High Resolution Waveform Capture with 1PPS GPS Synchronization for Precision PQ Analysis

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Abstract: The constraints on implementing power quality algorithms in a traditional Power Quality analyzer design are “Time and Space” constrained. With Hardware, there is a finite amount of time available to complete the calculations and a limited amount of memory for the executable code, working variables and data storage. The fundamental challenge for Power Quality Equipment designers is to implement the power quality algorithms in real time. New techniques utilizing a 1PPS synchronized data capture allow for precision hardware to focus on measurement and opens up a multitude of software packages to analyze the results.

1. INTRODUCTION

The introduction of microprocessor based power quality analyzers in the 1980’s was a big leap forward compared to analog meters and strip chart recorders. At that time the technology for microprocessor based electronics was in its infancy. Today’s instruments are multiple orders of magnitude more powerful. For example the Interlogger [1] was designed in the mid 1980’s using an 8 bit microprocessor and had a 1 micro-second instruction cycle vs. the Power Quality Auditor (PQA-300) [2] which was designed 30 years later using a 32 bit digital signal processor with a 2.5 nano-second instruction cycle. To determine the difference in processing power consider that the Interlogger sampled 128 times per cycle and computes RMS values once every 2 seconds while the PQA-300 samples 1024 times per cycle and computes RMS values every ½ cycle – a performance increase of almost 4000. The storage memory for the Interlogger was a 256KB SRAM card while the PQA-300 stores data on a 128GB Secure Digital card – memory that is 500,000 times more dense in a package less than 1/10th the size!

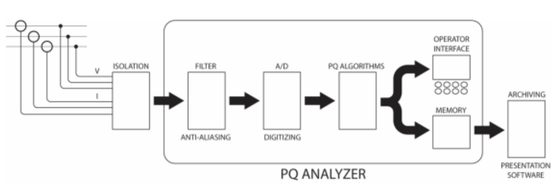

Fig. 1. Traditional PQ analyzer block diagram

While modern power quality analyzers are significantly more complex than they were 30 years ago their basic style of operation has not changed. Voltage and current signals are isolated, the signals are filtered to prevent aliasing which is a characteristic of sampled data systems and then digitized. Once the data is in digital form mathematical algorithms are used to calculate various electrical parameters such as RMS voltage and current, power, power factor, THD, harmonics, flicker, and the list goes on. The resulting values are stored in memory for later viewing, analyzing and archiving.

The constraints on implementing power quality algorithms in a traditional Power Quality analyzer design are “Time and Space” constrained – There is a finite amount of time available to complete the calculations and a limited amount of memory for the executable code, working variables and data storage. The fundamental challenge for Power Quality analyzer designers is to implement the power quality algorithms in real time.

Compromises that are sometimes made to overcome the “Time and Space” constraints may result in inconsistent results between instruments. You might think that advances in electronic technology will solve these constraints however it turns out that as the instruments get more powerful the Power Quality algorithms become more complex.

To address the issue of inconsistent results between instruments the widely used power quality measurement standard, IEC 61000-4-30 [3], specifies complex measurement and test conditions. For example there are a number of different timing constraints: voltage dip and swell measurements use RMS values calculated from a 1 cycle sliding window updated every ½ cycle, harmonics use a 12 cycle (at 60 Hz) fixed window and frequency uses a 10 second window that may or may not contain an integer number of cycles. There are also requirements to synchronize the internal clock time to a standard time signal with accuracy of +/- 16 milliseconds (at 60 Hz).

While following the IEC 61000-4-30 [3] standard does result in more consistent results between instruments it also increases the complexity of the algorithms that need to be implemented and executed in real time.

2. Next Generation Power Quality Auditor Designs.

There will always be situations where real time Power Quality results are needed which will require the traditional Power Quality analyzer design. For situations where real time power quality data is not required, which are most of the applications for portable power quality analyzers and many of the applications for fixed instrumentation, there is another way to implement power quality algorithms. These algorithms can be implemented off line by computers. This will virtually eliminate the “Time and Space” constraints.

