



## List of Figures

		Page No
Figure 1.4.1	Block Diagram of the Developed system	10
Figure 1.4.2	Photograph of the hardware developed for the thesis	11
Figure 1.4.3	Screen Shot of the VB Software	12
Figure 2.3.1	Block diagram of a Digital FIR filter	21
Figure 2.4.1	Block diagram of frequency measurement for single-phase system.	22
Figure 2.4.2	Magnitude response of band pass filter	24
Figure 2.4.3	Phase response of band pass filter	25
Figure 2.4.4	Impulse Response of filter	26
Figure 2.4.5	Amplitude response of the Low Pass Filter	29
Figure 2.4.6	Phase response of the Low Pass Filter	30
Figure 2.4.7	Impulse Response of the Low Pass Filter	31
Figure 2.4.8	Amplitude response of the All Pass Filter	32
Figure 2.4.9	Phase response of the All Pass Filter	33
Figure 2.4.10	Impulse Response of the Low Pass Filter	34
Figure 2.4.11	Amplitude and Frequency response of the LPF and APF	35
Figure 2.6.1	Block diagram of frequency measurement for three phase	40
Figure 2.7.1	Error under sinusoidal conditions	41
Figure 2.7.2	Error under harmonic conditions	42
Figure 2.7.3	Signal with multiple zero crossing.	43
Figure 2.7.4	Error with multiple zero crossing.	43
Figure 2.7.5	Error with various harmonic content.	44
Figure 2.7.6	Error in case of sub harmonic condition.	45
Figure 2.7.7	Fig Simulation results for case 1	46
Figure 2.7.8	Comparison results for frequency under sinusoidal conditions	47
Figure 2.7.9	Freq measurement for 3rd and 5th harmonic for 5%of the fundamental value	48
Figure 2.7.10	Comparison results for frequency measured by inserting 5% of Harmonic in fundamental signal	49
Figure 2.7.11	Results of the freq measurement for 3rd and 5th harmonic for 25%of the fundamental value	50
Figure 2.7.12	Comparison results for frequency measured by inserting 25% of Harmonic in fundamental signal	51

Figure 2.7.13	Results of the freq measurement for 3rd and 5th harmonic for 50%of the fundamental value	52
Figure 2.7.14	Error Obtained at 50%of the harmonic	53
Figure 2.7.15	Results of the freq measurement under multiple zero crossing	54
Figure 2.7.16	Results of the freq measurement under sub harmonic conditions	56
Figure 2.9.1	Multiprocessor architecture for power quality measurement	58
Figure 2.10.2	Screen Shot for Frequency Measurement	54
Figure 2.11.1	Screen shot of the software and Oscilloscope interfaced to PC	61
Figure 3.1.1	Series RLC Circuit	67
Figure 3.1.2	RLC Circuit with DC source	68
Figure 3.2.1	Resistive Circuit	69
Figure 3.2.2	Plot of Instantaneous active and reactive power	71
Figure 3.2.3	Inductive Circuit	71
Figure 3.2.4	Plot of Instantaneous active and reactive power	72
Figure 3.2.5	Plot for inductive load	74
Figure 3.2.6	Capacitive Circuit	75
Figure 3.2.7	Plot for instantaneous active and reactive power	76
Figure 3.3.1.2	Instantaneous power plot	78
Figure 3.3.4.1	Two phase plane	86
Figure 3.10.1	Four quadrant plane	96
Figure 3.10.1.1	Three phase voltage and current waveforms on simulink	101
Figure 3.10.1.2	Three phase voltage signals	102
Figure 3.10.1.3	Simulation Results for Four quadrant power	103
Figure 3.10.1.4	Screen Shot of power measurement window	104
Figure 3.10.1.5	Screen Shot for power measurement at resistive load	105
Figure 3.10.1.6	Three Phase to Two-phase conversation	106
Figure 3.10.1.7	Power computation Block	107
Figure 3.10.1.8	Three phase Voltage and Current Waveforms at resistive load	107
Figure 3.10.1.9	Voltage and Current Alpha and Beta components	108
Figure 3.10.1.10	Active and Reactive power components	108
Figure 3.10.1.11	Screen Shot for power measurement at inductive load	110
Figure 3.10.1.12	Three phase Voltage and Current Waveforms at inductive load	111
Figure 3.10.1.13	Voltage and Current Alpha and Beta components	112
Figure 3.10.1.14	Active and Reactive power components	112
Figure 3.10.1.15	Screen Shot for power measurement at capacitive load	113

