B. TECH. PROJECT REPORT

On

Implementation of Single Phase and Three Phase Power Quality Analyser on Simulink Platform

BY

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160002029

DISCIPLINE OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Implementation of Single Phase and Three Phase Power Quality Analyser on Simulink Platform

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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160002029

Guided by:

Dr. Amod C Umarikar

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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CANDIDATE'S DECLARATION

I hereby declare that the project entitled **Implementation of Single Phase and Three Phase Power Quality Analyser on Simulink Platform** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in **ELECTRICAL ENGINEERING** completed under the supervision of **Dr. Amod C Umarikar, Associate Professor, Electrical Engineering Department,** IIT Indore is an authentic work.

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

Signature and name of the student(s) with date

CERTIFICATE by BTP Guide(s)

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

Signature of BTP Guide(s) with dates and their designation

Preface

With great increase in use of power electronic devices, power electronic based equipment and use of different non-linear devices in commercial as well as in industrial sector create disturbance in Power quality. Maintaining the quality of the power supply become a significant concern for both power utilities as well as consumer. Therefore, to monitor and control the power quality it is necessary to have Power quality analyser devices.

It would help mitigate the losses in power systems and constant monitoring would enable protection of power grid and electronic devices connected to it.

Mani Sankar Biswas

B.Tech. IV Year

Discipline of Electrical Engineering

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Mani Sankar Biswas

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CHAPTER 1

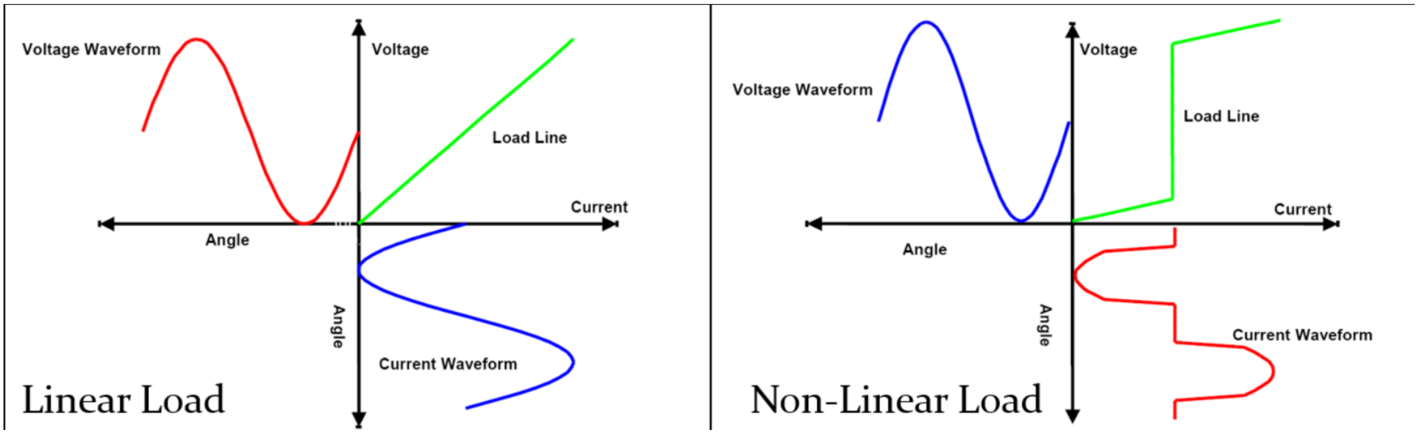
Introduction

Electric devices and Power Transmission Systems have evolved with growing need and dependence of modern industry and society. Harmonics which have always existed in power systems did not create lot of problems in older days when the instruments used were less sophisticated however, due to great increase in use of electronic devices in industries as well as the electronic age household, harmonics present in power system have increased many times. Thus, dealing with problems which arise due to presence of harmonics in power systems are now of utmost significance. A modern power transmission system, thus, needs a system which can be fast and can accurately monitor harmonics present in the power system, so as to enable maximum efficiency in power transfer and usage. Such a system will help in online monitoring of harmonics and would help identify the sources of harmonics and assist in designing of active power filters used to mitigate the harmonics, and metering of harmonics.

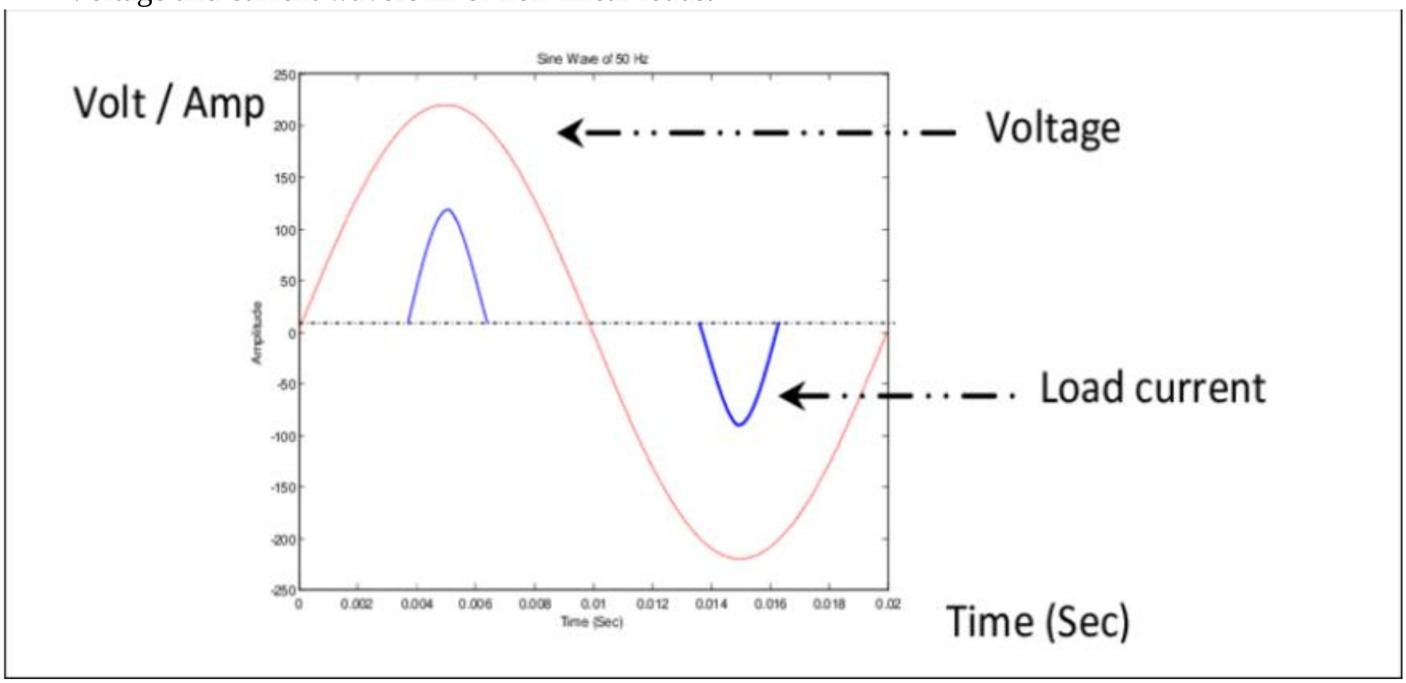
Types of Loads

Non-Linear Load devices, devices in which the current flow is not proportional to the voltage, are primary sources of harmonics. In earlier power systems, Linear Load devices, devices in which the current flow is proportional to voltage, were prevalently used, thus presence of harmonics was negligible. In linear loads, the impedance of the device remains constant despite variation in voltage, thus current drawn by the device for an input sinusoidal wave is a sinusoid. Incandescent lamps, heaters, motors and transformers are examples of linear loads between their work ratings.

In non-linear loads like DC/AC convertors, switch controllers, microprocessor-based devices and arc furnaces, the impedance of the device varies with the applied voltage, hence the current through such a device when a sinusoidal voltage is applied to it, though periodic is not of sinusoidal nature. This distortion in current contributes power wastage which greatly increases the power loss compared to that of loss due Linear Load devices.



Voltage and current waveform of non-linear loads.



What are harmonics?

