Different Power Quality Detection Algorithms Using Windowing Technique

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Abstract - Set of limits of electrical properties which allows electrical systems to function in their intended manner without substantial loss of performance is called power quality. Today's electricity consuming equipment's are very much sensitive to power quality problems; hence power quality is a growing concern. Problems like, sags and swells, last only for a fraction of a second, but cause severe damage and great loss in the power systems. Hence the detection of the voltage sags and swells is considered very important. The paper presents three algorithms based on a windowing technique to detect sag and swell using a PIC32 microcontroller. Also their comparisons are made. Simulation results using Mat lab are also presented to verify the effectiveness of the proposed methods.

Keywords- power quality; sag; swell; windowing technique

I. Introduction

Power quality determines the fitness of electrical power given to consumer devices. It describes electric power that drives an electrical load and the load's ability to function correctly. Without the proper power, an electrical device may not function in the intended manner, fail prematurely or not operate at all.

No real-life power source is ideal; they generally deviate in at least the following ways:

- Variations in the peak or RMS voltage
- A short duration decrease in voltage values - sag
- A Short duration increase in voltage values - swell
- Abrupt, very brief increases in voltage - spikes
- High over-voltage disturbances that last for a very short time called transients

Much of the electrical equipment in an industry requires high-quality electricity; it will not tolerate sags, swells, transients, or harmonics as these disturbances cause problems such as malfunctions, instabilities, short lifetime, failure of electrical equipment's etc.

Voltage Sag

Power systems have non-zero impedances, so every increase in current causes a corresponding reduction in voltage. Usually, these reductions are small enough that the voltage remains within normal tolerances. But when there is a large increase in current, or when the system impedance is high, the voltage can drop significantly [5].

Voltage sags are one of the most common power disturbances. Equipment's used in today's industries are becoming more susceptible to voltage sags due to increase in the equipment complexity.

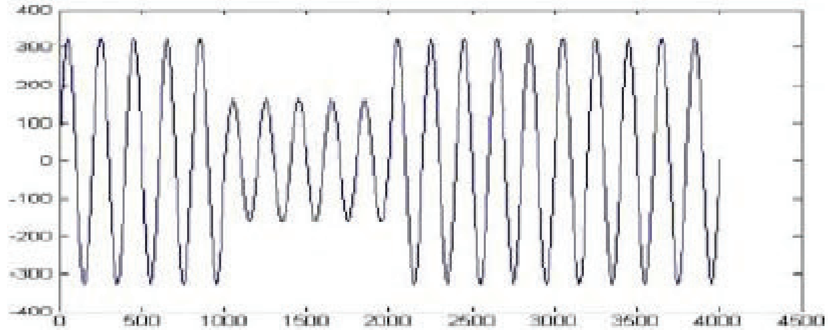

Fig.1 Voltage Sag

Voltage Swell

Voltage swells are short increases in voltage that lasts from a cycle to a second or so, or tens of milliseconds to hundreds of milliseconds. They are caused by sudden drop in the load on a circuit with poor voltage regulation or due to loose neutral connection. Although more obvious are the effects of a sags, the effects of a voltage swell are often more destructive. It may cause breakdown of components on the power supplies of the equipment, though the effect may be a gradual, accumulative effect. It can cause control problems and hardware failure in the equipment, due to overheating that could eventually result to shut down. Also, electronics and other sensitive equipment are prone to damage due to voltage swell.

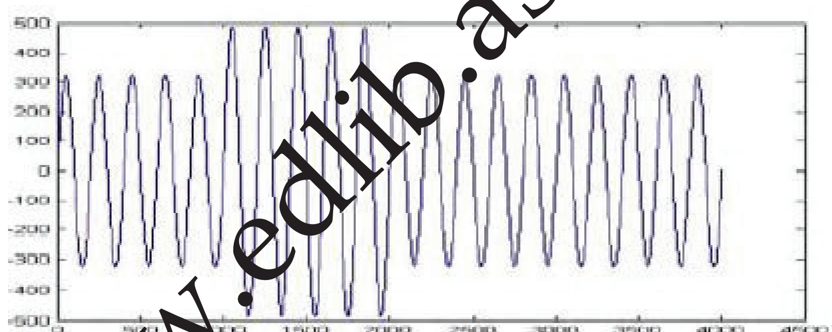

Fig.2 Voltage Swell

Rest of the paper includes the description of three algorithms based on moving window technique in order to detect the number of sags and swells occurred in an input voltage. All the three algorithms have been simulated in Mat lab and have been compared.

