International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 1, pp: 930-937 www.ijaem.net ISSN: 2395-5252

Experimental based Theoretical analysis of impact of harmonics in grid due to high power consuming plants using electrical equipment and Fourier series technique

T.V. Viknesh*, V. Manikandan
Department of Electrical and Electronics Engineering,
Coimbatore Institute of Technology, Coimbatore-641014, India.

Date of Submission: 25-06-2020 Date of Acceptance: 13-07-2020

ABSTRACT: This paper presents the field work data based theoretical study to determine the harmonic distortion proffered from individual non-linear loads and point of common coupling of foundry plant. This study includes the field measurements and harmonic analysis using power quality analyzer and extents to Fourier series analysis on distorted output current waveform. This identification technique of harmonics using Fourier series is well suited and accurate to any plant for deriving out the amplitude and frequency of n^{th} harmonic wave assorted with fundamental waveform. The fore-coming results in the paper recommend theoretical derivation and design of appropriate filter in utility side harmonics that tend to improve the plant productivity.

KEYWORDS: current harmonic distortion; Fourier series; power quality analyzer; magnitude and frequency spectrum Drive train

I. INTRODUCTION

Our mother earth challenges many problems in power generation, transmission and utilization, among these we face lot of problems during utilization that is due to lack of power quality [1]. In this modernized and industrialized state of living, all of our electrical and electronic gadgets, devices, and equipments rely on purity of power from the local power grid. The main role of the grid is to supply pure sinusoidal wave with constant voltage and frequency. But due to non-linear loads included in the grid, power transmission is with lot of dangerous harmonics [2]. These harmonics lead to disturbance in waveform, (leads to non-sinusoidal signals), variations in supply voltage and current. Prominent non-linear loads are variable frequency drives, electronic ballasts, and personal computers. These loads are the source of producing voltage and current harmonics in the power transmission lines. In order to safe guard,every individual must monitor and mitigate the harmonics in their power input premises. Already many researches are in this area and many power quality engineers and researchers are contributing to monitor and mitigate the harmonics. [3]For solving these problems, a comprehensive knowledge is very important in power quality problems in the power system. In the practical part, one has to measure and record the relevant data of the chosenpower plant using the measuring device (Krykard ALM-35).This device is capable of measuring individual harmonic distortion produced by the machinery and also total harmonics expelled from the machine. So these data will be helpful to calculate the total harmonic distortion (THD) and to design an appropriate harmonic filter for the plant. [4,5]In the theoretical side, there are many methods like Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), and Short time Fourier Transform (SFT) for periodic and non periodic signals to identify the current harmonics. Among these FFT[6,7] is very simple and reliable technique to analyze using mathematical models and software Mat-Lab simulation.[8,9] Many countries are suffering with the non-linear loads like foundry, welding industry, lathe machines, and various high power equipments.[10] This motivated us to analyze the impact of harmonics in grid due to high power consuming plants using electrical and equipments and also theoretically using Fourier series technique in this work.

In this research work, novel Fourier series technique is adopted in driving the amplitude and frequency of harmonic currents and validated with the field measurement values. The schematic representation of single line or phase diagram of foundry plant in which the research is focused on is as shown in Figure 1.

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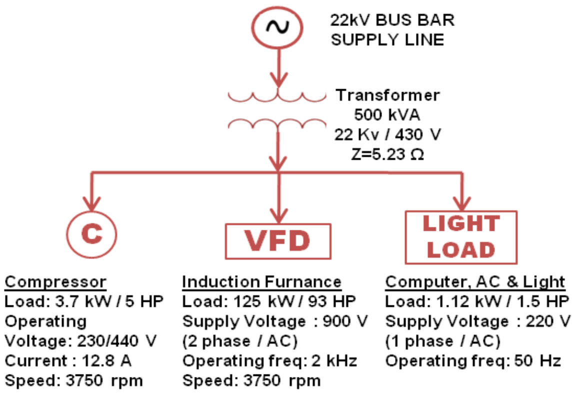

Figure 1. Schematic diagram of foundry unit

II. FOUNDRY UNIT- OVERVIEW

Foundry is a factory where metal is cast into shapes by melting them into a liquid, pouring the molten metal into a mold and removing the mold after the process. The most common processed metals are aluminum and cast iron. Foundry has different stages such as melting the metal, degassing, mold making, pouring the molten metal, shakeout, heat treatment, surface cleaning, machining, and inspection and testing[11]. Major high power consuming equipments in foundry are furnace and compressor. They are the cause for the production of harmonics in the grid. These equipments are fed from 500 kVA distribution transformer, whose primary is connected to the power grid and the secondary to the plants as given in the Table 1.

