ISSN 2278-3091
International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 504– 509 (2014)
Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

SIMULATIONAND HARMONIC ANALYSIS OF DOMESTIC LOADS AND HARMONIC REDUCTION TECHNIQUES IN INDUSTRIAL DISTRIBUTION SYSTEM

RAMESH LAKAVATH[1] MALLELA.KISHORE[2]
[1]ASST PROFESSOR IN ELECTRICAL DEPARTMENT, VIDYA BHARATHI INSTITUTE OF TECHNOLOGY-PEMBARTHI,JANGAON, INDIA rameshwgl4@gmail.com
[2]ASST PROFESSOR IN ELECTRICAL DEPARTMENT, VIDYA BHARATHI INSTITUTE OF TECHNOLOGY-PEMBARTHI,JANGAON, INDIA mallela.kishore@gmail.com

Abstract: This paper is to study the harmonic distribution in a typical distribution system and suggest suitable harmonic compensation technique . Various domestic loads such as TV/CPU, computer, fluorescent lamp, CFL(Compact Fluorescent Lamp), fan, light dimmer, washing machine, water pump, refrigerator, air conditioner dish washer and small scale industry loads such as adjustable speed drive, arc welder and lift water pump are modelled in PSCAD/EMTDC. These models are then used for harmonic analysis of domestic and small scale industrial system. Voltage and current harmonics injected at point of common coupling (PCC) due to these nonlinear loads is tested for an individual house, village and a typical industry. Current and voltage harmonic analysis is performed. The harmonic distribution in found and THD(Total Harmonic Distortion) of voltage and current is found at all buses. Harmonic mitigation is performed by using single tuned, double tuned and reactance one-port filters. Also, use of shunt and series active filters is made for mitigating harmonics at PCC. Sensitivity analysis is then performed to analyse the effect on harmonic distribution and filter performance various load conditions

Keywords : power quality ,analysis of harmonics, Simulation of domestic loads, harmonic reduction in distribution system

INTRODUCTION

In an ideal ac power system, energy is supplied at specified voltage and constant frequency, magnitudes. However, this situation is difficult in practice. The undesirable deviation from a perfect sinusoidal waveform is generally expressed in terms of power quality. The power quality is an umbrella concept for many individual types of power system disturbances such as harmonic distortion, transients, voltage variations, voltage flicker, etc. Of al1 power line disturbances, harmonics are probably the most degenerative condition to power quality because of being a steady state condition. The Power quality problems resulting from harmonics have been getting more and more attention by researchers.

I. Power Quality Problems

The characteristics of the utility power supply can have a detrimental effect on the performance of industrial equipment. Harmonics produced by industrial equipment, such as rectifiers or ASDs, can have a detrimental effect on the reliability of the plant's electrical distribution system, the equipment it feeds, and on the utility system. The characteristics of the current and voltage produced by ASDs can cause motor problems. While power quality is basically voltage quality, it is not strictly a voltage issue. Since the supply system has a finite, rather than an infinite, strength, currents outside the direct control of the utility can adversely affect power quality. These are harmonic load currents, lightning currents, and fault currents. How do we quantify voltage aberrations indicative of power-quality problems? One must employ an accurate voltage-measuring device, such as an oscilloscope.

II. Voltage Distortion

Voltage distortion is the degree to which the voltage wave shape deviates from a sine wave. Distortion can result from the following

- Harmonics
- Inter harmonics
- Voltage notching
- Noise

II.1: Harmonics

Voltage distortion (Fig.a) is well understood; it is defined and thoroughly discussed in IEEE Standard 519. Nonlinear elements in power systems, such as, power electronic switches, saturated magnetic components, and arc furnaces, create current distortions. Harmonic currents flowing through system impedances create harmonic voltages.

II.2: Inter harmonics

These are frequency components of distorted voltages that are not integer multiples of the fundamental 60-Hz frequency (Fig.a). They can result from ASDs with insufficient dc-link filtering. With inadequate dc-link filtering, inverter harmonics that are multiples of a non-60-Hz fundamental pass into the power system, where they appear as non multiples of the 60-Hz fundamental. This phenomenon can also occur with cycloconverter-type ASDs that have no dc link and with arc furnaces that develop an infinite spectrum of parasitic frequencies.

