

Modeling And Harmonic Analysis Of Domestic/Industrial Loads

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Abstract

This paper discusses the modeling of nonlinear electrical loads used in domestic and small scale industrial distribution systems. Harmonic analysis of the distribution system is essential to study the behavior of equipments connected in the non-sinusoidal system environment for designing and optimal location of filters. Simulation models are developed for various nonlinear loads based on practical waveforms of voltage and current obtained in the laboratory. Analysis of voltage and current harmonics is performed for these loads individually. These models are used for harmonic analysis of typical domestic and industrial loads. Validation of the load models is done by performing case study for an industrial supply system and comparing the THDs obtained from simulation using PSCAD/EMTDC package with the THD values obtained by measurement.

Index Terms-- Current harmonics, industrial system, nonlinear load, Total Harmonic Distortion.

I. INTRODUCTION

It is the objective of the electric utility to supply its customers with a sinusoidal voltage of fairly constant magnitude and frequency. The generators that produce the electric power generate a very close approximation to a sinusoidal signal. However, there are loads and devices on the system which have nonlinear characteristics and result in harmonic distortion of both the voltage and current signals. As more nonlinear loads are introduced within a facility, these waveforms get more distorted.

The planning, design, and operation of industrial and commercial power systems require several studies to assist in the evaluation of the initial and future system performance, system reliability, safety, and the ability to grow with production and/or operating requirements. The studies most likely to be needed are load flow studies, cable ampacity studies, short-circuit studies, coordination studies, stability studies, and routine motor-starting studies. Additional studies relating to switching transients, reliability, grounding, harmonics, and special motor-starting considerations may also be required. The engineer in charge of system design must decide which studies are needed to ensure that the system will operate safely, economically, and efficiently over the expected life of the system.

A harmonic-producing load can affect the neighboring sensitive loads if significant voltage

distortion is caused. The voltage distortion caused by the harmonic-producing load is a function of both the system impedance and the amount of harmonic current injected. The mere fact that a given load current is distorted does not always mean there will be undue adverse effects on other power consumers. If the system impedance is low, the voltage distortion is usually negligible in the absence of harmonic resonance. However, if harmonic resonance prevails, intolerable harmonic voltage and currents are likely to result.

Harmonic currents cause additional line losses and stray losses in transformers. Watt-hour meter error is often a concern. At harmonic frequencies, the meter may register high or low depending on the harmonics present and the response of the meter to these harmonics. The problems caused by harmonic currents are overloading of neutrals, overheating of transformers, nuisance tripping of circuit breakers, over stressing of power factor correction capacitors and skin effects.

Analysis is commonly done to predict distortion levels for addition of a new harmonic producing load or capacitor bank. The general procedure is to first develop a model that can accurately simulate the harmonic response of the present system and then to add a model of the new addition.

The objective of this paper is to consider the effect of nonlinear loads ranging from adjustable speed drives, to house hold appliances, such as Fans with Electronic Regulators on the utility voltage and current harmonics. Some of the commonly used loads in the domestic and industrial systems are modeled in PSCAD/ EMTDC, by considering the voltage and current waveforms obtained during laboratory experiments. Harmonic analysis of an industrial distribution system is performed.

II. MODELLING OF DOMESTIC/INDUSTRIAL LOADS

Modeling of household appliances

Nonlinear loads used in industries introduce current harmonics at the utility. This causes malfunctioning of the sensitive loads connected at the PCC. Hence harmonic analysis of the nonlinear loads is essential. Computer simulation is the most convenient way of harmonic analysis provided that the system components are modeled accurately and verified either through measurements or mathematically. This section presents the simulation

models for some of the commonly used industrial loads. This can be used for estimating the harmonic currents injected at PCC by an industry.

