B. TECH. PROJECT REPORT

On

Measurement of instantaneous power quality indices

BY

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DISCIPLINE OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Measurement of instantaneous power quality indices

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

Submitted by:

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Guided by:

Dr. Trapti Jain

INDIAN INSTITUTE OF TECHNOLOGY INDORE

DECEMBER 2018

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **Measurement of instantaneous power quality indices** submitted in partial fulfilment for the award of the degree of Bachelor of Technology in Electrical Engineering completed under the supervision of **Dr. Trapti Jain, Associate professor, Department of Electrical Engineering,** IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

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It is certified that the above statement made by the students is correct to the best of my/our knowledge.

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Preface

This report on **Measurement of instantaneous power quality indices** is prepared under the guidance of **Dr. Trapti Jain.**

The aims of the electric power system can be summarized as “to transport electrical energy from the power system or generator units to the terminals of electrical equipment or consumer side” and “to maintain the voltage at the equipment terminals within certain limits”. For decades research and education have been concentrated on the quality of power which is supplied to the customer. Reliability and quality of supply is a major issue. It is clear that the equipment is getting damaged due to the disturbances in power quality. For improvement of the quality of power, electrical utilities must provide a real-time monitoring system that is able to identify the disturbances and providing mitigation techniques to these power quality problems.

Rakesh

B. Tech. IV Year

Discipline of electrical engineering

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Abstract

Power quality has become one of the major concerns in the power industry. Power quality analysis is a good concept that used to evaluate the quality of electrical energy delivered to a customer. Due to the rapid increase in the use of non-linear loads, voltage and current signals are distorted. During the last decade, there has been an increasing focus on power quality (PQ). The aim of the electric power system is to generate electrical energy and to deliver this energy to the end-user equipment at an acceptable voltage. As nonlinear loads draw harmonic and reactive power components of current from ac mains, the quality of power deteriorates. In order to estimate signal spectra and fundamental frequency, current and voltage signals are processed in the first stage of algorithm, whereas in the second stage, the power components and PQ indices such as root mean square (RMS) values, the power factor (PF), the total harmonic distortion factor (THD), active power, reactive power, apparent power, current distortion power, voltage distortion power is calculated based on the results obtained from the first stage.

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Chapter 1

Introduction

1.1 Background

During the last decade, the focus on power quality (PQ) has been increasing. PQ has become one of the major concerns in the power industry. The aim of the electric power system is to generate electrical energy and to deliver this energy to the consumer equipment at an acceptable voltage. As nonlinear loads draw reactive power and harmonic components of current from ac mains, the power quality deteriorates.

1.2 Motivation of Work

The increasing penetration of nonlinear loads and power electronics devices are sources of low electric power quality (PQ). The power system has always had harmonics present in the power industry. Harmonics are present due to the use of nonlinear loads.

Power quality analysis is a good concept that used to evaluate the quality of electrical energy delivered to a customer. The consumer pays more for unused energy due to distortion in both voltage and current.

The electrical grid should be designed in such a way that the supplier is always capable of guaranteeing a certain power quality. When loads are connected the power quality is influenced more or less depending on the electrical network design. The basic parameters for power quality have been identified which can be measured and compared with reference values. The reference values may be absolute values.

The development of numerical algorithms for power quality (PQ) indices measurement has emerged as an important subject in recent years due to high interest in PQ monitoring and novel achievements in the field of producing powerful microprocessors and hardware architectures.

A variety of measurement techniques has been developed and used for PQ assessment. Among them, the fast Fourier transform (FFT) is commonly applied for harmonic components extraction.

Chapter 2
Fast Fourier Transform

2.1 Introduction

The development of the Fast Fourier Transform (FFT) has been quite interesting. The FFT is one of the most important numerical algorithm in science, engineering, and applied mathematics. Fourier analysis converts a signal from its original domain into frequency domain and vice versa. Fast Fourier transforms (FFTs) are fast algorithms and of low complexity, for discrete Fourier transform (DFT) computation.

Discovered by Cooley & Tukey in 1965 and widely adopted thereafter. It took another 160 years until Cooley and Tukey reinvented the FFT. Several scientists developed efficient methods to calculate the DFT, but none of them was success or the one of Cooley and Tukey. The publication by Cooley and Tukey in 1965 of an efficient algorithm for the calculation of the DFT was a major turning point in the development of digital signal processing. During the five or so years that followed, various modifications were made to the original algorithm of FFT. By the early 1970's the practical programs were basically in the forms used today.

The standard development shows how the DFT of a length-N sequence can be simply calculated from the two length-N/2 DFT's of the even index terms and the odd index terms. This is then applied to the two half-length DFT's to give four quarter-length DFT's, and repeated until N scalars are left which are the DFT values. Because of alternately taking the even and odd index terms, two forms of the resulting programs are called decimation-in-time and decimation-in-frequency. For a length of 2M, the dividing process is repeated $M = \log_2 N$ times and requires N multiplications each time. This gives the famous formula for the computational complexity of the FFT of $N\log_2 N$. The decimation methods are straightforward and easy to understand.

2.2 FFT Algorithm

The FFT is a fast algorithm for computing the DFT. If we take the 2-point DFT and 4-point DFT and generalize them to 8-point, 16-point… 2^r-point, we get the FFT algorithm. To compute the DFT of an N-point sequence would take N^2 multiplies and adds. The FFT algorithm computes the DFT using $N\log_2 N$ multiplies and adds. There are many variants of the FFT algorithm. We'll discuss one of them, the "decimation-in-time" FFT algorithm for sequences whose length is a power of two ($N = 2^r$ for some integer r).

The Discrete Fourier Transform (DFT) is the equivalent of the continuous Fourier Transform for signals known only at N instants separated by sample time T (i.e. a finite sequence of data).