II.3: Voltage Notching

Voltage notching is a periodic voltage disturbance resulting from the normal operation of power electronic devices, such as thyristors. Notching (Fig.a) is not normally a problem since it is controlled by circuit elements associated with the switching devices. It can be a significant problem on weak electric systems, where it can produce noise currents causing control system misoperation. Notching and ringing can cause extra zero crossings, resulting in equipment malfunction in some equipment.

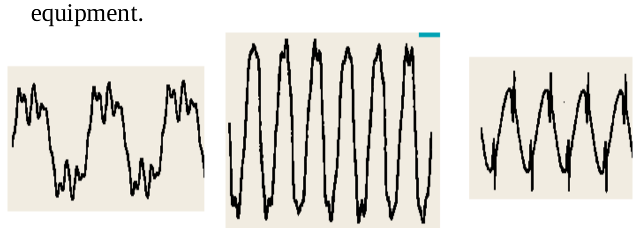


Fig a: Harmonic distortions, Inter harmonics, Notching

ISSN 2278-3091
International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 504– 509 (2014)
Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

II.4: Noise

Fast switching speed and high input impedance give insulated-gate bipolar transistor (IGBT) inverters the potential to produce stray currents resulting in electromagnetic interference (EMI). Stray currents can disrupt communications equipment, ASD control, programmable controllers, sensors, barcode scanners, and position sensing equipment. These common-mode noise currents are mainly conducted currents.. The magnitude of the stray currents is determined by the amount of phase-to-ground stray capacitance coupling available during the approximate 0.05-0.1-μs time period when the inverter voltage is transitioning to and from the dc-link voltage level.

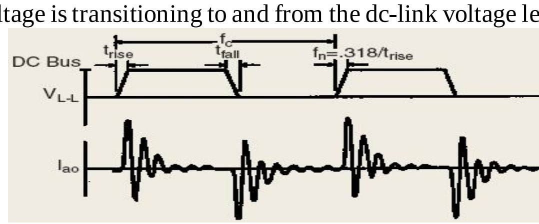


Figure b: Noise current

Harmonic contamination excites resonance in the tank circuit formed by line inductance and power factor correction shunt capacitors, which result in magnification of harmonic distortion levels.

III: Mitigation of power quality problem

The control or mitigation of the power quality problems may be realized through the use of harmonic filters. Harmonic filters, in general, are designed to reduce the effects of harmonic penetration in power systems and should be installed when it has been determined that the recommended harmonic content has been exceeded. Shunt passive filters have been widely used by electric utilities to minimize the harmonic distortion level. Filtering harmonics using passive filter is one of the earliest methods used to address harmonic mitigation issues. The problem of harmonics in distribution systems has been studied by using passive filters. They consist of passive energy storage elements (inductors and capacitors) arranged in such a way to provide a low impedance path to the ground just for the harmonic component(s) to be suppressed.

IV. HARMONICS

A harmonic is defined as a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Note that, for example, a component of frequency twice that of the fundamental frequency is called the second harmonic.

Thus, on a 60 Hz power system, a harmonic component, h, is a sinusoid having a frequency expressed by the following:h = n× 60 H z   Where n is an integer

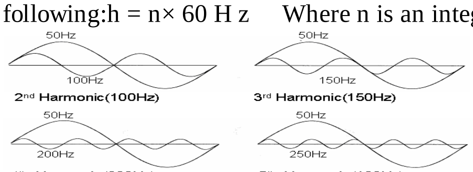


Figure.c: Harmonics

IV.1: Harmonic Analysis

(Fig.c) Illustrates one period of a distorted wave that has been resolved into its fundamental and two in-phase harmonic components (the third and fifth).