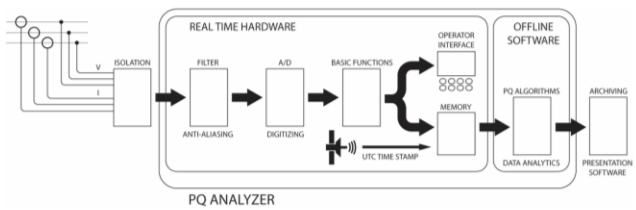

Fig. 2. Next Generation PQ analyzer block diagram

The key is to have access to continuous instantaneous voltage and current measurements with an accurate time stamp. Only recently has the technology been available to realize this. Advances in digital signal processing, analog to digital convertors, memory density and satellite communications (for accurate time stamping) now make this possible.

There have been solutions available, such as digital fault recorders that can store multiple cycles of instantaneous voltage and current data. However these usually require fault conditions to trigger the data storage and then the duration of data stored is measured in minutes. What is proposed, is that instantaneous data is recorded without the need for trigger conditions and the time period is as long as you may require – hours, days, months or even years. Presently the technology that we are working on can record to a single SD memory card. With a 128GB Secure Digital card the data duration varies from 1.8 days to 160 days depending on the samples per cycle and number of channels. However the concept that we have developed can be expanded to allow for effectively unlimited data storage.

Storing continuous instantaneous voltage and current measurements for off line computing supports the emerging field of Power Quality Data Analytics. Detailed studies on topics such as power system impedances, capacitor bank induced transients, propagation of transients through a power system, signaling and interharmonic characteristics and synchrophasors are now possible using convenient portable instruments to collect the data. Computers can be used to develop complex algorithms to investigate and characterize power quality issues.

3. Rapid Voltage Change Calculation

Traditional Power Quality Analyzers can recognize events and measurements differently.

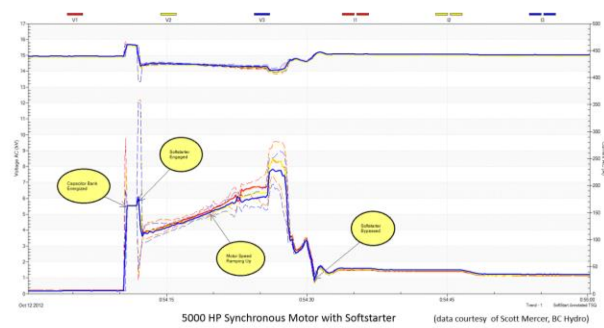

Fig. 3. 5000 HP Synchronous Motor with Softstarter

For example, here is some data that can be used offline to calculate Rapid Voltage Change.

This is the starting characteristic of a 5000HP synchronous motor with a 7MVar capacitor bank and softstarter. The capacitor bank is switched in just prior to the softstarter being engaged. The switching in of the capacitor bank caused a voltage rise and engaging the softstarter caused a voltage drop. This graph (fig.3) shows the RMS voltage and current during starting with a resolution of 200 milliseconds (12 cycles).

You can see from the graph that the largest rapid voltage change occurs when the softstarter is engaged. Continuous waveform data during this transient was exported to Excel in order to do Rapid Voltage Change calculations.

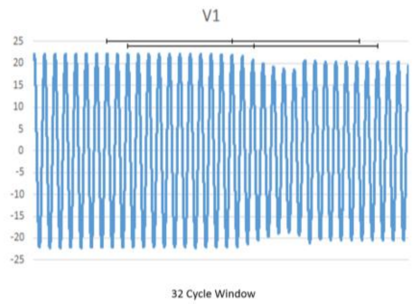

Fig. 4. Rapid Voltage Change period

This is a graph (fig. 4) done in Excel for a 36 cycle window at the time the softstarter was engaged. Rapid Voltage Change uses a 12 cycle window for RMS calculations. Results can vary depending on the synchronization of the 12 cycle windows with the data. For example by taking two consecutive 12 cycle windows, shown by the top line, you end up with RMS voltages of 15.62kV and 14.28kV resulting in an RVC of 8.6%. Move the starting point two cycles later and the results are 15.54kV and 14.12kV resulting in an RVC of 9.1%. Doing this in Excel is a little tedious but a program written specifically for calculating Rapid Voltage Change could quickly scan the data file and report the maximum Rapid Voltage Change and the time period over which it is calculated.

