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Simulation of Effect of Capacitor on Power Distribution System Harmonics with One Nonlinear Load

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Abstract

Distortion of waveform of voltage and current harmonics, caused by nonlinear loads, is one of main problem in power quality in industrial power system. There are many effects caused by power system harmonics. Aims of this research are to obtain voltage and current harmonics and frequency scan in every bus; as an effect by using of nonlinear loads before and after installing of capacitor. Harmonics voltage and current are reduced after installation of C. This research using software Matlab in m-file.

Keywords: Harmonics distrortion, non linear loads, distribution network.

I. INTRODUCTION

Quality of electric power in power system can be classified in two categories, there are quality in transient and steady state condition. Quality in transient situation is observed according to the duration of disturbance and it can be categorized in three group. The first is the fast transient such as switching-surge, spike (0.5 to 200 microsecond with frequency 0.2 kHz to 5kHz), pulse, and notch. The second is over voltage which more than 110% of nominal voltage, or under voltage which it is below of 80% – 85% of nominal voltage, that occurs continuously in 80 millisecond to one second. These disturbance usually called as voltage dip such as voltage sag, depression, interruption, flicker, and fluctuation. The third is blackout or outage.

Quality in steady state condition has continue property such as variation of voltage, variation of frequency, phase unbalance and harmonics [1,12].

Numerical analysis and simulations of harmonics are used to quantify the distortion in voltage and current waveforms on a power system distribution network in order to determine the existence and mitigation of resonant conditions.

Ribeiro, and Arillaga, et all [2,3] proposed the models of power system devices for calculating the harmonics propagation caused by a nonlinear loads.

Stavros, et all [4] shown the harmonics power flow caused by wind turbine. They use different devices models with Ribeiro's [3]. This work combine the both models.

II. GENERAL THEORY

2.1. Harmonics

Harmonics, in power system engineering, can be defined as a sinusoidal component of a periodic signals (complex waveform) have an integer multiplication of the fundamental power line frequency. One commonly used as index in harmonics problem is total harmonics distortion (THD). THD is affected by effective value of all its components as can be formulated as:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} X_h^2}}{X_1} * 100\% \qquad (1)$$

where X_1 is root mean square or effective value of the sinusoidal component. X_1 can be as a voltage (VTHD) or current (ITHD).

Generally harmonics in power system caused by non-linear loads used solid state equipment devices, and magnetic circuits. For example electronic ballast lamp, computers (power supplies), PC, mainframe, servers, monitors, video displays, Copiers, scanners, facsimile machines, printers, plotters, lighting controls, dimmers, Electronic ballast, UPS systems, battery chargers, storage systems, etc [5,6].

According to characteristics of solid state power conversion equipment, the harmonics currents will be injected into power system. The harmonics current, through harmonics impedance, will affects the sinusoidal form of fundamental waveform. This condition will disturb the equipments installed on the system that designed to be operated on sinusoidal waveform. This causes [5,6]:

- reduction of measurement accurateness of induction kWh-meter,
- additional heating on equipments and failure of isolation either reduce the lifetime of equipments,
- losses on electrical machine will be increased and malfunction on electronics equipments, computer systems, and control system,
- induction motor will *cogging* experienced,
- protection devices will failure in operation,
- overheating of neutral conductors, bus bar, lug connections, mercury vapor and fluorescent lighting (electronic ballast), motor control and switchgear, which may affect current interrupting capabilities,
- circuit breaker nuisance tripping, improper function of on-board breaker electronics, excessive arcing, improper fuse operation or nuisance blown fuse interruption (artificial heating, or "skin effect"),
- AC motor torque pulsation, voltage sags, notching; DC adjustable, speed drives creating high inrush currents,

- overheating in transformers and cable systems, insulation (dielectric) breakdown,
- power factor capacitors becoming overloaded, blown fuse, case swelling, insulation failure from excessive peak voltages, overheating due to high RMS currents,
- effective use of power factor capacitors minimized, increasing costs, potential for resonance conditions,
- meter, protective relaying, control and other communication and measurement-instrumentation devices (including ground fault detection and digital displays) malfunctioning or providing a faulty reading, missoperation of electronic components and other equipment,
- communications (telephone, data, video) susceptible to noise, interference in motor controls, control systems, signal distortion.