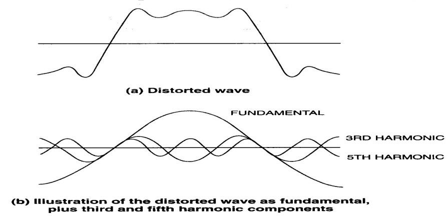


Figure.c: Decomposition of a distorted wave

IV.2: Harmonic Distortion Indices

The presence of harmonics in the system is measured in terms of harmonic content, which is defined as the ratio of the amplitude of each harmonic to the amplitude of the fundamental component of the supply system voltage or current. Harmonic distortion levels are described by the complete harmonic spectrum with magnitude and phase angle of each individual harmonic component. The most commonly used measure of the effective value of harmonic distortion is total harmonic distortion (THD) or distortion factor.. THD can be calculated for either voltage or current and can be defined as:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} M_h^2}}{M_1} \times 100\ \%$$

Where, M_l is the RMS value of the fundamental component and M_2 to M_n are the RMS values of the harmonic components of the quantity M. Another important distortion index is the individual harmonic distortion factor (DIF) for a certain harmonic h. HF is defined as the ratio of the RMS harmonic to the fundamental RMS value of the waveform,

$$HF = {M_h}/{M_1} \times 100\%$$

. The term the total demand at PCC distortion (TDD) is usually used which is the same as THD except that the distortion is expressed as a percentage of some rated load current rather than as a percentage of the fundamental current magnitude.

TDD is defined as:

$$TDD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L} \times 100\%$$

Where, I_h is the RMS magnitude of an individual harmonic current component, I_L is the maximum RMS demand load current and h is the harmonic order.

Bus Voltage at PCC	Individual Voltage Distortion (%)	THDV (%)
69 kV and below	3.0	5.0
69.001 kV - 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

Table.a: Harmonic voltage distortion limits (V_h) in % at PCC.

Table b. provides limits on every individual harmonic current component as well as limits on total demand distortion (TDD) for different voltage levels.

I_{sc} / I_L	h<11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	h ≥35	TDD
V ≤ 69kV						
20 <	4	2	1.5	0.6	0.3	5.0
20 – 50	7	3.5	2.5	1.0	0.5	8.0
50 – 100	10	4.5	4.0	1.5	0.7	12.0
100 – 1000	12	5.5	5.0	2.0	1.0	15.0
> 1000	15	7.0	6.0	2.5	1.4	20.0
69kV < V ≤ 161kV						
20 <	2.0	1.00	0.75	0.3	0.15	2.5
20 – 50	3.5	1.75	1.25	0.5	0.25	4.0
50 – 100	5.0	2.25	2.0	1.25	0.35	6.0
100 – 1000	6.0	2.75	2.5	1.0	0.50	7.5
> 1000	7.5	3.5	3.0	1.25	0.70	10.0
V > 161kV						
< 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.5	1.75	1.25	0.5	0.25	4.0

Table. b: Harmonic current distortion limits (I_h) in % of load current (I_L)

In balanced three-phase circuits where the currents are equal and in 120° relationship, the harmonics can be considered sequence components. The second harmonic has 240° (60 Hz base) between the phasers, the third 360°, etc.

Sequence		
Positive	Negative	Zero
1	2	3
4	5	6
7	8	9
10	11	12
13	14	15
16	17	18
Etc		

Table.c: Harmonic sequences in a balanced three-phase system

If the currents are not balanced, as in an arc furnace, each harmonic has its own set of sequence qualities. For example, the third harmonic, 180 Hz, will have its own set of sequence currents and the third-harmonic currents in each phase will not be additive in the neutral circuit.

IV.3: Fundamental and harmonic power

Power is the product of in phase current times the voltage, or

$$P_{fundamental} = V_{fundamental} \cdot I_{fundamental} \cdot \cos\theta_1$$

In the case of harmonics, it is also the in-phase harmonic current times the harmonic voltage, or

$$P_{harmonic} = V_{harmonic} \cdot I_{harmonic} \cdot \cos\theta_{harmonic}$$

Nonsinusoidal currents can be analyzed by considering the load as a current source for harmonic currents. As these harmonic currents flow through the harmonic impedance of the circuit, they cause a harmonic voltage drop. Since the majority of the impedance is reactive, the amount of harmonic current in phase with the harmonic voltage (harmonic power) is small.

The harmonic currents flowing through the resistance of the circuit represent a power loss as

$$P_h = I^2_{harmonic} \cdot R_{harmonic}$$

R_h can vary with applied harmonics because of skin effect, stray currents, eddy currents, etc. In rotating machinery, the harmonic flux in the air gap produces torques in the rotor. These torques can either add (positive sequence) or subtract (negative sequence) from the fundamental torque, depending upon the phase sequence of the harmonic. In general, the harmonic fluxes are small and their effects tend to cancel.

