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Power System Harmonics Identification using Harmonic analyzer based on FFT Methods

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(Abstract): In this paper, harmonic analysis in non-linear loads such as AC Drives, DC drives CFL, Welding Machine, are proposed. To analyze harmonics, Harmonic analyzer is used which is based on FFT Methods. The practical set-up used for this is available at Dr C.V. Raman University**.** Harmonics are one of the major power quality concerns. The objective of electricity utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. However a difficulty occurred by the fact that there are loads on the system that produce harmonics currents, which result in distorted voltage and current that can adversely impact the system performance in different ways. Therefore detection is essential to describe such event. One of the methods to detect harmonics is Fast Fourier Transform (FFT). The FFT plays important roles in the analysis, design, and implementation of discrete signal processing. FFT algorithms are based on fundamental of discrete Fourier computation. Such algorithms are more efficient than the discrete Fourier transform.

Keywords: Fast Fourier Transform (FFT), Power System Harmonics, AC Drive, DC Drive , CFL, Welding Machine, THD, PF, Harmonic Analyzer.

1 Introduction

The increasing application of power electronic facilities in the industrial environment has led to serious concerns about source line pollution and the resulting impacts on system equipment and power distribution systems. Power systems, in the presence of electronic equipment, can produce not only integer, but also sub- and non-integer harmonics in the power signal waveforms. Power converters, specifically, are responsible for a disproportionate amount of the harmonics troubling power systems today [1].

Converters are used in variable-speed drives, power supplies, and UPS (uninterruptible power supply) systems; the term converter can refer to rectifiers, inverters, and cyclo-converters. Arc furnaces are another significant source of harmonics. Harmonics in power systems can be the source of a variety of unwelcome effects, for examples, signal interference, over voltages, data loss, and circuit breaker failure, as well as equipment heating, malfunction, and damage.

Harmonics have been also known to be responsible for noise on both telephone and data transmission lines, and they can induce malfunction of relays and meters. Harmonic current components that react as the carrier signals in a particular system can interfere with the use of the carrier signals [2]. Electronic devices are particularly vulnerable; huge increases in computer data loss, up to 10 times the previous amount of data loss, were recorded after one installation of harmonics-producing equipment [3]. Harmonics can also cause excessive heating in transformers and capacitors, resulting in shortened life or failure. Rotor heating and pulsating output torque caused by harmonics can result in excessive motor heating and inefficiency. Consequently, active power filters (APF) have been used as an effective way to compensate harmonic components in non-linear loads. APFs basically work by detecting the harmonic components from the distorted signals and injecting these harmonic current components with a current of the same magnitude but opposite phase into the power system to eliminate these harmonics. Obviously, fast and precise harmonic detection is one of the key factors to design APFs [4-6]. It is, therefore, crucial to identify the harmonic components and determine their magnitudes and phase angles in waveform to reduce them to an acceptable level.

2. Source Of Harmonics

Harmonics are one of the major power quality concerns. Harmonics cause distortions of the voltage and current waveforms, which have adverse effects on electrical equipment. Some examples of nonlinear loads are:

• Adjustable drive systems

• Cyclo-converters

- Arc furnaces
- Switching mode power supplies
- Computers, copy machines, and television sets
- Static var compensators (SVCs)
- HVDC transmission
- Electric traction
- Wind and solar power generation
- Battery charging and fuel cells

3. Harmonic Effects

Harmonics have deleterious effects on electrical equipment. These can be itemized as follows:

A. Capacitor bank failure because of reactive power overload, resonance, and harmonic amplification. Nuisances fuse operation.

B. Excessive losses, heating, harmonic torques, and oscillations in induction and synchronous machines, which may give rise to torsional stresses.

C. Increase in negative sequence current loading of synchronous generators, endangering the rotor circuit and windings.

D. Generation of harmonic fluxes and increase in flux density in transformers, eddy current heating and consequent derating.

E. Overvoltage and excessive currents in the power system, resulting from resonance.

F. Derating of cables due to additional eddy current heating and skin effect losses. A possible dielectric breakdown.

G. Inductive interference with telecommunication circuits.

H. Signal interference and relay malfunctions, particularly in solidstate and microprocessor controlled systems.

I. Interference with ripple control and power line carrier systems, causing mis-operation of the systems, which accomplish remote switching, load control, and metering.