2.2. Harmonics Limitation

Harmonics voltage distortion has been regulated on IEEE 519-1992 as follows.

Table 1. IEEE Standard 519-1992 for Voltage Distortion Limits [7]

Bus Voltage at PCC	Individual Voltage Distortion (%)	VTHD (%)
< 69 kV	3.0	5.0
69.0001 kV - 161 kV	1.5	2.5
> 161.001 kV	1.0	1.5

2.3. Harmonics Propagation

Harmonics propagation at frequency $f_h = h.f_1$ is based on the solution of the set of linear equations:

$$[I_h] = [Y_h][V_h] \tag{2}$$

where [I_h] is the vector of the nodal harmonics current injections of each bus, [V_h] the vector of the resulting harmonics voltages and [Y_h] the network admittance matrix at frequency f_h.

In practice of standard power system analysis, the admittance matrix of the network [Y_h] is formulated by using the characteristic equations of all network elements such as lines, transformers rotating machines etc, as will be discussed on the next sub-part.

[Z_h] can be obtained by inverting the [Y_h]. It is important to seek the harmonics self impedance of the respective buses**,** i.e. the diagonal elements of [Z_h], that is [$Z_{h,ii}$]. The non-diagonal elements $Z_{h,ij}$ are *transfer impedances,* related to the effect on the voltage of bus ***i*** when a harmonics current is injected at bus *j*. *Frequency scan* can be calculated from [Z_h] for varying frequencies $f_h = h.f_1$ which reveals possible *harmonic resonance conditions* of self or transfer impedances.

2.4. Modeling of Distribution System and its component

For correctly assessing the magnitude of harmonics in power system, it is important to model all of system component.

Load Model

There are three alternative load models for harmonics analysis. Where in all cases, R_1 and X_1 are the fundamental frequency resistance and reactance, related to the nominal power of the load, where *h* is harmonics order (Stavros A. Papathanassiou & Michael P. Papadopoulos).

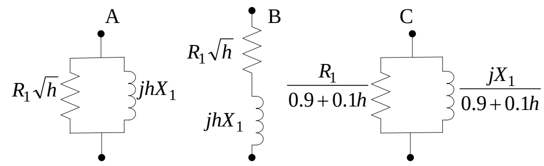

Figure 1. Alternative harmonic models considered for the system load [4].

Transformer Model

According to the reference in [3] it is not important to include capacitance of the transformer. It is caused by that the capacitance of transformer will affect the system on harmonics frequency on 10 kHz. Whereas in practically, the order of harmonics in power system is usually about 100 only. Transformer impedance is equivalent with the *leakage reactance* that linearly with the frequency [8,9].

The equations (3) to (7) can be used to calculate harmonics impedance of transformer.

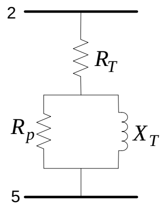

Figure 2. Transformer model [4].

$$Z_T = R_T + X_T \tag{3}$$

$$R_S = R_T \tag{4}$$

$$X_p = hX_T \tag{5}$$

$$R_p = 80R_T \tag{6}$$

$$Z_T h_{(25)} = R_1 + \frac{h^2 X_T^2 R_p}{R_p^2 + h^2 X_T^2} + j\frac{hX_T R_p^2}{R_p^2 + h^2 X_T^2} \tag{7}$$

Distribution Line Model [2]

Distribution line is represented in equivalent circuit exact *pi*. Correction factor for *skin effect* applied by replaced the value of line resistance with:

$$R = R\left(1+\frac{0.646h^2}{192+0.518h^2}\right) \tag{8}$$

Non-linear Loads [2]

Generally, the harmonic in power system analysis is caused by nonlinear loads, such as fluorescent lamp, solid state power conversion equipment like ASD. The terms "linear" and "non-linear" define the relationship of current to the voltage waveform. A linear relationship exists between the voltage and current, which is typical of an across-the-line load. A non-linear load has a discontinuous current relationship that does not correspond to the applied voltage waveform [9].