V.5: Harmonic Distribution in Distribution Systems

In electric distribution systems, the magnitude of the harmonic current component is often inversely proportional to its harmonic order, $I_{h.peak} \ \alpha \ \frac{1}{h}$, and $f_h \alpha h$,

Where $i_{h.peak}$ is the peak value of the magnitude of the harmonic current, h is the harmonic order and f, is the harmonic frequency.

V. EFFECTS OF HARMONICS ON POWER SYSTEM COMPONENTS

V.1: Generators

- Rotor heating (in cylindrical rotor synchronous generators).
- Production of pulsating or oscillating torques which involve torsional oscillations of the rotor elements and flexing of turbine buckets.

V.2: Motor

- Stator and rotor I^2R losses will increase due to the flow of harmonic currents.
- Core losses increases due to harmonic voltage
- Leakage fields set up by harmonic currents in the stator and rotor end windings produce extra losses.
- Excessive losses in and heating of induction and synchronous machines.
- Due to eddy currents and skin effect,

V.3: Transformers and reactors

- Winding stray (eddy-current) losses due to nonsinusoidal load currents rise in proportion to the square of the load current and the square of the frequency.
- Hysteresis losses increase.

ISSN 2278-3091
International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 504– 509 (2014)
Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

- Possible resonance may occur between the transformer inductance and the line capacitance.

V.4: Capacitors

- Reactive power increases due to harmonic voltages.
- Dielectric losses increase thus additional heating occurs.
- Capacitor bank failure from dielectric breakdown or reactive power overload.

V.5: Cable

- Additional heating occurs due to nonsinusoidal current and because of skin and proximity effects which are a function of frequency;
- Dielectric breakdown of insulated cables resulting from harmonic over voltage on the system;
- R_{ac} increases, therefore ($I^2 * R_{ac}$) losses increase.

V.6: Effects on Series and Parallel Circuits

Resonances at some harmonic frequencies can occur in power systems, such as the resonances between capacitors and other components. Harmonic resonances cause over voltages and excessive currents that dramatically increase the losses of system devices and can even damage them. The large currents caused by harmonic resonances, for instance, can flow in to power factor correction capacitor banks and damage their dielectric materials.

Over voltages can reduce the life time of the insulation materials of system components and often lead to their destruction .When a voltage source excites a series circuit, the circuit impedance reaches its minimum value during a resonance and excessive currents flow in the circuit. For a capacitor, the primary concern with series resonance is that a high capacitor current can flow for a relatively small harmonic voltage. The harmonic voltage is increased across a parallel circuit at the resonant frequency. Usually, high voltages across capacitors and inductors during resonances are of concern because of the high stress on their insulation.

V.7: Effects on Converter Stations

Harmonic currents increase the harmonic voltage drops across circuit impedances. In a "weak" system the harmonic currents, therefore, cause greater voltage fluctuation than in a "stiff' system. When the electric power is transmitted by cables, harmonic voltages increase dielectric stress in proportion to their crest voltages. The harmonics also have effects on corona. The corona starting and extinction levels depend on peak-to-peak voltages, which are affected by harmonics

V.8: Switchgear

- Medium-voltage, single-bar switchgear current carrying parts will behave similar to cables, with regard to skin and proximity effect;
- Changes the rate of rise of the transient recovery voltage;
- Affects the operation of the blow out coil.

V.9: Relaying

- Affects the time delay characteristics.
- Signal interference and relay malfunction
- False tripping may occur

V.10: Effects on Communication Circuits

Power system harmonics sometimes cause interference between power systems and telephone networks. The noise on communication circuits degrades the transmission quality of communication signals. Low noise levels lower the communication signal quality and high noise levels can result in the loss of information.