J. Unstable operation of firing circuits based on zero voltage crossing detection and latching.

K. Interference with large motor controllers and power plant excitation systems.

4. Harmonic Mitigating Techniques

Several different solutions are proposed for harmonic mitigation. The right choice is always dependent on a variety of to Variable Speed Drives, as this type of electrical equipment represents a large part of the installed power factors, such as the activity sector, the applicable standards, and the power level. Several solutions are relative in industrial installations and the most significant power harmonic current generators.

5. Theoretical Background of DFT and FFT

According to Fourier Transform theory, my continuous repetitive function in an interval T can be represented by the summation of a fundamental sinusoidal component with a series of higher order components at frequencies which are integer multiples of the fundamental frequency. Harmonic analysis is the process of calculating the magnitudes and phases of the fundamental and higher order harmonics of the distorted but periodic waveform. The resulting series establishes the relationship between time domain function x(t*)* and corresponding function ***x(f)*** in the frequency domain. The **X(f)** and **x(t)** are given by

$$X(f) = \int_{-\infty}^{\infty} x(t)\exp(-j2\pi ft)dt \qquad (1)$$

And

$$x(t) = \int_{-\infty}^{\infty} X(f)\exp(j2\pi ft)df \qquad (2)$$

5.1 Discrete Fourier Transform (DFT)

In real application, a distorted waveform needs to be sampled before application of Fourier Transform to determine its fundamental and harmonics content. For such a set of sample points (of one cycle of the distorted waveform) the equations (1) and (2) need to be modified in order to analyse this sampled time function. Let sampling inverval be At, and hence the frequency of sampling f_s=1/ Δt and Discrete Fourier Transform and the inverse are given by

$$X(f_k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n\Delta t)e^{-\frac{j2kn\pi}{N}} \qquad (3)$$

and

$$x(n\Delta t) = \sum_{k=0}^{N-1} X(f_k)e^{\frac{j2kn\pi}{N}} \qquad (4)$$

where ***k*** and *n* as-e integers and ***N*** is the number of sample points per period. It is this discrete form that is most suited to numerical evaluation by digital computation.

5.2 Fast Fourier Transform (FFT)

Equation (3) can be rewritten as

$$X(f_k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n\Delta t)W^{kn} \text{ .... } (5)$$

where = **exp(-j2.n** *I* ***N)*** **,** and **k=0,1,2** ,...... N. Calculation of the N frequency components from the N time domain samples therefore requires a total of *N2* complex multiplications. Depending on the value of the product *kn,* represents a unit vector with a clockwise rotation of ***2pi/N;*** where **p** is the remainder of *kn* divided by N. If N is an even number, the number of unique components need to be calculated will be further halved as components with **80"** phase shift can be paired together. Like wise, if N is an integer exponent of ***2*** (say ***N*** = ***2"***) pairing and regrouping can be performed m times over thus reducing the overall number of complex multiplications to (*N* / 2) Log_2 *N* . This procedure is known as Radix **-** 2 based Fast Fourier Transform (FFT) algorithm **[8,9,1o]** and for accurate results, the number of sampling points, N must be an integer exponent of 2. ***Kn*** Although the FFT algorithm should give 100% accurate results its performance is affected by the presence of noise and possible sub-harmonics in the distorted signal. Presence of sub-harmonics is particularly a problem for FFT computation. Some altemative methods, therefore, need to be investigated for harmonic analysis.

6. Harmonic Analyzer

The presence of Harmonics, distorts the waveform shape of Voltage and Current, Increases the current level and changes Power Factor of supply, which in turn creates so many disturbances. MECO “POWER & HARMONICS ANALYZER – Model 5850” which is a state of art versatile instrument using micro controller technology and having various functions that would be ideal for any Engineer / Inspector for carrying out Vigilance checks, Surveys, Audits and Periodic Visits for checking at Industrial and Consumers end.

The measurements can be done on Live loads. It is able to do almost all the Analysis for Single / Three Phase Power System and capable of analyzing standby Power consumption to the Maximum Demand of Factory. It Calculate Voltage & Current of Neutral with respect to ground. Large Dot Matrix LCD Display with Backlight of 35 Parameters in one screen to monitor Energy, Active Power, Apparent Power & Reactive Power, Power Factor, Energy, TRU RMS Value, AC Current, and Average Demand & Maximum Demand with Programmable Time Interval, CT & PT Ratios.

