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Comparison of Voltage Sag and Swell Detection Algorithms In Power System

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Abstract:- Power quality issues have been a source of major concern in recent years due to extensive use of power electronic devices and non-linear loads in electrical power system. Voltage sags and swells is a common power system disturbance, usually associated with power system faults. Therefore the effective detection of voltage sags and swells event is an important issue for both voltage sag and swell analysis and mitigation. There are several detection methods for voltage sags and swells such as RMS voltage detection, peak voltage detection, and Fourier transform methods. The problem with these methods is that they use a windowing technique and can therefore be too slow when applied to detect voltages sags for mitigation since they use historical value, not instantaneous value which may lead to long detection time when voltage sag has occurred.

A novel algorithm require for voltage sag detection. The algorithm can extract a single non-stationary sinusoidal signal out of a given multi component input signal. The algorithm is capable of estimating the amplitude, phase and frequency of an input signal in real time. No complex mathematics is required for implementation of the algorithm. It is compared to other methods of sag detection and same procedure for swell also.

Keywords:- Power quality, peak voltage detection, rms voltage detection, voltage sag.

I. INTRODUCTION

Voltage sag and swell may be caused by switching operations associated with a temporary disconnection of supply, the flow of inrush currents associated with the starting of motor loads, or the flow of fault currents. These events may emanate from the customers system or from the public network. A power system fault is a typical cause of a voltage sag. Faults occurs in transmission (EHV), sub transmission (HV), medium-voltage (MV), and low-voltage (LV) systems and the sags propagate throughout the power system. The sag distribution experienced by a low-voltage customer includes all these sags of different origin. Due to the increasing use of sensitive equipment, voltage sags have become in recent years, one of the central power-quality (PQ) concerns faced by utilities and customers. So as the voltage sags are very serious problem now a days. The very essential step before analyzing any power quality disturbances is detection. Accurate detection of undesired transient disturbances is very important to provide better service.

Much of the research in recent years has focused on the hardware performance of mitigation devices, B. P. Roberts et.al [7,8,9]. Surveys have shown that voltage sags and swells are considered as the dominant factor affecting power quality. Voltage sags can generally be characterized by sag magnitude, duration, and frequency. The sag magnitude detect by so many methods among mainly R.M.S, Peak Detection, D.F.T methods used in last decays and same as for swells also.

But these methods have some limitations are, the disadvantage of R.M.S method is that a window of historical data has to be obtained, processed and then only can a mitigation signal be sent to the hardware. Due to use of a low-pass filter and instantaneous reactive power theory to extract the voltage sag, this is complex for implementation in a digital signal processor or micro-controller (Raj Naidoo, Pragasen Pillay, et al, 2007).The DFT is ideal for calculating magnitudes of the steady-state sinusoidal signals but it does not have the capability of coping with sharp changes and discontinuities in signals.

The main objective is to be proposing a novel algorithm for rapid voltage sag detection better than other methods. This algorithm has the ability to track the amplitude of the voltage sag in real time. Proposed novel algorithm was compared to existing sag detection methods to show its fastness and robustness. The algorithms for voltage sag and swell detection using MATLAB/SIMULINK software.

This paper is organized as below. In Section II, the description of voltage sag detection methods is presented. Implementation of proposed algorithm is described in section III. In Section IV, the results and discussions are explained. Finally, the conclusion of this paper is presented in Section V.

II. DESCRIPTION OF METHODS

A. RMS Value Evaluation Method

RMS (voltage or current) is a quantity commonly used in power systems as an easy way of accessing and describing power system phenomena. The rms value can be computed each time a new sample is obtained but generally these values are updated each cycle or half cycle. If the rms values are updated every time a new sample is obtained, then the calculated rms series is called continuous. If the updating of rms is done with a certain time interval, then the obtained rms is called discrete. As long as the voltage is sinusoidal, it does not matter whether RMS voltage, fundamental voltage, or peak voltage is used to obtain the sag magnitude. But the RMS voltage, related to power calculation, make it more suitable for the characterization of the magnitude of voltage sag.

Voltage signals are recorded as sampled points in time and the RMS value of a sampled time-domain signal is calculated.