Let x (t) be the continuous signal which is the source of the data. Let N samples be denoted X [0], X [1], X [2] . . . X[n] . . . X [N-1].

$$X[k] = \sum_{n=0}^{N-1} X[n]\, e^{-j\left(\frac{2\pi}{N}\right)kn} \cdots\cdots (1)$$

$$X[n] = \frac{1}{N}\sum_{K=0}^{N-1} X[k]\, e^{j\left(\frac{2\pi}{N}\right)kn} \cdots\cdots (2)$$

i.e. the inverse matrix is $\frac{1}{N}$ times the complex conjugate of the original (symmetric) matrix.

Note: X [K] coefficients are complex.

Highly efficient computer algorithms for estimating Discrete Fourier Transforms have been developed since the mid - 60's. These are known as Fast Fourier Transform (FFT) algorithms and they rely on the fact that the standard DFT involves a lot of redundant calculations:

Re-writing $X[k] = \sum_{n=0}^{N-1} X[n]\, e^{-j\left(\frac{2\pi}{N}\right)kn}$

As $$X[k] = \sum_{n=0}^{N-1} X[n]\, W_N^{nk} \cdots\cdots\cdots \quad (3)$$

2.2.1 Decimation-in-time algorithm

Let us begin by splitting the single summation over N samples into 2 summations, each with $\frac{N}{2}$ samples, one for n even and the other for n odd.

Substitute $m = \frac{n}{2}$ for even and $m = \frac{n-1}{2}$ for odd and write:

$$X[k] = \sum_{m=0}^{\frac{N}{2}-1} X[2m]\, W_N^{2m} + \sum_{m=0}^{\frac{N}{2}-1} X[2m+1]\, W_N^{(2m+1)k}$$

Note that $W_N^{2mk} = e^{-j\frac{2\pi}{N}(2mk)} = e^{-j\frac{2\pi}{\frac{N}{2}}(mk)} = W_{\frac{N}{2}}^{mk}$

Therefore $X[k] = \sum_{m=0}^{\frac{N}{2}-1} X[2m]\, W_{\frac{N}{2}}^{mk} + \sum_{m=0}^{\frac{N}{2}-1} X[2m+1]\, W_{\frac{N}{2}}^{mk} W_N^k$

$$X[k] = \sum_{m=0}^{\frac{N}{2}-1} X[2m]\, W_{\frac{N}{2}}^{mk} + W_N^k \sum_{m=0}^{\frac{N}{2}-1} X[2m+1]\, W_{\frac{N}{2}}^{mk}$$

i.e. $X[k] = G[k] + W_N^k H[k]$

Thus the N-point DFT X[k] can be obtained from two $\frac{N}{2}$ - point transforms, one on even input data, G[k] and one on odd input data, H[k].

For Example, for N = 8:

- Even input data X [0], X [2], X [4], X [6].
- Odd input data X [1], X [3], X [5], X [7].

$$X[0] = G[0] + W_8^0 H[0]$$
$$X[1] = G[1] + W_8^1 H[1]$$
$$X[2] = G[2] + W_8^2 H[2]$$
$$X[3] = G[3] + W_8^3 H[3]$$
$$X[4] = G[4] + W_8^4 H[4] = G[0] - W_8^0 H[0]$$
$$X[5] = G[5] + W_8^5 H[5] = G[1] - W_8^1 H[1]$$
$$X[6] = G[6] + W_8^6 H[6] = G[2] - W_8^2 H[2]$$
$$X[7] = G[7] + W_8^7 H[7] = G[3] - W_8^3 H[3]$$

This is shown graphically on the flow graph of Fig 2.1

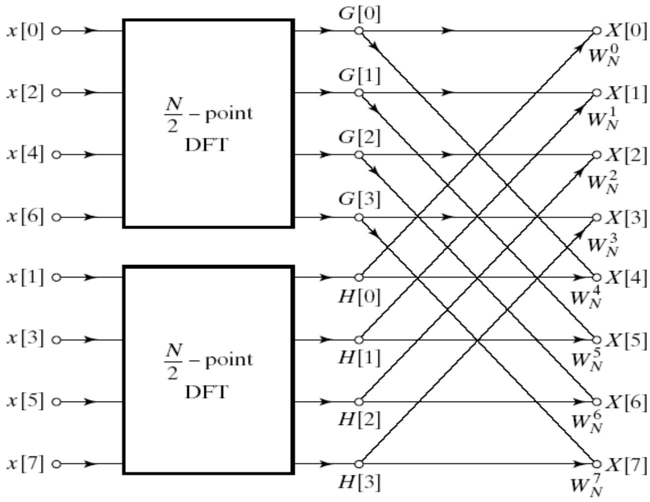

Figure 2.1: FFT flow graph 1.

The FFT is computed by dividing up or *decimating*, the sample sequence X [n] into sub-sequences until only 2-point DFT's remain. Since it is the input, or time, samples which are divided up, this algorithm is known as the decimation-in-time (DIT) algorithm. (An equivalent algorithm exists for which the output, or frequency, points are sub-divided – the decimation-in-frequency algorithm.)