The current and voltages of the industrial loads are nonsinusoidal due to their nonlinear characteristics. Laboratory experimentations were performed on the nonlinear loads listed in Table I. All the loads are supplied from 230 V, 50 Hz ac system. The supply voltage and current waveforms, and the instantaneous values are recorded using Tektronix TDS 3032B, 300 MHz digital storage oscilloscope. Harmonic spectrum for each load is also recorded and THDs are calculated for analyzing the effect of harmonics introduced by these loads. Based on these parameters simulation models are designed for every load and their combined effect is studied. This section presents the practically recorded waveforms for some of the loads and their simulation models in PSCAD/EMTDC.

TABLE I
RATINGS OF DOMESTIC AND INDUSTRIAL LOADS MODELLED IN PSCAD

S.No.	Domestic load	Ratings
1	Television set	50W
2	CPU & Monitor	100W
3	Battery Charger	12V; 3A
4	Fan with electronic regulator	80W
5	CFL lamp	2 x 55W
6	Air conditioner	cooling/heating 5/5 A; IP = 1100/1100 W
7	Refrigerator	190 liters; 1 door; 4.4A
8	Washing machine	500W; 2.8A
9	Water lifting pump	1hP; 4A
10	Hot water system	1000W; 5A
11	Adjustable speed drive	3-phase, 400 V, 10 hP

A) TV and Computer Monitors

Computers and T.V sets are modeled by the fronted end power supply consisting of single phase capacitor filtered bridge rectifier as shown in below figure. These loads are rich in harmonics and generally produced a pulse waveform with THDI nearly 100%.

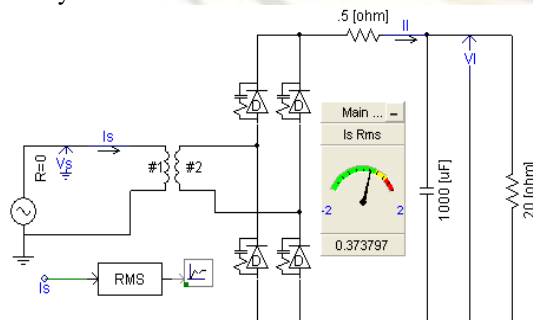


Figure 1: TV modeling in PSCAD/EMTDC

For radio receivers established in its time to define limits for the voltage of the remote controlled centrals in the network, is also valid for individual harmonics, indeed even for 2 or 3 harmonics.

In black and white TV receivers, non-regulated full-wave rectifiers produce a DC voltage which is directly proportional to the peak value of the input voltage, so the DC voltages can vary if a harmonic is superimposed on the fundamental voltages. The resultant effect consists of a light variation in the picture and its luminosity. The variations seem to be proportional to the average of the relative variations of the voltages amplitude.

In this case, it will be the arithmetic sum that will come into play. Such variations are of no importance with harmonics of constant amplitude. The color TV sets seem to be less sensitive because they are equipped with voltage stabilizers.

