Real-Time Power Quality Monitoring System Based On TMS320CV5416 DSP Processor

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Abstract – **Any disturbance in the power-line can cause disruption in manufacturing process or services provided. Under worst case conditions results in equipment failure and subsequent increase in cost of operation. Monitoring and analysis of power-line waveforms are essential to provide assessment of the power quality. This project presents a system that can monitor power-line voltage and current waveforms. Signal analysis techniques such as the periodogram and spectogram are employed to analyze power-line voltage and current variations. The heart of the system is the Texas Instruments DSP (Digital Signal Processing) TMS320CV5416 and user interface on a personal computer was developed using the Visual Basic version 6.0 to display power line measurement parameters.**

Keywords- Power Quality issues, harmonic problems, test, measurement and instrumentation.

I. INTRODUCTION

Power quality problem occurs as a result of nonstandard voltage, current or frequency deviation that results in a failure or a disoperation of end-use equipment [1]. For the past 20 years, awareness of the power-quality problem has greatly improved, with a report from *Business Week* (1991) stating that spikes, sags and outages cost the US nation US$26 billion in downtime. Contributing to this cost is lost time, lost production, lost sales, delivery delays and damaged production equipment [2]. Therefore, there is a need to understand and improve the power quality problems.

Various researchers have implemented real-time power quality measurements [3]-[5]. Spectrum estimation is included in [4] while the wavelet transform employed in [5] for analysis and compression. The proposed system consists of basic power measurements such as power factor, real power, frequency, voltage (rms) and current (rms). In addition, signal analysis techniques such as both the periodogram and spectrogram time-frequency analysis are included to identify power quality problems such transients and harmonics. Fig. 1 shows block diagram of the power quality monitoring system.

The system is built around the Texas Instruments TMS320CV5416 DSP evaluation board that is interfaced to a computer for presentation and data-logging purposes. Thus, this system will help users to identify any possible power-line problem and take the necessary corrective or preventive actions.

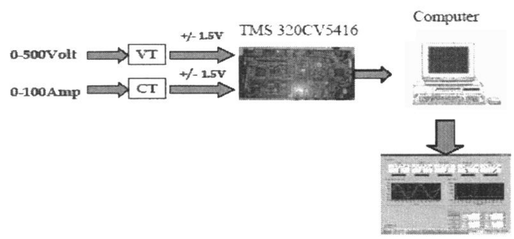

Figure 1. Block diagram of the project

II. THEORY

A. *Power quality Problems*

There are several common power quality problems in power line system. It normally divided into 7 categories. They are [6]

- Transients
- Harmonics
- Noise
- Voltage Sags and swells
- Interruptions
- Voltage Fluctuation

B. *Power Quality Measurement*

The power quality measurements performed by the system is voltage, current, frequency and power factor. In addition, signal analysis techniques such the periodogram power spectrum estimate and spectrogram time-frequency analysis are performed to analysis and identify power quality problems.

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1) Voltage Measurement

Voltage is measured between 0 to 500 volts. Since the DSP board can only allow input signals of less than 1.5 volts, a step-down transformer and voltage divider circuit is connected to the power-line. In addition, the step-down transformer acts as isolation between power line and DSP board. To allow discrete-time processing of power-line waveforms, sampling is performed continuously at the analog input at sampling frequency of 3000 Hz. The rms value of the sampled waveform is calculated by the following equation [7].

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|v(n)\right|^2} \tag{1}$$

Where $v(n)$ is the sampled voltage waveform and N is the number of samples.

2) Current Measurement

In this system, current is measured between 0 to 40 amps. The fig. 2 below shows a real picture of the current transducer.

Figure 2. Current transducer

This device is connected to analog input of DSP board. Similar to the voltage waveform, DSP board will sample the signal and the current rms value is calculated using equation below [7]

$$I_{rms} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|i(n)\right|^2} \tag{2}$$

Where $i(n)$ is the sampled current waveform and N is the number of samples.

