Novel Harmonic Analysis Method Improves Accuracy, Reduces Computation Overhead in Smart Meters

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IDEA IN BRIEF

A new approach to performing harmonic analysis is adaptive real time monitoring (ARTM). This article compares ARTM with FFT algorithms and band-pass filtering.

INTRODUCTION

With wider deployments of smart meters, smart grids, and distributed generation, power quality monitoring has become increasingly important. Harmonic analysis of current and voltage signals allows energy meters to characterize key power quality indicators, including the state of the load or supply, enabling predictive maintenance or system optimization.

The presence of harmonics is an ever increasing concern for energy providers and consumers alike, as excessive harmonic currents can lead to overheating of power transformers, reactive power compensators, and neutral conductors, and can cause false tripping of protective relays. Harmonic voltages and currents can also interfere with sensitive equipment operating in proximity to large harmonic generators.

To perform harmonic analysis, developers traditionally used a digital signal processor (DSP) that implemented some version of the Fourier algorithm or band-pass filtering. This article presents a new approach, adaptive real-time monitoring (ARTM), and compares it with FFT algorithms and band-pass filtering. ARTM will be featured in the next generation Analog Devices, Inc., products for energy applications.

FOURIER BASED METHODS

When harmonic analysis is performed in energy metering or power quality monitoring systems, phase currents and voltages are sampled simultaneously. Next, they are processed to compute power quality on the fundamental and harmonic components, including: active, reactive and apparent powers, rms values, power factors, and harmonic distortion. Fast Fourier transform (FFT) analysis comes immediately to mind. The procedure, as shown in Figure 1, is as follows:

- Determine the period of the fundamental component. This time consuming process is typically realized by low-pass filtering the phase voltages to isolate the fundamental, and then measuring the time between consecutive zero crossings. Any error in determining the period propagates to the error in amplitude and phase of the harmonics.
- Modify the sampling frequency to obtain 2^N samples per period. This implies using analog-to-digital convertors that allow variable sampling frequencies.
- Acquire 2^N samples corresponding to one or more periods.
- Execute FFT algorithm. Samples taken across multiple periods increase the accuracy of the computations, but impose a heavier burden on the DSP and a slower overall response.
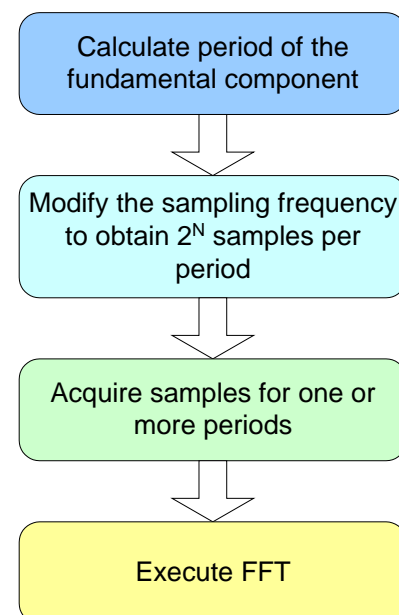

Figure 1. Steps required to implement FFT algorithm.

Modifying the sampling frequency as a function of the fundamental period affects other calculations usually executed in an energy meter. Energy computations include many filters that have coefficients computed as a function of the sampling frequency. Implementing an entire metering program with dynamic adjustment of such coefficients can be avoided by adopting the Goertzel algorithm. This approach does not require that the number of samples per period be equal to 2^N, thus allowing a constant sampling frequency independent of the fundamental period. The steps to implement this algorithm are as follows and shown in Figure 2:

- Determine the period of the fundamental component as presented for the FFT implementation.
- The sampling frequency is now constant and a certain number of samples per period are acquired.
- Compute the coefficients used in the Goertzel algorithm based on the number of samples per period.
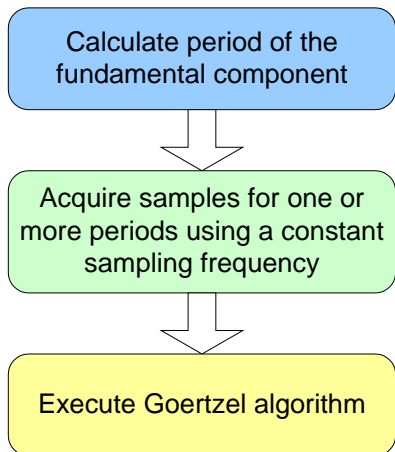- Execute the Fourier transform.