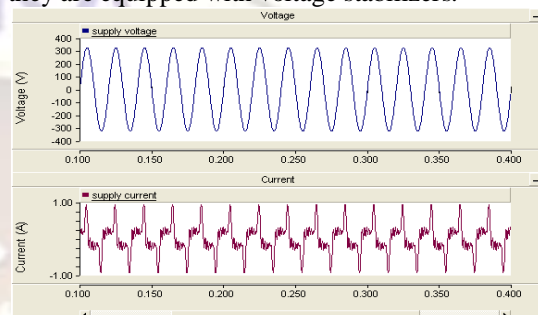


Fig. 2: Current and voltage wave forms of TV

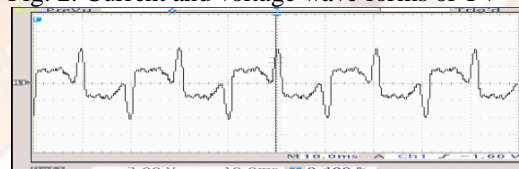


Fig. 3: Practical supply current waveform

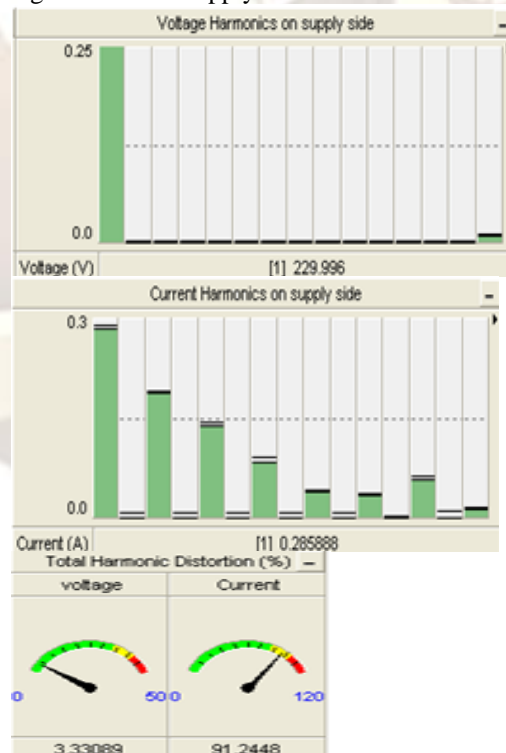


Fig. 4: FFT analysis

B) Battery Charger

Taking for an example in figure, a simple battery charger circuit with an ac source of 230V 50 Hz frequency, an ideal diode connected in series with a 5W resistor and a 12V dc battery. To explain the operation of the above schematic based on electrical understanding, the ac source will give out a sinusoidal waveform of 230V with 50Hz frequency from the voltmeter, V_{in} . Whereas, the voltmeter (V_d) will be a half rectified waveform.

The current I_{load} flowing across the resistor to the load will be equal to the current after the diode. And finally, V_{load} will be a dc voltage 12V above the zero crossing line because the battery will always carry a 12V dc voltage. To confirm that PSCAD gives an accurate graphical result, graphs were plotted below to show that the above explanation fits within the simulated waveform and theoretical understanding of the simple battery charger circuit in figure 12V, 3A.