As per IEEE-519 standard,

"Harmonics are sinusoidal component of a periodic wave or quantity (voltages or currents) operate at a frequency that is an integer (whole- number) multiple of the fundamental frequency" (50Hz in India) for example, 3rd harmonic would have frequency of 150Hz and 5th Harmonic would have frequency Individual harmonics frequency will vary in phase as well as amplitude depending upon the source which generates it.

These additional frequencies distort the original signal waveform and lead to undesirable impacts. We mainly focus only on the odd harmonics as even harmonics cancel themselves out and thus do not contribute much to distortion.

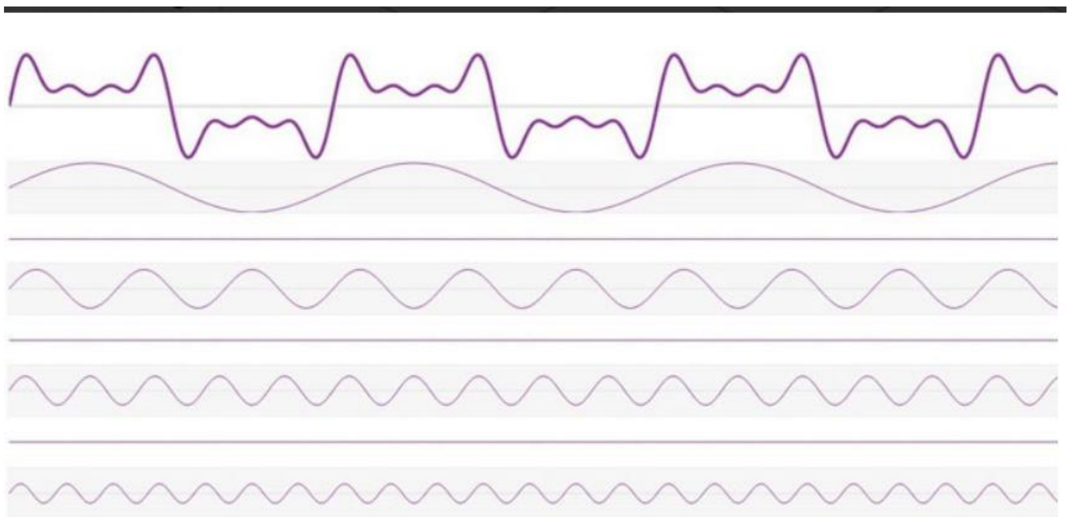
Modulated Signal

Fundamental Signal(50Hz)

3rd harmonic

5th Harmonic

7th Harmonic



Harmonics originate as currents but generate harmonic voltages as they flow through the impedances in the system. While investigating any problems which may be due to harmonics knowing the harmonic spectrum of the signal is of utmost importance as harmonic spectrum displays the magnitudes of various harmonics constituted in the distorted signal.

Total Harmonic Distortion is the ratio of the power of harmonic components to the power of fundamental frequency component. It is used to measure the wave-shape distortion of original wave.It gives a good estimate of how much energy is wasted when the distorted waveform is applied across a resistive load.

Systems which use non-linear devices, all contribute to creation of harmonics. Uninterruptible power supplies, Microcontroller based devices and variable speed motor drives which are indispensable to the industry are main contributors to harmonics. Domestic appliances like TV sets, Air Conditioners, Washing Machines, Vacuum cleaners, FAX machines and printers also contribute to harmonics.

EFFECTS OF HARMONICS

When non-linear loads constitute more than 20% of the load in a facility, harmonics generated can threaten to disrupt smooth functioning of the facility. Current harmonics can cause issues with distribution equipment and other components of the power system but generally do not cause any problems to the equipment using the supply. They may also lead to excessive heating of transformers.

Voltage harmonics on other hand can affect the equipment connected to the system. Voltage harmonics are able to create sags in voltage supply. The amount of sag depends upon many factors like impedance and wire size. These harmonics thus result into,

- Conductor Over-heating: This problem occurs mainly with neutral conduction in 3 phase systems. Due to imbalance in current caused due to harmonics, despite even harmonics components cancelling each other, the odd harmonics flow through the neutral wire.

- Capacitors: Due to increase in power loss, the capacitor often gets over-heated and it reduces the life of capacitor. If a capacitor is in tune with one of the harmonics then it may lead to dielectric failure.
- Circuit-Breakers: May lead to false tripping of residual current circuit breakers (RCCB). It may lead to spurious operation or trips, which could damage or blow the components for no apparent reasons.
- Transformers and Generators: have increased iron and copper losses which lead to heating of the windings. Sizing and designing thus becomes increasingly important

To mitigate or control the harmonics some measures are: reduce the harmonics of the load, but this is not always possible; Add filters to block the harmonic current from propagating in system; modify the frequency response of filters, capacitors and inductors in the circuit.

However, for any of these methods to be implemented, a system which can accurately measure amplitude of harmonics present is needed. This system should not only be accurate but also be fast and must respond quickly to fluctuations in real time. Such a system would not only help us minimize the losses due to harmonics but would also enable us to have a Distortion Based Tariff System. It would help penalize sources which introduce harmonics and those sources would either have to improve their technology to minimize the harmonics or pay the penalty for introducing them and for their share in distortion of the signal.

CHAPTER 2

Harmonics Analysis

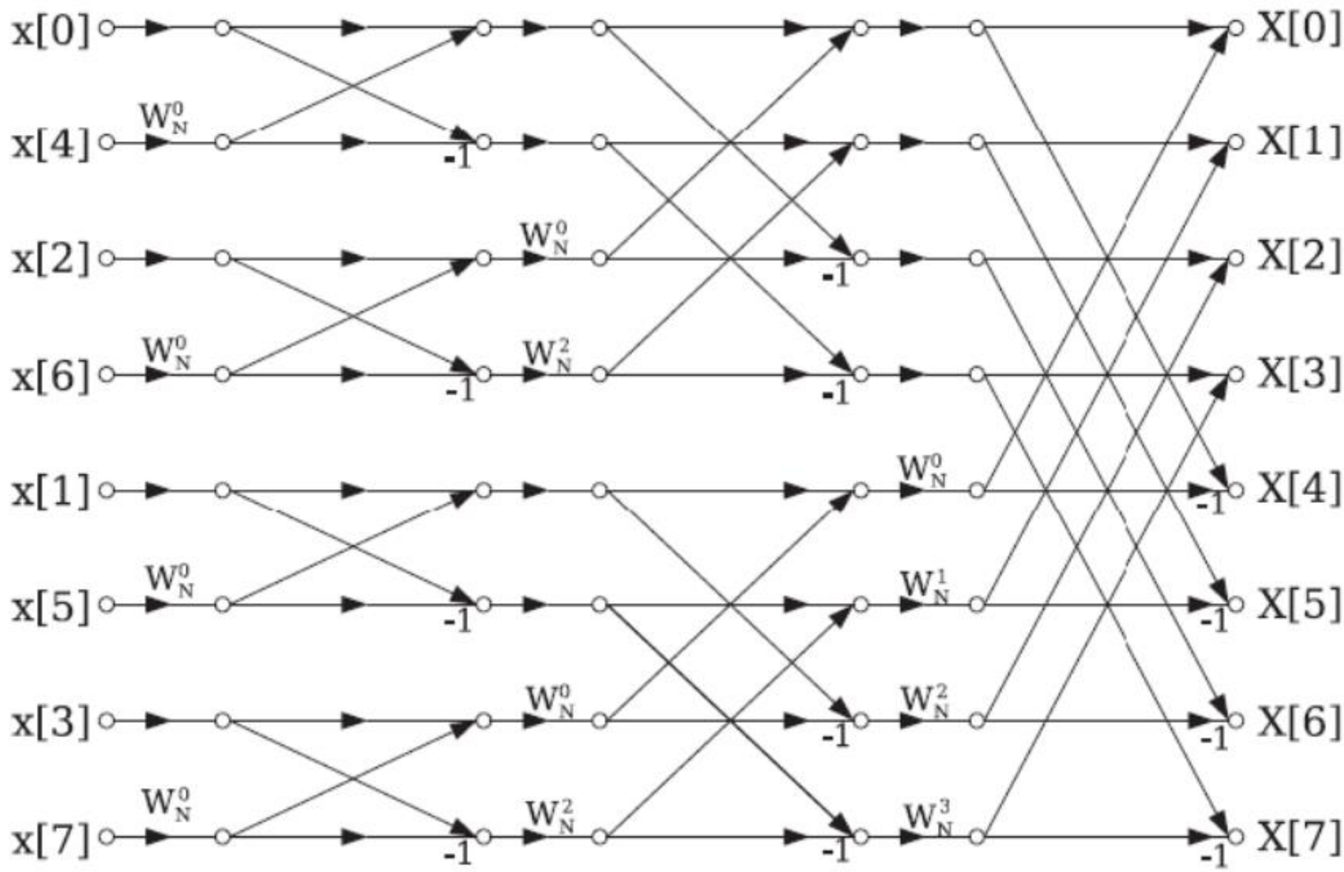
There are many techniques for estimation of harmonic, these are some signal processing tool for estimation of harmonics **Fast Fourier Transform (FFT),** Discrete Wavelet Transform (DWT), Discrete Wavelet Packet Transform (DWPT), Undecimated Wavelet Packet Transform (UWPT) etc. Amplitude of harmonics and a detailed analysis of distorted signal is necessary. It further leads us to many measurements, together clumped into Power Indices which give an idea of how closely the signal resembles an ideal signal for analysis, I have chosen Fast Fourier Transform (FFT) which is among the most popular and computationally inexpensive and simple processes to analyse a signal. It's very easy to implement in real time platform.