Figure 2. Steps to implement Goertzel algorithm.

BAND-PASS FILTER BASED METHOD

Perhaps the simplest approach for harmonic analysis is using band-pass filters: taking the phase currents and voltages and applying a narrow band filter around one harmonic. Multiple harmonics can be analyzed simultaneously if multiple filters are implemented in parallel. The steps to implement this approach are as follows and shown in Figure 3:

- Determine the period of the fundamental, as before. The accuracy of this measurement needs to be substantially increased due to the risk of missing the harmonic frequency of interest at higher harmonics. This means that more time must be allocated to filtering the time period between consecutive zero crossings.
- Compute the filter coefficients based on the fundamental period.
- The phase currents and voltages are filtered at the desired harmonic and the corresponding rms values are computed. One drawback of this method is that only the amplitude of the harmonic is preserved, and any phase information is lost. Therefore, the harmonic powers, the power factors, and harmonic distortion cannot be computed.
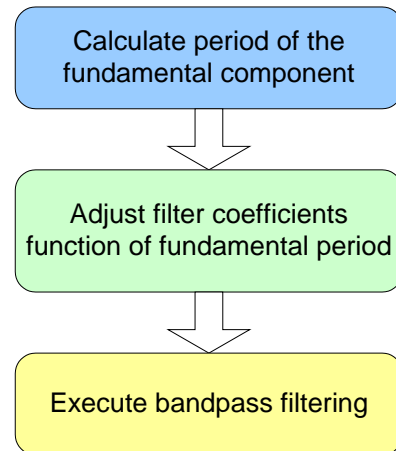
Figure 3. Steps to implement a band-pass filter.

ADAPTIVE REAL-TIME MONITORING (ARTM)

Since the fundamental frequency of the power grid can drift over time, there is a great advantage to a harmonic analyzer that can track these changes in frequency automatically, without user intervention. ARTM continuously estimates the likely value of the fundamental frequency and compares it to the real frequency present on the voltage line. Any error coming out of this comparison is used as a feedback factor to increase or decrease the value of the estimated frequency. This is basically the self-adapting element of ARTM.

A real-time procedure to extract spectral components is performed on the voltage and current of a selected phase based on the estimated frequency or integer multiples of it. This operation creates a set of values proportional to the energy present at the estimated frequency or multiples of it. Further signal processing can provide the real-time powers and rms values at the fundamental or integer multiples of the fundamental frequency (which, in fact, are the harmonics).

For poly-phase systems, independent frequency estimators are dedicated to each phase voltage. Thus, even if one phase voltage goes down, a user can select one of the remaining phases to estimate the frequency of the power grid and use it in the ARTM procedure.

The integer multiplication factor determines, in a flexible manner, which harmonic will be monitored. This has the advantage of dedicating all the DSP computational resources to monitor just the harmonics of interest. By contrast, an FFT approach will compute the values at multiple frequencies of the spectrum simultaneously, but will consume more resources. To achieve the same performance levels, the amount of memory needed to store the samples used by the FFT algorithm is significantly higher as compared with this proposed real-time method.

Monitoring a certain harmonic will become even more powerful and relevant if the fundamental values are also monitored in parallel: this enables the computations of harmonic distortion (HD) ratios for rms components of current and voltage, an indicator that is sometimes more meaningful than just the absolute values. In fact, from a purely theoretical DSP perspective, this is a widespread and accepted method of presenting data in a normalized fashion. In one further step, performing a sweep of the HD values for certain range of harmonic indexes allows the total harmonic distortion (THD) to be computed by adding the values obtained.

