FPGA Based Design and Implementation of Spectral Envelope Preprocessor

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Abstract: *The global issue of energy conservation demands the need of managing and coordinating power consumption. The current transients of various loads are unique, depending on application and some other parameters like load type. The "spectral envelope" representation of observed current and voltage signals used in the non-intrusive load monitoring can be a very flexible basis for computing and tracking all sorts of useful metrics about power consumption. With the help of spectral envelopes it is possible to estimate real and reactive power consumption and also harmonic contents. For power monitoring and energy scorekeeping, a FPGA (Field Programmable Gate Array) can be used to implement a Spectral Envelope Preprocessor to develop an inexpensive separate module for individual load to help precise monitoring of specific load.*

Keywords: *transients; spectral envelope coefficients; FPGA; load monitoring*

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I. Introduction

Power electronics and power electronic controls are growing in consumer electronics. There is an increasing expectation that advanced power conditioning electronics will play a role in managing and coordinating power consumption. This is expected that power managing and coordinating not simply for a particular load, but also in response to the dynamic needs and capability of the utility system.

The "spectral envelope" representation of observed current and voltage signals used in the non-intrusive load monitoring can be a very flexible basis for computing and tracking all sorts of useful metrics about power consumption [1],[14],[15]. With the help of Spectral Envelopes it is possible to estimate real and reactive power consumption and also harmonic contents. Even for waveforms with substantial high frequency content, the time-varying spectral envelopes can be relatively band-limited. This work proposes an integer-arithmetic implementation of a spectral envelope preprocessor on an inexpensive FPGA. The Spectral Envelope Preprocessor on FPGA computes 'Spectral Envelopes' without the need for floating point computation. Hence, the FPGA can be inexpensively used to acquire load power consumption data. This data minimizes the need for "downstream" computation later in the signal processing workflow. Of course, further computation can be used to track or control energy consumption.

II. Relevance

Digital power monitoring has also made its way to the "plug" and "power strip" level. Many different schemes for storing or communicating information are still under exploration . Most of these solutions deploy computation hardware that is either substantially complicated in both hardware and firmware such complicated work is proposed and in in which a DSP and a micro-controller work together to coordinate computation of real, reactive, and apparent power, or where fully integrated custom chips are specifically developed for a particular application.

A few examples from an enormous array of metering and measurement approaches for monitoring power, Harmonic-adjusted power factor meter, method for determining electrical energy consumption, programmable electrical energy meter utilization, revenue meter with power quality feature.

In Harmonic-adjusted power factor meter, Method for determining electrical energy consumption, Programmable electrical energy meter utilization, Revenue meter with power quality feature and their associated references describe various metering schemes that compute real, reactive, and apparent power, and also harmonic distortion in one form or another. S.R.Shaw et. al used multiple phase-locked loops , Analog multipliers and integrators were used to estimate spectral envelope coefficients [2]. A design using multiplying digital-to-analog converters, low-pass filters, and a single phase-locked loop was used to estimate spectral envelope coefficients by S. B. Leeb et al [1]. An expensive digital signal processing board was used to perform the calculations by S.R.Shaw et. al [2]. The processing power of a personal computer was used for spectral envelope coefficient estimation by S.R.Shaw [3]. All of these systems can provide accurate estimates of spectral envelope coefficients or related quantities. They serve as essential building blocks of various types of metering systems. They are often expensive and dedicated.

A. Need of System:

There is an increasing expectation that advanced power conditioning electronics will play a role in managing and coordinating power consumption not simply for a particular load, e.g., a variable speed drive in an air conditioning plant, but also in response to the dynamic needs and capability of the utility system. Loads that can respond not only to their own tasking but also to the needs of the utility are implicit in many visions. There is a need for flexible, inexpensive metering technologies that can be deployed in many different monitoring scenarios. Switch gear like circuit breaker panels may eventually be expected to provide detailed sub-metering information for different loads on different breakers or clusters of breakers and controls.

III. Proposed System Details

Typical turn-on and turn off current transients of various loads are different from each other and unique, depending on application and some other parameters like type of load. So these transients can be used to identify the load which is key thing of this work. Dynamic changes in the power and harmonic consumption of a load, e.g., during turn-on or turn-off transients, can serve as a fingerprint for identifying load operation [1]. For example, an observed turn-on transient from a training observation produced by one of a collection of loads can be used to identify the load in an aggregate current measurement. All that is needed, in principle, to determine the operating schedule of a collection of loads is to record the aggregate current drawn by those loads and then match each observed transient to the turn-on or turn-off fingerprint of a particular load in the collection.