Fast Fourier Transform

Fast Fourier Transform is an algorithm which is used to compute the Discrete Fourier Transform of a sequence. It has been used to calculate frequency components of signals. It requires data of at least one cycle of input cycle to produce a result however, those results are not accurate for one cycle of time-varying signals. The IEC 61000-4-7 [4] recommends use of FFT for estimation of harmonics considering minimum ten cycles window for 50Hz signals.

The Cooley-Tukey algorithm is amongst the most popular ways to generate FFT of a signal. It recursively breaks down DFT of any composite size ($N=N_1N_2$) into N_1 DFTs of smaller size which is N_2, thereby reducing the computation time to O (N log (N)) for highly composite N.

A radix 2 FFT is simplest and widely used form of the Cooley-Tukey algorithm. A radix 2 FFT divides the N sized FFT into two interleaved DFTs of size N/2 for each size until reduced to the simplest form. Which makes its implementation possible only when $N = 2^p$ that is when N is a power of 2. It can be performed either by Decimation In Time (DIT) approach or Decimation In Frequency (DIF) approach.



For $N = 2^p$ stages,

Required decimation stages = $p = \log_2 N$

Total Number of complex multiplications = $(N/2) * (\log_2 N)$

Number of complex additions are $N\log_2 N$.

In our context, at sampling frequency (F_s) = 1600 Hz, and with input signal being a sinusoidal wave of fundamental frequency 50 Hz, we obtain 32 samples from one cycle of the input signal. As suggested by IEC 61000-4-7[4] standards, we will have to consider at least 10 cycles which is equivalent to operating on 320 samples of data.

$X(k) = \sum_{n=0}^{N-1} x(n).e^{-j\left(\frac{2\pi}{N}\right)nk} \quad (k = 0,1,.N-1)$

$W_N = e^{-j\left(\frac{2\pi}{N}\right)}$

$X(k) = \sum_{n=0}^{N-1} x(n).W_N{}^{nk} \quad (k = 0,1,.....N-1)$

$|X[k]| = \sqrt{X_{re}^2 + X_{im}^2}$

$\angle X[k] = \tan^{-1}\left(\frac{X_{im}}{X_{re}}\right)$

Peak = $\frac{|X[k]|}{L}$ (L= length of FFT)

N= Sample , $F_s = Sampling\ frequency$, f= frequency of input signal;

$\Delta f = \frac{F_s}{N}$ (frequency resolution)

$\Delta t = \frac{1}{F_s}$ $(Sampling\ time)$

$K_f = \frac{f}{\Delta f}$ (f is the integral multiple of Δf)

n= K_f+1;

Harmonics/Frequency	Corresponding Index in 320 point FFT
DC Component (0Hz)	X[0]
Fundamental Frequency (50Hz)	X[11]
3rd Harmonic (150Hz)	X[31]
5th Harmonic(250Hz)	X[51]
7th Harmonic(350Hz)	X[71]
9th Harmonic(450Hz)	X[91]
11th Harmonic(550Hz)	X[111]