II. Detection Algorithm Using Moving Window Technique

To ensure the Power quality, power disturbance detection becomes important. In this paper basically three algorithms are described to detect the total number of voltage sags or swells that has occurred.

Moving Window

Calculations are performed with the samples enclosed by the window in Fig.3. Now as in the Fig.4, the window is moved by one sample such that the window encloses the same number of samples, but the new window deletes the first sample of the old window and adds the next sample after the last sample of the old window. Now with the samples in the new shifted window, calculations are performed.

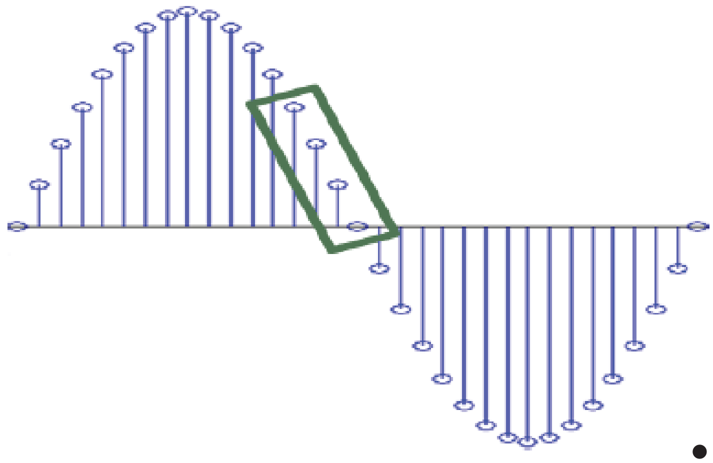

Fig.3 Window enclosing a few numbers of samples

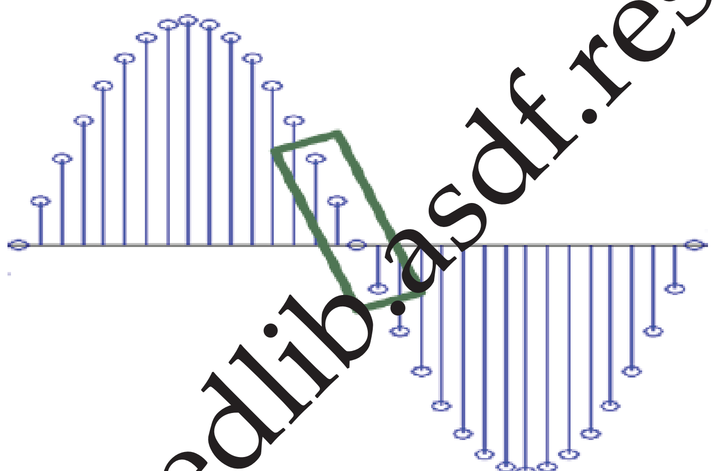

Fig.4 Same window enclosing the same number of samples but moved by one sample, hence moving window.

A. Moving Average Window Algorithm

A moving average is used to analyze a set of sample points of a sampled voltage by creating a series of averages of different subsets of the full sample set. It utilizes a window of certain size, taken to be a full cycle for determining the subset. Given a series of samples and a fixed subset or window size, the first element of the moving average is obtained by taking the average of the initial fixed subset or window of the sample series. Then the window is modified by "shifting forward"; that is, excluding the first sample of the series and including the next sample following the original window in the series. This creates a new window of samples, which is averaged. Each time the average over a window is calculated, it is checked to cross the threshold value set for causing sag. Every time we shift the window by one sample each, we repeat the procedure of finding the average value over the window and checking whether it crosses the threshold. If it is found to cross the threshold value continuously for a few succeeding average values that have been calculated, then a sag is detected. Similarly a swell is detected it crosses the swell threshold continuously.