K.V.A	500
Voltage (H.V side)	22kV
Voltage (L.V side)	433V
Current(H.V side)	13.12A
Current(L.V side)	666.6A
Number of phases	3
Impedance	5.23
Short circuit current	$125*10^2$A

Table 1: 500kVA Transformer Specifications

2.1 Arc furnace

The major load of distribution transformer in this study is Arc furnace. Mostly type I furnace is used in plant which is connected with three phase controlled rectifier and it works under six pulse rectification. The DC rectified output of the rectifier is 1273 V and it is fed into two phase inverter providing 2000 Hz frequency. The inverter output is connected to current and potential transformer for measurement and capacitor bank for impedance matching. The induction coil works at 800 – 900 V and the frequency above 1500 Hz. The power consumption is approximately 125 kW. The power quality is majorly deteriorated by 3^{rd}, 5^{th}, 7^{th} 11^{th} and minority by 13^{th} and 17^{th} harmonics. These harmonics are main cause for the distortion in the grid. From the real time recordings, it is identified that the built in capacitor bank reduces the major portion of 3^{rd} harmonics in the supply line. The measured value of total harmonic distortion from the plant side is approximately 17 %.

2.2 Compressor

Mostly 5HP industrial grade compressor is employed in the plants. It is identified that the ambient conditions in the foundries are bad for air compressors, since the layer of dust deposition and sudden turning of new equipments to brown color. Furnace also expels more heat, so the surrounding temperature raises and dust present on molten metal also gets stick with it.[12] In addition to the main production work, compressor is used to clean dust with high pressurized air and helps in metal paintings. In power quality point of view, it expels major total harmonic distortions 2 % (voltage side) and 15.3 % (current side).

III. CURRENT HARMONICS MEASUREMENT AND FOURIER ANALYSIS

The overall harmonics produced in the plant was identified by connecting the power quality analyzer at the point of common coupling of the plant. The individual harmonicsexpelled out from each load was measured by connecting voltage and currentprobes individually.Relevantdataforfilterdesignwerealsomeasuredandtabulated Table 1.

3.1 Load current of compressor

From the field measurement, current wave form is taken as shown in fig.2 for wave form analysis with equal interval regions. Among the three phase measured data, only one phase is taken (fig.2) into analysis. Fourier series of one phase is derived by separating into regular intervals of time. The function f(t) of current waveform satisfies the equations $f(-t) = -f(t)$ and $f(t) = -f(t+\frac{T}{2})$ and hence it is said to be half wave odd symmetry in nature. Its periodic function can be expressed in Fourier series as below.

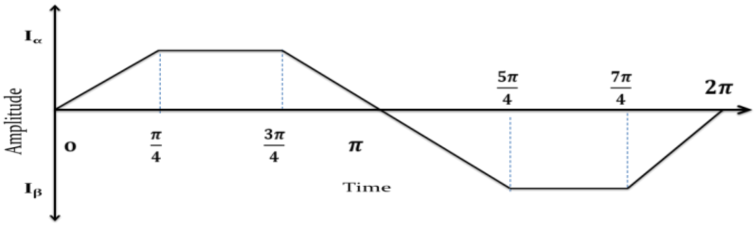

Figure 2: Load current of Compressor

A periodic function expanded in Fourier series as

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n cos\left(\frac{2\pi nt}{T}\right) + b_n sin\left(\frac{2\pi nt}{T}\right) \quad (1)$$

Whereas T=2π. Due to half wave symmetry the average value is zero, and it implies only odd harmonics are present. In equation (1) b_n can be written as

$$b_n = \frac{1}{T}\int_0^{T/2} sin\frac{2\pi nt}{T}dt \quad (2)$$

In terms of the regular intervals, b_n can be written as follow.

