Chapter 1

Introduction

1.0. Background

The increase in use of complex sensitive equipment for power system disturbances [1], related economic aspects [2], increase in awareness towards power quality issues and deregulation [3], which lead to extensive monitoring of power system operation. Customers with complex sensitive equipment, like adjustable speed drives, power electronics or computers, use monitoring to locate the source of the problems that might occur. On the other side, due to the demand for better Power Quality, they monitor to prove that the quality of the offered power is within the pre-specified standards and to obtain the necessary information for solving problems. This creates a challenging and competitive new environment, where power quality becomes a commodity and as such it must be monitored and measured.

1.1. Power quality and power system events

The term *power quality* refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location on the power system [4].

A *power system event* is observed as current or voltage excursion outside the predetermined monitoring equipment thresholds. A *power system disturbance* is observed current or voltage excursion (event) which results in an undesirable reaction in the electrical environment or electronic equipment or systems.

The term *power problem [5]* refers to a set of disturbances or conditions that produce undesirable results for equipment, systems or a facility.

The term *event* is typically used to describe significant and sudden deviations of the voltage or current from its normal or ideal waveform unlike the term *variation* which is used to describe small deviations from the nominal values [6]. Table 1.1-1 [4] gives the different categories of electromagnetic phenomena that appear in a power system.

These phenomenons are mainly caused by:

- External power system factors. For example lightning strikes causing impulsive transients of large magnitude.
- Switching actions of system. For example capacitor switching this causes oscillatory transients.
- Faults which can be caused, for example, by lightning (on overhead lines) or insulation failure (in cables). Voltage dips and interruptions are phenomena related to faults.
- Loads which use power electronics and introduce harmonics to the network.

Categories	**Typical spectral content**	**Typical duration**	**Typical voltage magnitude**
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5 nsec rise	< 50 nsec	
1.1.2 Microsecond	1 *use:* rise	50 nsec - 1 msec	
1.1.3 Millisecond	0.1 msec rise	> 1 msec	
1.2 Oscillatory			
1.2.1 Low frequency	< 5 kHz	0.3 -50 msec	0- 4 pu
1.2.2 Medium frequency	5 - 500 kHz	20 *us.*	0- 8 pu
1.2.3 High frequency	0.5 - 5 MHz	5 *us.*	0- 4 pu
2.0 Short duration variations			
2.1 Instantaneous			
2.1.1 Interruption		0.5 - 30 cycles	< 0.1 pu
2.1.2 Sag (dip)		0.5 - 30 cycles	0.1 - 0.9 pu
1.1 2.1.3 Swell		0.5 - 30 cycles	1.1 - 1.8 pu
2.2 Momentary			
2.2.1 Interruption		30 cycles - 3 sec	< 0.1 pu
2.2.2 Sag (dip)		30 cycles - 3 sec	0.1 - 0.9 pu
2.2.3 Swell		30 cycles - 3 sec	1.1 - 1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 sec - 1 min	< 0.1 pu
2.3.2 Sag (dip)		3 sec - 1 min	0.1 - 0.9 pu
2.3.3 Swell		3 sec - 1 min	1.1 - 1.2 pu
3.0 Long duration variations			
3.1 Interruption sustained		> 1 min	0.0 pu
3.2 Under-voltages		> 1 min	0.8 - 0.9 pu
3.3 Overvoltage's		> 1 min	1.1 - 1.2 pu
4.0 Voltage unbalance		Steady state	0.5 - 2 %
5.0 Wave distortion			
5.1 de offset		Steady state	0- 0.1 %
5.2 Harmonics	o - 100th harmonic	Steady state	0- 20 %
5.3 Inter-harmonics	0-6 kHz	Steady state	0-2 %
5.4 Notching		Steady state	
5.5 Noise	Broadband	Steady state	0.1 %
7.0 Power frequency variations		< 10 sec	

Table 1.1-1: Categorizations of Electromagnetic phenomena [4]

This categorization is done in terms of the frequency components (spectral contents) which appear in voltage signals during the phenomenon, the duration of the phenomenon and the typical voltage magnitude.