It displays Harmonics up to the 99th Order, THD with Waveform with peak value. PHA5850 Display Power Parameters and Harmonics of each individual phase of Current & Voltage. Analyzers having features like Real time Graphic Phasor Diagram & Capture 28 Transient Events with Programmable Threshold (%).

PHA-5850 has inbuilt memory of 512K for 17000 records & Optical Isolated RS-232 ~ USB Interface with users friendly Software for easy downloading of recorded data. Analyzers has facility to retrieve Power Data & Harmonics on Meter Screen at site.

Analyzers available with Clamp on CT having Multiple Range of 1/10/100A or 10/100/1000A or 300/3000A & 120/1200A (Flexible CTs) as per application.

[13]

Figure 1 Power Harmonic Analyzer

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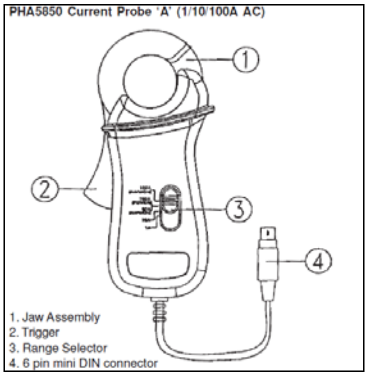


Figure 2 Power Harmonic Analyzer current probes

7. Experimental Setup and Data Collection And Result Analysis

The main objective of this chapter is to identify the harmonics generated in a non linear load in power system. The configuration of the experimental system block diagram is shown in Figure 3.

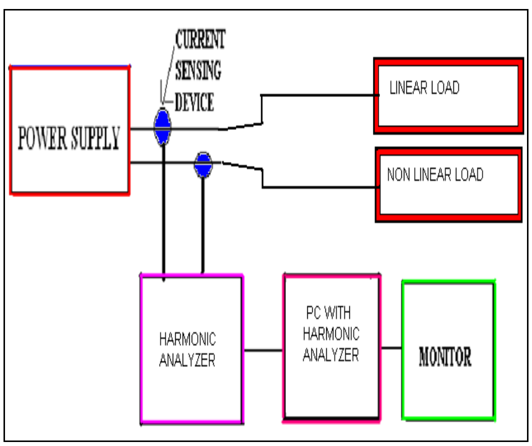


Figure 3 Experimental Set-Up

7.1 Welding Machine

All data collected in workshop lab Engineering Department, Dr.C.V.Raman University, in this lab have a single phase arc welding machine .

Table 1 Single Phase Welding Mchine (Oil cooled)

particulars	specification
Input voltage	220 V
Phase	1
Manufacture	Sharp Electric Works Rajkot (Serial no-19207 & Model-2007)
KVA	5
Input Current (max)	200 A
Cycle	50

Physical Set-up

Figure 4 Single phase ARC welding machine setup

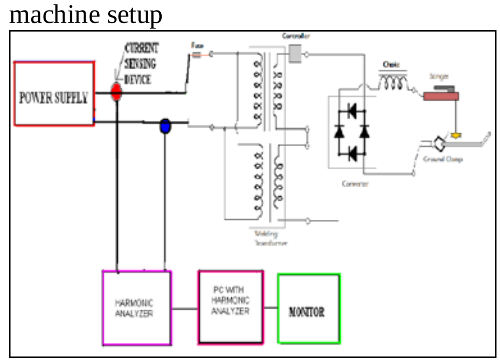


Figure 5 Block diagram of physical set-up for single phase ARC welding machine set-up

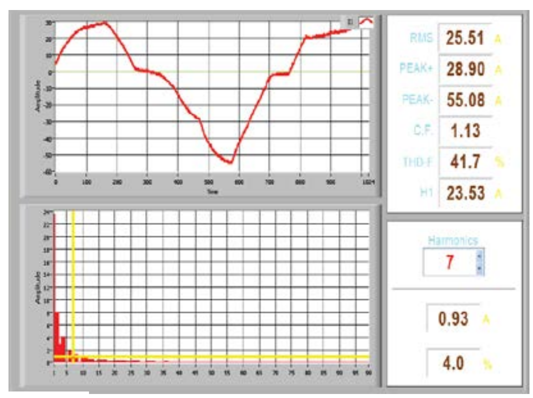


Figure 6 FFT For Current Waveform For Welding Machine

7.2 AC Drives

All data collected in machine lab of EEE Department , Dr.C.V.Raman University, this lab have a PWM based AC Drives with three phase induction motor load experimental set-up.