$$b_n = \frac{4I_\alpha}{\pi}\int_0^{\pi/4} t.sin\,ntdt + \frac{I_\alpha}{\pi}\int_{\pi/4}^{3\pi/4} \sin nt\,dt + \frac{4I_\alpha}{\pi}\int_{\pi/4}^{3\pi/4}\left(1-\frac{t}{\pi}\right)\sin nt\,dt + \frac{4I_\alpha}{\pi}\int_{3\pi/4}^{5\pi/4}\left(1-\frac{t}{\pi}\right)\sin nt\,dt$$
$$-\frac{I_\alpha}{\pi}\int_{5\pi/4}^{7\pi/4}\left(1-\frac{t}{\pi}\right)\sin nt\,dt + \frac{4I_\alpha}{\pi}\int_{5\pi/4}^{7\pi/4}\left(1-\frac{t}{2\pi}\right)\sin nt\,dt$$

On Solving above equation. We get

$$b_n = \frac{4I_\alpha}{n^2\pi^2}[sin(n\pi/4) + sin(3n\pi/4) - sin(5n\pi/4) + sin(7n\pi/4)] \quad (3)$$

The RMS current and its total harmonic distortion with compressor load are determined by Fourier series and they are 4.25 A and 21.7 % respectively.

3.2 Load current of arc furnace

Fig.3 represents the load current of arc furnace, which satisfy the half wave symmetry condition only, it implies a_n= 0. In this analysis only [0, π] interval is considered and Fourier analysis is applied as below.

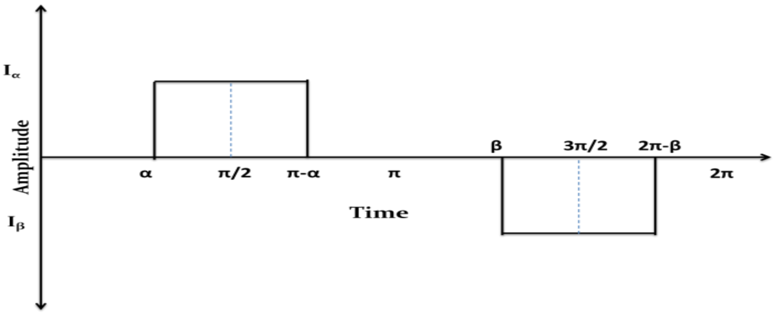

Figure 3: Load current of Arc Furnace

$$b_n = \frac{2}{n\pi}\int_\alpha^{\pi-\alpha} I_\alpha \sin nt\,dt + \int_{\pi-\alpha}^{\beta} I_\alpha \sin nt\,dt \quad (4)$$

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$$= \frac{2I_\alpha}{n\pi}(-cosnt)_\alpha^{\pi-\alpha} + (-cosnt)_{\pi-\alpha}^{\beta}$$

$$b_n = \frac{2I_\alpha}{n\pi}(\cos n\alpha - \cos(n\pi - \alpha)) \quad (5)$$

IV. RESULTS AND DISCUSSION

The plots as shown in Figure 4 and 5 show the current harmonics measurements in Arc furnace and compressor with respect to the harmonic frequency and respective Fourier series results with adjacent places. Fig.4 clearly indicates the absence of 3rd harmonics, since 3rd harmonic filter is connected with the furnace, whereas the 3rd harmonic is visible in the measured data. The Table 5 gives the numerical values of both measured and calculated data of RMS voltage and RMS current and total harmonic distortion of current with compressor and furnace loads. It is identified that the THD level difference between the arc furnace loads in both methods are nearly 3 %. With compressor load, the 2nd harmonics occurs in data of Fourier analysis, where as in real time it is very low. So the percentage of error between the observed and analysed data is 6.3 %. Snapshots taken from the power quality analyser for arc furnace, compressor, and point of common coupling is displayed in Figure.10 a,b,crespectively.

	Real Time Measurements		Fourier Series	
	Compressor Load	Arc FurnaceLoad	Compressor Load	Arc FurnaceLoad
V_{rms}	420 V	420 V	416V	416 V
I_{rms}	6.3 A	275 A	4.25 A	287 A
I_{THD}	15.3 %	28.8 %	21.7%	31.4%