For some of the events related to the classes in Table 1.1-1, protection operation is triggered. In case of a fault the protection system will isolate the part of the network where the fault occurred. The protection system is designed to respond in short time and eliminate the risk for both the system and the customers (high currents caused by the faults are threats for the elements of the system and the resulting voltage dips might cause problems to certain loads). In case of high amplitude transients (due to lightning or switching actions), over voltage protection equipment (for example surge arresters) are employed to avoid damage of elements of the system. However, for other events, protection operation is not expected. For example, the switching of large induction motor load might cause an increase in current and a voltage dip but normally no action is taken by the protection system.

1.2. Power quality monitoring objectives

The increasing requirement on supervision, control, and performance in modern power systems make power quality a major substantial for utilities. Power quality is necessary to characterize electromagnetic phenomena at a particular location of the network. The objective of quality can be:

- The diagnosis of incompatibilities of the power system with the load.

- The evaluation of the electric environment as a part of the system in order to redefine modeling techniques or to develop a power quality baseline.

- The prediction of future performance of load equipment or power quality mitigating devices.

An another aspect of power quality monitoring is collection of information about performance of system in case of interconnected power system. This information includes the total active and reactive power flow, frequency, harmonics and flicker.

In an Inter-connected power system network, inter-state transmission links carry active and reactive power from generating stations (which include private and public power plants) to the state grids. The tariffs for these power exchanges should be frequency and voltage dependent as proposed in the thesis unlike in the case of meters used in the distribution sector. These variable charges for active and reactive power are stated such that the inter-connected system functions efficiently. Hence algorithms and measurement instruments are required to measure four quadrant flows of power, frequency, real time harmonics and flicker.

1.3. Motivation of the work

The emphasis of this algorithm development is to measure real time power quality parameter in three phase system. Three-phase voltage and current signals will be measured and algorithms are deployed on a multiprocessor DSP (Digital Signal Processor) for measurement of these power quality parameters.

With the deregulation of the energy systems, energy has become a commodity. Utilities sell energy and power, the term power quality includes by itself voltages and currents so in this scenario we will measure flow of bidirectional active and reactive power to distinguish between total import/export of power. Work is also emphasized on a tariff structure which is based on frequency and voltage rather than on active power.

In recent years, DSP has expanded beyond filtering, frequency analysis, and signal generation. More and more markets are opening up DSP applications, where in the past, real-time signal processing was not feasible or was too expensive. Real-time signal processing using general-purpose DSP processors provides an effective way to design and implement DSP algorithms for real-world applications. However, this is very challenging work in today's engineering fields. With DSP penetrating into many practical applications, the demand for high-performance digital signal processors has expanded rapidly in recent years. Many industrial companies are currently engaged in real-time DSP research and development. Therefore, it becomes increasingly important to develop algorithms for real time measurement of various power quality parameters using available DSP's.

The final motivation for this work is to develop a multiprocessor hardware for Data acquisition and processing of various power quality parameters. These algorithms and application can be utilized further for other power quality parameters.

The power quality parameters covered by this work are as follows:

1. Three phase voltage, current, frequency and power factor.
2. Bidirectional measurement of active and reactive power.
3. Harmonics.
4. Flicker

1.4. Outline of the thesis

Chapter 2

In this chapter digital filter based frequency measurement is proposed. It covers the present scenario of conventional techniques for frequency measurement and compares the techniques based on the speed and accuracy of estimation. It concludes the limitations of frequency measurement under non-sinusoidal conditions and then proposed a modified model for frequency measurement using digital filters under non-sinusoidal conditions. The work results from the analysis of measurement of different techniques, simulations and mathematical modeling of the methods. It also covers the hardware design for frequency measurement and its expansion for multiprocessor system. It includes the actual results obtained on software developed on Visual Basic for this hardware.

Chapter 3

In this chapter various techniques are discussed for power measurement under sinusoidal and non-sinusoidal conditions. It includes the various theories proposed in the literature and discusses its suitability for measurement in an interconnected power system. It focuses on the theory applied in an interconnected system for bidirectional measurement of active and reactive power. It discusses the theory, mathematical analysis, simulation results on MATLAB™. It covers the hardware designed for active and reactive power measurement and its expansion for multiprocessor system. In this chapter a new tariff scheme is proposed based on frequency on voltage as compared to active and reactive power for an interconnected power system. It includes the actual results obtained on software developed on Visual Basic for this hardware.