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} {v_i}^2} \qquad (1)$$

Where N is the number of samples per cycle and v_i is the magnitudes of sampled signal. Real rms is obtained if the window length N is set to one cycle. In practical application, the data w interval. In order to distinguish each result, time instant stamps labelled 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

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

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.

B. Peak Voltage Detection Method

Voltage sag can be detected by calculating the peak value of the signal waveform. A Two-sample technique, based on the assumption of having pure sinusoidal voltage waveform, is used for peak voltage estimation, by finding the maximum of the absolute value of the sampled signal over half cycle propagating window.

Let v(n), v(n+1) be voltage samples measured at times t(n), t(n+1) respectively, and let Δt be the sampling time interval. Then

$$v(n) = Vsin\big((n-1)w_0T_s\big) \qquad (3)$$

$$v(n+1) = Vsin(nw_0T_s) \qquad (4)$$

$$= Vsin\big((n-1)w_0T_s\big)\,cos(w_0T_s) + Vcos((n-1)w_0T_s)sin(w_0T_s)$$

Substituting (3) into (4) and simplifying result in

$$Vcos\big((n-1)w_0T_s\big) = \frac{v(n+1) - v(n)cos(w_0T_s)}{sin(w_0T_s)} \qquad (5)$$

Adding the squares of (3) and (5) and then take the square root of the results, the corresponding equation the signal peak is simply

$$Vcos\big((n-1)w_0T_s\big) = \frac{v(n+1) - v(n)cos(w_0T_s)}{sin(w_0T_s)} \qquad (6)$$

Because the detector is based on the concept of an orthogonal function pair, it is called "Orthogonal detector". The significant advantage of the peak evaluation compared to others method is that only needs single phase values.

C. Discrete Fourier Transform (DFT) Method

In practice data are always available in the form of a sampled time function, represented by a time series of amplitudes, separated by fixed time intervals of limited duration. When dealing with such data a modification of the Fourier transform, the DFT (Discrete Fourier transform) is used. The implementation of the DFT by means of FFT algorithm forms the basis of the most modern spectral and harmonic analysis systems.

DFT transforms a signal from the time domain to the frequency domain. This makes available the amplitude and phase of the fundamental and the harmonics present in the signal. The dc component is also available in the first bin.

The Fast Fourier Transform (FFT) is the DFT's computational efficient implementation, its fast computation is considered as an advantage. With this tool it is possible to have an estimation of the fundamental amplitude and its harmonics with reasonable approximation. FFT performs well for estimation of periodic signals in stationary state; however it does not perform well for detection of sudden or fast changes in waveform e.g. transients or voltage sags. In some cases, results of estimation can be improved with windowing, i.e. Hanning, Hamming or Kaiser window By applying Fourier transform to each supply phase, it is possible to obtain the magnitude and phase of each of the frequency components of the supply waveform. The fundamental voltage component is extracted normally from a time sequence over a fundamental frequency cycle. The source voltage v(t) can be expressed as the following equation using the Fourier series[11].

$$V(t) = \frac{a_0}{2} + \sum_{n=0}^{\infty}(a_n \cos nw_0 t + b_n \sin nw_0 t) \qquad (7)$$

The fundamental component for n= 1 is obtained, separating the real and imaginary parts.

$$a_1 = \frac{2}{T}\int_0^T v(t)\cos w_0 t dt \qquad (8)$$

$$b_1 = \frac{2}{T}\int_0^T v(t)\sin w_0 t dt \qquad (9)$$

By applying the DFT for (8) and (9), (10) and (11) are obtained.

$$a_1 = \frac{\sqrt{2}}{N} v\left(t - i\frac{T}{N}\right)\cos\left(2\pi\frac{i}{N}\right) \qquad (10)$$

$$b_1 = \frac{\sqrt{2}}{N} v\left(t - i\frac{T}{N}\right)\sin\left(2\pi\frac{i}{N}\right) \qquad (11)$$

Using the values of a, and hi, the magnitude of the fundamental component can be easily obtained as follows:

$$V = \sqrt{{a_1}^2 + {b_1}^2} \qquad (12)$$

Window length dependency resolution is a disadvantage e.g. the longer the data window (N) the better the frequency resolution

Sets of sliding window DFTs can however be can be used to analyze non-stationary signals.