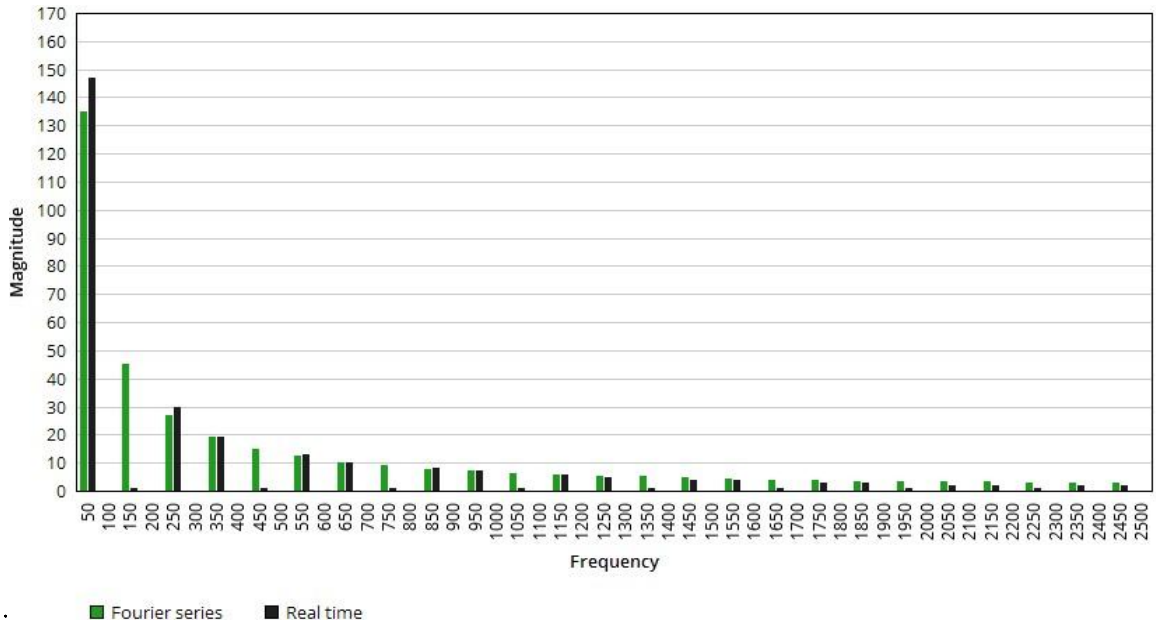

Figure 4: Magnitude (vs.) Frequency of Arc furnace load current

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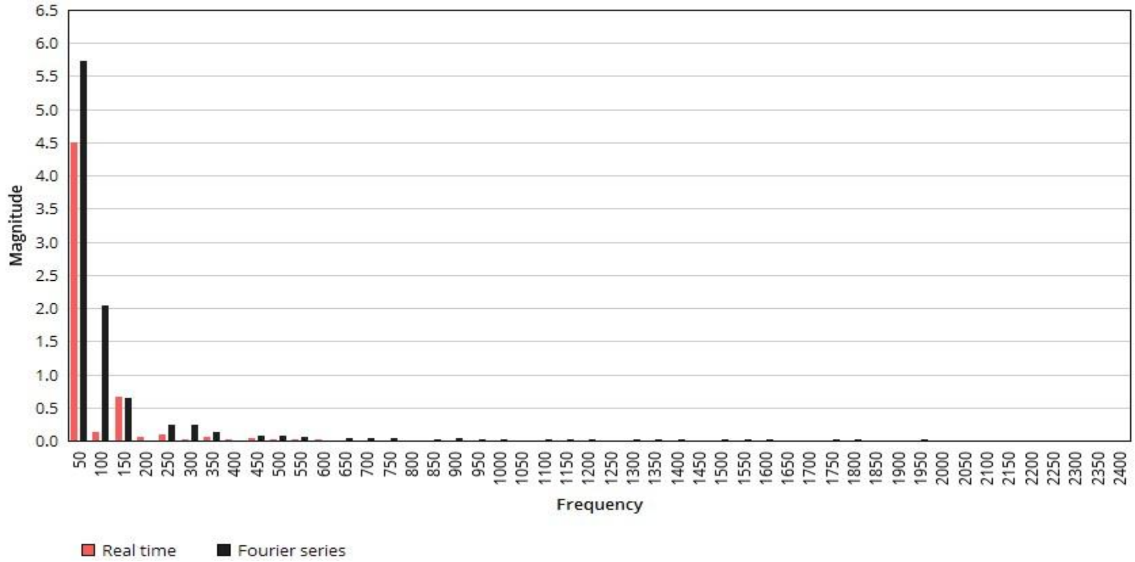

Figure 5: Magnitude (vs.) Frequency of Compressor load current

4.1 Arc furnace

i) RMS voltage and current

the following Figure 6 and 7 are the snapshots of the 3ϕ line to line RMS voltage and current from the analyser, using the full load of arc furnace. The waveforms are almost sinusoidal but still similar and repeated distortions are observed. There is a need of proper analysis of the cause for the distortion and remedy to mitigate, so that the grid may not be polluted. Though the numerical values of RMS current and voltage are not necessary to this research, still it may be useful to the proper distribution of power from grid to various customers. The fluctuations in RMS voltage and current are 7 % and 10 % and below the rated value respectively. These data (fluctuation values) might be useful for the manufacturers to safeguard their equipments as well as increase the efficiency and productivity of the plant.