Chapter 4

In this chapter on line tracking of harmonics using Kalman filter is proposed. The chapter also covers the presently used conventional FFT (Fast Fourier Transform) and compares the techniques based on the speed and accuracy of estimation of the harmonics. The chapter covers the limitation of presently available technique and discusses the advantage of the Kalman filters. Simulation and mathematical modeling of the methods are discussed in detail. It covers the hardware designed for frequency measurement and its expansion for multiprocessor system. It includes the actual results obtained on software developed on Visual Basic for this hardware.

Chapter 5

In this chapter digital flicker meter based on IEC 61000-4-12 is proposed. It covers the presently used analog flicker meter and compares with the digital flicker meter. Simulation and mathematical modeling of the methods are discussed in detail. It also covers the hardware designed for frequency measurement and its expansion for multiprocessor system. It includes the actual results obtained on software developed on Visual Basic for this hardware.

Chapter 6

This chapter includes the hardware details of a multiprocessor platform using digital signal processor (DSP) (TMS320F2806). The block diagram of the hardware is shown in Fig. 1.4-1 and photograph is shown in Fig. 1.4-2 .It includes the various circuits used for the development of multiprocessor hardware. It includes the flowcharts and the firmware detail for each power quality parameters. It includes the timing diagram and task scheduling used by each processor for computation of individual parameter. It includes the development of the Visual Basic (VB) software as shown in Fig. 1.4-3 developed for capturing and displaying all the data from a multiprocessor platform to the computer.

Chapter 7

This chapter brings out the conclusions drawn and suggests future work that can be carried out from this platform