D. Novel Algorithm

Let V(t) represent a voltage signal in which n(t) denotes the superimposed disturbance or noise. For power system operation, parameters V, w and δ are functions of time

$$V(t) = \sum_{n=1}^{\infty} V_i \sin(wt + \phi) + n(t) \qquad (13)$$

In the case of power systems, this function is usually continuous and almost periodic. A sinusoidal component of this function is

$$s(t) = V_i \sin(wt + \delta_s) \qquad (14)$$

In which Vs is the amplitude, W the frequency (in rad/s), and δ is the phase angle. During power system operation, parameters Vs, W, and δ vary with time depending on load changes and faults. For sag analysis and detection, the important parameters are sag magnitude, duration and phase angle jump.

A sag is detected when Vs goes below 0.9 p.u of the declared voltage. Let M be the manifold containing all sinusoidal signals

$$M(t) = \{V(t)\sin(w(t) + \delta))\} \qquad (15)$$

Where

$$V(t) \in [V_{min}, V_{max}],$$
$$w(t) \in [w_{min}, w_{max}],$$
$$\delta(t) \in [\delta_{min}, \delta_{max}]$$

Therefore

$$\Im(t) = [V(t), w(t), \delta(t)]^T \qquad (16)$$

is the vector of parameters that belong to the parameter space

$$V(t) = [V, w, \delta]^T \qquad (17)$$

And T denotes the transposition matrix. The output is defined as the desired sinusoidal component, namely

$$s\big(t, \Im(t)\big) = V(t)\sin\big(w(t)t + \delta(t)\big) \qquad (18)$$

To extract a certain sinusoidal component of V(t) , the solution has to be an optimumϕ that minimizes the distance function between s(t, ϕ(t))and V(t)

$$\Im_{opt} = arg \min_{\Im(t) \in v} d\big[s\big(t, \Im(t)\big), v(t)\big] \qquad (19)$$

Without being concerned about the mathematical correctness of the definition of the least squares error which, strictly speaking, has to map onto the set of real numbers, the instantaneous distance function d is used.

$$d^2(t, \Im(t)) = [v(t) - s(t, \Im(t))]^2 \triangleq e(t)^2 \qquad (20)$$

The cost function is defined as

$$J(t, \Im(t)) \triangleq d^2(t, \Im(t)) \qquad (21)$$

Although the cost function is estimated using the gradient decent method not quadratic, the parameter vector -3 is

$$\frac{d\Im(t)}{dt} = -\mu \frac{\partial[J(t, \Im(t))}{\partial\Im(t)} \qquad (22)$$

The estimated parameter vector is denoted by

$$\hat{\Im}(t) = [\hat{v}(t), \hat{w}(t), \hat{\delta}(t)]^T \qquad (23)$$

The governing set of equations for the algorithm is

$$\dot{V} = k_1 e \sin\emptyset$$
$$\dot{w} = k_2 eV \cos\emptyset$$
$$\dot{\emptyset} = k_3 eA \cos\emptyset + w$$
$$s(t) = V \sin\emptyset$$
$$e(t) = v(t) - s(t)$$

Where $v(t)$ and $s(t)$ are the input and output signals to the core algorithm, respectively. The dot represents the differentiation with respect to time and the error signal $e(t)$ is $v(t) - s(t)$. State variables V, f and w directly provide estimates of amplitude, phase, frequency of v(t). Parametersk_1, k_2andk_3,are positive numbers that determine the behaviour of the algorithm in terms convergence speed and accuracy. Specifically, parameter h controls the speed of the transient response of the algorithm with respect to variations in the amplitude of the interfering signal. Parameters band b mutually control the speed of the transient response of the algorithm with respect to variations in the frequency of the interfering signal.