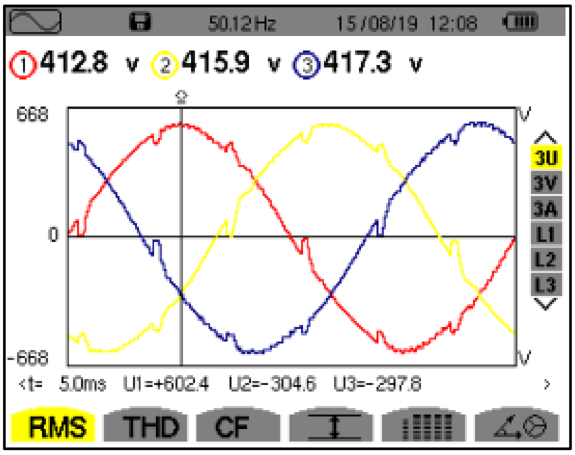

Figure 6. 3φ Line-line RMS voltage

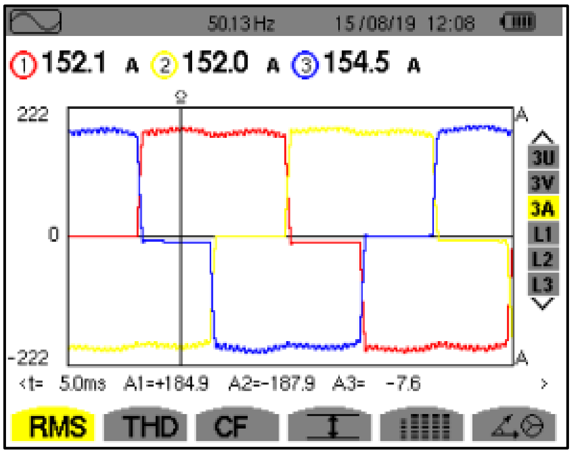

Figure 7. 3φ Line-line RMS current

ii) THD

The following snapshots (Figure.13 and 14) are revealing the percentage of THD values during the measurement of RMS voltage and current with full load of arc furnace in the plant. The percentage of THD values RMS voltage and current are in the range of 4.4 % to 5 % and 28.3 % to 29.3 % respectively.

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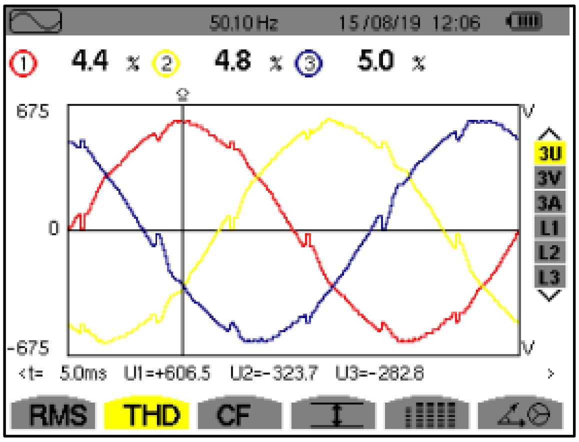