However, direct examination of current waveforms may not be practical for many stages of some applications, including many components in energy scorekeeping, monitoring, or conservation systems. Direct operations on the current waveform require sample rates adequate to capture the highest harmonic content of interest. [4]. In some metering, monitoring, and control applications it is more practical to either store data for a period of time or examine it later, or to transmit data to another location for interpretation and control. In either of these cases, it is convenient to have a useful representation of the data that avoids excessive storage or communication bandwidth requirements.

Spectral envelopes provide a useful separation between data collection and analysis. They permit a small, inexpensive system with low processing power to collect data continuously. A system with larger available processing power, potentially physically remote from the data collection front-end, can either review a storage device at a later time or continuously process a relatively low bandwidth information stream over a convenient communication channel, wired or wireless.

The spectral envelopes of current represent the harmonic content of the input waveform for each line-locked period of the service voltage. Given N samples i[n] of a waveform i(t) over one period, the samples can be expressed in terms of their spectral content by,

$$\mathrm{i[n]} = \frac{1}{\mathrm{N}} \sum_{k=1}^{N-1} \left(a_k \sin \frac{2n\pi k}{N} + b_k \cos \frac{2n\pi k}{\mathrm{N}} \right)$$

Where, the spectral envelope coefficients are a_k and b_k for that period and are defined as below.

$$a_k = \sum_{k=1}^{N-1} \mathrm{i[n]} \left(\sin \frac{2n\pi k}{N} \right)$$

$$b_k = \sum_{k=1}^{N-1} \mathrm{i[n]} \left(\cos \frac{2n\pi k}{N} \right)$$

Here, k denotes the multiple of the line frequency to which a particular spectral envelope corresponds; for example, k = 1 corresponds to the 50 Hz component and k = 3 to the 150 Hz component. The values of these spectral envelopes are calculated for each period of the line voltage; the values at period m will be denoted $a_k[m]$ and $b_k[m]$. With this definition, spectral envelopes can naturally be calculated from the real and imaginary parts of the Discrete Fourier Transform (DFT) of i[n] over each period of the line voltage.

Given the DFT coefficients over one period of the service voltage, it is possible to exactly reconstruct or preserve all of the information in the raw current samples over that period. Of course, simply recording all of the DFT coefficients will not reduce the data handling requirements—if there are N samples of current, the DFT will produce N DFT coefficients. While it may appear that storing the complex DFT coefficients would take twice as much space as storing the raw current samples, because they are complex numbers, note that the DFT will be symmetric (because the raw current samples are real), so only Nx2 of the N complex numbers need to be stored. The data requirements for storing all meaningful DFT coefficients is the same as storing all raw current samples at the same level of precision.

In situations where the significant or relevant current drawn by an electrical load consists predominantly of the fundamental frequency only a few DFT coefficients [1]. These relatively few DFT coefficients can be used to reconstruct the original current samples with a relatively small error. Furthermore, the time varying values of the DFT coefficients themselves can be used directly as fingerprint signatures for the loads, or to track important quantities associated with load operation, with reasonable accuracy. Because only a few DFT coefficients may be needed to accurately represent the current waveforms, this “spectral” approach to the representation of the waveforms serves as a form of compression.

To calculate, store, and communicate a relevant subset of DFT coefficients for power monitoring and energy scorekeeping, a prototype FPGA (Field Programmable Gate Array) will be used to implement a Spectral Envelope Preprocessor. This system makes use of a low-cost FPGA. The spectral preprocessor consists of four subsystems: the first, to obtain current and voltage samples; second, to compute spectral envelope coefficients; third to store computed spectral envelope coefficients; and fourth, to transmit the spectral envelope coefficients to another computation or display platform for further analysis.