In addition to magnitude response over frequency, a classic and complete harmonic analyzer should provide information about the phase response at certain frequencies. The ARTM provides phase information in terms of calculated power factor, which is the ratio of active power to the apparent power. ARTM computes power factor corresponding to both fundamental frequency (known as displacement power factor) and to various harmonic frequencies. Having these values in real-time can be very useful as a global indicator of power quality, but also for systems trying to implement control loops aimed at keeping the power factor within given boundaries.

Another benefit of computing active, reactive, and apparent power in real-time is that energy values at the fundamental or harmonics can be obtained through accumulation. This allows the user to analyze how the total energy consumption is distributed between fundamental and harmonic components.

In three-phase systems, there is further interest in harmonic analysis of the neutral current and on the sum of phase currents, especially in the presence of triplen harmonics (odd multiples of the third harmonic) created by various nonlinear loads. Because the net effect of triplen harmonics is additive, the neutral conductor may end up carrying more current than it was designed for, leading to overheating and possible fire. Triplens can also cause problems in three-phase delta transformers due to circulating currents that can overheat the windings. Being able to monitor the harmonic components on the neutral current as well as on the sum of phase currents can also be useful in indicating these potential imbalance issues.

In conclusion, it can be said that ARTM has all the advantages associated with systems performing real-time monitoring or control. And, because ARTM concentrates most of the DSP resources on monitoring just harmonics of interest, it provides higher efficiency and better performance.

A sweep of the frequencies can be performed to get a full picture of the harmonic spectrum.
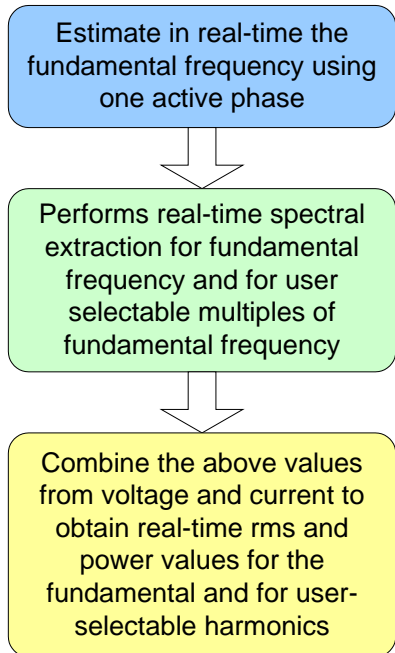
Estimate in real-time the fundamental frequency using one active phase

↓

Performs real-time spectral extraction for fundamental frequency and for user selectable multiples of fundamental frequency

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Combine the above values from voltage and current to obtain real-time rms and power values for the fundamental and for user-selectable harmonics

Figure 4. Steps to implement adaptive real-time monitoring.

Table 1 presents a comparison summary of various methods discussed in this article. Band-pass filtering and ARTM can be used to monitor the fundamental and harmonic components in real time. If the fundamental frequency of the power line changes, the ARTM method is proven to respond immediately with sufficient accuracy. The memory occupied by an eventual implementation is very large in case of the FFT (because of the need for sample storage) and quite small in the case of the other methods. The accuracy of the results is very high for ARTM, medium for the Goertzel algorithm and band-pass filter, and low for the FFT.

Table 1.

Method	Real-Time Monitoring	Adaptive	DSP Memory Requirements	Relative Accuracy	Spectral Harmonics Snapshot
ARTM	Yes	Yes	Small	Very High	Yes
FFT	No	No	Very Large	Low	Yes
Goertzel Algorithm	No	No	Small	Medium	Yes
Band-Pass Filtering	Yes	No	Small	Medium	No

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