Table 2 AC PWM Drive (IGBT based)

Particulars	Specification
Input Voltage	230 V
Model No	VPE-100A
Manufacture	VI Microsystems Pvt Ltd Chennai

Table 3 Three Phase induction motor (for AC PWM Drive)

Particulars	**Specification**
Machine power	1hp
Input voltage	415 V
Input Current (Max)	1.8 A
Manufacture	Siemens
RPM	1415
Frequency	50Hz

Physical Set-up

Figure 7 AC Drives Experimental set-up

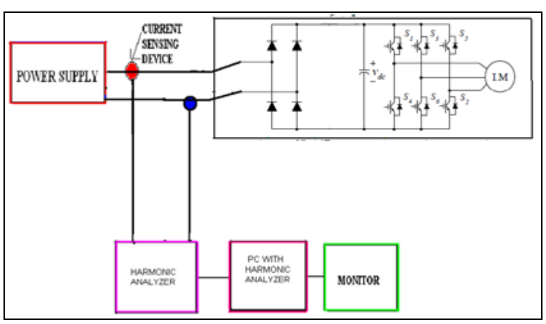


Figure 7 Block diagram of AC Drives Experimental set-up .

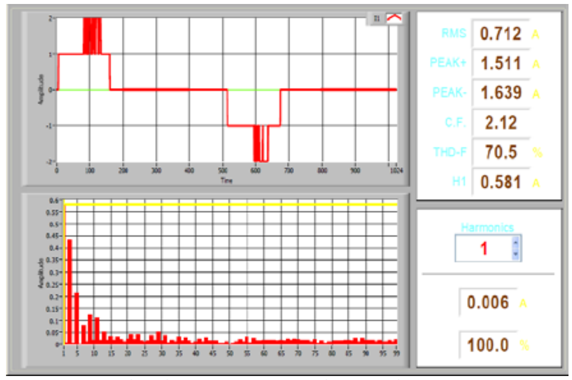


Figure 8 Fft of Current waveform of AC DRIVES

7.3 D.C. Motor Drives

All data collected in machine lab of EEE Department , Dr.C.V.Raman University, this lab have a DC Motor Drives with dc motor load experimental set-up.

Table 4 DC Motor Drive

Particulars	Specification
Input Voltage	230 V
Output Voltage	200 V
Model No	PEC14HVI
Rectifier	MOSFET based
Manufacture	VI Microsystems Pvt Ltd Chennai

Table 5 DC Motor (for DC Drive)

Particulars	specification
Machine power	1 Hp
Input voltage	180 V
Input Current (Max)	5.1 A
Manufacture	Benn
RPM	1500
Frequency	50Hz

Physical Set-up

Figure 9 D.C. Motor Drives experimental set-up

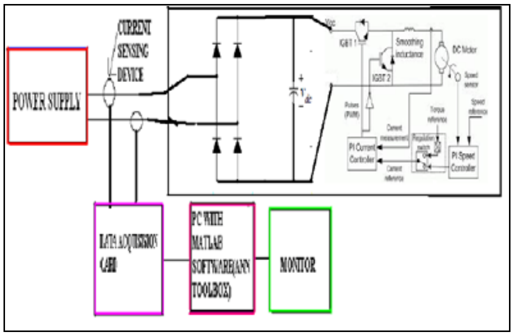


Figure (10) Block diagram of D.C Drives Experimental set-up .