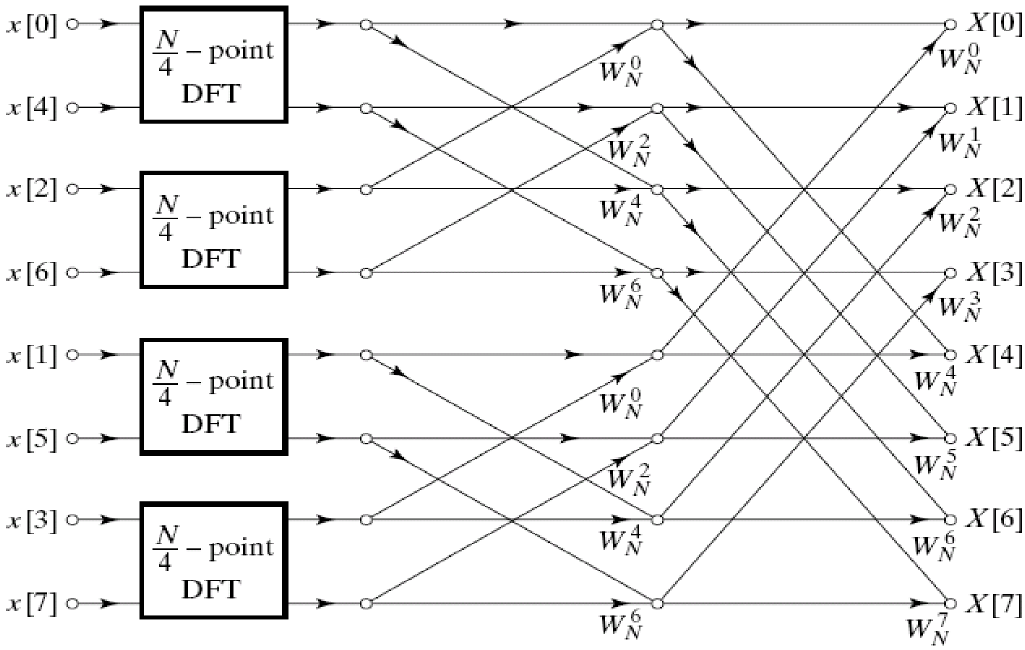

Figure 2.2: FFT flow graph 2

The basic computation at the heart of the FFT is known as the *butterfly* because of its criss-cross appearance. For the DIT FFT algorithm, the butterfly computation is of the form of Fig 2.3.

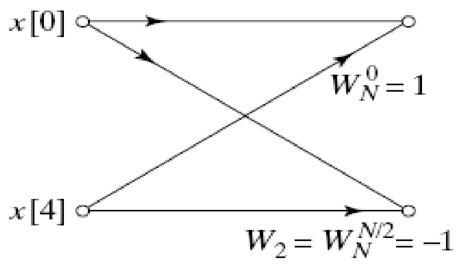

Figure 2.3: Butterfly operation in FFT

Thus a butterfly computation requires one complex multiplication and 2 complex additions. Note also, that the input samples are "bit-reversed" (see table below) because at each stage of decimation the sequence input samples are separated into even- and odd- indexed samples. The bit-reversal algorithm only applies if N is an integral power of 2.

The binary representation of 3 is (011) and the bit-reversed binary is 6 (110).

Chapter 3

Power Quality

3.1 Introduction

Electrical Power Quality is the study of how close to the ideal sinusoid the voltage and current waveforms are. In reality, the Voltage Quality is of most concern as it is through the terminal voltage that the devices interact. Disturbance in the current, that flowing through the system and its impedance, results in poor voltage quality. The power system has always had harmonics present due to non-linear loads. Due to their non-linearity, all these loads cause disturbances in the voltage waveform. Power quality problems are defined as the deviation of voltage or current waveforms from the ideal value.

PQ mainly deal with:-

1 Continuity of supply.

2 Quality of voltage.

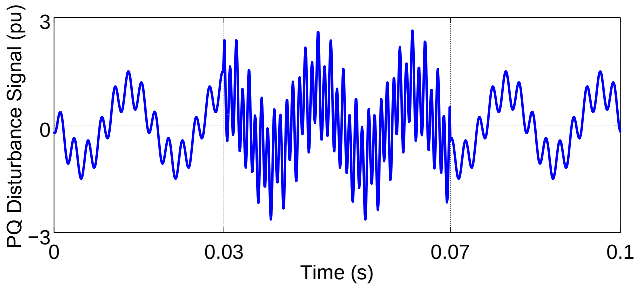

Figure 3.1: A nonstationary PQ disturbance signal comprised of 50 Hz, 3rd, 5th, 7th and higher order harmonic components. *[3]*

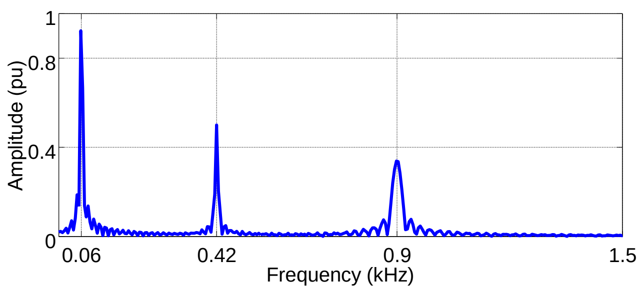

Figure 3.2: FFT of the nonstationary PQ disturbance signal. *[3]*

3.2 Non-Linear Loads and Harmonics

In AC power distribution systems, harmonics occur when the normal electric current waveform is distorted by non-linear loads.

Linear Loads:-

- A linear load is one where voltage (a sine wave) is applied across a constant resistance resulting in current (another sine wave).
- Impedance is constant.
- Current is proportional to the Voltage.

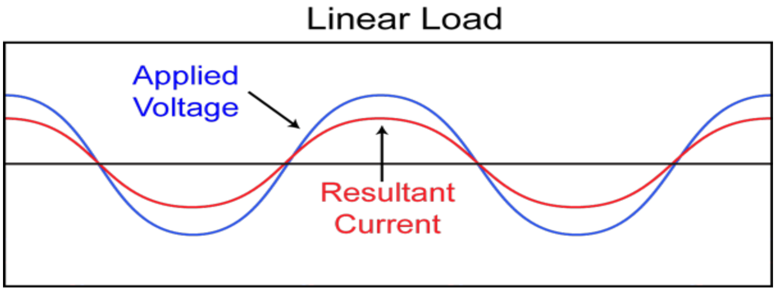

Figure 3.3. Linear load sine wave. *[4]*

Non-Linear Loads:-

- A **load** is considered **non-linear** if its impedance changes with the applied voltage.
- Impedance is not constant.
- Current is not proportional to the Voltage.
- The changing impedance means that the current drawn by the **non-linear load** will not be sinusoidal even when it is connected to a sinusoidal voltage.
- Due to their non-linearity, all these loads cause disturbances in the voltage waveform.