B. Moving average window algorithm using RMS

The most common technique used for detecting purpose is the calculation of the root mean square (RMS) value of the voltage supply. Here similar to the above method a window is used. All the samples in the window are initially squared, then their average is obtained and finally its square root is found. This obtained RMS value is checked to cross the threshold value set for causing sag. We repeat the procedure of calculating the RMS value and doing the sag checking by shifting the window by one sample each. If it is found to cross the threshold value continuously for a few succeeding average values that have been calculated, then a sag is detected. Similarly a swell is detected it crosses the swell threshold continuously.

$$V_{rms} = \sqrt{1/N \sum_{i=1}^{N} v(i)^2}$$

Where N is the number of samples and v (i) is the i^{th} voltage sample. Real nestgroup.net is obtain if the window length N is set to one cycle. In practical application, the data window is sliding along the time sequence in specific sample interval. In order to distinguish each result, time instant stamps labeled K are added to RMS voltage as independent variable i.e., it makes RMS voltage to be a function of time.

Rewrite the eq.(1) to the sequence, shown as follows

$$V_{rms(k)} = \sqrt{\frac{1}{N} \sum_{i=k-N+1}^{i=k} vi^2}$$

The time stamp k is restricted to be an integer that is equal to or greater than 1. Each value from (2) is obtained over the processing window. RMS calculation can also be performed by considering samples for one half-cycle. The window length has to be an integer multiple of one-half cycle. Any other window length will produce an oscillation in the RMS plot with a frequency twice the fundamental frequency [1] [3].

The main advantage of this technique in terms of calculation, it is simple, fast and much sensitive in sags and swells. But, the drawbacks of this technique it is dependence on the size of the sample window. A small window makes the RMS parameter less relevant, as it follows the tendency of the temporal signal, and loses the meaning of mean value of power. The basic idea is to follow the voltage magnitude changes as close as possible during the disturbing event. The more RMS values are calculated, the closer the disturbing event is represented. RMS calculation can also be performed by considering samples for one half-cycle. The window length has to be an integer multiple of one-half cycle. Any other window length will produce an oscillation in the plot with a frequency twice the fundamental frequency [4].

C. Detection by Comparing With A Reference Window

This method utilizes two windows, one window for the samples of one of the input voltage cycles and other for samples of normal reference cycle. Here the magnitude of a sample at any one sample point of the current input cycle is compared with that of the sample at the same sample point on the reference wave. The difference between them is checked to cross the threshold set for causing sag. This is repeated for a few successive samples in a cycle. If the difference in values between them crosses the threshold values that have been set for causing sag, that particular cycle will be detected to cause sag. Now the window is shifted to the same sample points of the next input cycle. If it continuously crosses the sag threshold for a few succeeding cycles, sag is finally detected. Similarly if the difference in magnitudes between the two windows crosses the swell threshold continuously for a few succeeding cycles, a swell is detected.