III. IMPLENTATION OF PROPOSED ALGORITHM

The dynamics of the algorithm presents a notch filter in the sense that it extracts one specific sinusoidal component and rejects all other components including noise. It is adaptive in the sense that the notch filter accommodates variations of the characteristics of the desired output over time. The centre frequency of such an adaptive notch filter is specified by the initial condition of frequency. It is in the form of the composition of simple blocks suitable for schematic software development tools. Implementation of the proposed algorithm entails the discretization of the differential equations describing the algorithm. The discredited form of the governing equations of the proposed algorithm can be written as:

$$V[n+1] = V[n] + 2T_s k_1 e[n] sin\phi[n] \qquad (24)$$
$$w[n+1] = w[n] + 2T_s k_2 e[n] V[n] cos\phi[n] \qquad (25)$$
$$\phi[n+1] = \phi[n] + T_s + 2T_s k_2 k_3 e[n] V[n] cos\phi[n] \qquad (26)$$
$$s[n] = V[n] sin\phi[n] \qquad (27)$$
$$e[n] = V[n] - s[n] \qquad (28)$$

First order approximation for derivatives is assumed, Ts is the sampling time and n is the time index.

The values of the k parameters determine the convergence speed of the algorithm. The valves of the k parameters have to be chosen such that the two conditions $0 < k_1 < 2f_0$ and $0 < k_2 < (\frac{2f_0}{v})$ of are roughly satisfied. Quantity f_0 is the frequency of the sinusoidal signal of interest and V is the amplitude. The choice of k_3 is the independent of k_2• The proposed algorithm is found to be robust not only with regards to its internal structure, but most importantly with regards to the adjustment of its k parameters.

The terms of the engineering performance of the system, this indicates that the output of the system will approach a sinusoidal component of the input signal. Moreover, time variations of the parameters in $V(t)$ are tolerated by the system. One of the issues that needs to be considered when using the proposed algorithm is the setting of its parameters$k_{1,}$. The valve of the parameters k_1, k_2andk_3 determine the convergence speed versus error compromise.

Simulations were performed to test the performance of the proposed algorithm and to verify its ability of detecting voltage sags and swell by using mat lab software.

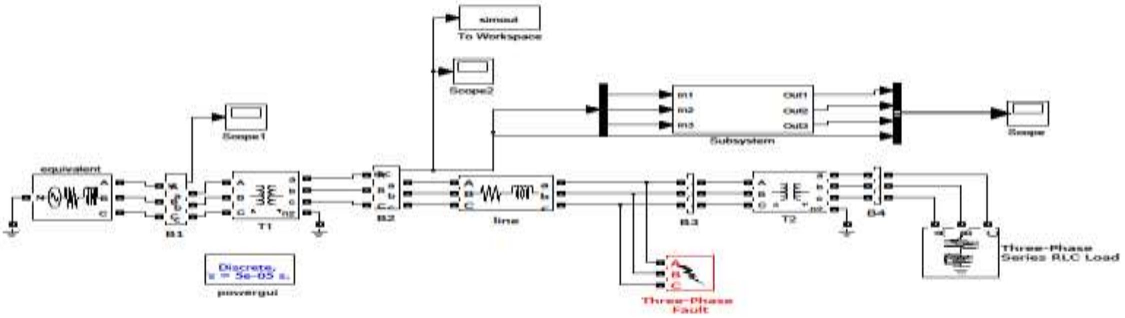


Fig. 1 Simulation Block Diagram

IV. RESULTS AND DISCUSSIONS

A. Algorithm Method for Voltage Sag Detection

The algorithm is capable of extracting sinusoidal component in a highly noisy input signal and demonstrates the ability of the algorithm to track a voltage sag in real time. The algorithm has the ability to track the sag. Additional parameters that can be include the system frequency and phase angle jump at sag initiation.