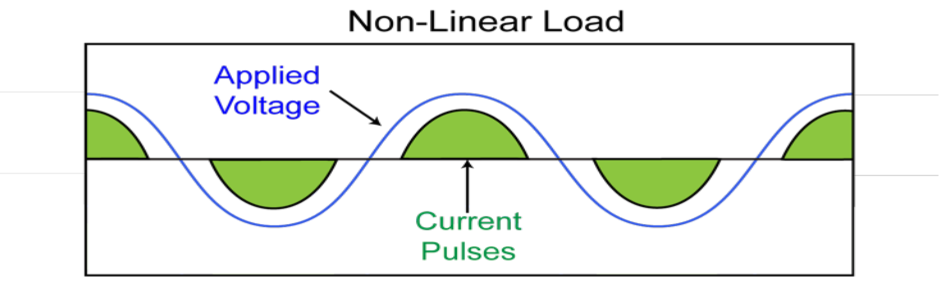

Figure 3.4. Non-linear load current pulses. *[4]*

Harmonics

Harmonics are defined as positive integer multiples of the fundamental frequency.

1. Even harmonics
2. Odd harmonics

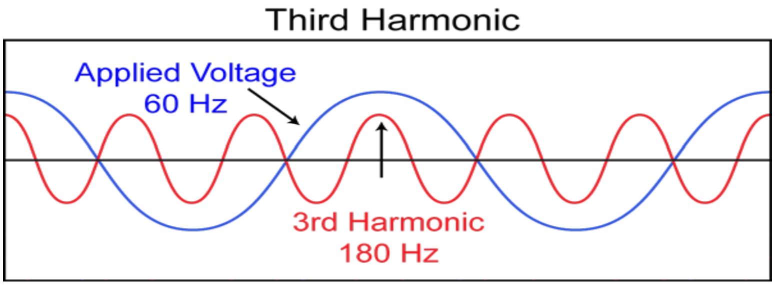

Figure 3.5.Third harmonic *[4]*

3.3 Power Quality Component

1. RMS values of voltages and currents:-

$$I_{mrs} = \sqrt{(I_1^2 + \sum_{k \neq 1} I_k^2)} = \sqrt{(I_1^2 + I_H^2)}$$

$$V_{mrs} = \sqrt{(V_1^2 + \sum_{k \neq 1} V_k^2)} = \sqrt{(V_1^2 + V_H^2)}$$

2. Total harmonic distortion factors for voltage and current:-

$$V_{thd} = \frac{V_H}{V_1} \quad , \quad I_{thd} = \frac{I_H}{I_1}$$

3. Current distortion power:-

$$D_i = V_1 I_H$$

4. Voltage distortion power:-

$$D_v = V_H I_1$$

5. Active power:-

$$P = P_1 + P_H = V_1 I_1 cos\theta_1 + \sum_{k\neq 1} V_k I_k cos\theta_k$$

6. Reactive power:-

$$Q = Q_1 + Q_H = V_1 I_1 sin\theta_1 + \sum_{k\neq 1} V_k I_k sin\theta_k$$

7. Fundamental apparent power:-

$$S = V_1 I_1$$

8. Non-fundamental power :-

$$S_N = \sqrt{D_i^2 + D_v^2 + S_H^2}$$

9. Total Apparent power(S):-

$$S = V_{rms} I_{rms}$$

10. Power factor:-

$$\mathrm{PF} = \frac{P}{S}$$

Chapter 4

Design and Tools Used

In order to estimate signal spectra and fundamental frequency, current and voltage signals are processed in the first algorithm stage, whereas in the second stage, the power components and PQ indices are calculated based on the results obtained from the first stage.

In the first stage of the algorithm, two 50Hz and 3rd, 5th, 7th, &9th order harmonics signal taken. The sampling frequency was taken at 1600 Hz. And 9 stage FFT calculated.

In the second algorithm stage, the unknown PQ indices, such as root mean square (RMS) values, the power factor (PF), the total harmonic distortion factor (THD), active power, reactive power, apparent power, current distortion power, voltage distortion power, etc. are calculated and compared with reference values which is obtained on Matlab.

