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Investigation into Power Quality Issue due to House Hold Equipments

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Abstract: With the ever increasing demand for electricity, conservation of energy is given importance. Conventional method of control is being replaced with electronic methods of control. With this harmonics are introduced into the power system. This is applicable to all types of electrical loads, industrial, domestic and commercial. As on now, the presence of harmonics in domestic sector is not monitored, as the quantity of electricity used by domestic sector is not significant as compared to industrial and commercial sector. Yet with the lighting sector dominated by CFL bulbs and LED bulbs, fans being controlled electronically and increasing use of desktops, laptops, laser printers, air conditioners etc., it is a matter of concern to study the harmonics produced by these devices and its effect on distribution transformer and neighbouring utility services. Harmonic analysis is done using expensive power analysers, digital storage oscilloscope etc., In this project a simple method of analysing harmonics is discussed. Initially the voltage and current drawn is sensed, fed to the computer using data acquisition card, total harmonics, 3rd, 5th, 7th and 9th harmonics, power factor etc., is measured. The average values of these is taken and represented as source in Matlab Simulink, passive filters are designed and analysed using simulation.

Keywords-- Power Quality, harmonics analysis, domestic load, passive filter, THD

I INTRODUCTION

Electric power quality has become an important part of power systems. Power quality is the term used to assess and to maintain good quality of power at the point of generation, transmission, distribution and utilization of AC power. Some of the major causes of disturbances in power systems are presence of harmonics, voltage fluctuations, voltage dips, power frequency variations, transients and so on. Harmonics are of major concern mainly due to increase in nonlinear loads on the distribution system with the effect of deterioration power quality significantly.

II PREVIOUS WORK

Determination of power quality is of prime importance today, with the increasing trend of using non-linear devices [1]-[3]. Harmonics produces various deteriorating effects in generators, transformers, circuit breakers and fuses, increase in neutral current etc., [2][5].

IEEE has provided suitable guidelines for control of harmonics [2]. Even though the power consumed by domestic load is not significant, with the increasing trend of using nonlinear devices like CFLs, LED bulbs, electronic fan regulators, laptops and laser printers the distortion on power system will be increasing in great proportion. The distortions can be observed individually by comparing different harmonic components. More general approach to quantify the distortions is the use of total harmonic distortion level (THD) [4]. The different methods of harmonic analysis can be classified under the time domain and frequency domain [6].

Reference [7] discusses the modelling of nonlinear electrical loads used in domestic and small scale industrial distribution systems based on practical waveforms of voltage and current obtained in the laboratory using PSCAD /EMTDC package.

Another research study [8] makes an effort to evaluate the harmonic distortion in the distribution systems caused by the various non-linear residential loads using Electrical Transient Analyzer Program (ETAP).

In another study [9], the impacts of various home nonlinear electric equipment on the power quality of electrical distribution system is studied. The influence of operating modes on the harmonic pollution is studied using the CA 8334B three -phase power quality analyzer. It is found that although home electric appliances are low power receivers, the cumulative effect produced by a large number of small harmonic sources can be substantial.

National Instrument's white paper [10] describes the use of its software Lab VIEW as powerful monitoring and analysis tool. It states that power disturbances arising within customer facilities have increased significantly due to the increasing use of energy efficient equipment. The monitoring and data collection of power disturbances therefore has to be conducted at the users' premises. A configurable and programmable PXI/Compact PCI, high-performance PC with high-speed data acquisition units and VI software using LabVIEW can perform the required task.

Virtual instrumentation utilizes simulation of power system monitoring using LabVIEW, a graphical programming language. By using the powerful tools of LabVIEW [11] various harmonics are simulated within the G programming/coding.

In reference [12] Matlab Simulink has been used to model FL and CFL for harmonic studies. Since Matlab simulation offers versatility for harmonic analysis, the same has been in this project for design of passive filter and analysis.

III Methodology

3.1 Circuit Diagram : The circuit diagram is shown in Fig (1). Voltage and current signal from the supply system is sensed using Hall Effect sensors. The standard instrument transformers cannot be used for this purpose as they are designed and calibrated for 50Hz. But some of the power quality disturbances of interest like harmonics, transients require the measurement of significantly higher frequencies. For those frequencies the accuracy of the instrument transformers can be no longer taken for granted. Hall Effect sensors suited the application in all the ways.