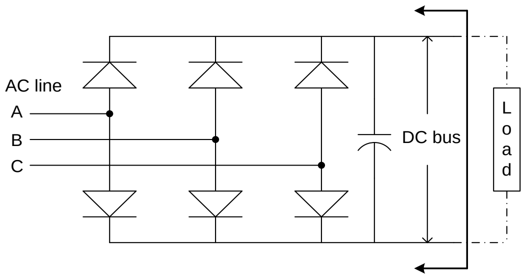

Figure 3. Typical Six-Pulse Front End Converter for AC Drive

Table 2. Current Harmonic Source Data (Product Data Bulletin).

Harmonic #	%	Relative Angle
1	100.00	0.00
5	18.24	-55.68
7	11.90	-84.11
11	5.73	-143.56
13	4.01	-175.58
17	1.93	111.39
19	1.39	68.30
23	0.94	-24.61
25	0.86	-67.64
29	0.71	-145.46
31	0.62	176.83
35	0.44	97.40
37	0.38	54.36

One example of nonlinear loads is ASD. The characteristics of harmonics on it are based on the number of rectifiers (pulse number) used in a circuit and can be determined by the following equation:

$$h = (n \times p) \pm 1 \tag{9}$$

where: n = an integer (1, 2, 3, 4, 5 …)

p = number of pulses or rectifiers

For example, using a 6 pulse rectifier, the characteristic harmonics will be:

h = (1 x 6) ± 1 $\Rightarrow$ 5th & 7th harmonics

h = (2 x 6) ± 1 $\Rightarrow$ 11th & 13th harmonics

h = (3 x 6) ± 1 $\Rightarrow$ 17th & 19th harmonics

h = (4 x 6) ± 1 $\Rightarrow$ 23rd & 25th harmonics

Spectrum of harmonics current caused by six pulse ASD is described on Figure 4, where its ITHD is 23.06%.

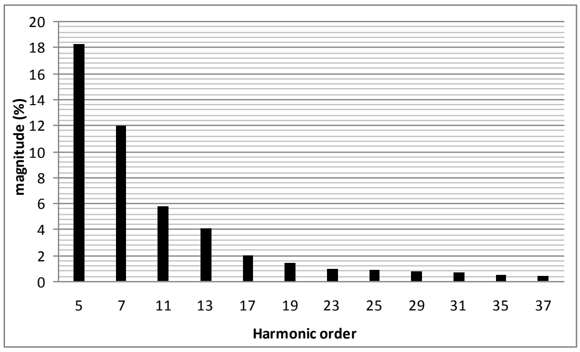

Figure 4. Spectrum of harmonic current caused by 6- Pulse ASD [9].

Signal of harmonics current caused by six pulse ASD is plotted on Figure 5.

Admittance matrices of system [10,11] can be formed as

$$Y_h = \begin{bmatrix} Y_h(1,1) & Y_h(1,2) & \dots & Y_h(1,13) \\ Y_h(2,1) & Y_h(2,2) & \dots & Y_h(1,13) \\ \dots & \dots & \dots & \dots \\ Y_h(13,1) & Y_h(13,2) & \dots & Y_h(n,n) \end{bmatrix} \tag{10}$$

Impedance matrices of Equation (10) is:

$$Z_h = Y_h^{-1} \tag{11}$$

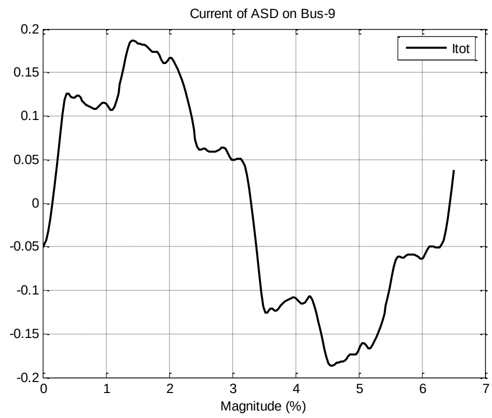

Figure 5. Waveform of harmonics current caused by 6- Pulse ASD

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*Furthermore, circuit on Figure 6 can be used to c*alculate the harmonics voltage, harmonics currents, VTHD, and ITHD in every bus. Formula for voltage harmonics calculation is as follows.

