TRANSIENT DETECTION ALGORITHM FOR LOW-COST ELECTRONIC BILLING METER

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ABSTRACT

Customers billed through single-phase energy meters can amount to 70% of total customers in Brazilian utilities. Any increase on the cost of such meters largely impacts utility costs.

This article proposes the use of algorithms that need low computational resources to be embedded in low-cost single-phase electronic billing meters for the detection of power quality events. The transformation of the single-phase sampled signal into virtual poly phase signals allows the detection of many power quality events, with reduced processing effort.

The results, obtained by using a low cost meter and by simulations, show that this solution can be implemented on low-cost meters to detect power quality disturbances.

INTRODUCTION

A large Brazilian utility with 5.5 million customers have 4.2 million connections through single-phase meters. Any cost change, in single-phase meters, produces a large impact on the utility costs. The design of those meters is oriented for low cost. Complex algorithms for power quality, like real-time filtering and Fourier analysis, cannot be used in most low cost meters.

Event detection algorithms for poly-phase billing meters were proposed on previous works [1] and [2], including voltage sag and swell, voltage unbalance and harmonic distortion. The necessary processing capabilities prevent its use in low cost meters. Changes on the detection algorithms can add power quality functions to single-phase billing meters.

A technique used by BOLLEN [3] to extract transients, is based on the comparison of samples from one cycle with samples from previous cycles. CUTRI [5] extracts symmetrical components and harmonic distortions in three phase systems working with delayed samples.

The method herein presented proposes the transformation of a single phase sampled signal into a virtual poly-phase signal. This transformation allows low cost processors to detect some power quality events and to detect some harmonic orders present in voltage signal. Simulation results for 2, 3 and 5 phase virtual signals are shown. A low-cost meter created with an Arduino platform is used to validate this method for low cost processors.

The detection of load switching is also tested with this method. This function can improve meter intelligence by offering customers detailed load information. Simulation results for load switching detection are also presented.

CONVERTING SINGLE-PHASE SAMPLES INTO VIRTUAL POLY-PHASE SIGNALS

Transient Detection Using Instantaneous Sum of Voltage Phases

Instantaneous sum of voltage phases (zero-sequence) equals to zero in a balanced system without distortions. Unbalances and distortions change the sum result and can be used to detect some events. In BOLLEN [4], V_0 is one of 7 components used to classify events in three-phase power systems.

Figure 1 shows a simulated transient event in phase C, which is detected with this method in a tree phase system.

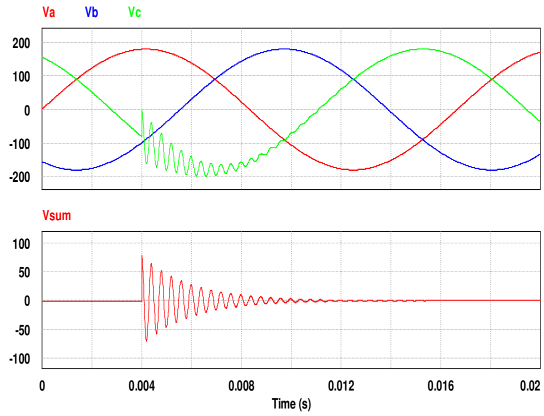

Figure 1 – Transient detection in a three-phase system

In a single phase system, delayed samples can be used to create virtual phases. A virtual three-phase system can be created with delayed samples by 1/3 and 2/3 of the fundamental cycle.

The sampled signal is stored in a circular buffer, and the incoming sample is summed with delayed samples at 120° and 240°. The resulting signal is also stored in a circular buffer for transient detections. This process is shown in figure 2.

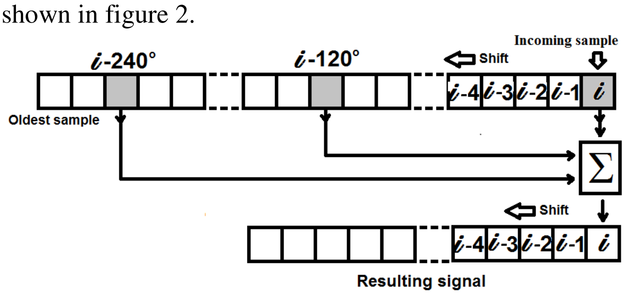

Figure 2 – Generating a virtual three-phase

There are two main differences in relation to the method where the previous cycle is used as reference. First, the detected transient is repeated, because it appears in phase A and in virtual phases B and C. It is not a problem when it is used only as a trigger for event detection and storage. Second, all the zero-sequence harmonics are seen on the composed signal, because the delay elements have the exact period of those harmonics.

Figure 3 shows the result of a transient detection in a single phase system. The transient detection is repeated for each virtual phase.