SIMULATION OF DOMESTIC AND COMMERCIAL LOADS

VI: Design of household appliances

Different electronic and electrical home appliances and its ratings are shown in below table 5.1.1. All those are supplied by different suppliers, depending on consumer requirements.

s.no	Equipment name	Ratings
1	Television set	50W
2	CPU & Monitor	100W
3	Battery Charger	12V; 3A
4	Fan with electronic regulator	80W
5	Fluorescent tube	40W
6	CFL lamp	2x55W
7	Lighting dimmer	0.8kW; 3.5A
8	Air conditioner	cooling/heating 5/5 A; IP = 1100/1100 W
9	Refrigerator	479 liters;1 door; 4.4A; 7drawers
10	Washing machine	500W; 2.8A
11	Cloths dryer	900W; 4.5A
12	Dish washer	2 cycles; 6A
13	Water lifting pump	1hP; 4A
14	Hot water system	8 liters; 1000W; 5A
15	Electric oven	1.2A

Table VI.1.1: Different home appliances and its ratings

VI.1: CPU and Monitor

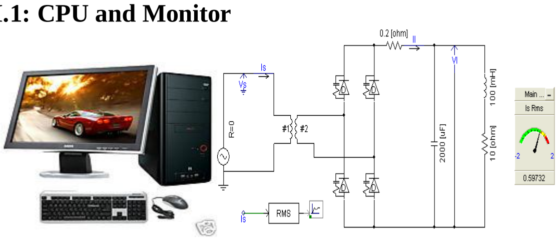


Figure VI.1.1 CPU and monitor model and its equivalent circuit in PSCAD/EMTDC

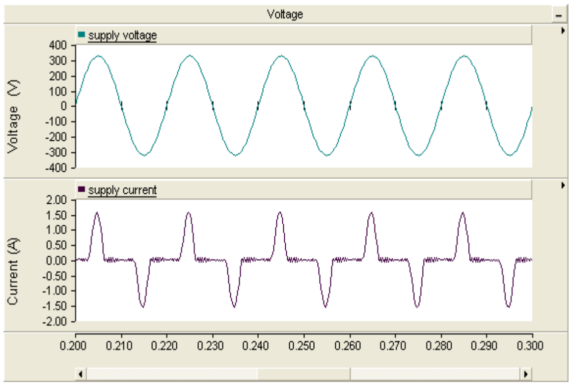


Figure VI.2: Current and voltage wave forms

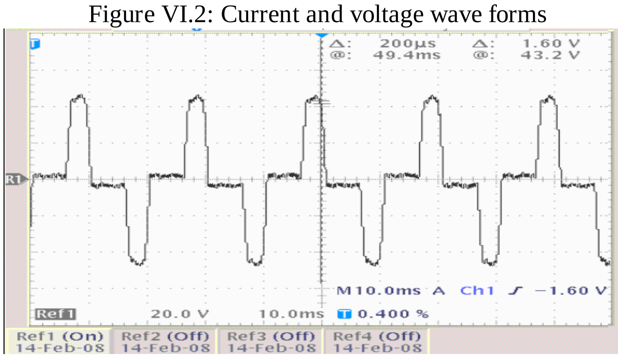


Figure VI.1.3: Practical current wave form

VI.2. Fans with Electronic Regulators

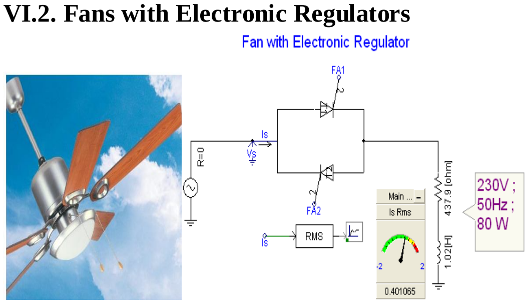


Figure VI.2.1: Fan with electronic regulator modeling in PSCAD

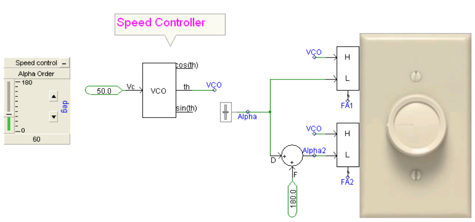


Figure VI.2.2: Speed control (Regulator)