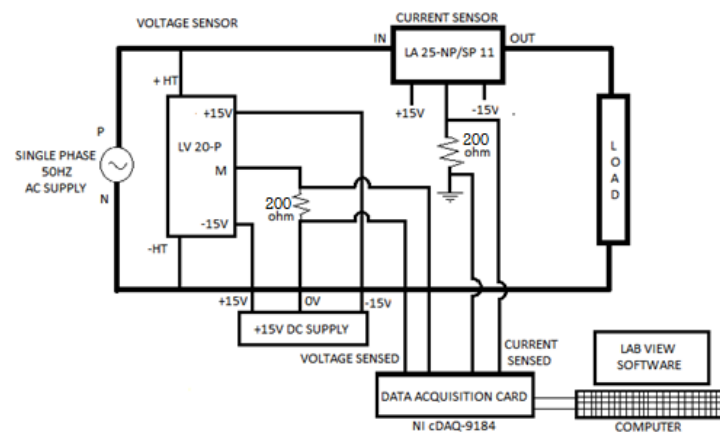


Fig (1) Circuit for measuring harmonics

The data acquisition hardware NI cDAQ-9184 , which can measure upto 128 channels of sensor, analog I/O and digital I/O signals is used. Standard 802.3ab Gigabit Ethernet Communication Interface is used. Using NI signal streaming technology, it delivers high speed data. NI compact DAQ can integrate the measurement of voltage, current, temperature etc., into a single device that outputs all the data via the same bus interface. Programming becomes easier because we use the same driver for all measurements.

Harmonic Analyzer is simulated using LabVIEW. **LabVIEW** - Laboratory Virtual Instrument Engineering Workbench is a system-design platform and development environment for a visual programming language from National Instruments. LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various versions of UNIX, Linux, and OS X.

3.2 Measurement of harmonics

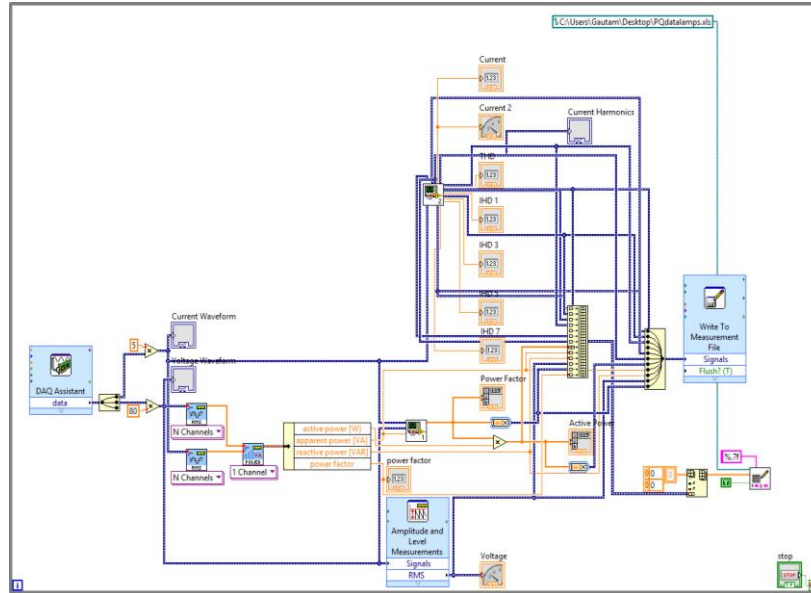


Fig (2) Front panel of Harmonic Analyzer

The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. The circuit developed for harmonic analysis is shown in Fig (2).

3.3 Loads Considered : The following domestic loads were considered for analysis.

Sl.No.	Domestic Load	Rating/Remarks
1	Incandescent lamp	100W
2	CFL lamp	Phillips 8W
3	CFL lamp	Surya 15W
4	LED bulb	Crown 7W
5	LED bulb	Crown 12W
6	LED bulb	Ever ready 3W
7	LED bulb	Ever ready 7W
8	LED bulb	Ever ready 15W

9	LED bulb	Scolar 5W
10	Laptop Charger	Dell Make 90W
11	Fan Regulator	Measured for 5 different speeds

Table (1) Domestic loads considered

Incandescent load is taken for reference as we know that the harmonics induced by incandescent lamp is negligible. The electronic ballast of CFL lamps cause harmonics. CFL lamps of two brands are considered. LED lamps is replacing all other lamps in lighting sector since power conserved is very high. LED lamps of different brands and ratings are considered for comparison. Desktops are being replaced by laptops. So a laptop charger which causes harmonics is considered. Conventional fan regulators is being replaced by electronic regulators. The performance of this regulator at five different speeds are considered.