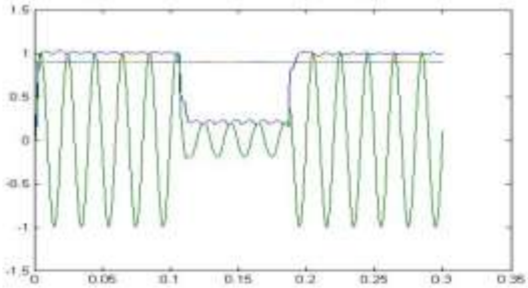


Fig. 2 Extraction of a sinusoid Sag tracking a voltage

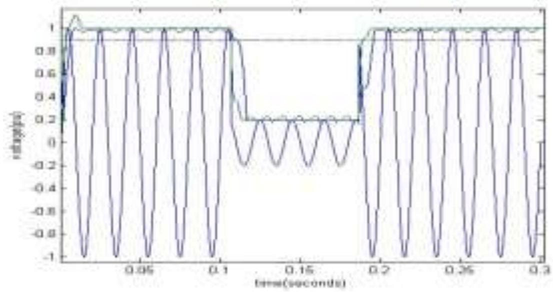


Fig. 3 Comparison between R.M.S and algorithm for voltage sag detection

B. Comparison of RMS Voltage and Algorithm Method

The result of MATLAB Program shows comparison between the one-cycle rms voltage sag with the algorithm as shown in Fig. 3.0 It shows the sag imitation point, the rms, and the algorithm. The proposed algorithm detects sag at 106.8 m.sec, while the one cycle rms detects it at 110.8ms.The difference in detection time between the two methods is 5 ms.

C. Comparison of Peak Voltage and Algorithm Method

Fig. 4 shows the performance of the peak voltage detection method when compared to the algorithm. The algorithm detects the sag at 106.8 ms and the peak voltage method at 108.2 ms. So that difference in sag detection time of 1.4 ms

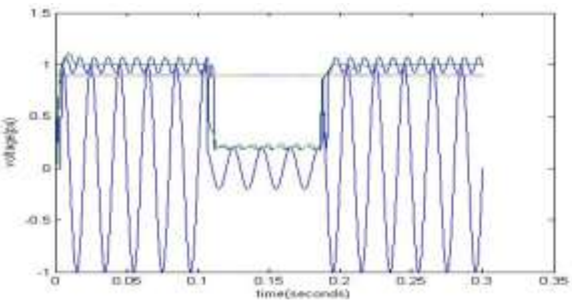


Fig. 4 Comparison between peak and algorithm for voltage sag detection

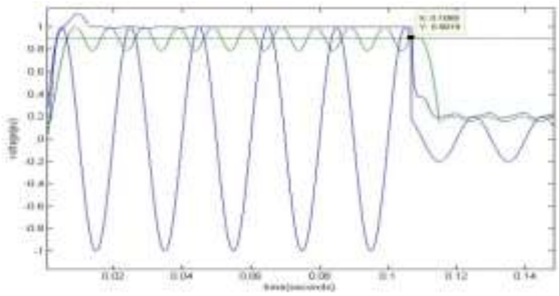


Fig. 5 Comparison between DFT and algorithm for voltage sag detection

D. Comparison of DFT and Algorithm Method

sag estimation Fig. 5 shows the comparison of the proposed algorithm and DFT for voltage sag detecting in real time. DFT detects the sag at 109.4 ms, and the difference in detection time is 2.6 ms. The simulation results show that the algorithm is faster to detect the starting of the voltage sag. The estimation of sag magnitude is not much difference and do not affect the

E. Algorithm Method for Voltage Swell Detection

A typical set of k parameters, used in the algorithm for voltage swell detections is k_1, = 1000, k_2 = 1000 and k_3 = 0.02. Where the values of k_1, and k_2 are normalized with respect to the nominal frequency of the incoming signal. Fig. 6 shows that the algorithm is capable of extracting sinusoidal component in a highly noisy input signal. Fig. 6 shows the input signal, extracted signal amplitude and demonstrates the ability of the algorithm to track a voltage swell in real time