$$V_{bus-h} = hxZ_h(n,9)xI_{bus-h} \tag{12}$$

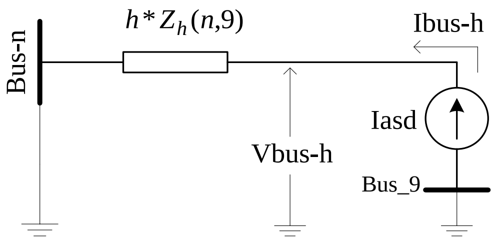

Figure 6. *Circuit for c*alculating the harmonics voltage, harmonics currents, VTHD, and ITHD [9].

The shunt power capacitors are not recommended to be applied in the presence of load-generated harmonics. These must be turned into harmonic filters after a careful study and applied at an appropriate location in the power system [14].

III. CASE STUDY

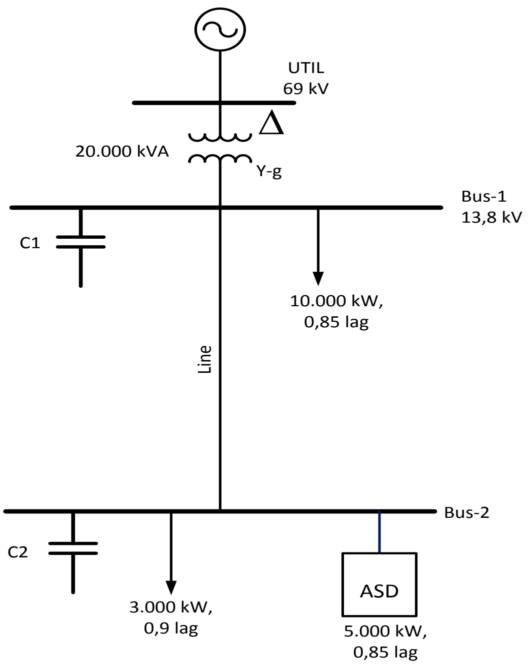

Figure 9. One line diagram of system will be researched [13]

This is the data from system made of Constantine Hatziadoniu [13,15]:

1. Utility: __________________________69 kV, infinite bus.

2. Transformer: ___________69kV/13.8kV-Y-g, 20,000 kVA, R=0.5%, X=8%.

3. Line: _________________________Short distribution line 3-phase with ground wire: Total positive sequence R= 0.02, Total positive sequence reactance X= 0.06.

4. Load on Bus-1: ________________10,000 kW, 0.85 lag pf. Of this load, 60% is motive.

5. Load on Bus-2: __________________3,000 kW, 0.9 lag pf. Largely residential and commercial.

6. Converter on Bus-2: ____3-phase line commutated rectifier, 5,000 kW, 0.85 lag pf.

The rectifier produces the full spectrum of its characteristic orders at their normal amplitude and phase. Non-characteristic harmonic orders are not produced.