Figure 8. Voltage THD

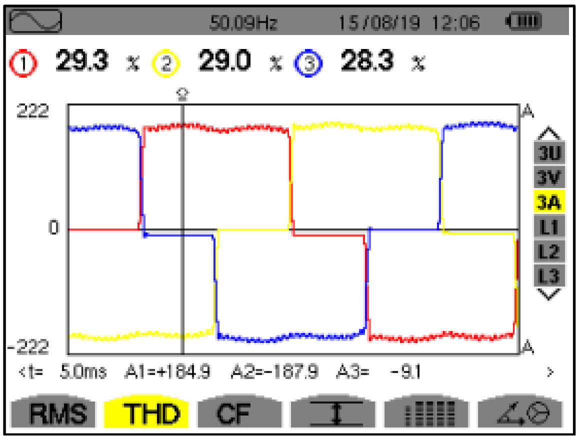

Figure 9. Current THD

4.2Compressor

i) RMS voltage and current

Fig.6 and 7 represent the RMS voltage and current of three phase line-line snapshots taken using analyser from the compressor load. The distortions in the wave shapes are minimum and appreciable variations in the magnitude of RMS current and RMS voltage. The percentage of deviations is 2 to 5 % for both. The fig. 8 and 9 show the THD of voltage and current using compressor load. The percentage of voltage and current deviation are 0.5 % to 2 % above the rated values. This data may be useful to maintain the motor in the compressor.

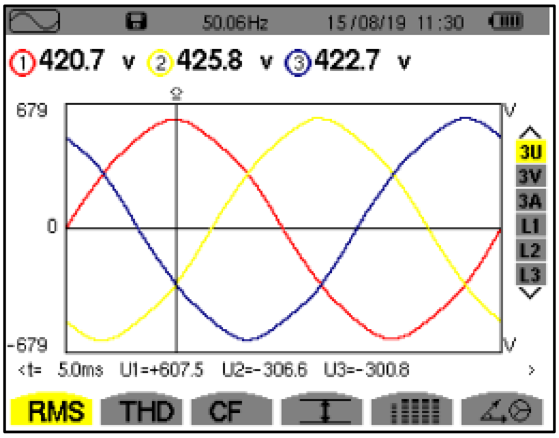

Figure 8. 3φ Line-line RMS voltage

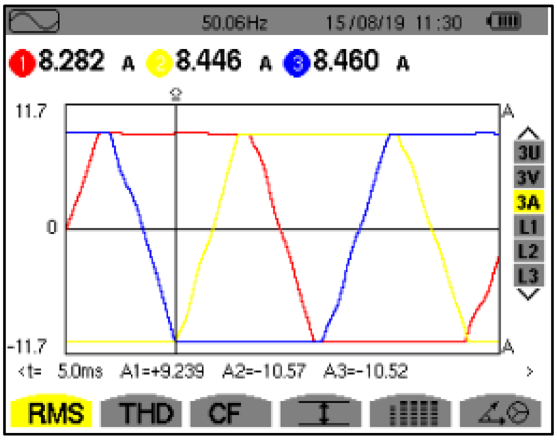

Figure 9. 3φ Line-line RMS current

ii) THD

The following snapshots (Figure 10 and 11) are revealing the percentage of THD values during the measurement of RMS voltage and current with full load of compressor in the plant. The percentage of THD values RMS voltage and current are in the range of are 1 % to 2 % and 13 % to 17 % respectively.

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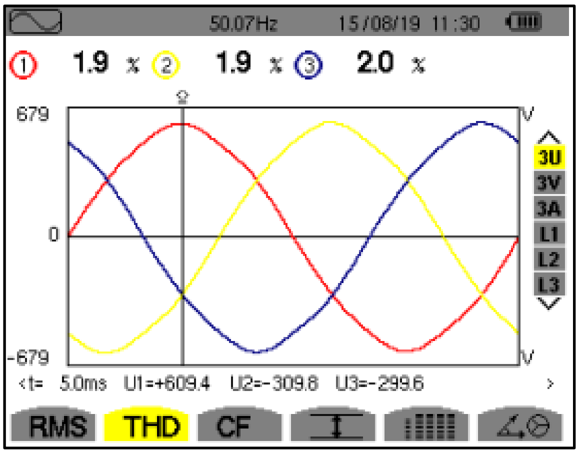