4.1 Logic Flow Chart

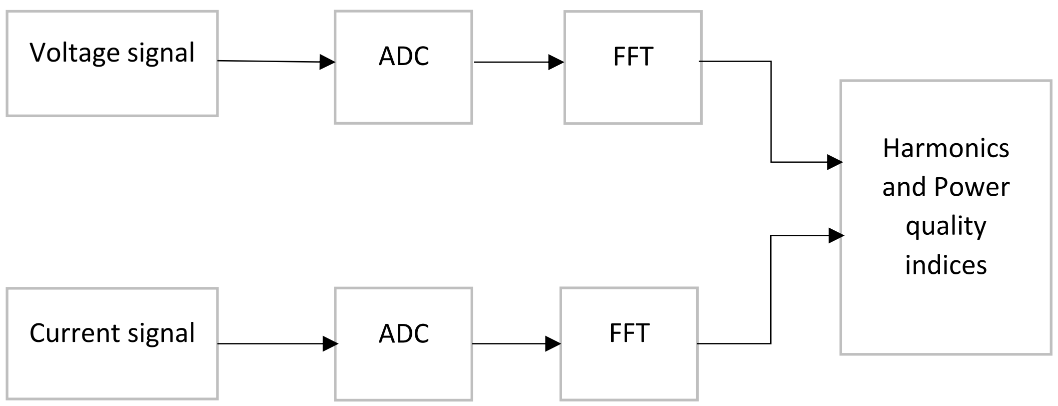

Figure 4.1: Design Flow Chart

4.2 EXPERIMENTAL SETUP

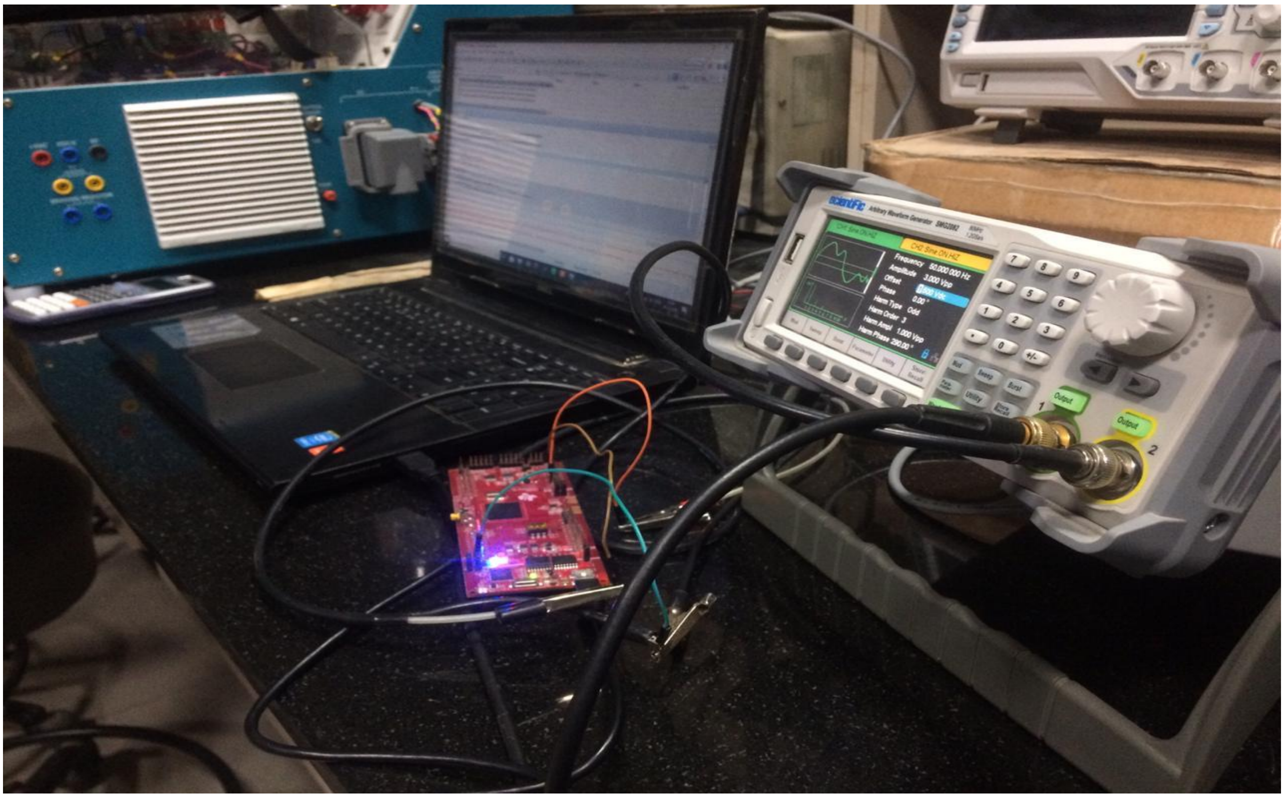

Figure 4.2: Experimental setup

4.3 Tools Used

Software

- MatLab: - It is using for simulation purpose and taking their data as a reference values.
- Code Composer Studio: - It is using for implementing FFT based algorithm for finding the harmonics and measurement PQ indices.

Board

- TMS320f28379D Digital Signal Controller

TMS320f28379D Digital Signal Controller

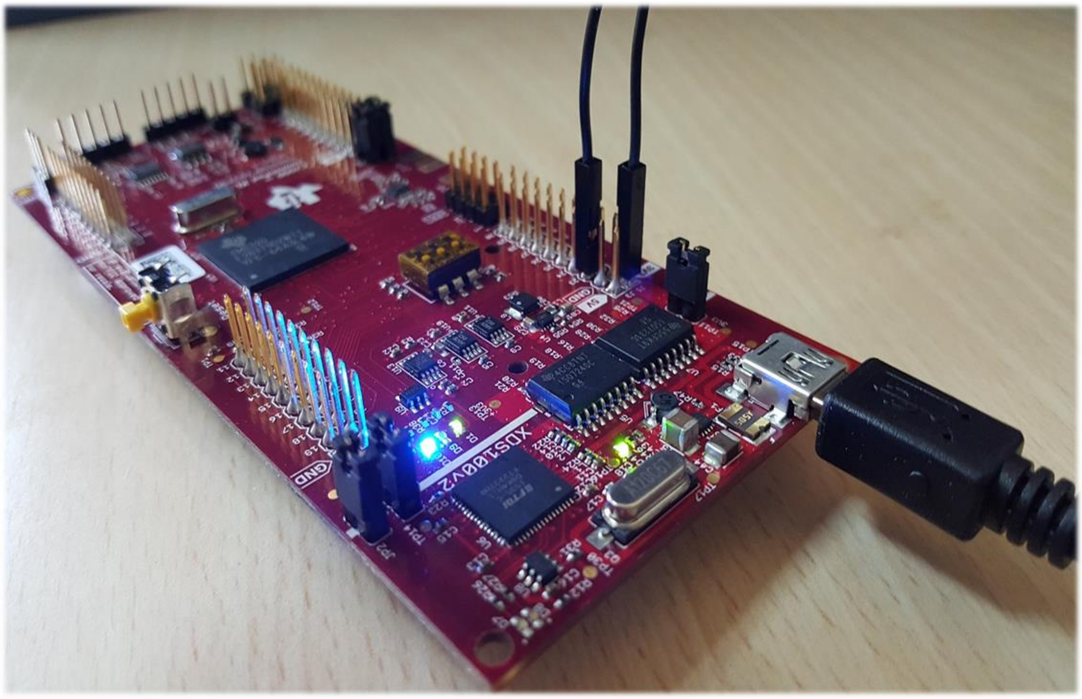

Figure 4.3: TMS320f28379D Digital Signal Controller

- **It has Two TMS320C28x 32-Bit CPUs.**
- **Both are working on 100 MHz frequency.**
- **On-Chip Memory (1MB of Flash and 204KB RAM).**
- **We can Apply3.3-Volt I/O signals.**
- **It has four Analog-to-Digital Converters (ADCs).**
- **Three DAC Outputs.**

Chapter 5

Observation and Analysis

Most countries use **50Hz** (**50 Hertz** or **50** cycles per second) as the AC frequency signal. The voltage and frequency of **AC** electricity varies from country to country throughout the world. Most of the countries use 220V and 50Hz Voltage signal. 50Hz voltage signal and current signal are shown in figure 5.1 and figure 5.2.