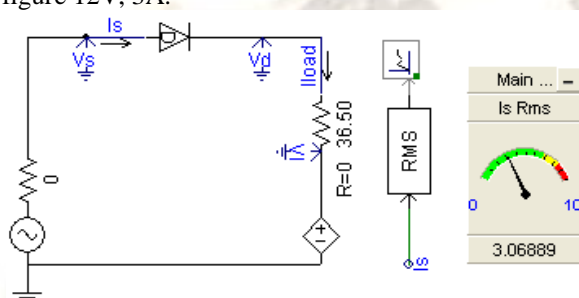


Fig. 5: Simulation of 12V, 3A, Battery charger in PSCAD/EMTDC

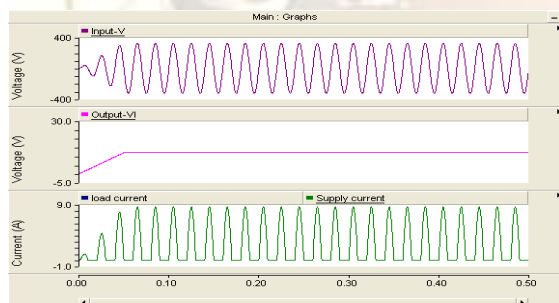


Fig. 6: Current and voltage wave forms

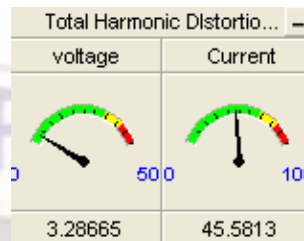
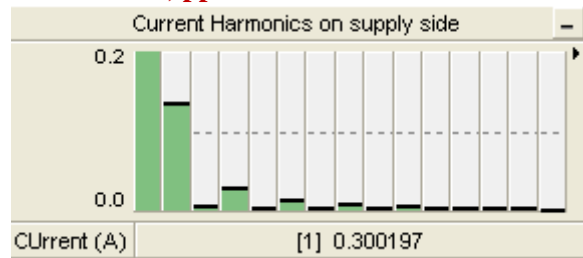
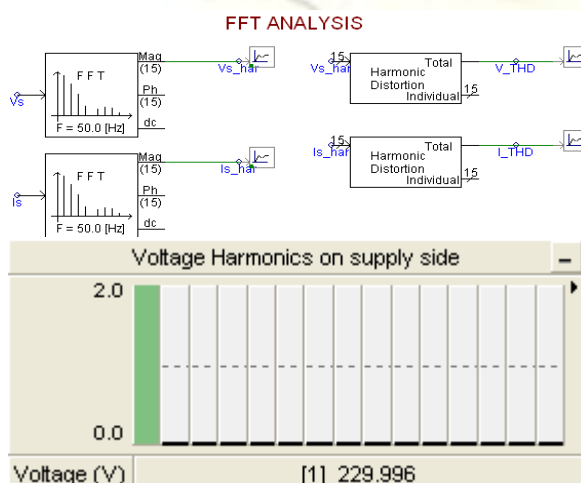


Fig. 7: FFT analysis

Harmonic analysis of a house load

Let us consider in a town, a person having all types of electronic and electrical home appliances, he is the first person to generate harmonics in to distribution system.

The amounts of THD produced by him on distribution system are analyzed by using PSCAD/EMTDC simulation. The obtained results are shown in below figure.

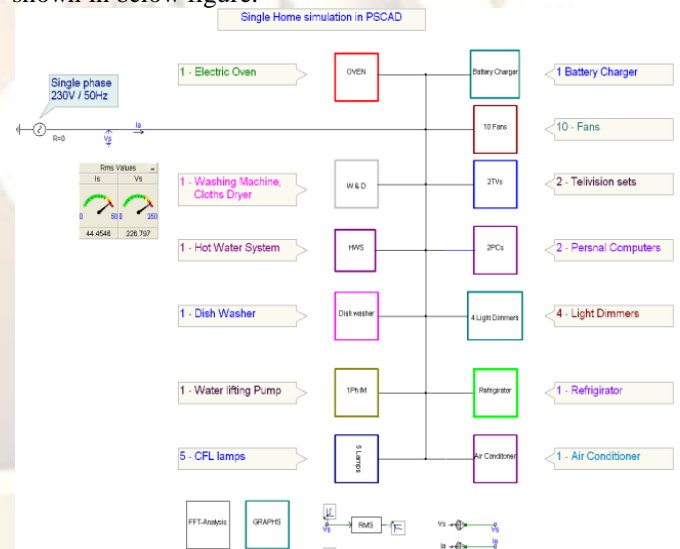


Fig. 8:PSCAD/EMTDC Simulation of Single Home

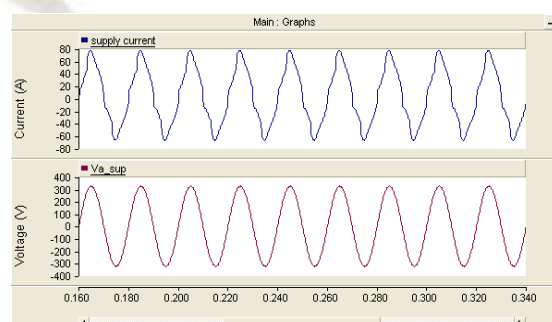


Fig. 9: Home Voltage and current wave forms

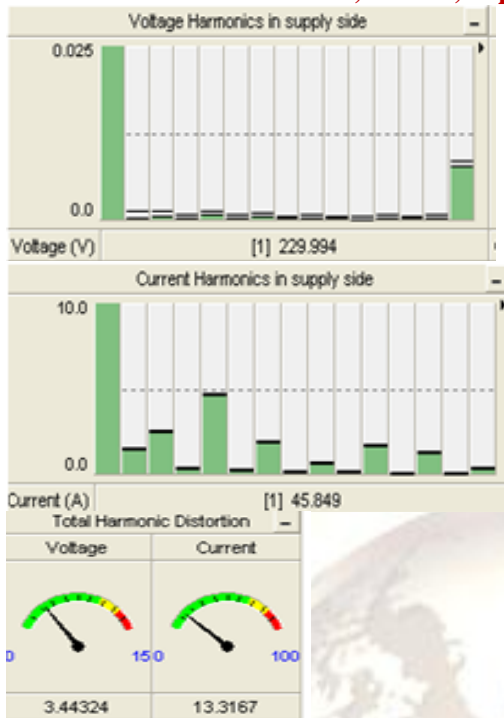


Fig. 10: Home FFT analysis for Voltage and Current

Conclusion:

When all above loads discussed loads are in switched on total harmonic distortions of both voltage and current (THDI & THDV) are with in the limits. So no need of using a filter, if a person having above rated loads in his house.

III.Domestic Load Modeling in PSCAD/EMTDC

In small residential system having three villages. 33kV/11kV substations supply the power to those villages. Among those village1 is the most sources for harmonic generation. The people who are living in other villages are labors; now a day also they are using incandescent bulbs. These bulbs are not that much sources of harmonics. Nobody can using some costliest equipments like AC, HWS, Oven, Washing machine and dryer etc. So these two villages are less sources of producing harmonics.

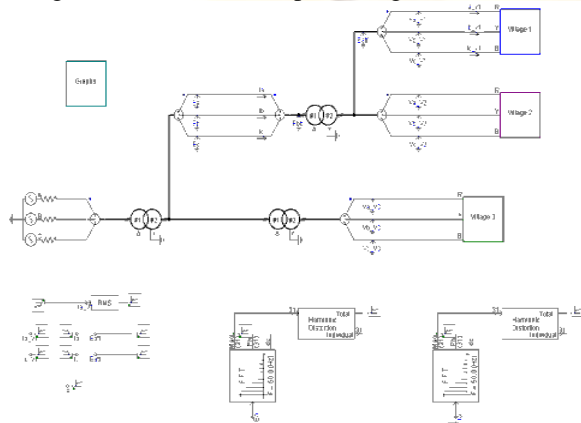


Fig. 11: Domestic load modeling in PSCAD/EMTDC

No. of Houses	CFL	FAN	TV	P C	B C	A C	R G	W M	C D	O V	H W	W P
Total	85	44	36	4	4	1	2	2	2	1	1	6

Where: CFL – Compact fluorescent lamp TV – Television set
 PC – Personal computer BC – Battery charger
 AC – Air conditioner RG – Refrigerator
 WM – Washing machine CD – Clothes dryer
 OV – electric oven WP – Water lifting pump
 HW – Electric hot water system

If total houses are distributed like given figure



Figure. 12: Houses distribution in Village1

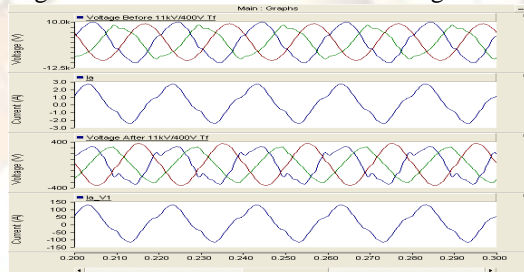


Fig. 13: Current and Voltage wave forms of Village1

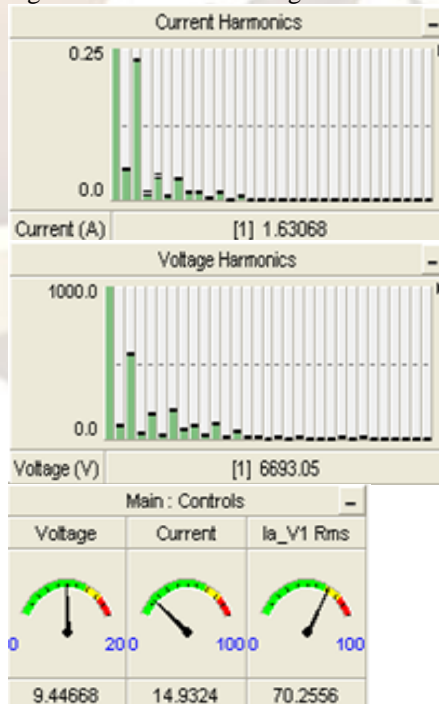


Fig. 14: FFT analysis of Village1

Conclusion:

Village-1 drawing nearly 70A rms value of current. THDI is within the limit but THDV more than its limit so we need a filter to reduce voltage harmonics. Series active filter can reduce those harmonics.