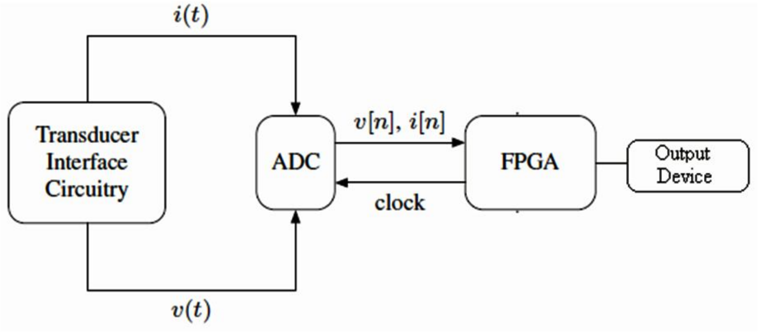

Figure 1. Proposed system block diagram

Figure 1 shows the overall block diagram of the system. Data flows through the system as follows. The transducer interface circuitry first measures the line voltage and aggregate current, producing the signals v (t) and i (t). These signals are sampled and quantized by an analog-to-digital converter (ADC) that produces the samples v[n] and i[n]. The FPGA processes these samples to compute spectral envelopes. The spectral envelope coefficients can be stored for later use. The FPGA provides control logic for each of the subsystems. Current and voltage measurements from at least one voltage channel and at least one current channel are used to compute spectral envelopes. The system is easily expanded to measure more channels, supporting three-phase electrical services, for example.

The prototype system uses current transducer to measure aggregate current and a transformer to measure the line voltage. A transformer with dual secondary coils is used in the prototype. This provides one coil for measurement, and a second coil for powering the preprocessor. The two coil arrangement provides a voltage sense with very little phase distortion, ensuring accurate calculation of in-phase and quadrature spectral components. Figure 2 illustrates this utility connection.

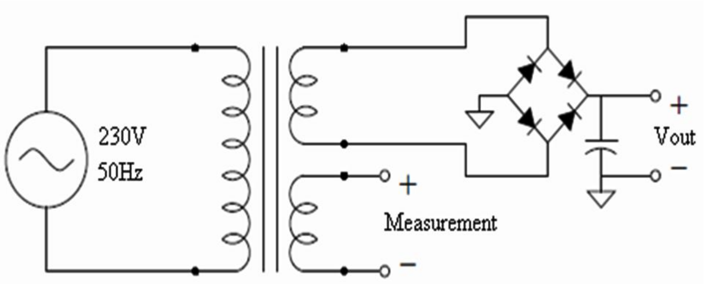

Figure 2 - Power supply and measurement schematic

The FPGA system receives both line voltage measurement and low voltage supply through a transformer with dual secondary coils. The preprocessor takes as input the discrete-time samples of i[n] and v[n] and produces estimates of the spectral envelope coefficients a_k and b_k of the current i[n].

IV. Discussion

The proposed system is inexpensive which can be used as a separate module to individual load. This helps precise monitoring of specific load status, which otherwise would indicate average status of multiple loads. Individual load status monitoring can further display failure conditions by comparing load status parameters with load ratings and thus help to take corrective measures. Since the load status information is provided on the respective LCD display human supervisor intervention is required. This demands periodic observation of the display.

V. Conclusion and Future Scope

Individual loads may be expected to compute information about their power consumption. They may also be expected to communicate information about their power consumption through wired or wireless means.

The metering hardware and access to metered information will likely limit the implementation of new electric energy conservation strategies in the near future. So “sensing and measurement” is one of the essential technologies for near future.

The FPGA can directly control communication as well, providing wired or wireless access, or storage on flash memory or may on other media also. The spectral envelope FPGA is a cost-effective building block that can be used to enable a huge array of power monitoring and control applications, either for the individual load or for several loads. It can be used to provide necessary power consumption information for coordinating power electronic controls.

References

[1] S. B. Leeb, S. R. Shaw, and J. L. Kirtley, “Transient event detection in spectral envelope estimates for nonintrusive load monitoring,” IEEE Trans. Power Del., vol. 10, no. 3, pp. 1200-1210, Jul. 1995.

[2] S. R. Shaw, C. B. Abler, R. F. Lepard, D. Luo, S. B. Leeb, and L. K. Norford, “Instrumentation for high performance nonintrusive electrical

load monitoring," Trans. ASME J. Sol. Energy Eng., vol. 120, no. 3, pp. 224-229, Aug. 1998.

[3] S. R. Shaw, "System identification techniques and modeling for non-intrusive load diagnostics," Ph. D. dissertation, Mass. Inst., Technol., Cambridge, MA, Feb. 2000.R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[4] J. Paris, et al. "Scalability of Non-Intrusive Load Monitoring for Shipboard Applications," ASNE Day 2009, National Harbor, Maryland, April, 2009.

[5] Shaw, S. R., S. B. Leeb, L. K. Norford, R. W. Cox, "Nonintrusive Load Monitoring and Diagnostics in Power Systems," IEEE Transactions on Instrumentation and Measurement, Volume 57, No. 7, July 2008, pp. 1445-1454.

[6] Khan, U. A., S. B. Leeb, M. C. Lee, "A Multiprocessor for Transient Event Detection," IEEE Transactions on Power Delivery, Volume 12, Number 1, pp. 51-60,January1997.

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