5.1 Fundamental Signals Waveform

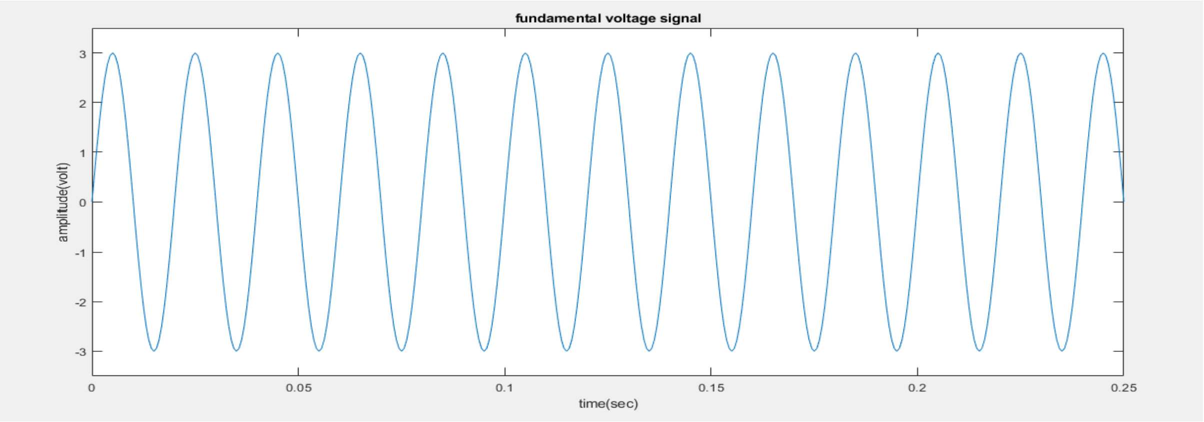

Figure 5.1: Fundamental Voltage Signal of 50 Hz.

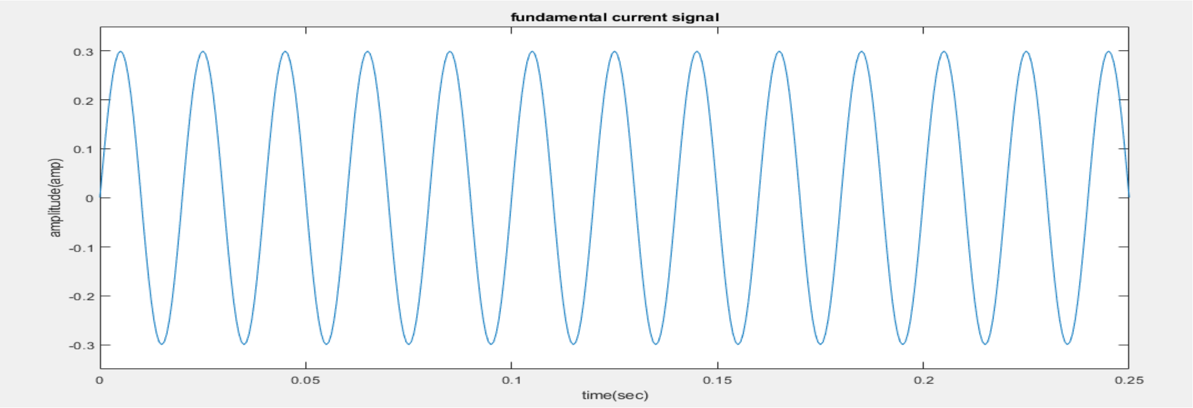

Figure 5.2: Fundamental Current Signal of 50 Hz.

5.2 Distorted Signals Waveform

Nowadays Power Quality is disturbed because the excessive use of power electronic devices are used in power system. Due to the use of electronic devices voltage and current signal are distorted because the harmonics are introduced in the power system. When harmonics are added in a signal the waveform of the signal has changed. Figure 5.3 and figure 5.4 are distorted signal waveform.

