	23.618
Harm 357	10.036	7.02	4.958	13.096
Sine	0.126	0.024	0.008	0.21
Square	33.432	19.912	13.964	41.192

Table 3. Type of voltage source Vs IHD and THD current

V_{source} A	3^{rd}I	5^{th}I	7^{th}I	THDi
Harm 313	1.804	22.494	10.792	24.6
Harm 357	0.842	15.836	7.676	17.372
Sine	0.17	0.616	0.378	1.178
Square	2.9	43.726	22.084	44.92

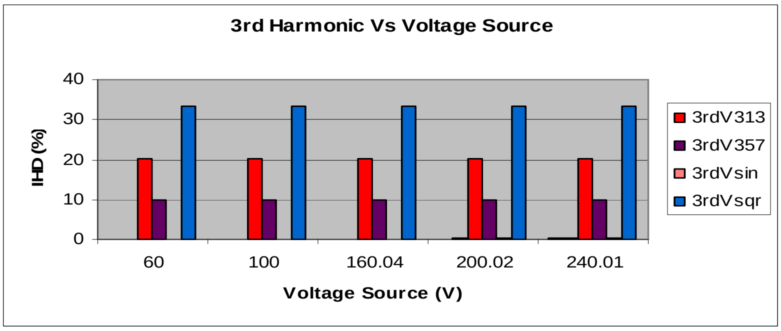

Figure 6. Voltage source vs 5^{th} harmonic voltage

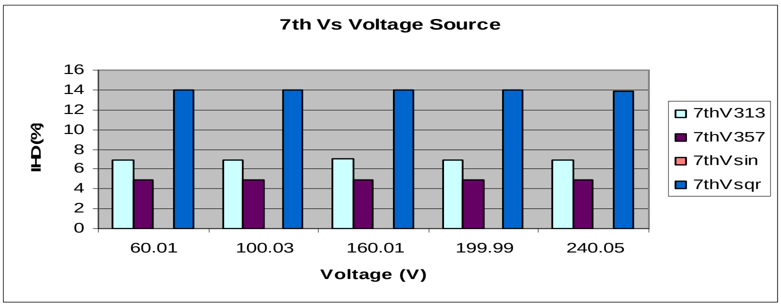

Figure 7. Voltage source vs 7^{th} harmonic voltage

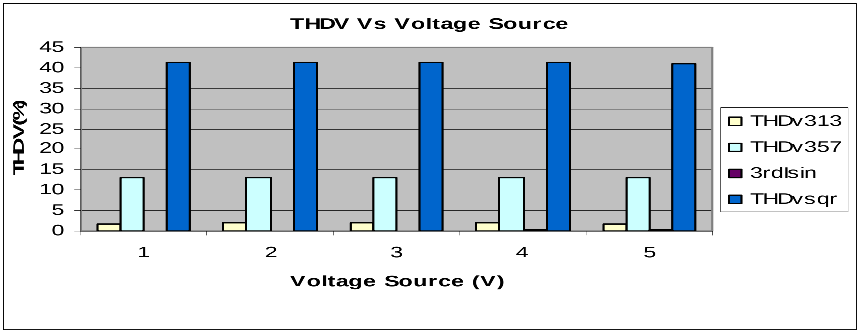

Figure 8. Voltage source vs thd voltage

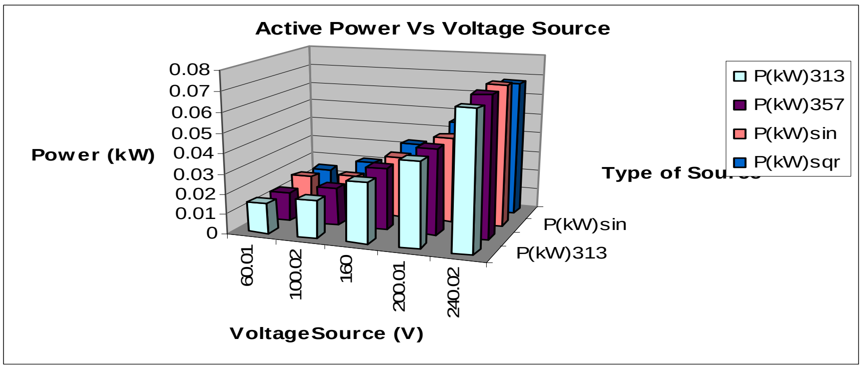

Figure 9. Voltage source vs active power

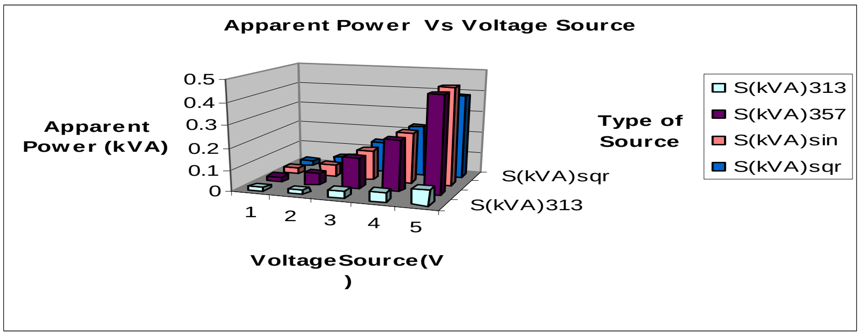

Figure 10. Voltage source vs apparent power

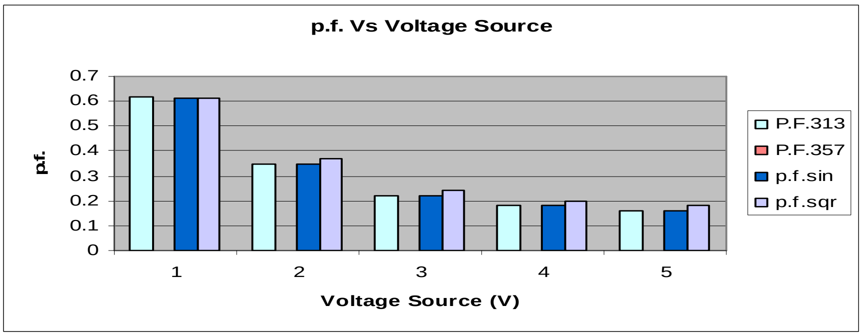

Figure 11. Voltage source vs power factor

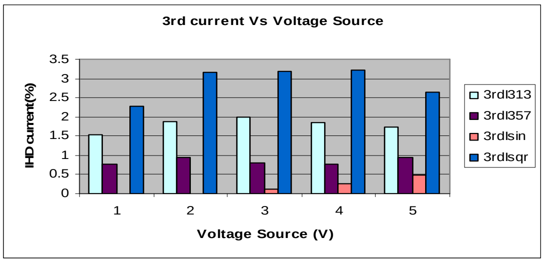

Figure 12. Voltage source vs 3rd harmonic current

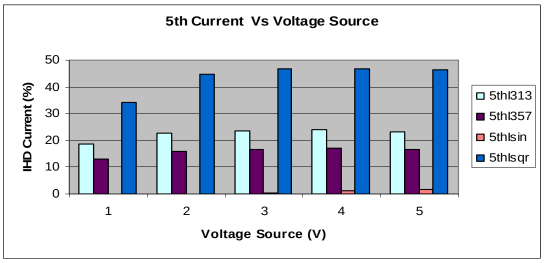

Figure 13. Voltage source vs 5th harmonic current