Single Phase Parameter computation

Voltage and Current Parameters

$$V_{RMS} = \sqrt{\frac{1}{N}\sum_{i=0}^{N} V_{2i+1}^2}$$

$$THD_V = \frac{V_H}{V_1} = \sqrt{(\frac{V}{V_1})^2 - 1}$$

$$I_{RMS} = \sqrt{\frac{1}{N}\sum_{i=0}^{N} I_{2i+1}^2}$$

$$THD_I = \frac{I_H}{I_1} = \sqrt{(\frac{I}{I_1})^2 - 1}$$

Distortion Power Parameters

$$D_I = V_1\ I_H = S_1(THD_I)$$

$$D_H = \sqrt{{S_H}^2 + {P_H}^2}$$

$$S_H = \sqrt{{P_H}^2 + {D_H}^2}$$

$$D_V = V_H\ I_1 = S_1(THD_V)$$

$$S_N^2 = D_I^2 + D_V^2 + S_H^2$$

Power Parameters

$$P_1 = V_1\ I_1 \cos \emptyset_1$$

$$Q_1 = V_1\ I_1 \sin \emptyset_1$$

$$P_H = V_1 I_1 + \sum_{h\neq 1} V_h\ I_h \cos \emptyset_h$$

$$P = P_1 + P_H$$

$$S = VI$$

$$PF_1 = \cos \emptyset_1 = \frac{P_1}{S_1}$$

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

Three phase Parameter Computation

Voltage *and* Current Parameters

$$THD_{eV} = \frac{V_{eH}}{V_{e1}}$$

$$V_{eH} = \sqrt{{V_{RSH}}^2 + {V_{STH}}^2 + V_{TRH}^2}$$

$$V_{e1} = \sqrt{{V_{RS1}}^2 + {V_{ST1}}^2 + V_{TR1}^2}$$

$$V_e = \sqrt{{V_{RS}}^2 + {V_{ST}}^2 + V_{TR}^2}$$

$$DIN_{eV} = \frac{V_{eH}}{V_e}$$

$$THD_{eI} = \frac{I_{eH}}{I_{e1}}$$

$$I_{eH} = \sqrt{{I_{RH}}^2 + {I_{SH}}^2 + I_{TH}^2}$$

$$I_{e1} = \sqrt{{I_{R1}}^2 + {I_{S1}}^2 + I_{T1}^2}$$

$$I_e = \sqrt{{I_R}^2 + {I_S}^2 + I_T^2}$$

$$DIN_{eI} = \frac{I_{eH}}{I_e}$$

Power Parameters

$$D_{e1} = 3V_{e1}I_{eH} \qquad D_{eV} = 3V_{eH}I_{e1}$$

$$S_{eH} = 3V_{eH}I_{eH}$$

$$P = P_R + P_S + P_T \qquad Q = Q_R + Q_S + Q_T$$

$$P_R = V_R I_R \cos \emptyset_r \qquad Q_R = V_R I_R \sin \emptyset_R$$

$$(\emptyset_R = \alpha_R - \beta_R)$$

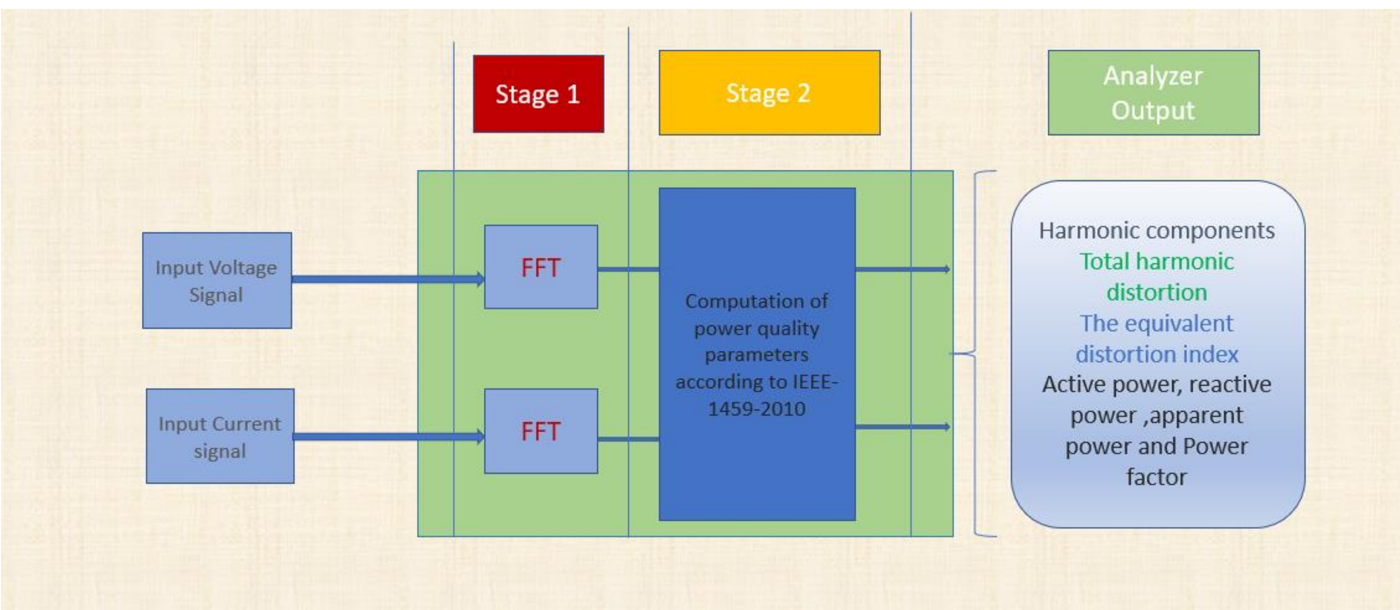
$$PF_1 = \frac{P_1}{S_1} \qquad PF = \frac{P}{S_e}$$

CHAPTER 3

Flow of Algorithm

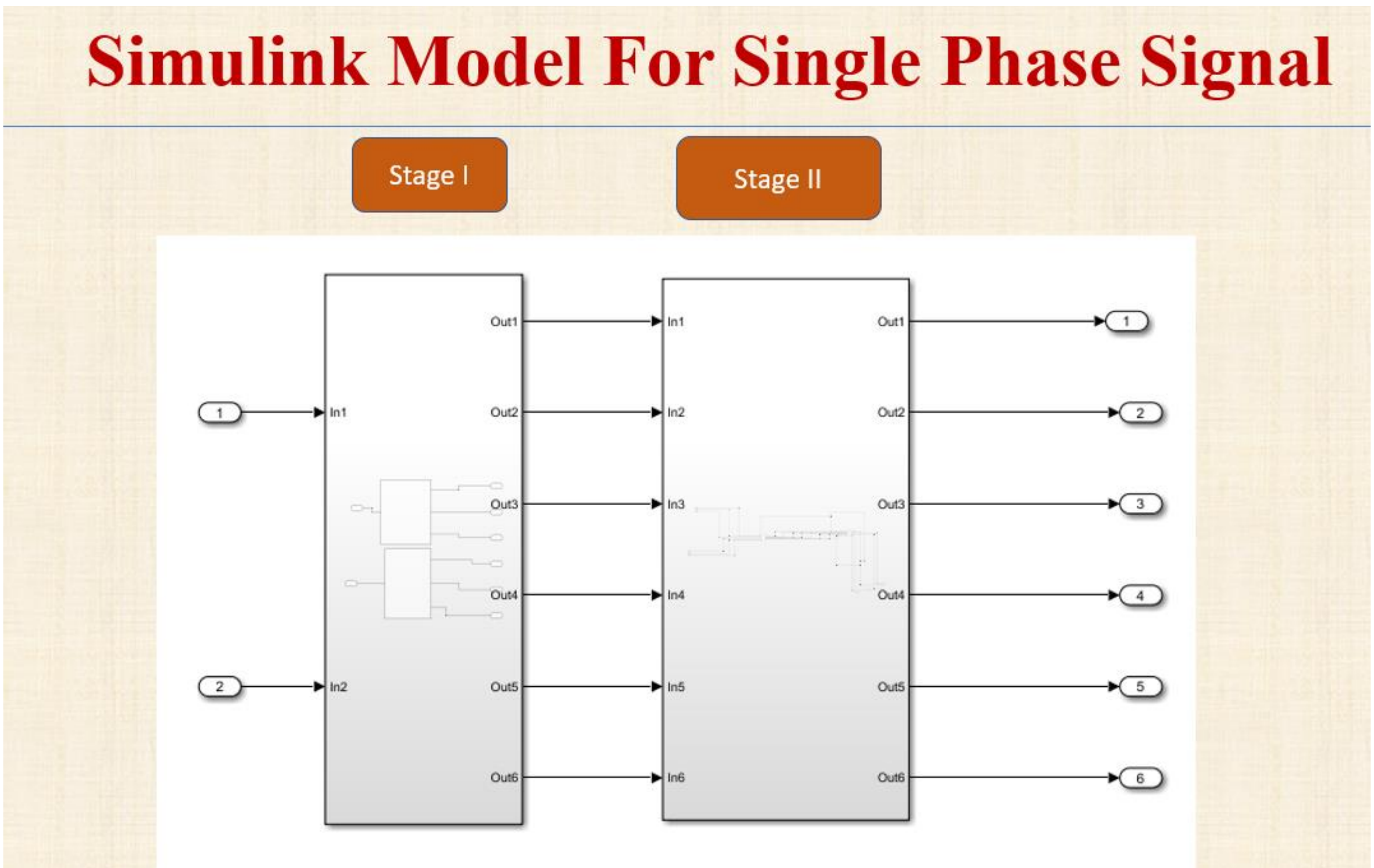
The implemented design will measure the amplitudes of harmonics present and other power indices. The block diagram of measurement system of the power quality analyser is shown in Fig. 1. Measurement of amplitude and frequency has been achieved in two steps. Since FFT coefficients of voltage and current signal are required for the analysis of power quality analyser, therefore, in first step, voltage and current signal are fed into FFT block for computation of FFT coefficient voltage and current signal. Then in second step, power component has been calculated using equation according to IEEE Standard 1459-2010.

BLOCK DIAGRAM



The sampling frequency (F_s) for Simulink Model used is set to 1600 Hz. A frequency lower than this would reduce our number of samples per wave, making the process less accurate while increasing frequency would make it more accurate but increase the complexity of the process. At 1600Hz frequency 32 samples are obtained from each cycle of sinusoidal wave of fundamental frequency 50Hz. The IEC standards require us to sample a minimum of 10 cycles for estimation, which would mean processing a minimum of 320 samples.

Each input signal is sampled at a frequency of 1600 Hz and the sampled data is processed using the stage (I) FFT algorithm which then provide with the output of FFT. This FFT output is then processed to calculate the amplitudes of harmonics present and total harmonic distortion (THD). the output of stage (I) provide data to stage (II) to calculate further power indices.