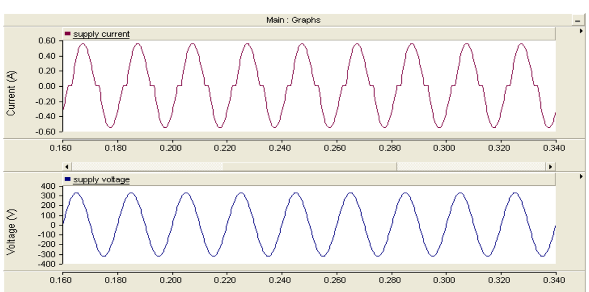


Figure VI.2.3: Current and voltage wave forms

VI.3. Battery Charger

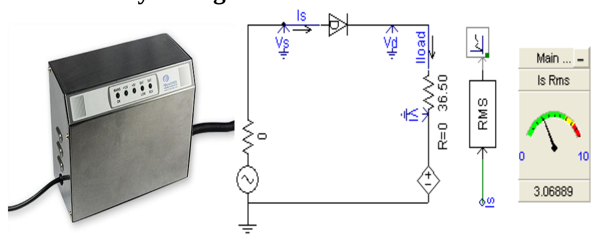


Figure VI.3.1: Simulation of 12V, 3A, Battery charger in PSCAD/EMTDC

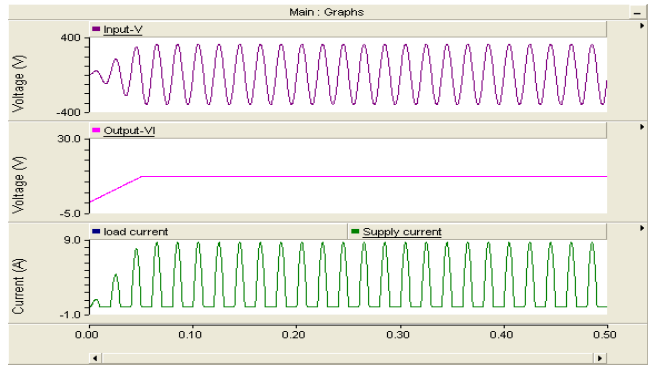


Figure VI.3.2: Current and voltage wave forms

VI.4. Washing Machine

FIG VI.4.1: WASHING MACHINE, INTERIOR OF A WASHING MACHINE

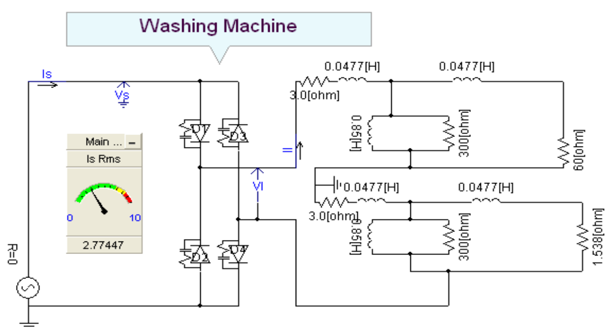


Figure VI.4.2: Washing Machine simulated in PSCAD/EMTDC

ISSN 2278-3091
International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 504– 509 (2014)
Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

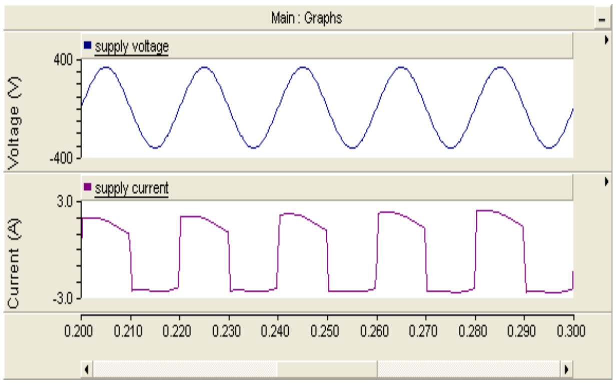
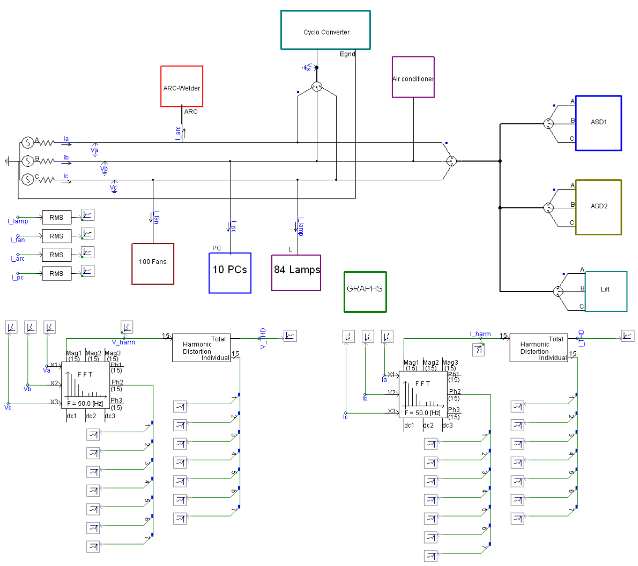