Figure 10. Voltage THD

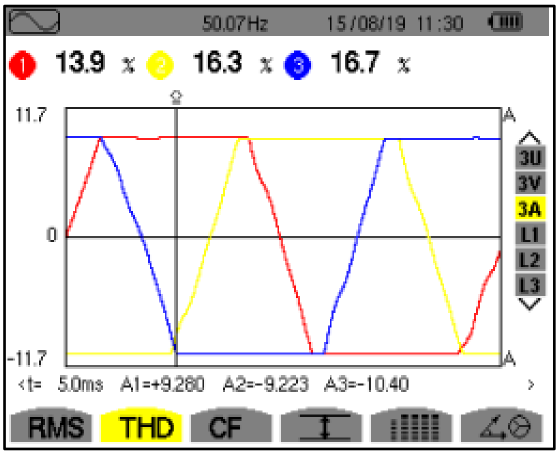

Figure 11. Current THD

4.3Point of common coupling

The following Figure. 12 and 13 show the RMS voltage and RMS current in the three phase line-line of the point of common coupling to the grid. The waveforms are almost sinusoidal but still similar and repeated distortions are observed. There is a need of proper analysis of the cause for the distortion and remedy to mitigate, so that the grid may not be polluted. Though the numerical values of RMS current and voltage are not necessary to this research, still it may be useful to the proper distribution of power from grid to various customers. The fluctuations in RMS voltage and current are 7 % and 10 % and below the rated value respectively. These data (fluctuation values) might be useful for the manufacturers to safeguard their equipments as well as increase the efficiency and productivity of the plant.

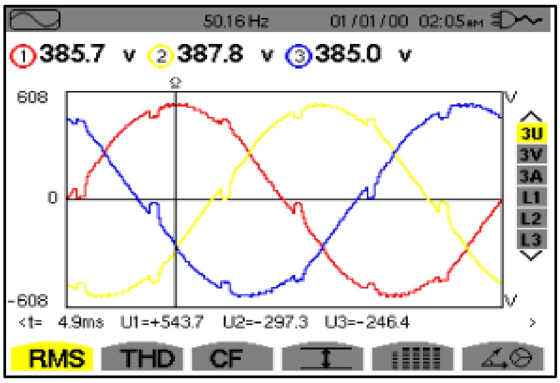

Figure 12. 3φ Line-line RMS voltage

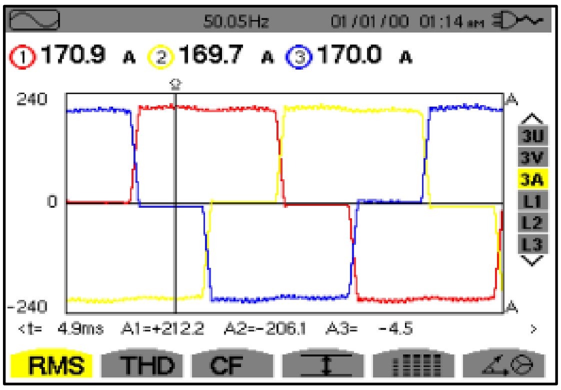

Figure 13. 3φ Line-line RMS current

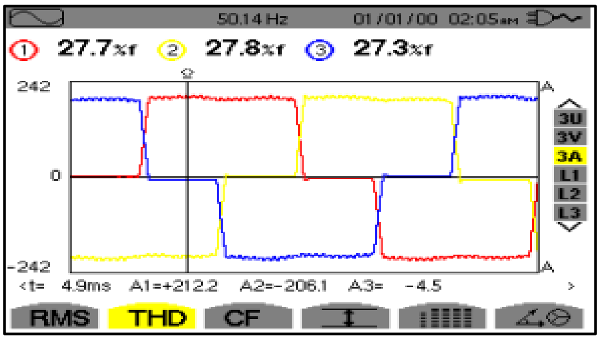

Figure 14. Current THD

V. CONCLUSION

This research presents the real time studies in the load side of individual loads especially arc furnace, compressor, and point of common coupling. The complete data based theoretical study to determine the harmonic distortion proffered form the individual non-linear loads of the foundry plant and common coupling point. This study includes the field measurements and harmonic analysis using power quality analyzer and extents to Fourier series analysis on distorted output current waveform. This identification technique of harmonics using Fourier series is well suited and accurate to any plant for deriving out the amplitude and frequency of n^{th} harmonic wave assorted with fundamental waveform. The fore-coming results in the paper recommends theoretical derivation and design of appropriate filter in utility side harmonics that tend toe improve the plant productivity.

ACKNOWLEDGEMENT

The authors would like to express their sincere thanks to Dr. S R K Prasad (Correspondent, CIT), Dr. R. Prabhakar (Secretary, CIT), Dr. V. Selladurai (Principal, CIT), Mr. S. Rajiv Rangasamy (Director, CIT), Dr. S. Vasantharathna (Head) and all Professors in the Department of Electrical and Electronics Engineering for their help and encouragement during this research work.

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International Journal of Advances in Engineering and Management
ISSN: 2395-5252

IJAEM

Volume: 02 Issue: 01 DOI: 10.35629/5252

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