Each of these devices are operated separately for 3 minutes and the reading are recorded continuously. The average of these readings are taken and recorded as shown in table (2).

Consolidated table showing the harmonics contents of the domestic appliances considered

Sl.No.	Device	Voltage	Current mA(RMS)	THD	IHD 1	IHD 3	IHD 5	IHD 7	IHD 9
1	100W Incandescent	236.925	451.783	1%	100%	1%	0%	0%	0%
2	8W CFL Phillips	238.057	43.333	25%	100%	18%	4%	15%	5%
3	15 W CFL SURYA	236.168	60.998	27%	100%	19%	3%	16%	5%
4	7 W LED CROWN	236.869	107.850	24%	100%	15%	11%	8%	7%
5	12W LED CROWN	237.386	110.077	25%	100%	17%	13%	9%	5%
6	3W LED Everready	237.291	20.774	17%	100%	15%	7%	4%	3%
7	7W LED EVERREADY	237.103	39.497	13%	100%	10%	6%	5%	4%
8	15W LED Everready	237.992	77.238	26%	100%	21%	7%	10%	4%
9	5W LED Scholar	233.188	74.680	19%	100%	11%	8%	9%	8%
10	Laptop Charger	237.152	294.776	165%	100%	90%	83%	73%	63%
11	Fan low Speed	104.559	260.138	94%	100%	76%	43%	23%	20%
12	Fan second speed	118.207	277.768	86%	100%	72%	36%	20%	19%
13	Fan third speed	137.554	301.558	74%	100%	64%	26%	19%	15%
14	Fan fourth speed	181.927	351.314	50%	100%	43%	16%	14%	10%
15	Fan High Speed	224.050	393.846	15%	100%	9%	8%	6%	4%

Table (2) Consolidated readings

3.4 Design of Passive shunt Filter

For any selected harmonic, eg 3rd harmonic, the series combination of inductor and capacitor is tuned and this acts as a low impedance path for that harmonic(3rd in this case). The size of the capacitor is calculated from the reactive power requirement (Q_c) of the load.

The absolute value of capacitance (C_n) is calculated as

$$C_n = \frac{Q_c}{m\omega V_s^2} \quad (1)$$

Where m is the number of branches in the passive filter for all the phases, V_s is per-phase fundamental voltage across it and ω is the fundamental frequency of the supply.

The inductance of the n^{th} order filter is calculated as

$$L_n = \frac{1}{n^2\omega^2 C_n} \quad (2)$$

The series resistance for the inductor of the n^{th} order filter is calculated as

$$R_{n=} = \frac{n\omega L_n}{Q_n} \quad (3)$$

Where Q_n is the quality factor of the inductor of the n^{th} order filter, which is normally considered as $10 < Q < 100$.

3.5 Modelling, Simulation and Performance of Passive Power filter

In order to check the effectiveness and presence of resonance, the filters are connected in the system configuration and waveform analysis is done through simulation using Matlab Simulink. Matlab Simulink is the most versatile software for FFT analyzing using Powergui feature.

Based on the result obtained from Lab-view, average values of 3rd, 5th, 7th and 9th harmonic content is considered. The percentage content of higher harmonics were found to be negligible. Hence those harmonics are not considered. Harmonic current sources are created in Simulink based on the average values. The combined effect of this is considered for designing the filter. Separate filter branches are designed for each harmonic. Current waveforms are analysed before and after the insertion of the filter. Total FFT is analysed using Powergui feature of Simulink.

3.6 Generation of harmonic source

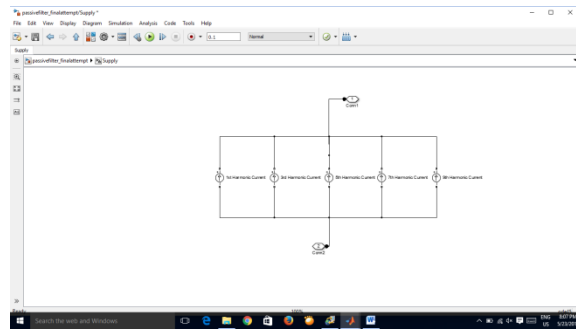


Fig 3 Generation of harmonic sources

Based on the average values of harmonics generated, harmonic source is created using Matlab Simulink as shown in Fig (3). This harmonic source is considered as source for measurement of harmonics and its reduction using passive filters as shown in Fig (4).