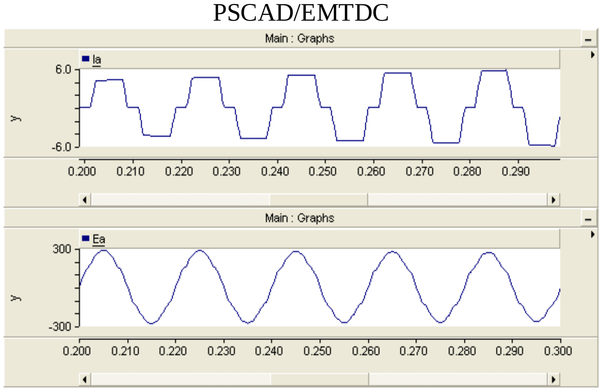
Figure VI.4.3: Current and voltage wave forms

VII. Harmonic Analysis of a Typical Small Scale Industry

Normally in any small scale industry having ASD, lift motors, drives, arc welders, fans, Cycloconverter, personal computers, air conditioners and fluorescent lamps. All those loads are simulated by using PSCAD/EMTDC are shown in below.



VII.1.Simulation of Typical small scale industry in PSCAD/EMTDC



VII.2.Voltage and Current wave forms

CONCLUSION

Linear and non-linear loads are the most sources of harmonic generation. Power electronic devices are introducing non-linear loads in the distribution system resulting in the distortion of current voltage waveforms.

In this paper some of domestic loads such as TV/CPU, computer fan, washing machine, dryer, water pump, refrigerator, air conditioner, hot water system, oven and dish washer are simulated by using PSCAD/EMTDC and some of those loads are verified experimentally. These models are then used for harmonic analysis of domestic and small scale industrial system to find out THD(Total Harmonic Distortion) of voltage and current. Harmonic mitigation is performed by using STF, DTF and ROF. Also, use of shunt and series active filters is made for mitigating harmonics at all buses which are placed at PCC. Sensitivity analysis is then performed to analyse the effect on harmonic distribution and filter performance various load conditions, load position, type of filter we are using, change in filter positions, variation in system or transformer and feeder X/R ratio, small changes in passive filter parameters and effect of power factor correction capacitor.

REFERENCES

[1] Hybrid filters for power quality improvement" IEE Proceedings General. Transmission and Distribution, Vol. 152, No. 3, May 2005.

[2] "Reduction of Voltage and Current Distortions in Distribution Systems with Non Linear Loads using Hybrid Passive Filters"; E.F.El-Saadany; M.M.A. Salama; A.Y. Chikhani; IEE Proceedings-Generation, Transmission and Distribution , Volume 145, No 3, May 1998.

[3] "Implementation of Different Mitigation Techniques for Reducing Harmonic Distortions in Medium Voltage Industrial Distribution System"; T.K. Abdel-Galil, E.F. EI-saadany and M.M.A. Salama. 2001 IEEE

[4] "Algorithm for the parameters of double tuned filter"; Harmonics and Quality of Power, 1998. Proceedings. Volume 1, PP. 154-157, 1998; Xiao Yao

[5] "Harmonic Analysis for Industrial Power Systems Computation Techniques and Filtering". Ali Moshref Shoaib Khan, St. Bruno.

[6] "Understanding Power System Harmonics"; IEEE Power Engineering Review, November 2001 W.Mack Grady, Surya Santoso.

[7] "www.pscad.com "

[8] PSCAD/EMTDC Manual, 2006

[9] "Simulation of Harmonic Currents and Voltages Due to Power Electronic Equipments"; Shahlan b.Fadel

[10] "IEEE Recommended Practice for Electric Power Distribution for Industrial Plants", IEEE Std 141-1993 (Revision of IEEE Std 141-1986)

[11] "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" IEEE SM 519-1992, Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY l0017 USA. April 12, 1993.