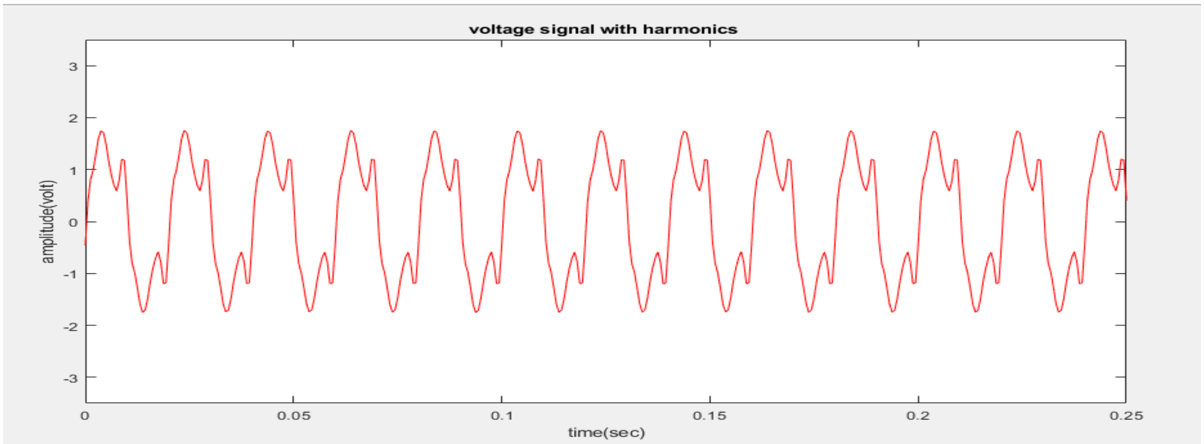

Figure 5.3: Distorted Voltage signal

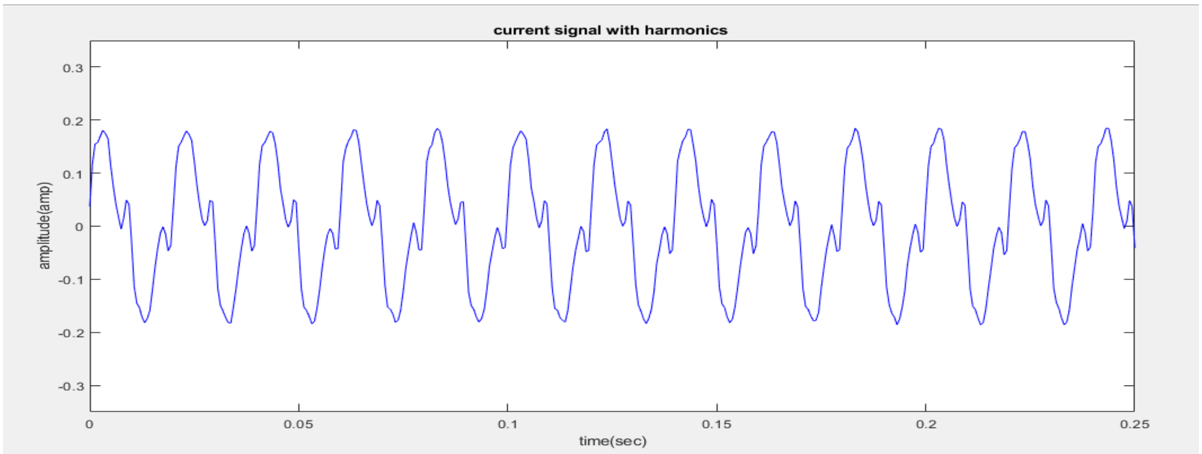

Figure 5.4: Distorted Current signal

5.3 FFT of Distorted Wave

Frequency resolution is the distance in Hz between two adjacent data points in the DFT. The frequency resolution of a DFT is defined as Fr=Fs/N. Where Fs is the sampling rate and N is the number of data points. The denominator can be expressed in terms of sampling rate and time,

N=Fs*t

*Fr = Frequency resolution

*Fs = Sampling Frequency which is 1.6k Hz.

*N = Number of data points

For extracting fundamental, 3rd, 5th, 7th, 9th, harmonics 512 (9 stages) FFT is calculating. In below given FFT is shows both the FFT output comes from Matlab and Code Composer Studio.

$$Fr = \frac{Fs}{N}$$

$$Fr = \frac{1600}{512} = 3.125$$

For 50Hz fundamental frequency FFT output gives the peak at 16 number data.
Similarly for 3rd, 5th, 7th, 9th order harmonics the peak is on 48, 80, 112, 144.

512 point FFT plots for Voltage and Current signal are given in figure 5.5 and figure 5.6.

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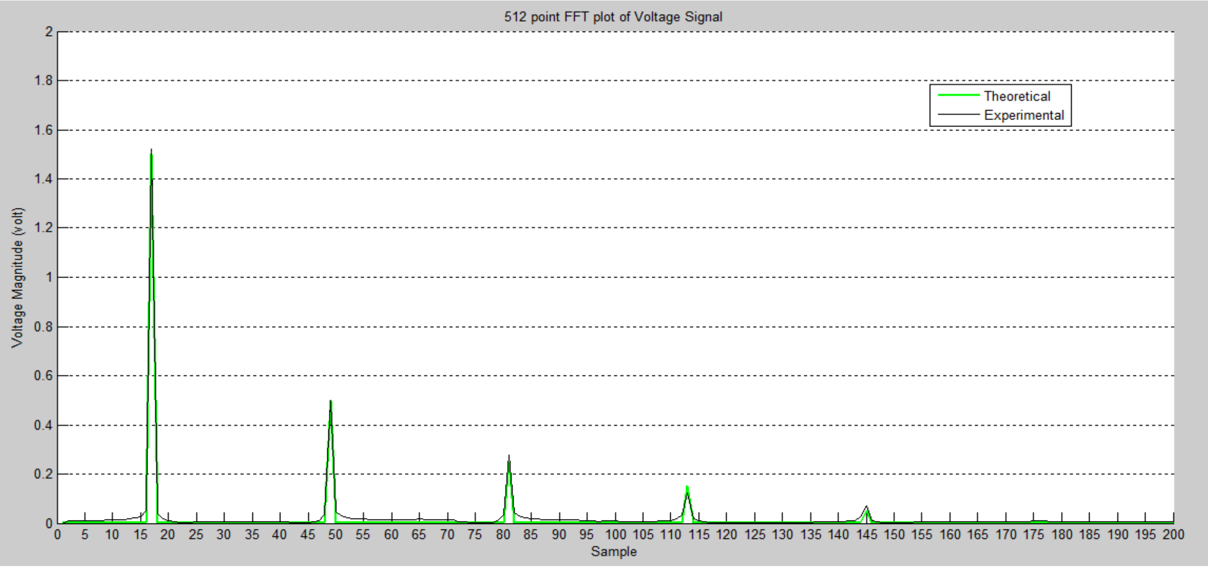