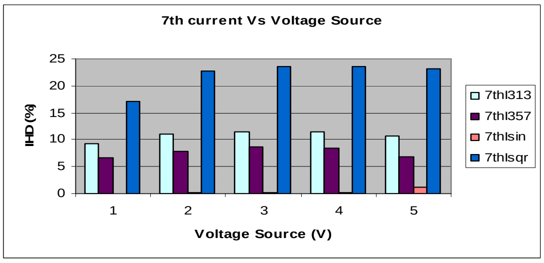

Figure 14. Voltage source vs 7th harmonic current

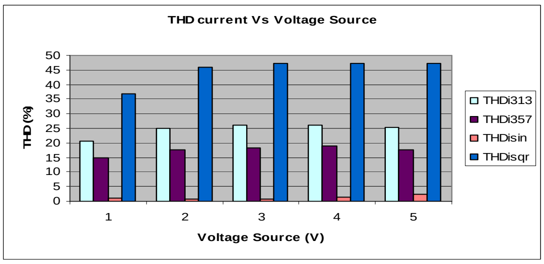

Figure 15. Voltage source vs THD harmonic current

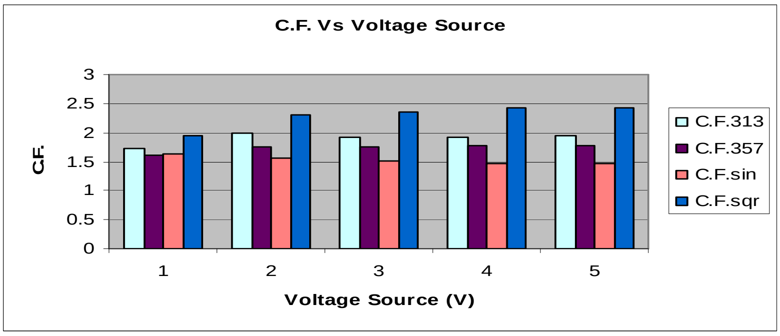

Figure 16. Voltage source Vs crest factor

4. Conclusion

From analysis we can conclude that sinusoidal waveform is better than square waveform to harmonic effect; because the square waveform was have distortion from sinusoidal waveform. Crest Factor for sine wave is constant for variety voltage, while for square wave is proportional with voltage value. Distortion due to square wave is larger than sine wave. Voltage source due to combination of harmonic 357 is better than harmonic 313 because almost all the harmonic characteristics such as p.f., THD, IHD, active power, apparent power is better than the harmonic 313. Voltage source due to combination of harmonics is better than square wave. Real power due to various voltages is highest for square wave, but for apparent power is smallest.

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