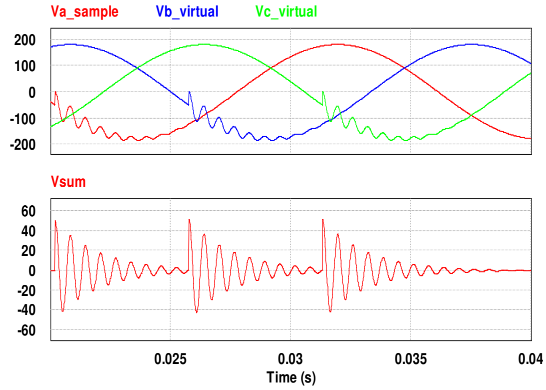

Figure 3 – Transient detection in a single-phase system

Low cost meters usually work at a fixed sample rate and have no synchronism with the power system. Low sample rate, as 32 samples/cycle, are common for those meters. The phase error produced at this sample rate can be greater than 5°. To reduce this phase error, the duration of each cycle is measured and an interpolation is calculated for the correct point. A voltage signal from the power grid, sampled at 10 bit resolution is presented in fig. 4. The resulting signal calculated directly with the samples is shown in blue; the obtained signal with interpolated points is shown in red. The rms voltage of the generated signal reduces from 7.7V to 4.2V with the interpolation.

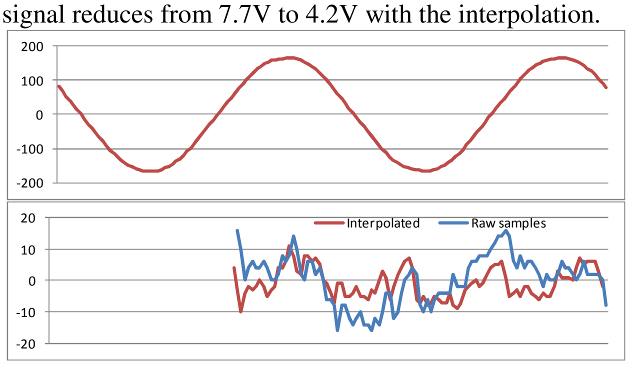

Figure 4 – Interpolation effects over the resulting signal

Harmonic Group Detection

This virtual poly-phase system may be created with any number of phases. For a N phase system, the resulting signal is the sum of incoming sample and N-1 samples with $2*\pi/N$ delay. Diagrams for the use of this method with 2, 3 and 5 phases are shown in fig 5.

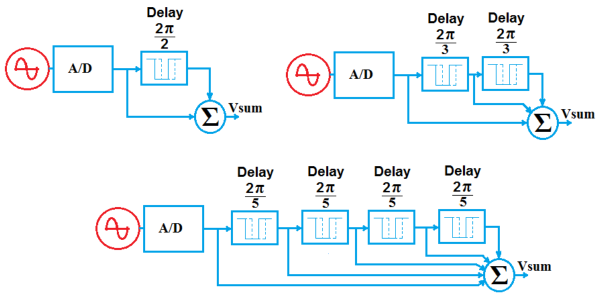

Figure 5 – Detection with different number of phases

For a N-phase system, steady state harmonics (multiples of N) are detected in the resulting signal. Working with multiple detectors at the same time, a meter can register the groups of harmonics that are present on the voltage net along the time. Any specific harmonic group can be programmed to be monitored by the system.

SIMULATION RESULTS

Simulations with MatLab, PSIM and a custom C++ program are used to verify the detection of transient voltage events. The simulated events are tested with 2, 3 and 5 phases systems.

Short duration voltage sag and swell simulations with PSIM (half-cycle) are shown in figure 6 for a two-phase system and in figure7 for a three-phase system. During voltage sags, a signal of opposite phase is generated whereas during voltage swells, a signal with the same phase is generated.