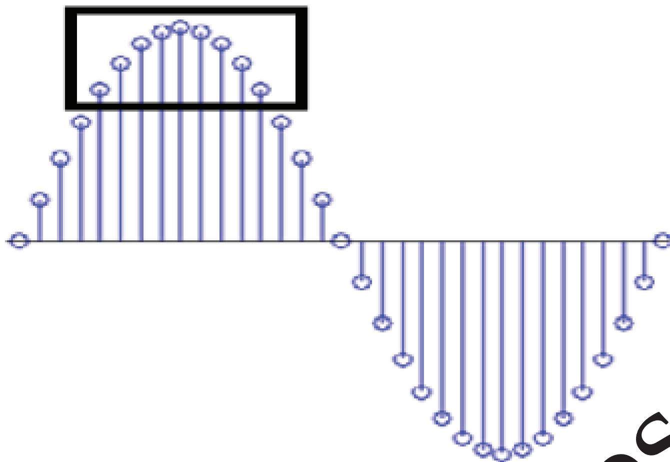

Fig.5 Window in the reference cycle

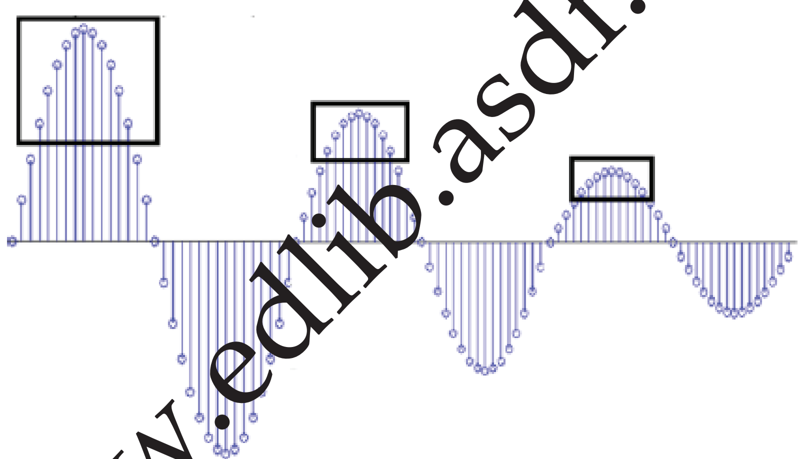

Fig.6 Window moving from one cycle to another in the input voltage
after comparing the same samples of each cycle with the reference cycle

III. Algorithms on PIC32 Microcontroller

A 110v RMS – 50 Hz supply is used. Each cycle is 20mseconds and it is divided into 32 equally spaced samples. Hence each half cycle holds 16 samples. Swell is to happen if there is rise in RMS voltage above 120v for at least 320milliseconds. Sag is to happen if there is fall in RMS voltage below 100v for at least 320milliseconds. PIC32 Ethernet Starter with PIC32MX795F512L microcontroller is used.

A. Moving Average Window Algorithm

The window size is taken as 16 or a half cycle. As explained earlier, the average of samples over a window is calculated. This is repeated by moving the window by one sample. Average value obtained over every window is compared with the threshold value. This is repeated so as to obtain the total number of occurrences of sag and swell. If the calculated average values remain less than that of 100v rms for 320msec or more continuously, then it is called sag. If the calculated average values remain more than that of 120v rms for 320msec or more continuously, then it is called a swell.

B. Moving Average Window Algorithm using RMS

The window size is taken as 16 or a half cycle. The RMS of samples over a window is calculated. This is repeated by moving the window by one sample each. RMS value obtained over every window is compared with the threshold value. This is repeated so as to obtain the total number of occurrences of sag and swell. If the calculated RMS values remain less than that of 100v RMS continuously for 320msec or more, then it is called sag. If the calculated RMS values remain more than that of 120v RMS for at least 320msec continuously, then it is called a swell.

C. Detection by Comparing with A Reference Window

Here a window size of 16 samples is taken. Magnitudes of each sample within the window of input cycle are compared with the samples that are at the same position in the reference cycle. It is checked if the difference in the magnitudes crosses the threshold values set for causing sag. If it crosses the sag threshold continuously for at least the samples of 32 cycles, i.e. 320msec it causes sag. Similarly if it crosses the swell threshold continuously for 320msec, it can cause swell. This is repeated to find the total number of sags and swells occurred.

IV. Comparison Result

Time taken by the first method is 11.2usec and that by the second method is 37.4usec, while that taken by the third is 16,2usec. As the time taken by and code size of the second algorithm is maximum, it consumes the maximum power. In the first and second method the detection of sag or swell is delayed by a half cycle while in the third case, it is detected in the present cycle itself. All the three algorithms can take in Direct Current, while it requires a rectifier if A.C. is given the input. The third algorithm needs an extra hardware to detect the zero crossing that determines the 16 samples of a half cycle.