Harmonic Analysis of a Typical Small Scale Industry

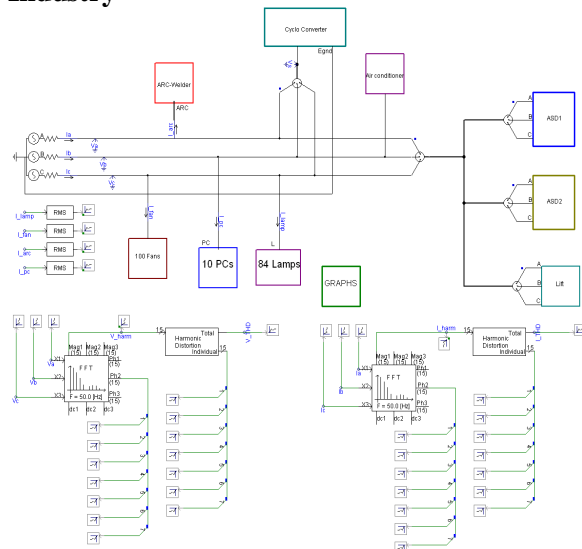


Fig. 15: Simulation of Typical small scale industry in PSCAD/EMTDC

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 fig 15.

A) ASD Modeling

There are two mechanisms through which an ASD generates harmonic currents. The first mechanism is the converter operation which injects harmonic currents into the supply system by an electronic switching process. The second mechanism is the inverter operation. The inverter can introduce additional ripples into the DC link current. These ripples in turn can penetrate into the supply system side. The extent and the frequency of inverter-caused ripples are largely a function of inverter design and motor parameters. An ASD can therefore be represented with a generic three-phase bridge converter circuit of Figure. A significant feature of this circuit is that the inverter and the motor are collectively modeled as a direct current source.

Theoretically speaking, the inverter and motor should be represented as a harmonic current source. The magnitudes and phase angles should be determined from the inverter design and motor operating conditions. Attempts were made in this research to develop a procedure that automatically determines the harmonic current source. However, the complexity and variety of the inverters make the work extremely difficult. Even if such a procedure

were in place, it is very likely that there is no adequate data available.

Fortunately, extensive sensitivity studies, as described later, show that there is little need to model the current source as a harmonic source. Namely, the inverter harmonics are negligible as seen from the converter AC side. This is because, in the case of PWM and VSI type ASDs, the inverter harmonics are largely bypassed by the DC link capacitor before they can penetrate into the supply system side. In the case of CSI type ASD, the series inductor serves as a large impedance to block inverter harmonics from ever getting into the converter.

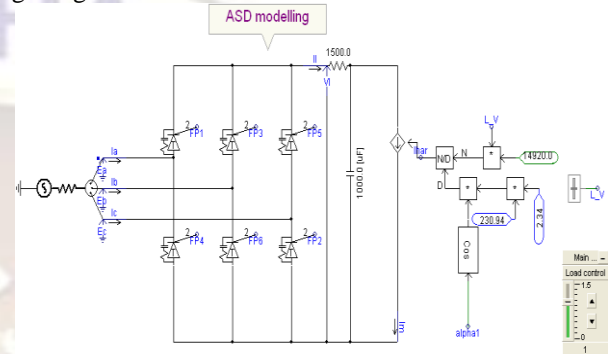


Fig. 16: Simulation of ASD in PSCAD/EMTDC
Input data needed to construct the above model are as follows:

- 1) The firing angle of the converter thyristors α ,
- 2) The direct current flowing into the inverter I_{dc} ,
- 3) The DC link R and C component parameters.