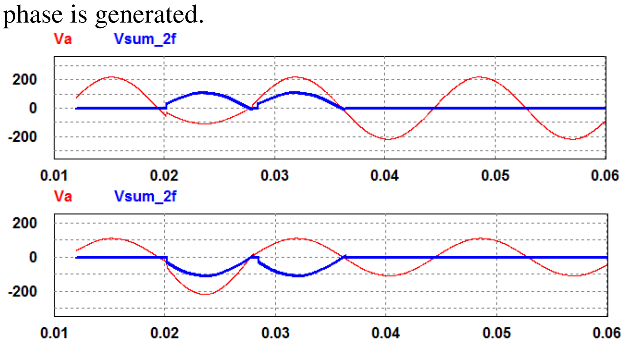

Figure 6 – Sag and swell in two-phase detector

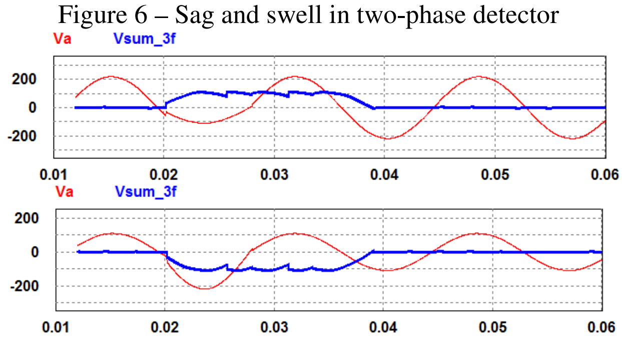

Figure 7 – Sag and swell in three-phase detector

Long duration voltage sags and swells generate a detection event at the start and another at the end. Figure 8 shows a long duration voltage sag simulation detected at start, and detected again at end.

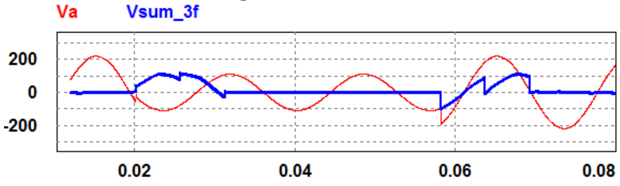

Figure 8 – Long duration voltage sag in three-phase detector

A custom simulation program was created to test the algorithms. Parameters like sample rate, frequency, harmonics and A/D resolution can be tested with this program. The program interface is shown in figure 9.

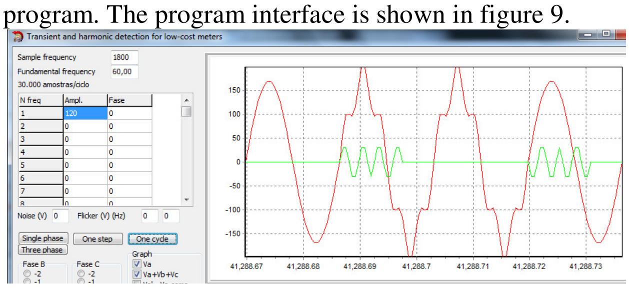

Figure 9 – Custom program created to test the method

Simulation results can be exported to a graphic or spread-sheet format. Figure 10 shows a simulation for 6th harmonic detection. The red line is the phase voltage, the green line is the virtual three-phase system detector and the black line is the detector using previous cycle samples.

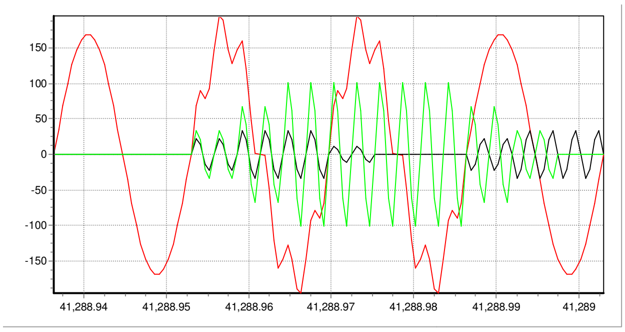

Figure 10 – Custom simulator output screen

RESULTS IN A LOW-COST PLATFORM

A low-cost meter based on Arduino platform was built to test the algorithm. The meter configuration has a 8 bit processor ATmega328, running at 16MHz. This processor has a 10 bit A/D converter, 2kB RAM and 32kB flash. Some peripherals (LCD display, real-time clock and a 4GB memory SD card) were added to enhance the interface with the user and to allow file storage of measurements. Those peripherals did not affect the processor performance. A conditioning board was added to adjust the input signal amplitude and to filter frequencies greater than Fs/2.

Voltage and current RMS values are calculated every 12 cycles and aggregated each 180 cycles, as IEC 61000-4-30 [6] recommends. Frequency is calculated each 10 seconds, but the duration of each cycle is measured to reduce the error of interpolated values.

The events were generated with a 390 AMX Pacific Power Source and the detected signals were stored in the memory SD card.

Figure 11 – Hardware used to test the propose algorithms

The meter was programmed to store two cycles in the detection of an event. The stored values have 10 bit resolution, they are not processed, there is no offset adjust and no gain correction. Figure 12 shows the detection of a harmonic distortion generated by AMX Pacific source. In the sequence, figure 13 shows the stored samples when meter detects the end of harmonic distortion.