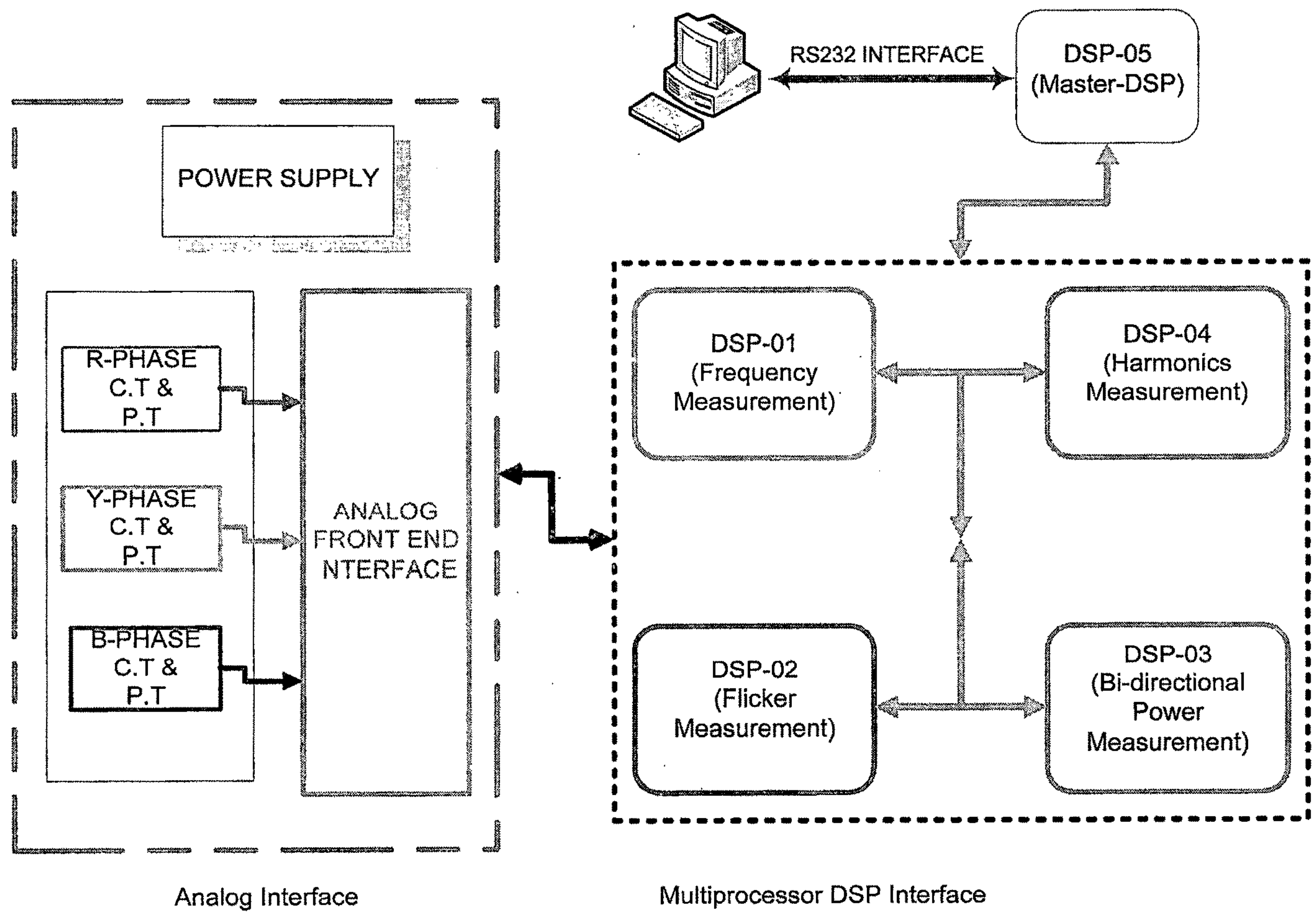

Fig.1.4-1: Block Diagram of the Developed system.