CHAPTER 4

Observations

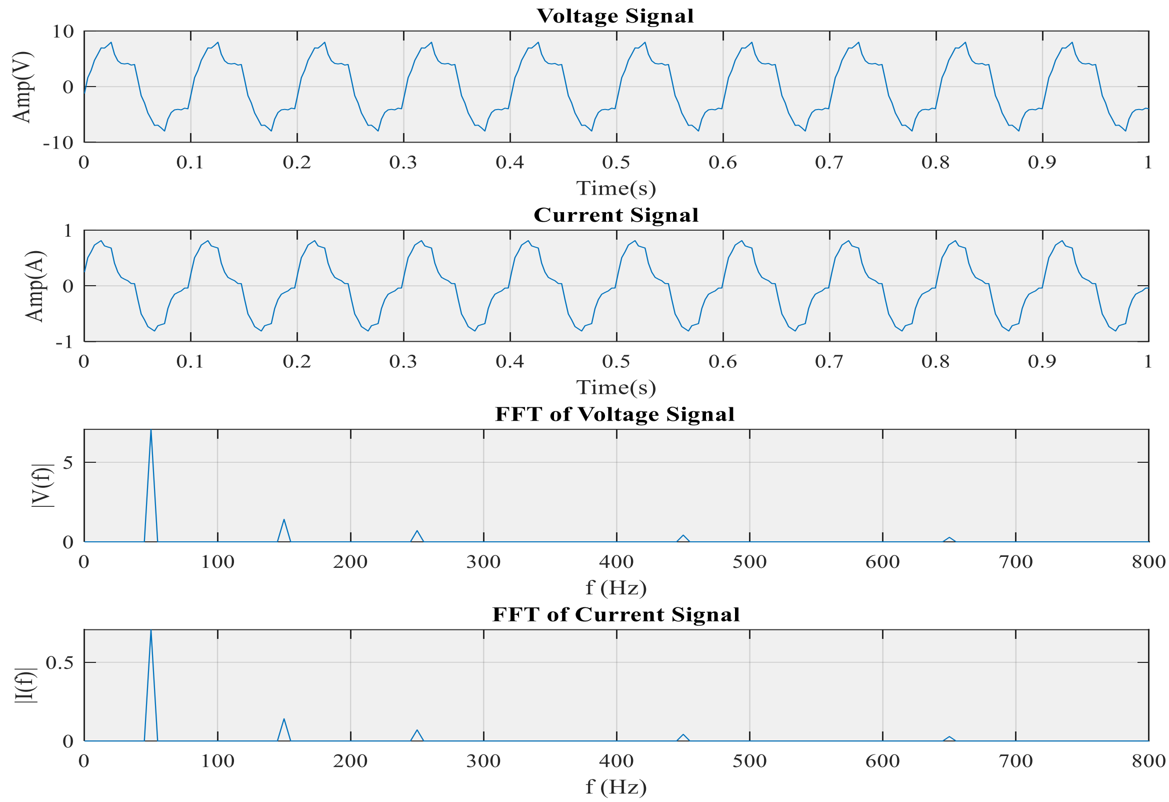
To verify the Simulink model, we consider case study which include single phase and three phase stationary and non-stationary signal. As the input parameters are known to us so we compare the true value and the analyser result. Further, amplitude of Harmonics and other power parameter were found out and it was found that the algorithm implemented gave results in accordance to the true values.

CASE 1:

Single Phase Stationary Signal.

Parameters of voltage signal: Amplitude*√2 , Frequency (Hz) and phase angle (in degree)				
5,50,0	1,150, -70	0.5,250,0	0.3,450,0	0.2,650,20
Parameters of current signal: Amplitude*√2 , Frequency (Hz) and phase angle (in degree)				
0.5,50,30	0.1,150, -60	0.05,250,0	0.03,450,0	0.02,650,30

As we can see, the graph of input voltage and current signal are not purely sinusoidal due the presence of harmonics components. In the FFT graph we can see peak on different frequency and this figure tell us abut the magnitude of the harmonic components.



	V_{rms}	V_{THD}	I_{rms}	I_{THD}	P(Watt)	PF	S(VA)	V_H(V)	I_H(A)	P_0(Watt)
True	5.1361	0.2349	0.5136	0.2349	2.301	0.8722	2.638	1.1747	0.1174	2.165
Analyser Output	5.1522	0.2349	0.5152	0.2349	2.3014	0.8669	2.6545	1.1784	0.1178	2.165
% Error	**0.31**	**0.0001**	**0.31**	**0.0001**	**0.017**	**0.60**	**0.62**	**0.34**	**0.34**	**0.001**
	P_H(Watt)	S_n	D_H	D_H	N	Q_B	D_i	D_V	S_H(VA)	dPF
True	0.1364	0.8420	0.0200	1.25	1.2901	1.2901	0.5873	0.5873	0.1379	0.8660
Analyser Output	0.1364	0.8473	0.0259	1.25	1.3228	1.2681	0.5910	0.5910	0.1388	0.8606
% Error	**0.001**	**0.59**	**29.5**	**0.001**	**2.53**	**1.70**	**0.63**	**0.63**	**0.65**	**0.62**

These are the Power Quality Analyser output and as input parameter are known to us so we compare with the true value and we can see the %error is is almost negligible so it proved that its working properly as expected.

Case 2

Single Phase Non-Stationary Signal

Time	Parameters of voltage & current signal (amp , phase (in degree)) Fundamental frequency =50Hz								
		1st	3rd	5th	7th	9th	11th	13th	15th
0.0-0.1	V	1,152	0.2,35	0.2,0	0.1,0	0.1,152	0.1,35	0.1,0	0.1,0
	I	0.1,152	0.02,35	0.02,0	0.01,0	0.01,152	0.01,35	0.01,0	0.01,0
0.1-0.2	V	0.8, 152	0.18, 0	0.18,0	0.08, 0	0.08,152	0.08, 35	0.08, 0	0.08, 0
	I	.08, 152	.018, 0	.018, 0	0.008,0	0.008,152	0.008,35	0.008,0	.008, 0
0.2-0.3	V	1,152	0.2,35	0.2,0	0.1,0	0.1,152	0.1,35	0.1,0	0.1,0
	I	0.1,152	0.02,35	0.02,0	0.01,0	0.01,152	0.01,35	0.01,0	0.01,0
0.3-0.4	V	1.2,152	0.22,0	0.22,0	0.12,0	0.12,152	0.12,35	0.12,0	0.12,0
	I	0.12,152	0.022,0	0.022,0	0.012,0	0.012,152	0.012,35	0.012,0	0.012,0
0.4-0.5	V	0.8, 152	0.18, 0	0.18,0	0.08, 0	0.08,152	0.08, 35	0.08, 0	0.08, 0
	I	.08, 152	.018, 0	.018, 0	0.008,0	0.008,152	0.008,35	0.008,0	0.008,0
0.5-0.6	V	1,152	0.2,35	0.2,0	0.1,0	0.1,152	0.1,35	0.1,0	0.1,0
	I	0.1,152	0.02,35	0.02,0	0.01,0	0.01,152	0.01,35	0.01,0	0.01,0
0.6-0.7	V	1.2,152	0.22,0	0.22,0	0.12,0	0.12,152	0.12,35	0.12,0	0.12,0
	I	0.12,152	0.022,0	0.022,0	0.012,0	0.012,152	0.012,35	0.012,0	0.012,0
0.7-0.8	V	0.8, 152	0.18, 0	0.18,0	0.08, 0	0.08,152	0.08, 35	0.08, 0	0.08, 0
	I	.08, 152	.018, 0	.018, 0	.008,0	.008,152	0.008,35	0.008,0	.008, 0
0.8-0.9	V	1,152	0.2,35	0.2,0	0.1,0	0.1,152	0.1,35	0.1,0	0.1,0
	I	0.1,152	0.02,35	0.02,0	0.01,0	0.01,152	0.01,35	0.01,0	0.01,0
0.9-1.0	V	0.8, 152	0.18, 0	0.18,0	0.08, 0	0.08,152	0.08, 35	0.08, 0	0.08,