7. Power factor correction capacitors at Bus-1 and Bus-2: _______________Provide full compensation of the bus loads.

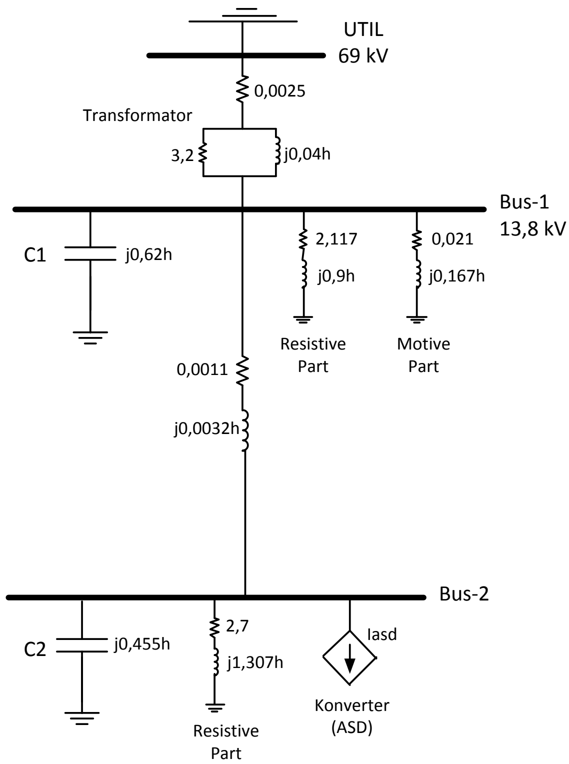

Figure 10. Impedance scan before installation of C

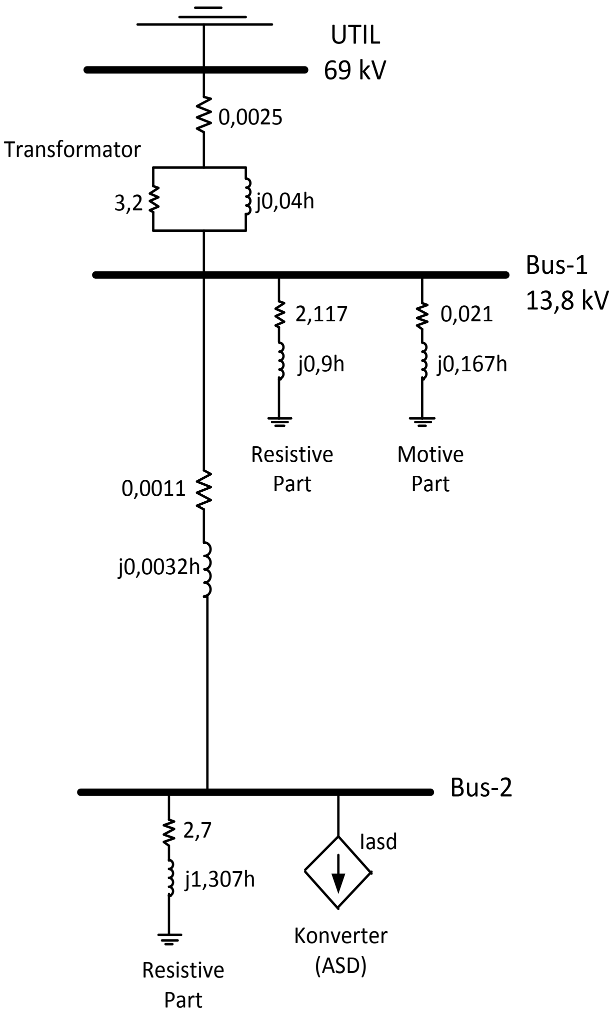

Figure 11. Impedance scan after installation of C

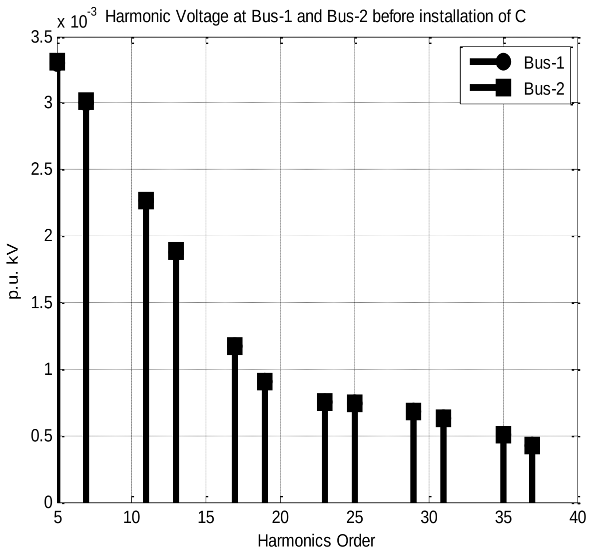

Figure 12

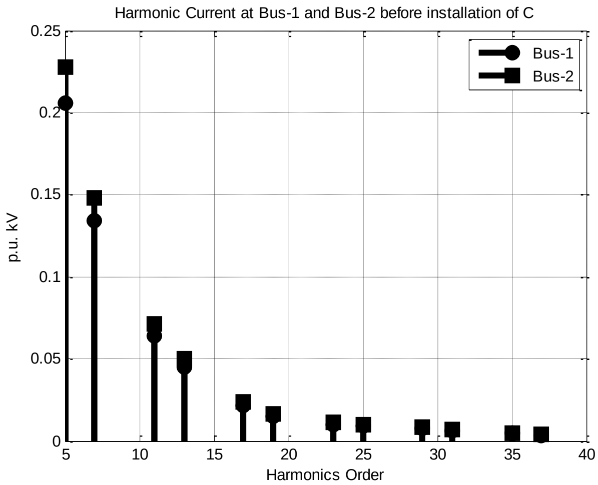

Figure 13

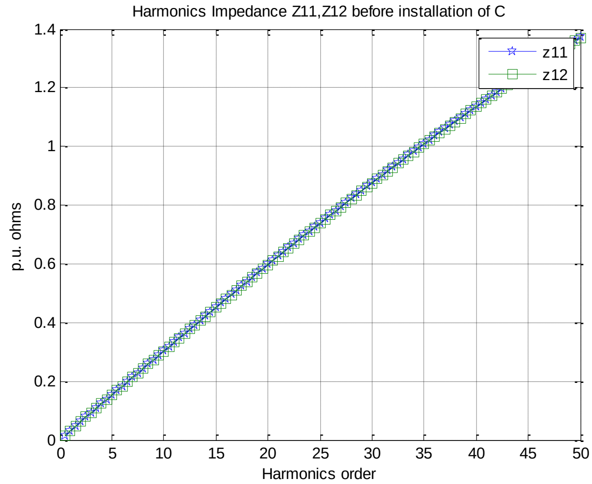

Figure 14

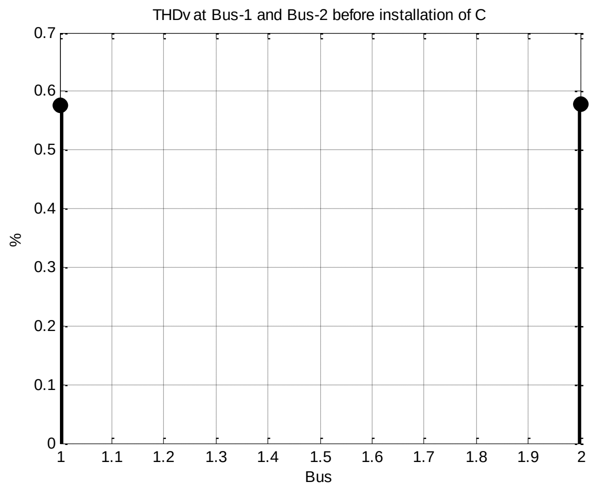

Figure 15

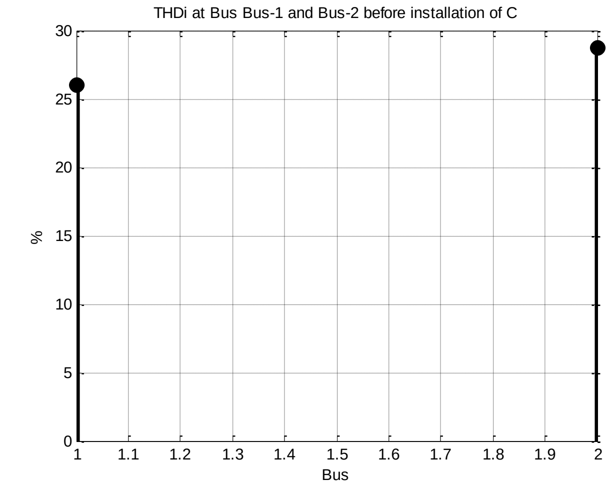

Figure 16

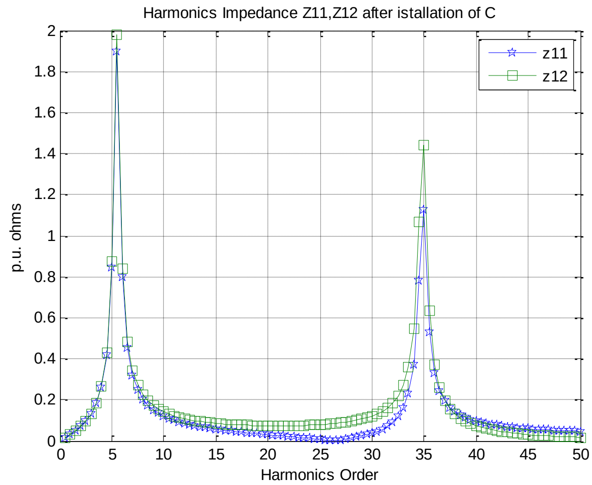

Figure 19

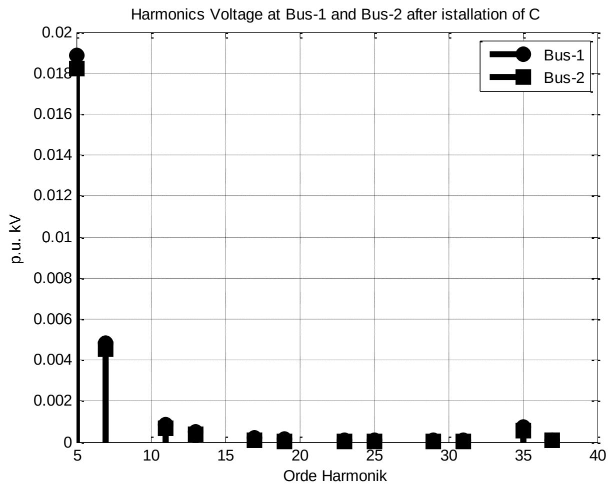

Figure 17

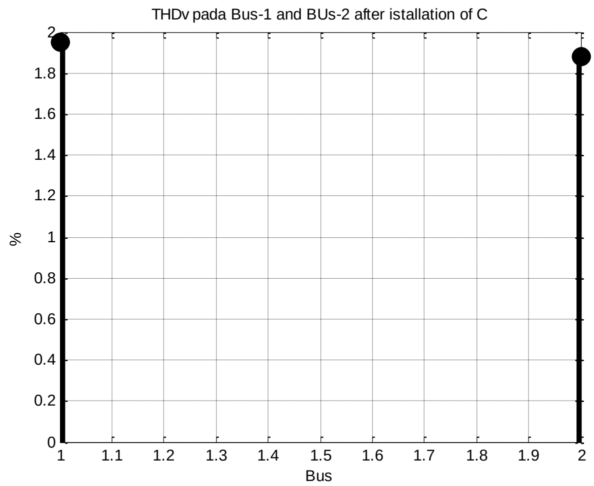

Figure 20

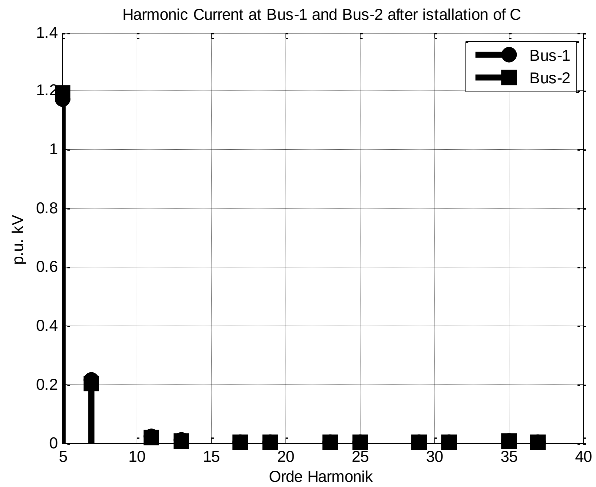