3) Power Factor Measurement

Power factor measures how much power is usable relative to that is supplied. This is calculated by comparing between real power and apparent power. Real and apparent power is calculated as follows for discrete-time voltage and current waveforms.

$$P = \frac{1}{N}\sum_{n=0}^{N-1} v(n)i(n) \tag{3}$$

$$S = \left|V_{rms}\right|\left|I_{rms}\right| \tag{4}$$

The power factor is the ratio of the real power to the apparent power [7].

C. Periodogram

The periodogram power spectrum estimate [8] represents the distribution of the signal power over frequency. From the spectrum, the frequency content of the signal can be estimated directly from the frequency sample values that correspond to the peak value. It is calculated based on the frequency representation of the discrete-time waveform. The periodogram is calculated for the voltage and current waveforms as follows.

$$S_w(k) = \frac{1}{N}\left|\sum_{n=0}^{N-1} v(n)e^{-j\frac{2\pi kn}{N}}\right|^2 \tag{5}$$

$$S_{ii}(k) = \frac{1}{N}\left|\sum_{n=0}^{N-1} i(n)e^{-j\frac{2\pi kn}{N}}\right|^2 \tag{6}$$

$$0 \le k \le N-1$$

Where $V(k)$ is the frequency representation of the discrete-time voltage waveform $v(n)$ and $I(k)$ is the frequency representation of the discrete-time current waveform $i(n)$.

In addition to frequency measurement, the periodogram can detect the presence of harmonics and transients in the power-line waveform.

D. Spectogram

Limitation of the periodogram power spectrum estimate is it represents only the frequency content of the signal and does not gave any information of its temporal characteristics. This is resolve by representing the signal jointly as a time-frequency representation [9]. For an arbitratry discrete-time waveform of length N, the spectrogram time-frequency representation is calculated as follows.

$$p_x(n,k) = \frac{1}{M}\left|\sum_{n=0}^{M-1} w(n-m)x(n)e^{-j\frac{2\pi kn}{M}}\right|^2 \tag{7}$$

$$0 \le k \le N-1$$

Where $x(n)$ is the discrete-time waveform, $w(n)$ is the window function of length M, and M is chosen to be less than N. Any one of the popular window functions such as Hamming, Hanning or Blackman can be used in the spectrogram.

III. SOFTWARE DEVELOPMENT ON COMPUTER

The voltage and current waveforms are sampled and processed on the TMS320CV5416 DSP processor. The basic measurements performed are voltage (rms), current (rms), frequency, power factor and real power. Besides that, the periodogram and spectrogram of voltage and current waveforms are also computed. Data from DSP board is transferred to computer for display and storage. Fig. 3 shows the main GUI (Graphic User Interface) display that controls and represents the measurement results on the PC. The first row shows readings for voltage (rms), current (rms), frequency, power factor and real power. Simultaneously, voltage and current waveforms are represented on the next row. User can set specific time or duration of time to log data into computer automatically.

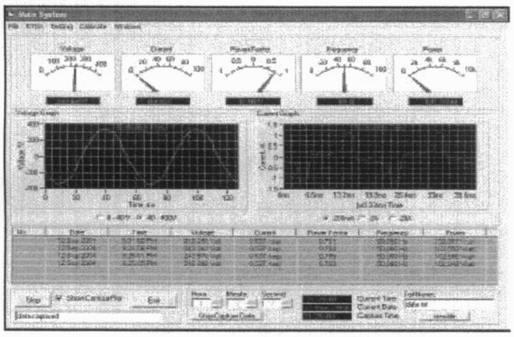


Figure 3. Main GUI display on computer

The periodogram analysis results for the power-line waveform can be selected from the main GUI menu. This is shown in the graph in Fig. 4. The vertical scale represents power per frequency while the horizontal represents frequency.

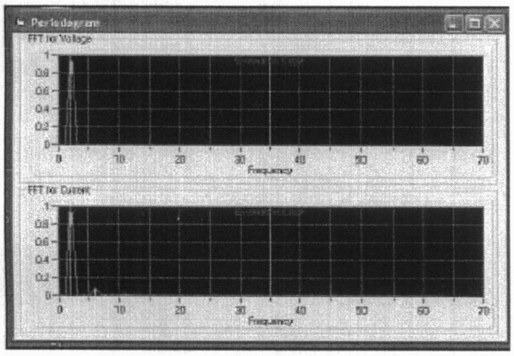


Figure 4. Periodogram for voltage and current

Besides periodogram, the spectrogram analysis can be chosen from the main GUI menu. This is a contour plot when the vertical scale represents frequency, horizontal scale represents time and the power is represented in terms of the color intensity of the plot. The highest power is represented as red color while the lowest power by blue color. Fig. 5 shows an example of a contour plot for a voltage waveform.