Figure5.5: 512 point FFT for Voltage Signal

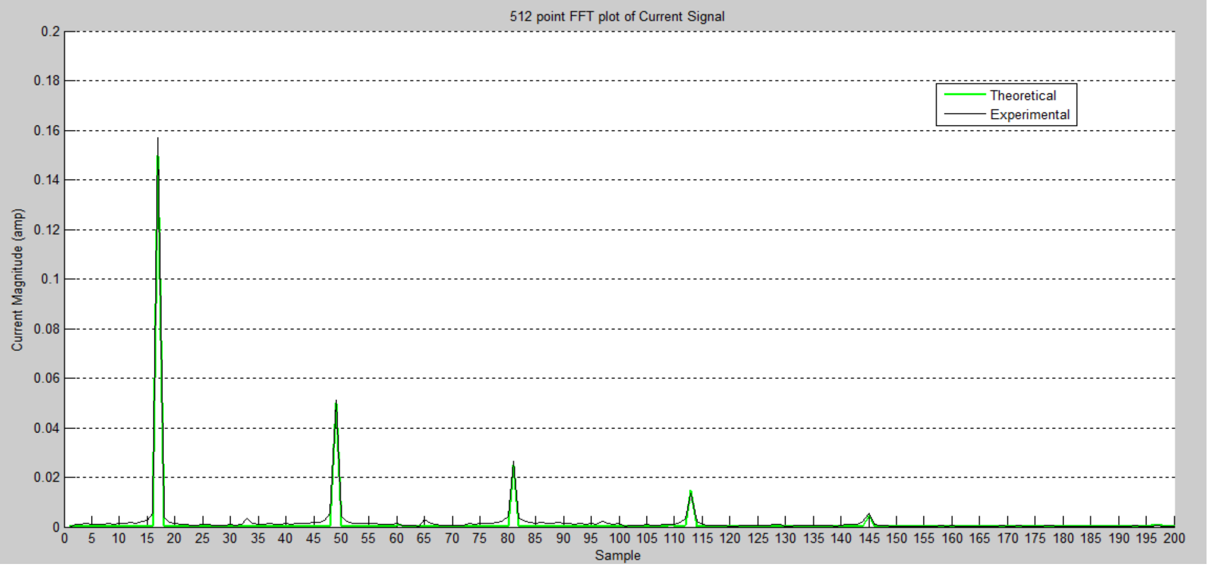

Figure 5.6: 512 point FFT for Current Signal

5.4 PQ indices Parameter

5.4.1 Voltage Signal parameters

	Matlab	Experimental	Relative % Errors
fundamental Vrms (volt)	1.0606	1.0233	3.52
3rd harmonics Vrms (volt)	0.3539	0.3298	6.81
5th harmonics Vrms (volt)	0.1768	0.184	4.07
7th harmonics Vrms (volt)	0.106	0.0913	13.87
9th harmonics Vrms (volt)	0.0354	0.0532	50.28
Total harmonics Vrms (volt)	0.4111	0.3922	4.6
Total Vrms (volt)	1.137	1.095	3.65
Voltage harmonic distortion (VHD)	0.3876	0.3832	1.14

5.4.2 Current Signal parameters

	Matlab	Experimental	Relative % Errors
fundamental Irms (Amp)	0.1062	0.1043	1.79
3rd harmonics Irms (Amp)	0.0355	0.0347	2.25
5th harmonics Irms (Amp)	0.0176	0.0179	0.57
7th harmonics Irms (Amp)	0.0105	0.0096	8.57
9th harmonics Irms (Amp)	0.0033	0.004	21.21
Total harmonics Irms (Amp)	0.0412	0.0404	1.94
Total Irms (Amp)	0.113	0.1119	1.76
Current harmonic distortion (IHD)	0.3879	0.3873	0.16

5.4.3 Active Power Parameters

	Matlab	Experimental	Relative % Errors
fundamental Power (Watts)	0.09756	0.10398	6.58
3rd harmonics Power (Watts)	0.01238	0.01045	15.58
5th harmonics Power (Watts)	0.00315	0.00306	2.86
7th harmonics Power (Watts)	0.00112	0.00077	31.25
9th harmonics Power (Watts)	0.00011	0.00019	72.72
Total harmonics Power (PH) (Watts)	0.01676	0.01447	13.66
Total Power (P) (Watts)	0.11432	0.1119	3.61

5.4.4 Reactive Power Parameters

	Matlab	Experimental	Relative % Errors
fundamental Power (VAR)	0.05628	0.02407	57.23
3rd harmonics Power (VAR)	0.00212	0.00379	78.77
5th harmonics Power (VAR)	0.00005	0.00004	20
7th harmonics Power (VAR)	0.00001	0.000015	50
9th harmonics Power (VAR)	0.00002	0.00003	50
Total harmonics Power (QH) (VAR)	0.0022	0.00387	76.13
Total Power (Q) (VAR)	0.05848	0.02795	52.21

5.4.5 Apparent Power Parameter

	Matlab	Experimental	Relative % Errors
fundamental Power (VA)	0.11264	0.10673	5.24
3rd harmonics Power (VA)	0.01256	0.01147	8.67
5th harmonics Power (VA)	0.00315	0.00329	4.44
7th harmonics Power (VA)	0.00112	0.00088	21.42
9th harmonics Power (VA)	0.00012	0.00021	75
Total harmonics Power (SH) (VA)	0.01694	0.01586	6.37
Total Power (S) (VA)	0.12958	0.12258	5.4

5.4.6 Other Parameters

	Voltage distortion Power (Dv) (VA)	Current distortion Power(Di) (VA)	Power factor (pf)
Matlab	0.04365	0.0437	0.8823
Experimental	0.04091	0.04134	0.9653
Relative % Errors	6.28	5.4	9.4

Chapter 6
Conclusion and Future Work

6.1 Conclusion

- The Algorithm has been simulated on MATLAB and successfully implemented on the Digital Signal Controller and the results obtained were in accordance with the results obtained from MATLAB.
- Monitors the unbalance current and voltage in the power signal.
- It is clear from the power quality survey that there is significant economic loss due to poor power quality.
- Save equipment for getting damaged.
- Eliminate harmonics which is present due to the excessive use of non-linear Loads.

6.2 Future Work

- Mitigate the PQ disturbances present in power system.
- It can be used in smart grid for better result.
- And can be used for improving the energy supplied by the generator side.

References

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