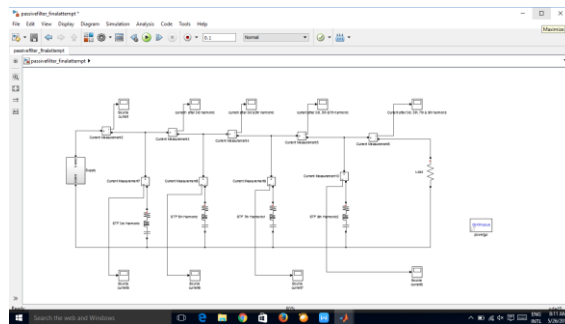
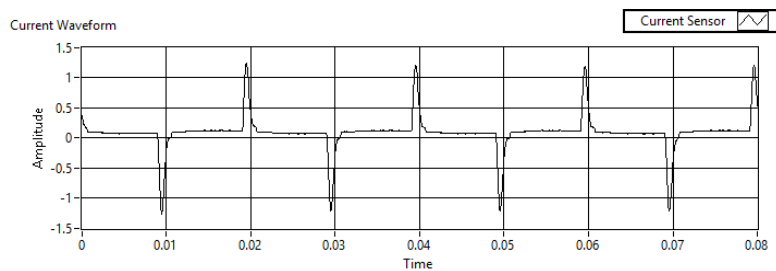


Fig 4 Circuit for measurement of harmonics

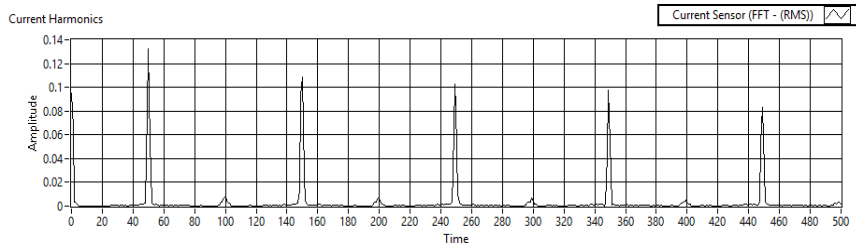
IV RESULTS

Laptop Charger

4.1 Current Waveform



4.2 FFT



4.3 Readings

Laptop Charger								
Sl. No.	Voltage	Current mA (RMS)	THD	IHD 1	IHD 3	IHD 5	IHD 7	IHD 9
1	237.273	285.449	161.93%	100.00%	89.41%	81.97%	71.80%	60.77%
2	237.286	298.013	164.63%	100.00%	89.95%	82.89%	73.13%	62.72%
3	237.400	302.732	165.94%	100.00%	89.83%	83.09%	73.83%	63.99%
4	236.933	289.058	163.07%	100.00%	89.41%	82.23%	72.36%	61.83%
5	236.867	298.630	167.03%	100.00%	89.72%	83.31%	74.47%	65.03%
Avg	237.152	294.776	165%	100%	90%	83%	73%	63%

Looking into the consolidated table, it is seen that harmonics in case of laptop charger is highest with a total harmonic distortion of 165%. Hence a filter is designed for lap top charger.

$$\text{Apparent Power} = V_s \times I = 237.152 \times 294.776 \times 10^{-3}$$

$$= 69.906 \text{ volt-amperes.}$$

$$\text{Real Power} = 60.327 \text{ Watts}$$

$$\text{Reactive Power} = \sqrt{(\text{Apparent power} - \text{Real power})^2}$$

$$= \sqrt{69.906^2 - 60.327^2}$$

$$= 35.319 \text{ VAR reactive}$$

$$C_n = \frac{Q_c}{mWV_s^2} = \frac{35.319}{2 \times 2 \times 3.14 \times 50 \times 237.152^2} = 1 \times 10^{-6} \text{ Farad}$$

For 3rd harmonic

$$L_n = \frac{1}{n^2 \omega^2 C_n} = \frac{1}{3^2 \times 314^2 \times 1 \times 10^{-6}} = 1.126 \text{ henry}$$

$$R_n = \frac{n \omega L_n}{Q_n} = \frac{3 \times 314 \times 1.126}{100} = 10.6 \text{ ohm}$$

For 5th harmonic

$$L_n = \frac{1}{n^2 \omega^2 C_n} = \frac{1}{5^2 \times 314^2 \times 1 \times 10^{-6}} = 0.40536 \text{ henry}$$

$$R_n = \frac{n \omega L_n}{Q_n} = \frac{5 \times 314 \times 0.40536}{100} = 6.364 \text{ ohm}$$