The firing angle of PWM type ASDs is always zero. For VSI and CSI type ASDs, the angle increases with the AC motor speed (or inverter frequency). The purpose is to maintain a constant ratio of DC voltage to motor frequency. Assuming that the rated

ASD frequency is ω_r , and the operating frequency ω , the firing angle can be determined as

$$\cos \alpha = \text{Minimum}\left(\frac{\omega}{\omega_r}, 1\right)$$

The direct current into inverter can be estimated from the motor load as

$$I_{dc} = \frac{P}{2.34 V_{lg} \cos \alpha}$$

Where P is the motor load including losses, V_{ph} is the line to ground voltage of the supply system.

For typical harmonic studies, α and I_{dc} should be varied so that the various ASD-motor operating conditions are investigated. Representation of the DC link filter is essential for the correct simulation of ASDs. It is the filter that makes the ASD harmonic current waveforms different from those of the DC drives.

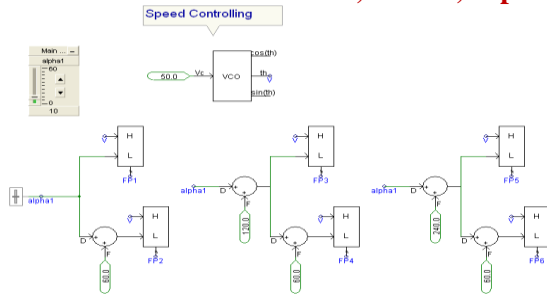


Fig. 17: Speed control logic for ASD

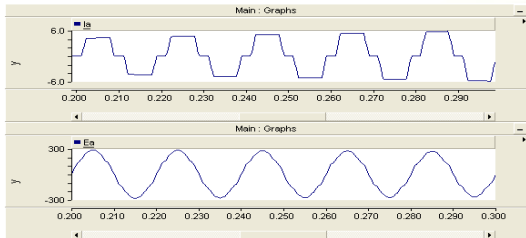


Fig. 18: Voltage and Current wave forms

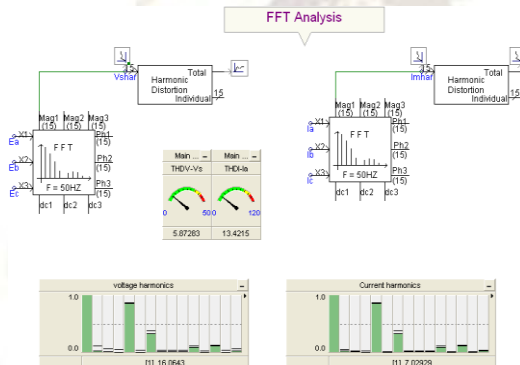


Fig. 19: FFT analysis of ASD