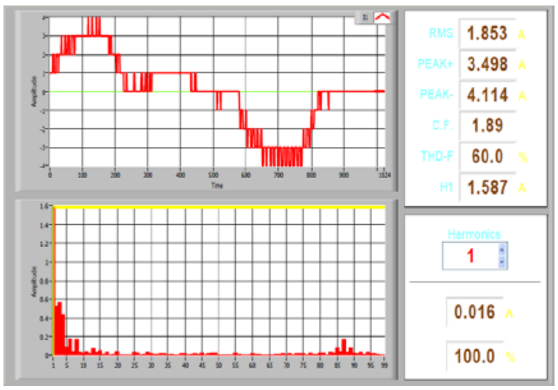


Figure (11) Fft of Current waveform of CC DRIVES

7.4 C.F.L

All experimental data has been collected in machine lab of EEE Department, of Dr.C.V.Raman University. This lab has a 20W 9 CFL load set-up.

Figure (12) C.F.L Load Experimental Setup for CFL

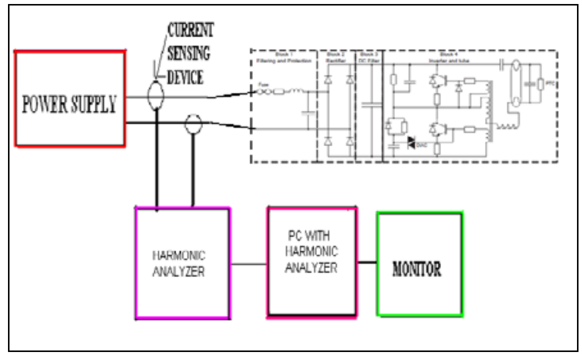
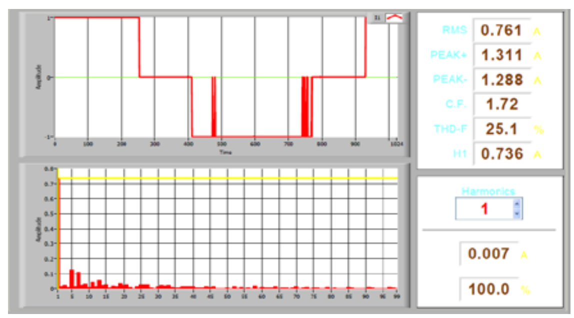


Figure (13) Block diagram of physical set-up for CFL load

Table 6 Electrical specification of CFL

Operating Voltage	22OV-240 Volts
Frequency	50Hz
Power Consuption	20W
Current	85mA
Standard	ISI(IS:-15111)
Made in	INDIA
Manufacture	Orient



Figure(14) FFT for current waveform for cfl load

7.5 Single Computer and Printer

All experimental data has been collected in machine lab of EEE Department, of Dr.C.V.Raman University. This lab has a 20W 9 CFL load set-up.
6.6.2.1 Technical specification of experimental set-up
Table 7 Technical specification of computer and printer

Particulars	specification
CPU	HCL
PRINTER	CANNON
UPS	FRONTECH
MONITOR	LCD

Physical Set-up

Figure(15) Computer and printer Load Experimental setup

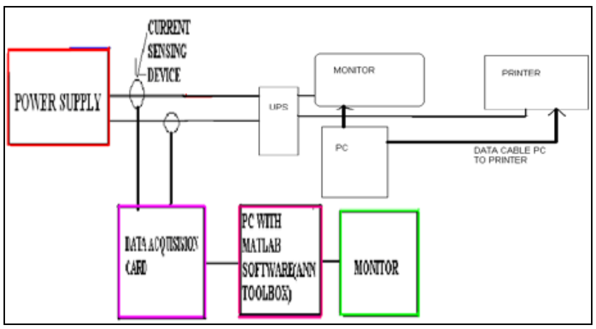


Figure (16) Block diagram of physical set-up for Computer and printer Load

8. Conclusions

In this paper, harmonic sources are identified in power system where non-linear loads such as AC Drives, DC drives CFL, Welding Machine, are used. To analyze harmonics, Harmonic analyzer is used which is based on FFT Methods. The practical set-up used for this is available at Dr C.V. Raman University**.** The FFT plays important roles in the analysis, design, and implementation of discrete signal processing. FFT algorithms are based on fundamental of discrete Fourier computation. Such algorithms are more efficient than the discrete Fourier transform. After the analysis of waveform we have find the rms value crest factor thd and harmonic component of distorted waveform. we used the practical setup of AC Drives, DC drives CFL, Welding Machine and find that these equipment are the sources of harmonic generator.

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