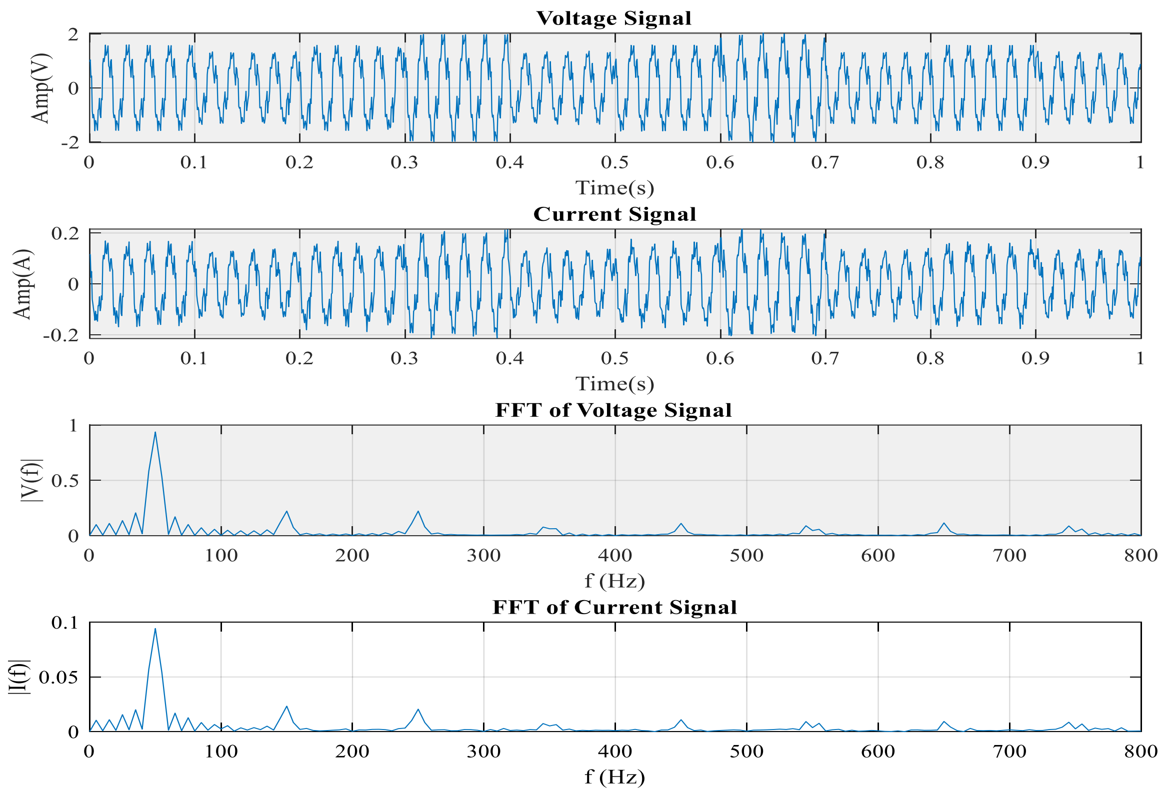


Fig:2 (Input signal and FFT of input signal)

Active Power For Non stationary single phase Signal

Time(sec)	P_1(watt)	P_3 (watt)	P_5(watt)	P_7(watt)	P_9(watt)	P_{11}(watt)
0.0-0.2	0.07921457457	0.003557325789	0.002537163893	0.000331842547	0.000225819617	8.77E-05
0.2-0.4	0.1161219132	0.001745078197	0.001438963905	6.45E-05	2.67E-05	0.000412764888
0.4-0.6	0.07078961037	0.001908364703	0.000130925390	0.000463674449	0.000789889591	0.000433309859
0.6-0.8	0.07564920092	5.39E-05	0.002660771926	0.000829883911	5.64E-05	0.000578846874
0.8-1.0	0.04378566891	0.002692856251	0.002622322743	0.00018440578	0.000647536151	0.000120320990

Reactive Power For single phase Non-Stationary signal

Time(sec)	Q_1(VAR)	Q_3(VAR)	Q_5(VAR)	Q_7(VAR)	Q_9(VAR)	Q_{11}(VAR)
0.0-0.2	8.01E-05	1.79E-07	7.57E-08	4.41E-09	7.82E-10	1.99E-10
0.2-0.4	0.0001685	5.15E-08	2.74E-08	2.28E-09	2.36E-11	2.47E-09
0.4-0.6	6.50E-05	4.99E-08	1.82E-10	3.47E-09	1.32E-08	2.61E-09
0.6-0.8	7.56E-05	8.04E-11	1.04E-07	7.65E-09	2.53E-11	4.88E-09
0.8-1.0	2.40E-05	8.70E-08	8.47E-08	8.25E-10	1.62E-08	1.95E-10

Apparent Power for Non-Stationary Single-Phase Signal

Time(sec)	S_1(VA)	S_3(VA)	S_5(VA)	S_7(VA)	S_9(VA)	S_{11}(VA)
0.0-0.2	0.080180063	0.003780901	0.002410045	0.000385227	0.000237935	6.97E-05
0.2-0.4	0.116354593	0.001710983	0.001447287	7.93E-05	4.24E-05	0.000414870
0.4-0.6	0.072273744	0.001934892	0.000117216	0.000520899	0.000781167	0.000420421
0.6-0.8	0.077904716	2.24E-05	0.002744636	0.000718965	3.18E-05	0.000555283
0.8-1.0	0.043822465	0.002525939	0.002449835	0.000201497	0.000560398	0.00010156

Parameters of Power quality analyser

Time (sec)	**0.0-0.2**	**0.2-0.4**	**0.4-0.6**	**0.6-0.8**	**0.8-1.0**
VRMS	0.9333515452	1.105348462	0.8713693275	0.9059892259	0.7134694703
VH	0.2614750491	0.2309781206	0.2017666775	0.22170541	0.257828684
VTHD	0.291832119	0.2136814541	0.2380200147	0.2523843371	0.3875642001
IRMS	0.09435916051	0.1107404691	0.08554584741	0.0899182602	0.07123696184
IH	0.02764654875	0.02371666022	0.01970000796	0.0220674601	0.02636704414
ITHD	0.3064410031	0.2192514986	0.2366463069	0.2531590979	0.3984281256
P0	0.08032892852	0.1161971381	0.07012553263	0.07609444842	0.04374763583
PH	0.007163550428	0.005436417697	0.003923874819	0.004853116322	0.006735410141
P	0.08749247894	0.1216335557	0.07404940745	0.08094756474	0.05048304597
SN	0.0349617299	0.03621453594	0.02401645041	0.02780643356	0.02539730955
QH	3.43E-07	9.16E-08	7.33E-08	1.20E-07	2.20E-07
QB	8.17E-05	1.70E-04	6.22E-05	7.31E-05	2.46E-05
N	0.01007165726	0.0137369782	0.008555648664	0.009167000973	0.005889235381
PF	0.9934394509	0.9936829373	0.9933913781	0.9936486789	0.9932641656
dPF	0.9937582814	0.9937575871	0.9937417531	0.9937571611	0.9937006005

Case 3

Three phase Stationary signal

Parameters of Voltage Signal: Amplitude, Frequency (Hz) and Phase Angle (in degree)				
1st	3rd	5th	7th	9th
120,50,0	0,0,0	24,250,0	0,0,0	0,0,0
Parameters of Current Signal: Amplitude, Frequency (Hz) and Phase Angle (in degree)				
1st	3rd	5th	7th	9th
12,50,0	5,150,0	2.028,225,0	1.452,350,0	0,0,0

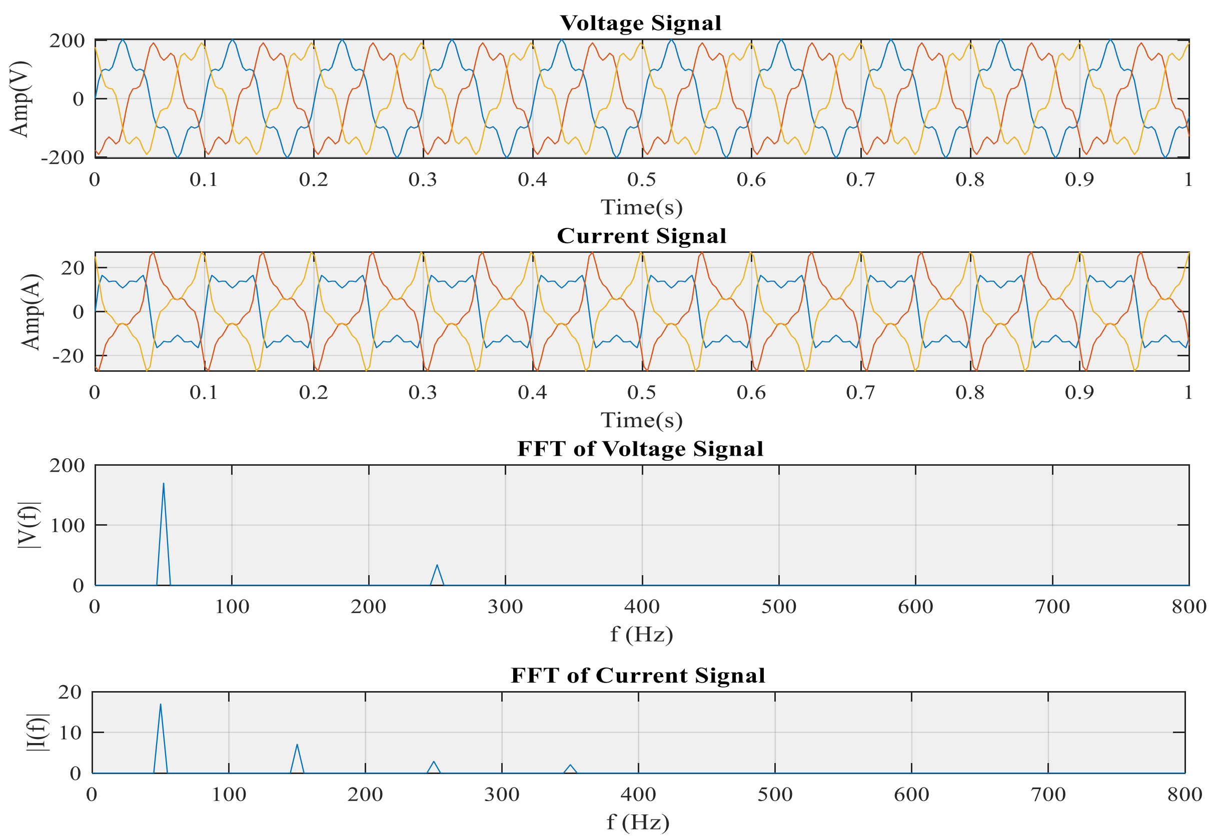


Fig :3

Analyser Output:

Parameters	V_0	V_{THD}	DIN_eV	I_0	I_{THD}	DIN_eI
Simulation result	120	0.200	0.1961	12.04	0.4656	0.422
Parameters	V_H	I_H	Q	P	S_e	PF
Simulation result	24	5.605	3.5e-12	4480	4480	1

	1st	**3rd**	**5th**	**7th**	**9th**	**11th**	**13th**	**15th**
True value(V)	120	0	24	0	0	0	0	0
FFT (V)	120	1.69e-13	24	1.91e-14	7.1e-14	8.62-14	6.9e-14	8.1-14
% Error	**≅0**	**≅ 0**	**≅0**	**≅0**	**≅0**	**≅0**	**≅0**	**≅ 0**
True value(I)	12	5	2.0.28	1.452	0	0	0	0
FFT(I)	12.04	5.016	2.037	1.457	1.27e-14	6e-14	2.1e-13	1.7-13
% Error	**0.33**	**0.32**	**0.44**	**0.34**	**≅0**	**≅0**	**≅0**	**≅0**

Case 4

Three Phase Non-stationary signal

Parameters of voltage & current signal (amp, phase (in degree)) Fundamental frequency =50									
Time(s)		1st	3rd	5th	7th	9th	11th	13th	15th
0.0-0.1	V	120, 0	0,0	24, 0	0,0	0,0	0,0	0,0	0,0
	I	10,-15	2,-15	3,-15	1, -15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.1-0.2	V	48,0	0,0	24,0	0,0	0,0	0,0	0,0	0,0
	I	4,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.2-0.3	V	120, 0	0,0	24, 0	0,0	0,0	0,0	0,0	0,0
	I	10,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.3-0.4	V	48,0	0,0	24,0	0,0	0,0	0,0	0,0	0,0
	I	4,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.4-0.5	V	120, 0	0,0	24, 0	0,0	0,0	0,0	0,0	0,0
	I	10,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.5-0.6	V	48,0	0,0	24,0	0,0	0,0	0,0	0,0	0,0
	I	4,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.6-0.7	V	120, 0	0,0	24, 0	0,0	0,0	0,0	0,0	0,0
	I	10,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.7-0.8	V	48,0	0,0	24,0	0,0	0,0	0,0	0,0	0,0
	I	4,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.8-0.9	V	120, 0	0,0	24, 0	0,0	0,0	0,0	0,0	0,0
	I	10,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15
0.9-1.0	V	48,0	0,0	24,0	0,0	0,0	0,0	0,0	0,0
	I	4,-15	2,-15	3,-15	1,-15	0.5,-15	0.2,-15	0.05,-15	0.01,-15

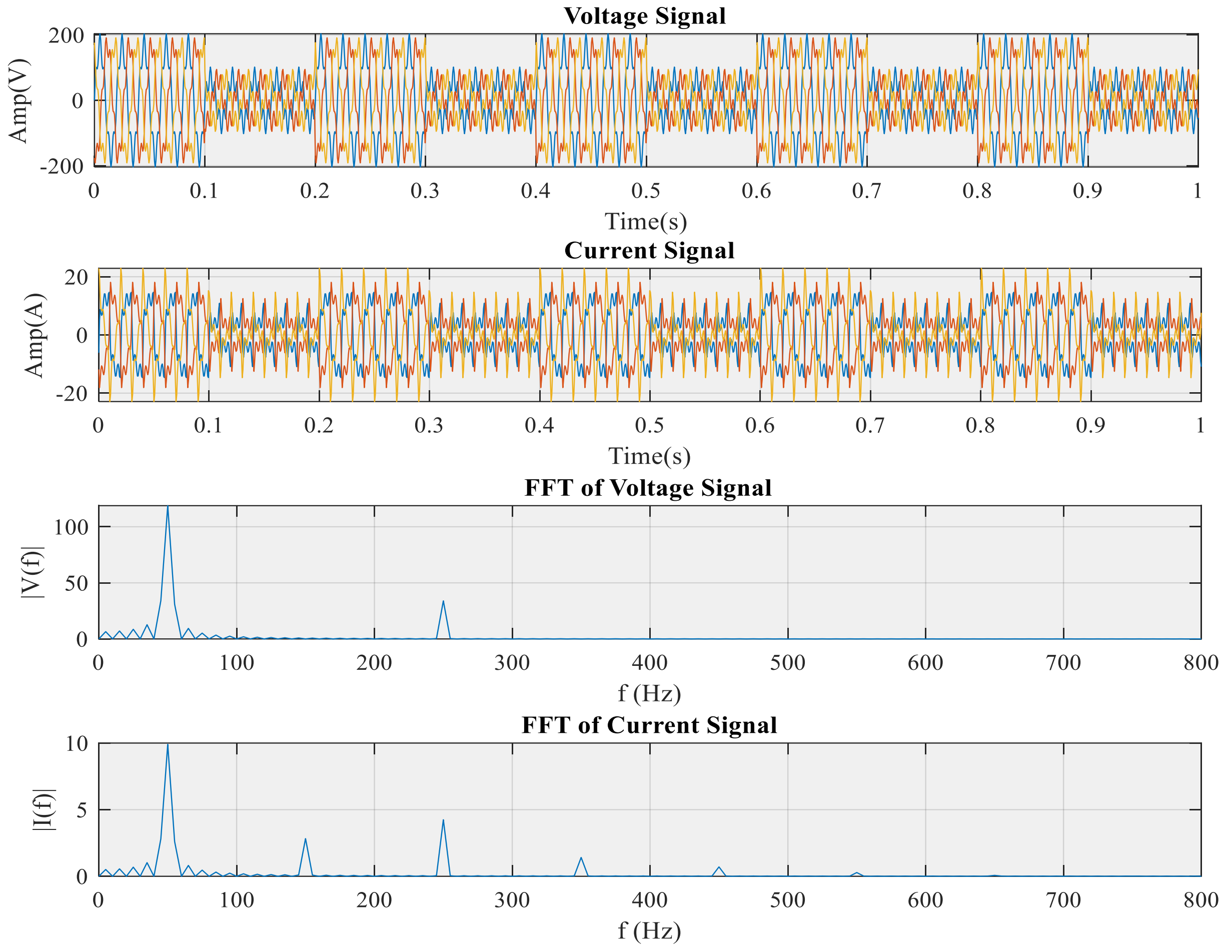


Fig:4(Input signal and FFT of input signal)

Power analyser parameters					
Time (sec)	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
PF	0.929842507	0.9298425077	0.9298425077	0.9298425077	0.9298425077
P	1681.031511	1681.031511	1681.031511	1681.031511	1681.031511
Se	1807.86692	1807.86692	1807.86692	1807.86692	1807.86692
Q	665.2186566	665.2186566	665.2186566	665.2186566	665.2186566

Observed parameters of Three Phase Non stationary Signal

Current Parameter three phase Non-stationary signal					
Time (sec)	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	**0.8-1.0**
Ie1	7.021943574	7.021943574	7.02E+00	7.021943574	7.021943574
IeH	3.792406786	3.792406786	3.792406786	3.792406786	3.792406786
THDeI	0.5400793592	0.5400793592	0.5400793592	0.5400793592	0.5400793592
Ie	7.980604036	7.980604036	7.980604036	7.980604036	7.980604036
DINeI	0.4752029757	0.4752029757	0.4752029757	0.4752029757	0.4752029757
Voltage Parameters for three phase non-stationary signal					
Ve1	84	84	84	84	**84**
Ve	87.36131867	87.36131867	87.36131867	87.36131867	87.36131867
DINeV	0.2747211279	0.2747211279	0.2747211279	0.2747211279	0.2747211279
VeH	24	24	24	24	24
THDeV	0.2857142857	0.2857142857	0.2857142857	0.2857142857	0.2857142857

Case 5: Study of PWM signal

In the previous case input parameters were known to us and the signals were generated by mathematical module. In this case we studied the signal which is output of inverter whose signal parameters were unknown.