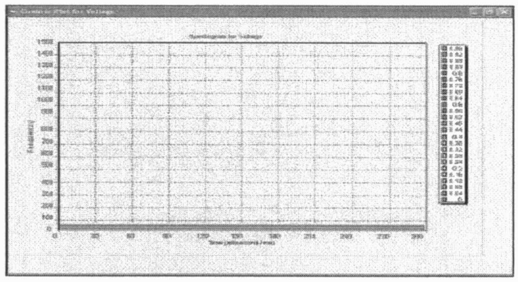
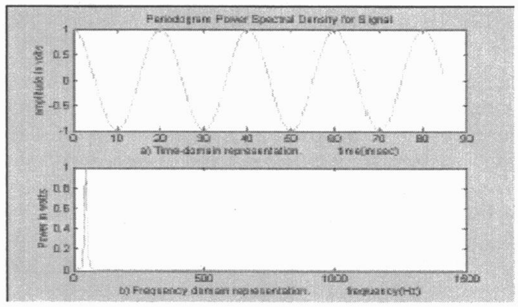


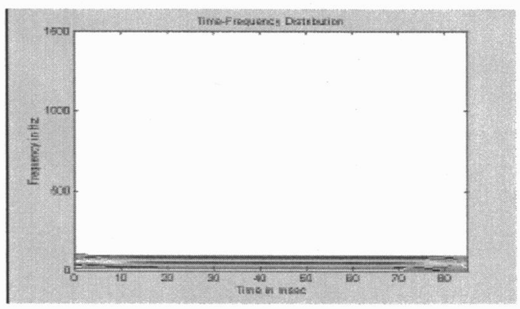
Figure 5. Spectogram for Voltage waveform.

IV. RESULT

Several analysis results based on the periodogram and spectrogram were made by simulation using MATLAB and on actual power-line waveforms. The objective is to show how each of the method differentiate the power-line waveforms and identify the various power quality problems. Fig. 6 and 7 shows the simulation results for normal and transient power-line waveforms. The signal frequency is represented by the at peak value of the power spectrum and time-frequency representation. For the transient signal, it is only represented on the time-frequency representation as a spike for duration of 10 msec at frequency of 1000 Hz and not on the power spectrum.

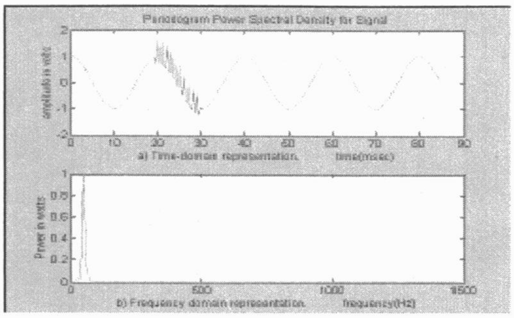


a) Time and power spectrum representation.

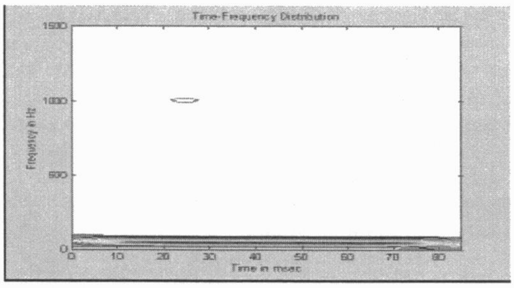


b) Time-frequency representation.

Figure 6. Simulated normal power-line waveform.