For 7th harmonic

$$L_n = \frac{1}{n^2 \omega^2 C_n} = \frac{1}{7^2 \times 314^2 \times 1 \times 10^{-6}} = 0.20681 \text{ henry}$$

$$R_n = \frac{n \omega L_n}{Q_n} = \frac{7 \times 314 \times 0.20681}{100} = 4.545 \text{ ohm}$$

For 9th harmonic

$$L_n = \frac{1}{n^2 \omega^2 C_n} = \frac{1}{9^2 \times 314^2 \times 1 \times 10^{-6}} = 0.125 \text{ henry}$$

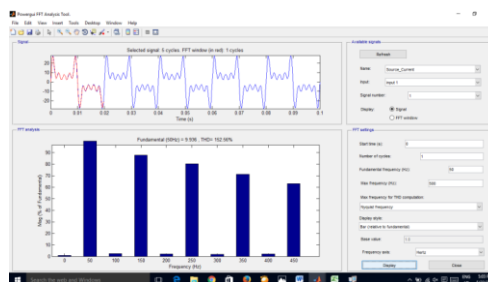
$$R_n = \frac{n \omega L_n}{Q_n} = \frac{9 \times 314 \times 0.125}{100} = 3.5325 \text{ ohm}$$

Filters are designed using the above values.

V ANALYSIS

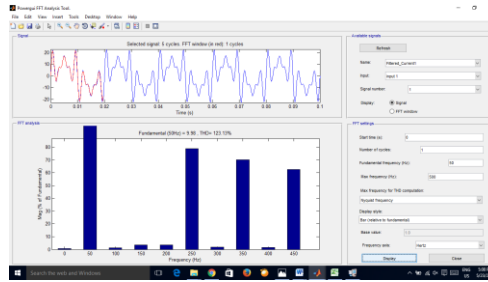
Laptop charger was considered as the THD of it is higher compared to all other devices Individual harmonic distortion and total harmonic distortion is measured at various points of the circuit, like before the insertion of the filter and after the insertion of each of the above designed filter, using Powergui feature of Matlab Simulink.

5.1 Source current along with harmonics- FFT Analysis



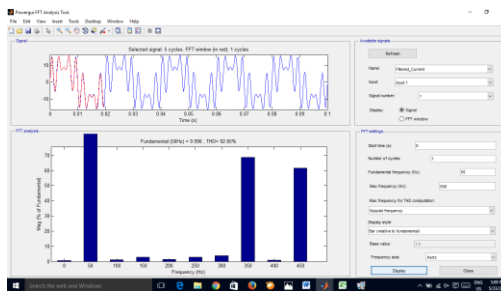
Total harmonics distortion is found to be 152.66%

5.2 Output after removal of 3rd harmonic



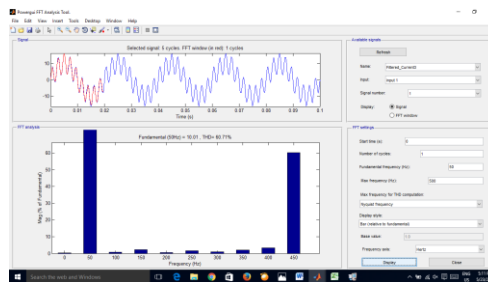
Total harmonic distortion is reduced to 121%

5.3 Output after removal of 3rd and 5th harmonic



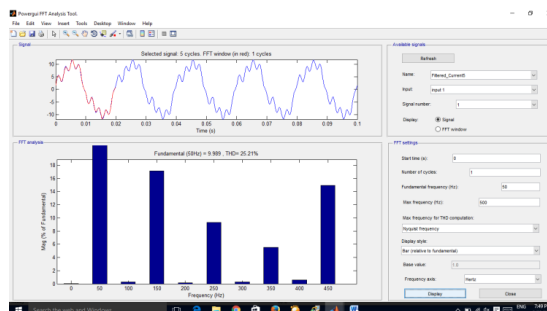
Total harmonic distortion is reduced to 92%

5.4 Output after removal of 3rd, 5th and 7th harmonic



Total harmonic distortion reduced to 60%

5.5 Output after removal of 3rd, 5th, 7th and 9th harmonic



Total harmonic content reduced to 25%

It is observed that the THD has been reduced from 152% to 25%. Hence the overall power quality is improved.

VI Future scope of the work

The harmonics in CFL, LED, Fan regulator and laptop charger is measured individually. The same can be extended to include air conditioner, microwave oven, induction heater, refrigerator etc., Also these devices can be connected in different parallel combination and the total harmonics can be analysed.

Passive filter have been designed here for simplicity. Effects of using active filters can be looked into.

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