B) Lift Motor

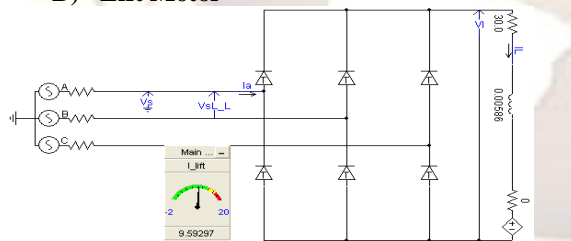


Fig. 20: Simulation of Lift motor in PSCAD/EMTDC

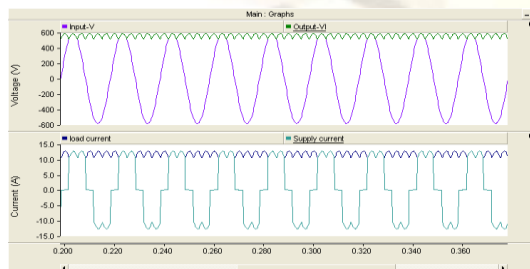


Fig. 21: Voltage and Current wave forms

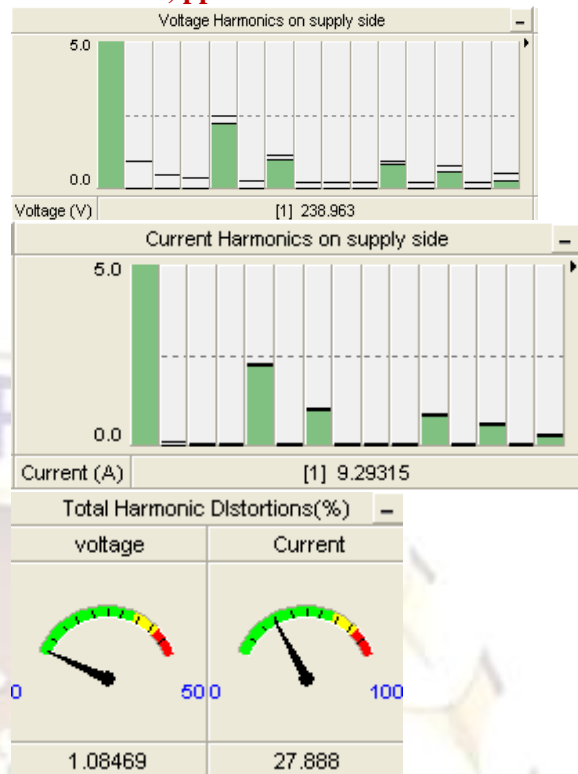


Fig. 22: FFT analysis

Harmonic Analysis of a Typical Small Scale Industry

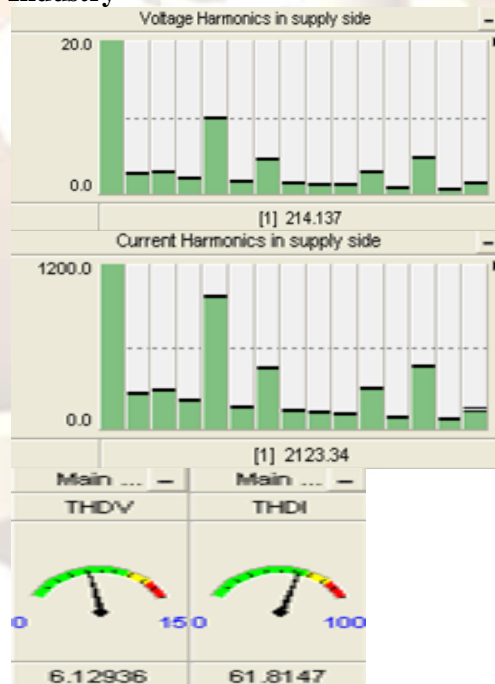


Fig. 23: FFT Analysis of Small Scale Industry

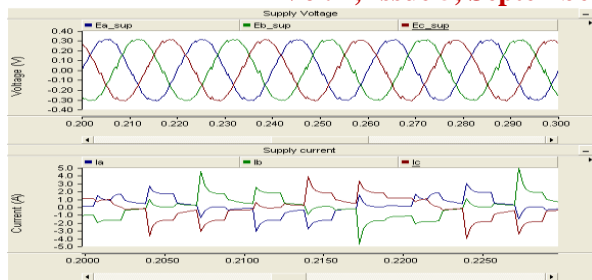


Fig. 24: Voltage and Current wave forms of small scale Industry

Conclusion:

After completion FFT analysis of small scale industry both THDI and THDV values are crossing their limits. So the owner of that industry must be use filters to mitigate harmonics other wise he may face sever problems with those harmonics.

IV.CONCLUSIONS

This paper discusses the modeling of nonlinear electrical loads used in domestic and small scale industrial distribution systems. In this some of domestic loads such as TV/CPU, Battery Charger are modeled and simulated by using PSCAD/EMTDC. Simulated results are shown and Small scale industry loads such as ASD, Lift motor are simulated in PSCAD/EMTDC.

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