Figure 3.10.1.16	Three phase Voltage and Current Waveforms at capacitive load	114
Figure 3.10.1.17	Voltage and Current Alpha and Beta components	114
Figure 3.10.1.18	Screen Shot for power measurement at non-linear load	115
Figure 3.10.1.19	Three phase voltage waveforms at non-linear load	116
Figure 3.10.1.20	Three phase current waveforms at non-linear load	116
Figure 3.10.1.21	Voltage and Current Alpha and Beta components	117
Figure 3.10.1.22	Active and reactive power components	117
Figure 3.11.1	Block Diagram for four quadrant power measurement	120
Figure 3.12.1	VB Screen Shot for Power Measurement	121
Figure 3.14.1	Flow-Chart for four-quadrant power measurement	122
Figure 3.15.1	Screen shot of the DSP hardware interfaced to PC	124
Figure 3.15.2	Experimental photo of power measurement using inductive load	125
Figure 3.15.3	Phase shift rectifier	126
Figure 3.15.4	Experimental photo of power measurement using PSR	127
Figure 4.2.1.1	Comparison plot for different techniques	136
Figure 4.3.1	Discrete Kalman filter cycle	141
Figure 4.3.2	High Level diagram of the Kalman filter	143
Figure 4.5.1	Screen shots for harmonic measurement using Matlab	153
Figure 4.5.2	Screen Shot of the input block	154
Figure 4.5.3	Screen Shot of the Kalman block	155
Figure 4.5.4	Screen Shot of the m-file linker block	155
Figure 4.5.5	Screen Shot of the output block	156
Figure 4.5.6	Simulation results of the Kalman filter	157
Figure 4.5.7	Kalman filter estimated and actual signal	157
Figure 4.5.8	Estimated Magnitude of Fundamental and Third Harmonic	158
Figure 4.5.9	Estimated Magnitude of Fundamental and Fifth Harmonic	159
Figure 4.5.10	Estimated Magnitude of Fundamental and Seventh Harmonic	159
Figure 4.5.11	Estimated Magnitude of Fundamental and Ninth Harmonic	160
Figure 4.5.12	Estimated Magnitude of Fundamental and Eleventh Harmonic	160
Figure 4.5.13	Estimated Magnitude of Fundamental and various Harmonic	161
Figure 4.6.14	Input signal with harmonic upto 25th order	162
Figure 4.6.1	Experimental Set-up for harmonic measurement	164
Figure 4.7.1	Flowchart for harmonic estimation using Kalman filter	165
Figure 4.8.1	VB Screen shot for harmonic measurement	166
Figure 4.8.2	Results displayed on VB Software	167

Figure 5.0.1	Historical Flicker Curve	170
Figure 5.1.3.1	Block diagram as per IEC 61000-4-15	174
Figure 5.2.1	Block diagram of Flicker Meter	179
Figure 5.2.1.1	Main blocks of the Flicker Meter	179
Figure 5.3.1	Voltage signal with 8.8 Hz component	181
Figure 5.3.2	FFT windows at various record lengths.	182
Figure 5.3.3	GUI plot of Simulated fundamental signal	183
Figure 5.3.4	GUI plot of harmonic signal	184
Figure 5.3.5	GUI plot of harmonic and flicker signal	185
Figure 5.3.6	Simulation with harmonic signal	186
Figure 5.3.7	Fundamental signal and flicker with low magnitude	187
Figure 5.3.8	Fundamental signal and flicker with more magnitude	188
Figure 5.3.9	Fundamental signal and interharmonic with more magnitude	189
Figure 5.3.10	Fundamental signal with interharmonics	190
Figure 5.3.11	Fundamental signal with harmonic and interharmonic case 1	191
Figure 5.3.12	Fundamental signal with harmonic and interharmonic case 1	192
Figure 5.3.13	Actual flicker signal	194
Figure 5.4.1	Measurement System Set-up	194
Figure 5.5.1	Flowchart for the flicker estimation	198
Figure 6.1.1	General Block diagram of DSP based measuring instrument	205
Figure 6.1.2	Uniform sampling of signals	207
Figure 6.1.1.1	Von Neumann architecture	209
Figure 6.1.1.2	Harvard architecture	210
Figure 6.1.1.3	Modified Harvard architecture	210
Figure 6.1.1.4	Block diagram of TMS320F2806	212
Figure 6.1.1.5	Internal architecture of TMS320F2806	213
Figure 6.2.1	Block diagram of multiprocessor system	215
Figure 6.2.1.1	Analog Signal conditioning circuit	217
Figure 6.2.1.2	Photograph of Signal conditioning circuit	202
Figure 6.2.1.3	Box for P.T and C.T	203
Figure 6.2.2.1	Schematic for DSP board	205
Figure 6.2.2.2	Photograph of DSP board	206
Figure 6.2.3.1	Photograph of Multiprocessor cards	208
Figure 6.2.3.2	Final photograph of the multiprocessor system	210
Figure 6.2.3.3	Test set-up of the complete system	211

Figure 6.2.3.4	Multiprocessor system with PC interface	212
Figure 6.2.4.1	Real time timing window	214
Figure 6.2.4.2	Data transfer from three slave DSP to master DSP	215
Figure 6.2.4.3	Data transfer from slave to master and vice versa	216
Figure 6.2.4.4	Waveform zoomed for data transfer	216
Figure 6.2.4.5	Real time flow of data	217
Figure 6.2.5.1	Screen shot of main window	218
Figure 6.2.5.2	Screen Shot of waveform data	219
Figure 6.2.5.3	Screen Shot of frequency data	220
Figure 6.2.5.4	Screen Shot of harmonic data	221
Figure 6.3.1	Flowchart of Multiprocessor System	222
Figure 6.4.1	Multiprocessor System with PC interface	224