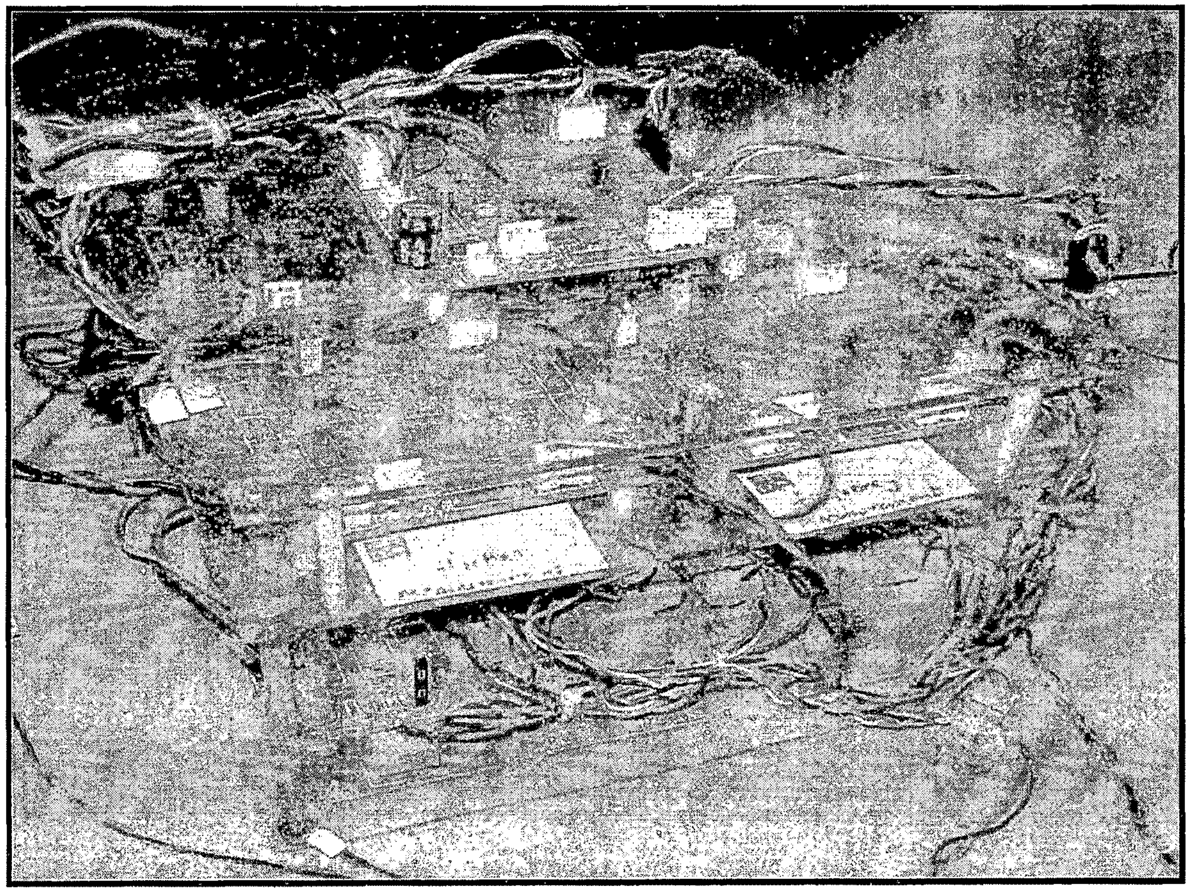

Fig.1.4-2: Photograph of the hardware developed for the thesis

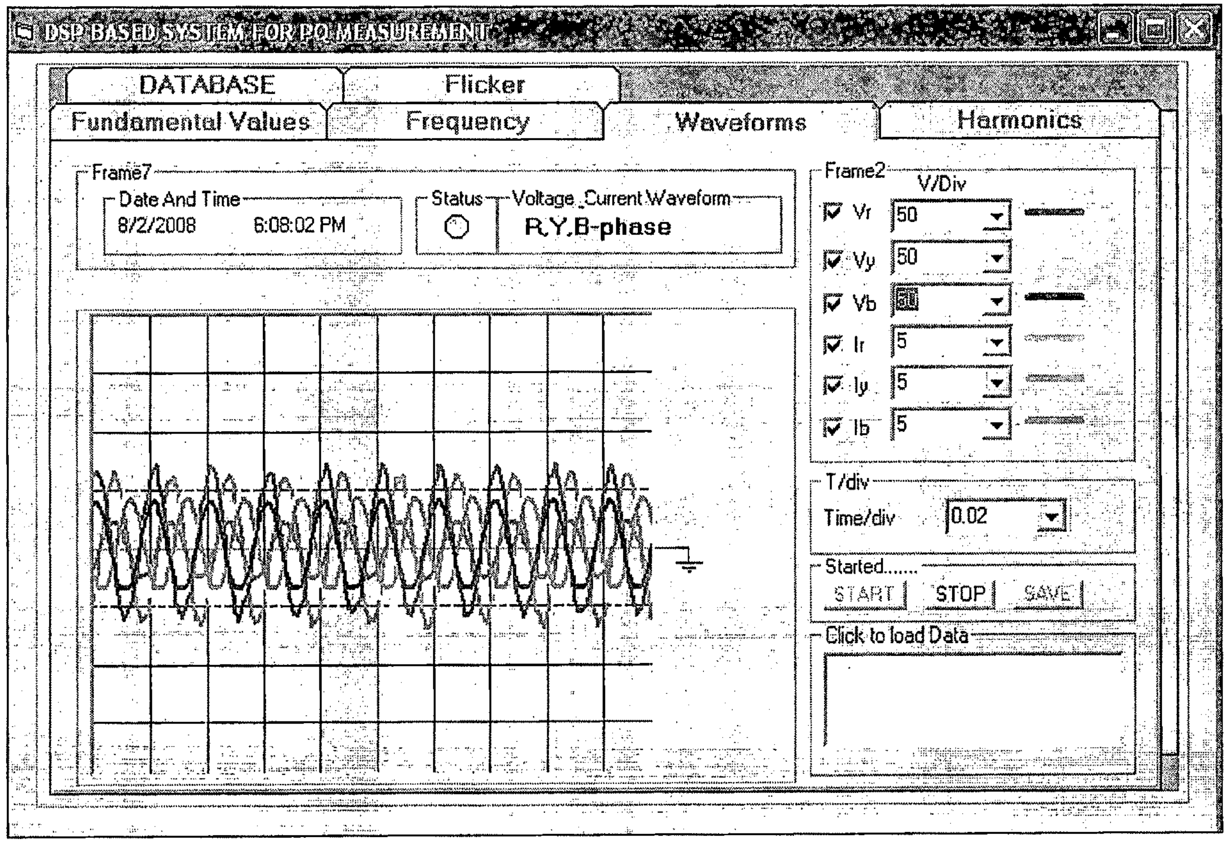

Fig. 1.4-3: Screen shot of the VB Software