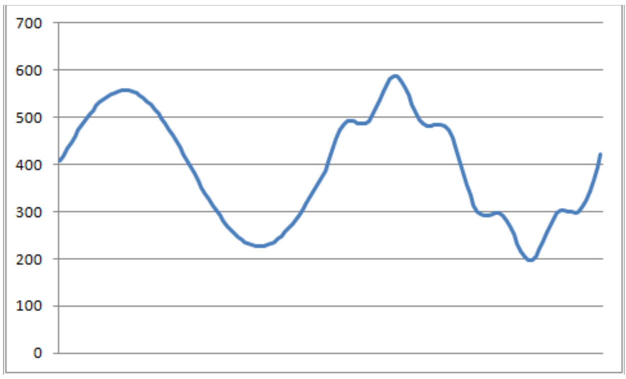

Figure 12 – Stored samples after transient detection

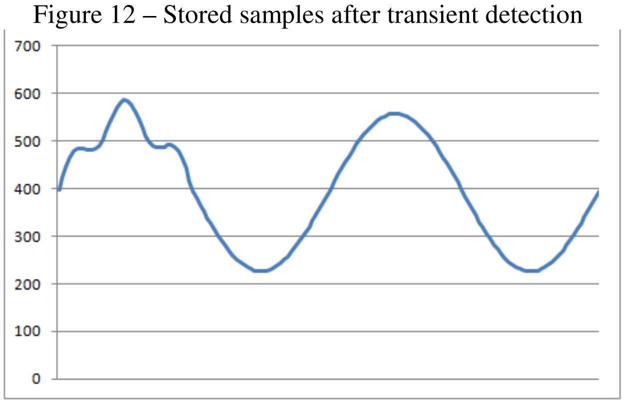

Figure 13 – Stored samples after stopping distortion

CURRENT MEASUREMENT TO DETECT LOAD SWITCHING

Another application of this method is the detection of load switching. In this case, the objective is to identify the occurrence and to measure the new current. The simulated model is the same used with voltage detection, but only a 360° delay element is used for the comparison with the previous cycle. The PSIM simulation model is shown in figure 14.

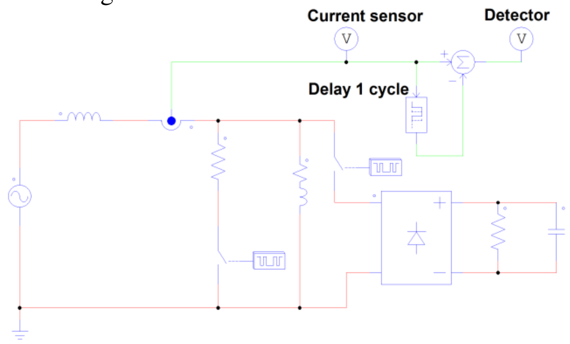

Figure 14 – PSIM model for load switch detection

A single resistive load switch was simulated in a circuit with non-linear loads. The load on-off switching is shown in figure 15.The total current is in blue and the detected variations are in red. The detected current is in phase with other loads when turned on and in opposite phase when turned off.

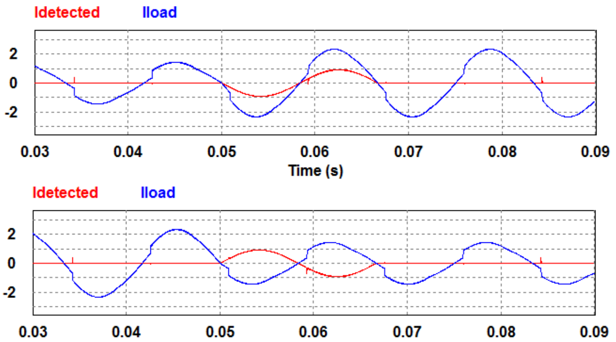

Figure 15 – Detection of a resistive load switching on-off

A problem detected with this method occurs for loads varying in time. A simulation of an incandescent lamp, with a high current at start and decreasing along time, is shown in figure 16. As the load current decreases, the detector senses and indicates a current in opposite phase, as a load switching off. This problem will need a processor with a larger buffer capability, to store samples until the load reaches steady state.

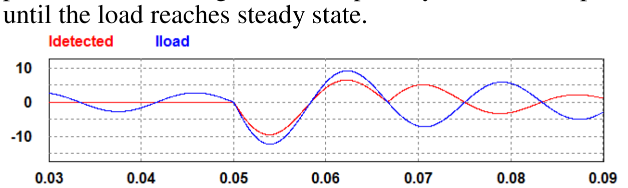

Figure 16 – Time varying load detection

CONCLUSIONS

The proposed method can be used to detect transient events on the power grid. Voltage sags, swells, oscillatory transients and harmonic variation could be detected with simulation programs and with low-cost meters. The results obtained with the low-cost meter show that this algorithm can be used with single-phase billing meters.

Load switching could be detected with simulation programs and will be tested with another version of the Arduino meter, because the memory in this version cannot handle the necessary buffer.

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