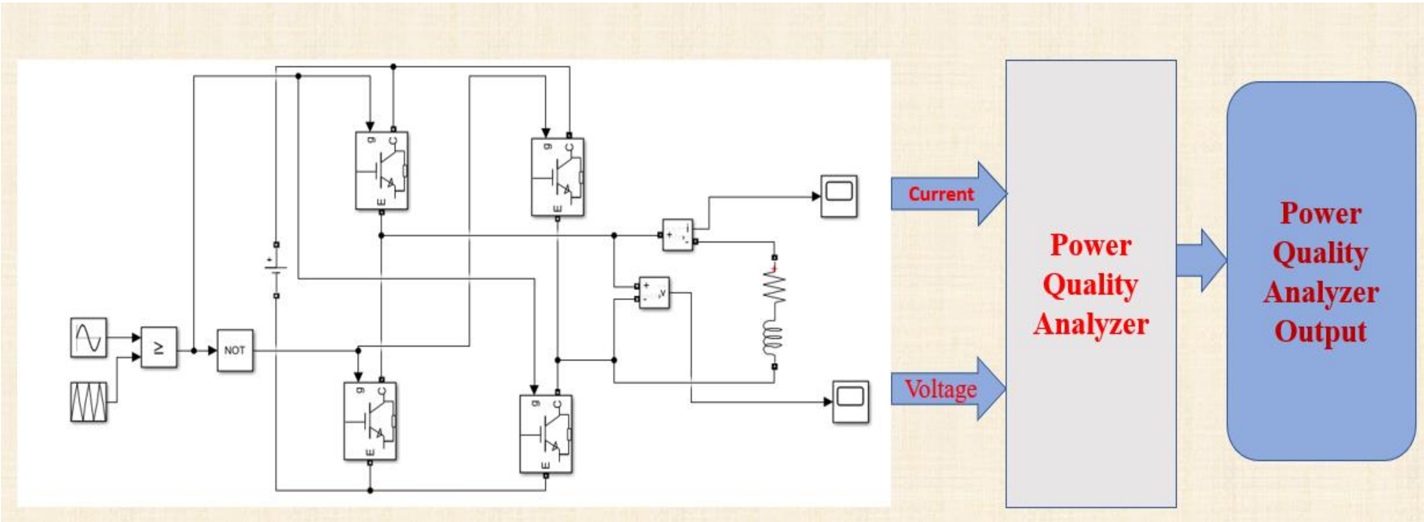
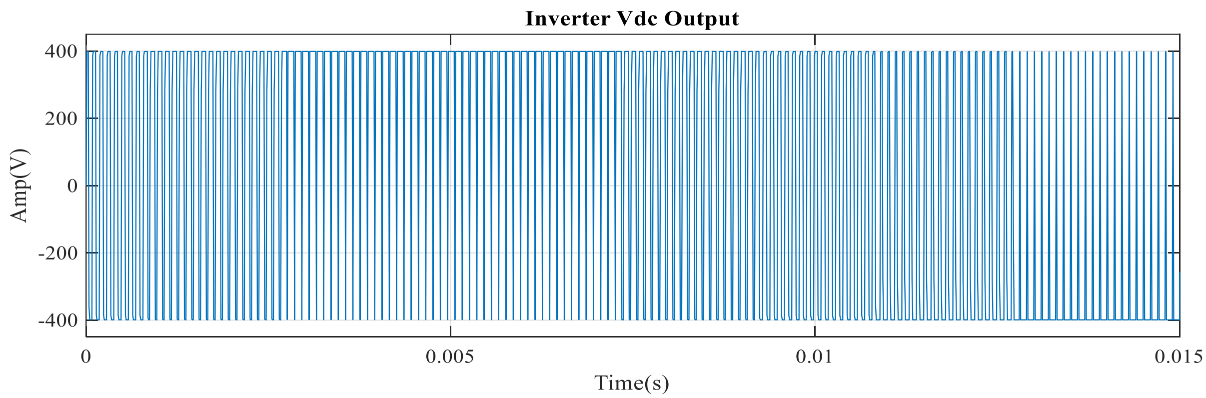


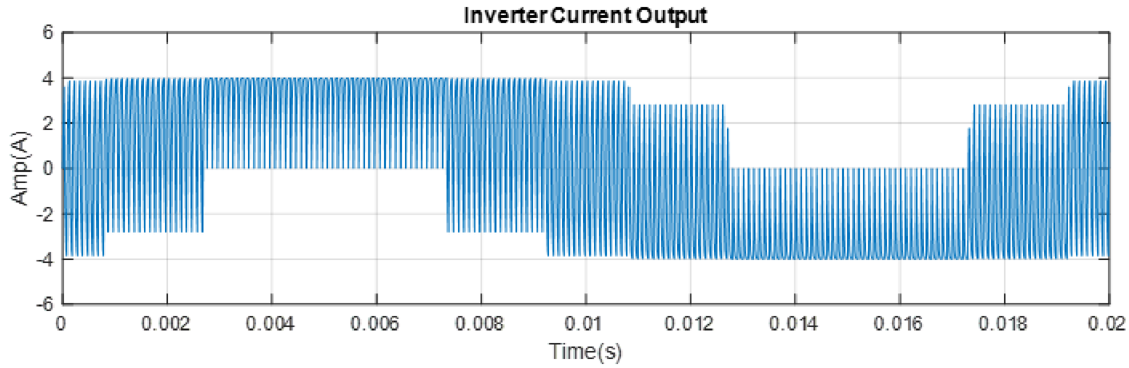
Fig: 5(Inverter Model)

System Parameter:

m= 0.8, **Vdc =400 V**, L **= 1 mH**, **R = 100 Ohm,**

Switching Frequency = 10 kHz.





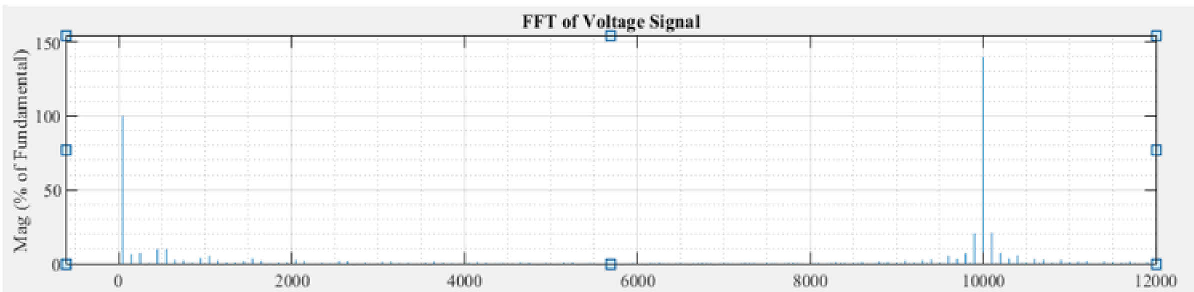


Fig:6(Input signal and FFT of input signal)

Parameter	V_{rms}	V_{THD}	V_0(V)	V_H(V)	I_{rms}	I_{THD}	I_0(A)	I_H(A)	P_0(Watt)
Analyser Output	321	0.9688	230.5	223.6	2.888	0.7337	2.325	1.713	536.5
Parameters	P_H(Watt)	S_H(VA)	S(VA)	P(Watt)	PF	D_H	D_i	D_V	S_n
Analyser Output	340.2	383.02	927.9	876.7	0.9449	175.93	395.37	519.73	757.06

CHAPTER 5

Conclusion

- Implementation of Power Quality Analyser was successfully implemented and verified on MATLAB Simulink.
- Simulink method based on FFT estimates the power quality indices of stationary, non-stationary and PWM power signal.
- Performance in terms of accuracy, resource utilization and timing requirements confirm that proposed scheme completes the requirement as provided by IEC-61000-4-30 and IEEE Standard 1459-2010

Future Scope

- The hardware can be designed on FPGA
- Suitable methods can be applied to mitigate harmonics.

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