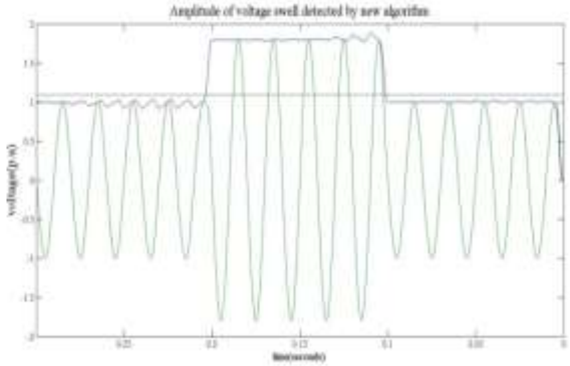


Fig. 6 Extraction of a sinusoid Sag tracking a voltage

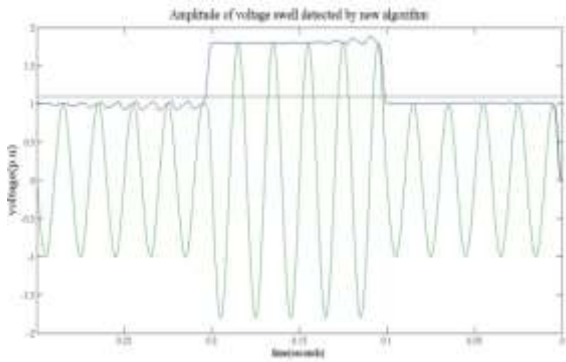


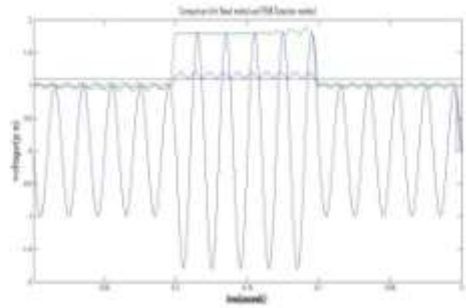
Fig. 7 Comparison between R.M.S and algorithm for voltage swell detection

F. Comparison of RMS Voltage and Algorithm Method

The result of MATLAB Program shows comparison between the half-cycle rms voltage sag with the algorithm as shown in Fig. 7. It shows the swell imitation point, the rms, and the algorithm. The proposed algorithm detects sag at 0.1013sec , while the one cycle rms detects it at 0.1032sec.The difference in detection time between the two methods is 19ms

G. Comparison of Peak Voltage and Algorithm Method

Fig. 8 shows the performance of the peak voltage detection method when compared to the algorithm. The algorithm detects the swell at 101.3 ms and the peak voltage method at 102.9 ms. That results in a difference in sag detection time of 1.6 ms.



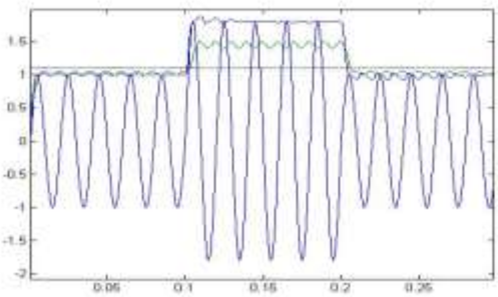


Fig. 8 Comparison between peak and algorithm for voltage swell detection

Fig. 9 Comparison between DFT and algorithm for voltage sag detection

H. Comparison of DFT and Algorithm Method

Fig. 9 shows the comparison of the proposed algorithm and DFT for voltage sag detecting in real time. DFT detects the sag at 103.1 ms, and the difference in detection time is 2. 1ms.The simulation results show that the algorithm is faster to detect the starting of the voltage sag. The estimation of sag magnitude is not much difference and do not affect the sag estimation

V. SUMMARY

Voltage sag and swell can be detected with R.M.S, Peak voltage detection method, DFT and new algorithm on MAT LAB/SIMULINK software successfully.Table.10 and Table.11 shows the time taken to detects sag or swell and shows delay time compared with actual applied time.

Method	Detected time (m.sec)	Difference with actual time at 106.7m.sec
R.M.S	110.8	4.1
PEAK	108.2	1.5
D.F.T	109.4	2.7
NOVEL	106.8	1

Table10: Time taken to detects sag by different methods

Method	Detected time (m.sec)	Difference with actual time at 106.7m.sec
R.M.S	103.2	3.2
PEAK	102.9	2.9
D.F.T	102.1	2.1
NOVEL	101.3	1.3

Table 11: Time taken to detects sag by different methods

The comparison between proposed method and other methods gives clarity about how much fast magnitude can detected

VI. CONCLUSION

The New algorithm was successfully tested for the voltage sag and swell detection in distribution network in MATLAB environment. The MATLAB results illustrate the capability of the proposed algorithm to detect voltage sag in real time. The proposed algorithm has been compared with the rms voltage sag detection method, DFT and Peak voltage. Simulation results shows that the proposed algorithm able to detect the sag faster than the conventional methods. It has the ability to track the amplitude. Phase and frequency of a voltage signal in real time. No complex mathematics is required for implementation of the algorithm on a digital signal processor. This is distinct advantage over other methods of sag detection.

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