Integrating power quality analysis and protection relay functions

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Key words

power quality, protection relay, digital resampling

1. Introduction

The amount of energy extracted from renewable sources, e.g. wind or hydro power plants, photovoltaic arrays, fuel cell systems is growing. These sources must be either synchronized or converted to alternating current before their energy can be injected into the grid. During this process disturbances in the form of harmonics, voltage sags and overshoots are created which have to be kept under control. There will be a growing need for power quality metering devices placed at nodes where local power sources connect to the grid. As the power quality measurement process is a demanding one, power quality analyzers have developed into specialized, complex devices. Power quality analyzers available on the market today are too expensive and specialized to be applied on a mass scale.

The objectives of the work which we try to describe have been to equip a conventional protection relay with power quality analysis functions at a very small additional cost to the end customer. The tremendous advance in the DSP microprocessor technology enables us to use in real time advanced signal processing algorithms like signal resampling in the digital domain that are the key to achieving design objectives. To keep the cost of the developed protection relay low, the developed algorithms should put minimal requirements on hardware.

2. Power quality analyser architecture

Architecture of power quality analyzer is shown in Fig. 1. Each voltage input signal is separated into low frequency component with spectrum cut above some frequency f_g (typically f_g is equal to 3 kHz) and high frequency component with spectrum cut below f_g.

The high frequency component is used for detecting and recording transient voltage surges. This is done in a module composed of a high speed A/D converter – with sampling rate above 1 Ms per second per channel and a FIFO memory. The recording process is triggered when the voltage crosses a threshold value. As transient voltage surges last less than 10 ms, only one line period is recorded. The transient voltage surges recording module is largely independent of the rest of power quality analyzer; in Fig. 1 it consist of blocks outside the dotted line.

The low frequency component of input current or voltage signal, processed by blocks contained within dotted line in fig. 1) is used for determination of signal characteristics like frequency, RMS value, harmonic content, THD etc.

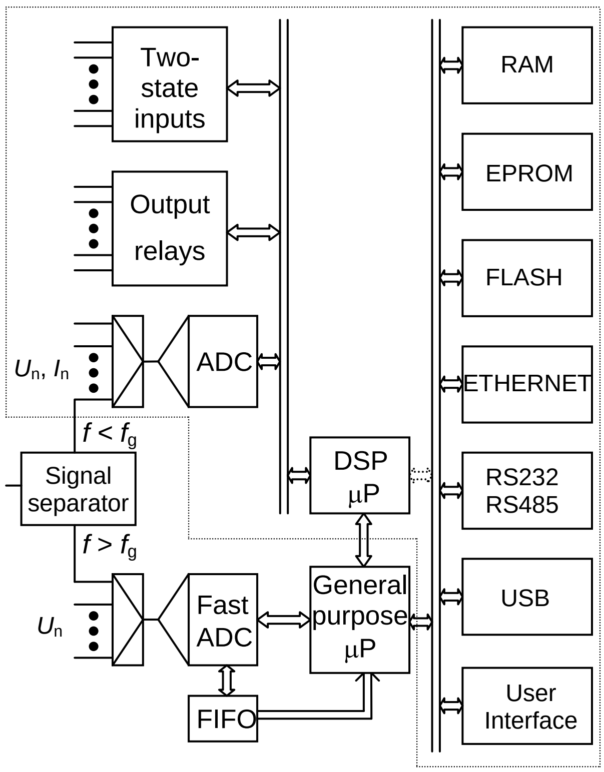

Fig. 1 Block diagram of power quality analyzer

Protection relay with 2 kHz bandwidth input signal path, equipped with advanced digital signal processing and statistical software can replace power quality analyzer. Extremely fast DSP processor and high density memory chips enable concurrent performance of protection and quality analysis functions.

3. Spectrum determination algorithms for power quality analysis

In the device that combines protection relay functions with power quality analysis functions it is necessary to satisfy several conflicting requirements concerning sampling frequency. For protection functions the frequency spectrum of voltage or current signal has to determined from measurement interval equal to one line period. For power quality analysis the frequency spectrum has to be determined from measurement interval equal to ten line periods. It is impossible to choose the sampling frequency in such a way that the number of samples over both measurement intervals is equal to a power of two, which is necessary for efficient computation of DFT [4]. Moreover, in compliance with relevant standards [2],[3] and in accordance with Fourier theory [4], synchronization of sampling frequency to the multiple of line frequency is needed. However, synchronization of sampling frequency to line frequency deprives the protection relay of a very useful feature, namely waveform recording that preserves time scale.

The solution that can reconcile the above mentioned conflicting requirements is to use multirate digital signal processing with effective sampling rate change performed entirely in digital domain.

Using digital resampling technique, it is possible to approximate any desired sampling rate by an effective sampling rate equal to $f_s \cdot (N/M)$, where f_s is the original sampling frequency and N and M are natural numbers. The values for N and M have been chosen so that $f_s \cdot (N/M)$ approximates the ideal sampling frequency with accuracy required by relevant standard [2].

For each of the N, M pair (N and M have been calculated individually for each line frequency f), a number of simulations have been performed with software generated data on a real DSP processor implemented in a protection relay.

The simulation results confirmed that resampling in digital domain is equivalent to synchronization of sampling frequency to the multiple of line frequency. If the error of approximating ideal sampling frequency by the effective sampling frequency is equal to or less than 0.03% [2], the accuracy of frequency spectrum determination, up to 40th harmonic, is very good – provided the level of interharmonics is well below the level of closest harmonics. If the level of interharmonics is comparable to the level of closest harmonics, an effect known in theory as spectrum leakage is taking place and the level of harmonics is computed with very large (>50%) error.

The error of spectrum determination can be reduced if the ideal sampling frequency is better approximated by the effective sampling frequency. This results however in larger values for N and M and entails greater computational effort, roughly proportional to the greater of two values for N and M (with common factors cancelled out).

4. Conclusion

Power quality analysis functions can be divided into three categories. One category is transient voltage surges detection and registration. The second category consists of functions that determine how the RMS value of voltage signal behaves over time. The functions in the third category deal with frequency spectrum determination and they are the most demanding in terms of the processing power required.

The research has shown that it is possible to implement functions that compute in real time frequency spectrum of voltage and current signals with harmonic and interharmonic content up to 2 kHz in a conventional protection relay. The algorithms that have been developed for that purpose use advanced signal processing techniques like resampling carried out entirely in the digital domain.

The main advantage of developed algorithms is that they put minimal requirements on hardware. Only one constant sampling frequency is needed both for protection functions and power quality analysis functions.

Acknowledgement

This research work has been financed by public money for science in the years 2007 – 2008 as a targeted research project.

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