Figure 18

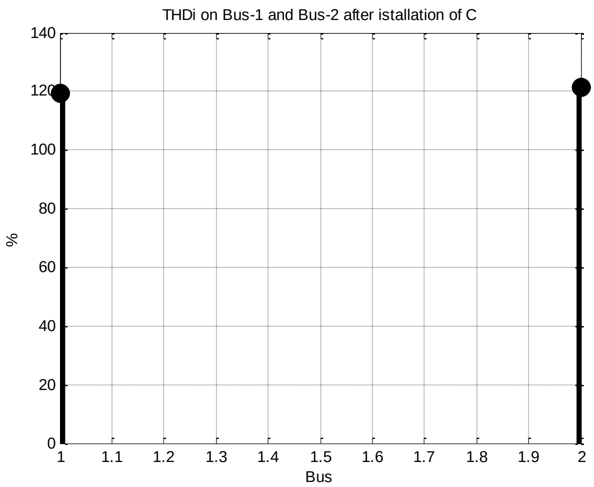

Figure 21

IV. CONCLUSIONS

Voltage harmonics are reduced after installation of C.

Also current harmonics are reduced after installation of C.

THDv before installation of C shows same in both bus.

THDi more high on Bus-2 than Bus-1 before installation of C.

REFERENCES

[1] Wagner, V.E., (*Chairman*), Balda, J.C., Barnes, T.M., Emannuel, A.E., Ferraro, R.J., Griffith, D.C., Hartmann, D.P, Horton, W.F., Jewell, W.T., McEachern, A., Phileggi, D.J., dan Reid, W.E., April 1993, "Effects of Harmonics on Equipment", *IEEE Transactions on Power Delivery*, 8(2), pp: 672 - 680.

[2] Arillaga, L., Bradley, D.A., dan Bodger, P.S., 1985, Power System Harmonics, John Wiley.