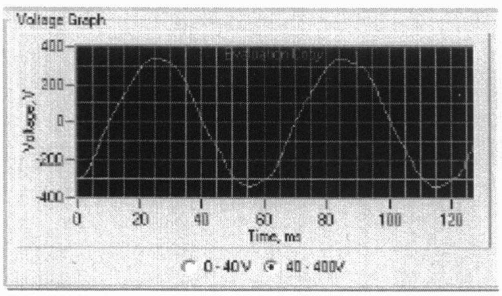
a) Time and power spectrum representation.



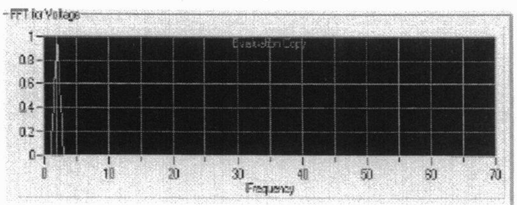
b) Time-frequency reprentation.

Figure 7: Simulated transient power-line waveform.

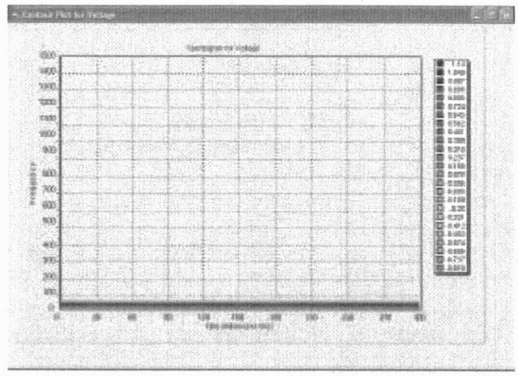
Analysis of actual normal and noisy power-line voltage waveforms are presented in Fig. 8 and Fig. 9. Both power-line waveforms are represented on the power spectrum and time-frequency representation. The true power-line voltage lies within the frequency of 50 Hz while the noise appears at a higher frequency of 1000 Hz. However, the time-frequency representation provides additional information that shows that the noise waveform appears at all times during the observation interval.



(a) Time representation.

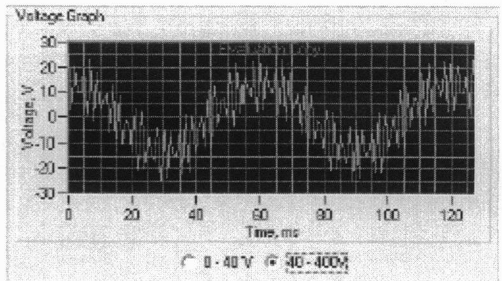


(b) Power Spectrum.

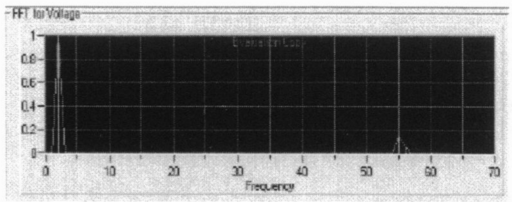


(c) Time-frequency representation.

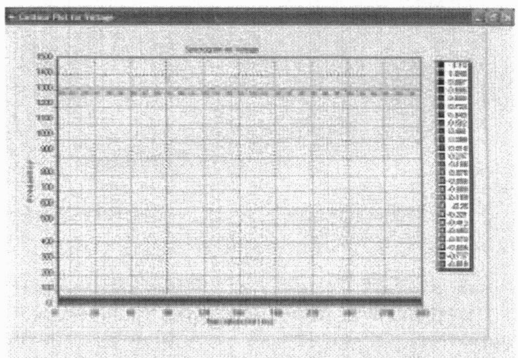
Figure 8. Measured normal power-line waveform.



(a) Time representation.



(b) Power spectrum.



(c) Time-frequency representation.

Figure 9. Measured noise voltage waveform.

V. CONCLUSIONS

The power quality monitoring system is built around the Texas Instrument's TMS320VC5416 DSP processor. Besides basic power measurements such as voltage, current, frequency and power factor, the system can also perform analysis such as power spectrum and spectrogram. The results are available in real time through a graphical user-interface. Analysis results shows that the spectrogram gives better characterization of power quality problems compared to power spectrum. The system allows users to identify power quality problems and take the necessary corrective or preventive action.

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