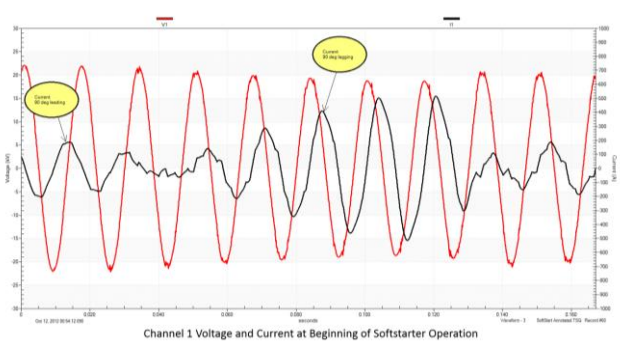

Fig. 5. Phase shift example

Notice (Fig. 5) that power factor changes so quickly from 0 lead to 0 lag, in less than 2 cycles! Just before the softstarter is engaged and the load is completely due to the capacitor bank where the current is leading the voltage by 90 degrees. Less than 2 cycles later the softstarter has shifted the current so that it is now 90 degrees lagging.

3.1. Interharmonics Calculation

A 120V 60Hz voltage signal with a 6V interharmonic at 927.1 Hz was generated. The following images (fig. 6) illustrate using multiple cycles for fine resolution interharmonic investigation.

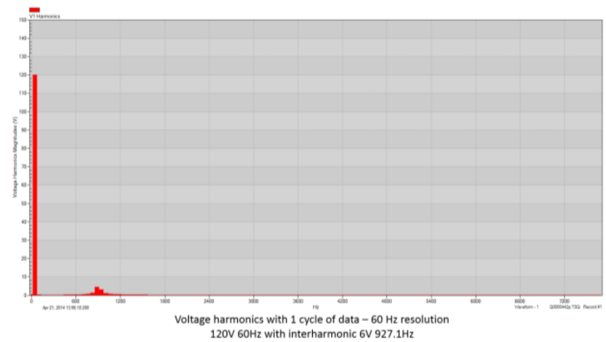

Fig. 6. Interharmonic Capture

With only one cycle it can be noted that an interharmonic exists but without a good measure of the magnitude or frequency (fig. 7).

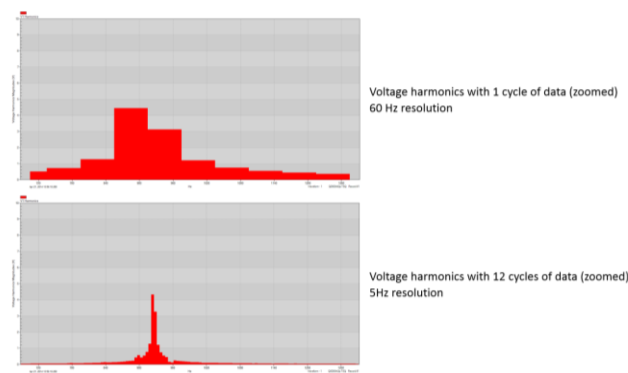

Fig. 7. Interharmonic comparison

Using the IEC 61000-4-7 [4] specification of a 12 cycle window gives us a better measurement with 5 Hz resolution. However to get an accurate measurement of this signal 0.1 Hz resolution is needed requiring 600 cycles.

For comparison (fig 8.) a finer resolution calculation was done using 1200 cycles with no difference in results as 600 cycles was able to resolve the interhamonic exactly to 927.1 Hz.

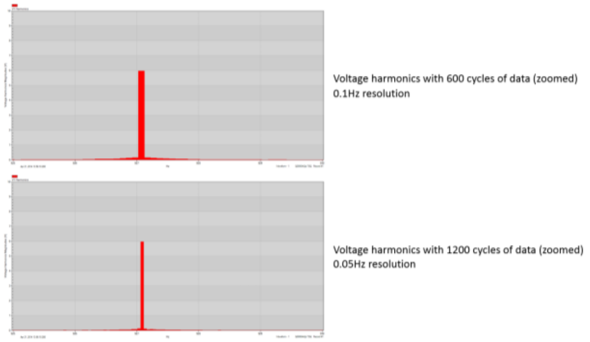

Fig. 8. Interharmonic Calculation comparison

3.2. Syncrophasor Calculation

Sychrophasors are another example of a Power Quality calculation that can be done offline. Syncrophasor is the magnitude and phase angle of a sinusoidal waveform with respect to an exact time reference. The exact time reference that is used is called the 1PPS signal or one pulse per second. This signal comes from multiple satellites and is accurate to less than +/- 100 nanoseconds. This signal is available almost anywhere in the world where you can place a receiving antenna with a view of the sky.