[3] Ribeiro, P.F., without year, "Distribution system and other elements modeling", BWX Technologies, Inc. Naval Nuclear Fuel Division, Lynchburg, VA.

[4] Stavros A. Papathanassiou & Michael P. Papadopoulos, Harmonic Analysis in a Power System with Wind Generation, National Technical University of Athens (NTUA), 9 Iroon Polytechnioust., 15780 Athens, Greece.

[5] Sankaran, P.E., October, 1995,"Effects of Harmonics on Power Systems-Part1", *EC & M*, pp: 33-42.

[6] http://ecmweb.com/mag/electric_effects_ harmonics_power_2/ : Effects of harmonics on power systems (28/04/2009)

[7] IEEE Standard 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

[8] R.C. Dugan, M.F. Granaghan, Surya Santoso, H.W. Beaty, Electrical Power System Quality, McGraw Hill, 2004.

[9] Product Data Bulletin, Power System Harmonics Causes and Effects of Variable Frequency Drives Relative to the IEEE 519-1992 Standard, Bulletin No. 8803PD9402, August, 1994, Raleigh, NC, U.S.A.

[10] Grainger, J.J., dan Stevenson W.D., 1994, Power Systems Analysis, McGraw-Hill Book Inc, New York.

[11] Gungor, B.,R., 1988, Power Systems, Harcourt Brace Jovanovich, Publishers, USA.

[12] Wardhani, April 1996, "Pengaruh Beban Industri pada Mutu Tenaga listrik", *PT. PLN (Persero) Distribusi Jawa Timur*, pp: 15 – 23.

[13] Constantine Hatziadoniu, "Step by step example of a siple harmonics study" with out year.

[14] J.C Das, "Power System Harmonics and Passive Filter Design", IEEE Press, 2015.

[15] http://grouper.ieee.org/groups/harmonic/simulate/