Algorithm	A	B	C
Program Memory	1.196KB	2.043KB	1.251KB
Data Memory	125Bytes	197Bytes	68Bytes
Time	11.2usec	37.4usec	16.2usec
Power Consumed	Minimum	Maximum	Medium
Delay in Detection	1 Half Cycle Delay	1 Half Cycle Delay	No Delay
For 32 Half Cycles to be Detected as Swell	33 Half Cycles Need to be Swell	33 Half Cycles Need to be Swell	32 Half Cycles Need to be Swell
Input Voltage Type	D.C A.C Needs Rectifier	D.C A.C Needs Rectifier	D.C A.C Needs Rectifier
Need of Zero Crossing Hardware	No	No	Yes

Table 1 Comparison of three algorithms using PIC32

V. Matlab Simulation

A 110v r.m.s – 50 hz supply is used. Each cycle is 20mseconds and it is divided into 32 equally spaced samples. Hence each half cycle holds 16 samples. Swell is to happen if there is rise in RMS voltage above 120v for 320milliseconds. Sag is to happen if there is fall in RMS voltage below 100v for 320milliseconds. In order to detect sag and swell, the input voltage is given as a combination of a normal voltage, i.e.110v RMS , a swell causing voltage, i.e. input greater than 120v RMS and a sag causing input, i.e.; voltage less than 100v RMS for 1 second time.

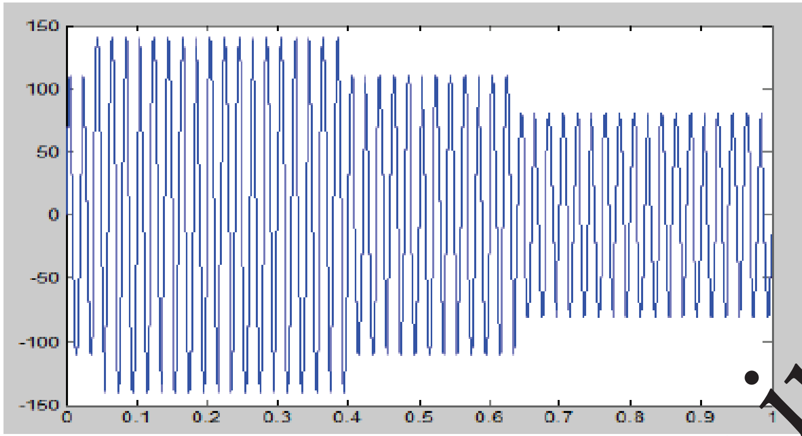

Fig.5 Input signal given for simulation

VI. Simulation Results

Time taken by the first method is 49us and that by the second method is 95us, while that taken by the third is 128us. In the first and second method the detection of sag or swell is delayed by a half cycle while in the third case, it is detected in the present cycle itself. A swell requires a continuous rise in voltage for 320msec or more, which counts up to 32 half cycles. But first and second method needs an extra swell or sag half cycle for its detection. Thus it needs 32+1 low voltage half cycles to detect sag or 32+1 high voltage half cycles to detect a swell. The third method does not require this. It takes correct 32 half cycles only. [6]

Algorithm	A	B	C
Time	49us	95us	128us
Code Size	2KB	2KB	3KB
Delay in detection	Needs an extra swell or sag half cycle for detection	Needs an extra swell or sag half cycle for detection	Do not need the extra half cycle

Table 2 Comparison of three algorithms in Matlab

VII. Conclusion

Three algorithms based on a windowing technique are described to detect the number of sags and swells that has occurred in input voltage. The three described algorithms are compared after running in MpLab onto a PIC32 micro-controller. Also a comparison after simulating in Matlab is also made. In Matlab the second algorithm takes lesser time than that of third, while it is the opposite on PIC32. The reason is that squaring takes more time when running on a hardware as multiplication is done using repetitive additions, unlike that done on Matlab.

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