The Synchrophasor angle is determined using a cosine reference which means that a 1PPS signal at the peak of the sinusoidal waveform corresponds to a phase angle of 0 degrees (fig. 9).

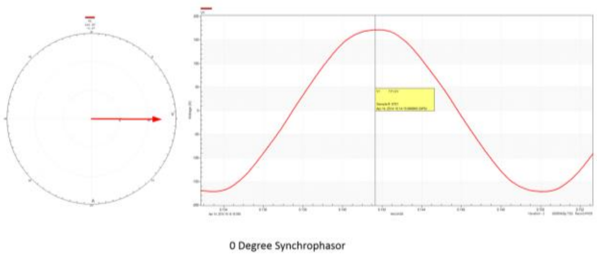

Fig. 9. Synchrophasor at 0 deg

A 1PPS signal at the negative zero crossing corresponds to a phase angle of 90 degrees (fig. 10).

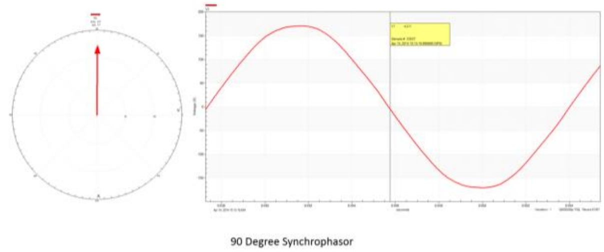

Fig. 10. Synchrophasor at 90 deg

Analyze an absolute synchrophasor angle and System Frequency (fig. 11). If the system frequency is exactly 60 Hz then the Synchophasor angle will be constant. Typically the long term average of frequency will be almost exactly 60 Hz but at any instance in time the frequency may be slightly higher or lower which will cause the Synchrophasor angle to change. Synchrophasor analysis is a relatively new field of power systems study and is being used to monitor and potentially to control power system stability.

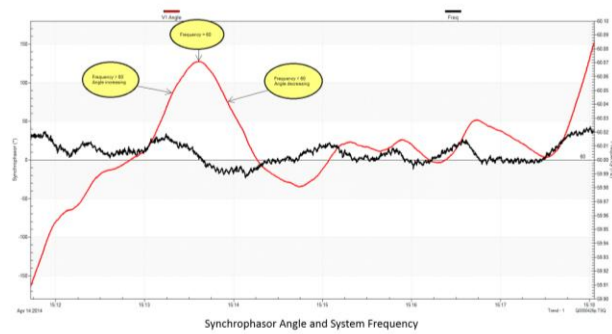

Fig. 11. Absolute Synchrophasor

The relative synchrophasor angle between different locations in a power system is used to determine how the system is operating and the stability of the system. Much of the study concerning Synchrophasors is with respect to real time monitoring and control of a power system however there is a use for examining synchrophasors in non-real time. Offline examination of synchrophasors can be used for Post Event Analysis and system characterization – that is normal vs. abnormal behavior.

4. DISCUSSION

Having a Power Quality Analyzer provide instant confirmation of a problem is indeed valuable. But limitations to processor speeds have shown that the analysis of entire data captured may provide information that is typically lost and ignored during the event. Ideally, equipment designs in the future will minimize these impacts and have everything in “real time”.

5. CONCLUSIONS

As the field of Power Quality Analysis advances and new algorithms are developed these algorithms can be implemented and tested quickly using archived continuous instantaneous voltage and current data.

ACKNOLWEDGMENTS

Radian Research would like to thank Gordon Hoops of Candura Technologies for their expertise and assistance in the Power Quality Auditor Development and Expertise.

REFERENCES

[1] Power Quality Data logger: http://www.techno-canada.com

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[3] IEC61000-4-30 Edition 2 – 2008-10 Electromagnetic compatibility (EMC) Part 4.30: Testing and measurement techniques – Power quality measurement methods.

[4] IEC61000-4-7 Edition 2 – 2002.08 EMC – Part 4.7: testing and measurement techniques – General guide on harmonics and interhamonic measurements and instrumentation, for power quality measurement methods.