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A New Method of Voltage Sag and Swell Detection

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ABSTRACT

The essential voltage, modern, and segment perspective are required for a wide variety of electricity system programs. An algorithm this is able to calculating or estimating those portions In real time, in the presence of distorted waveforms, reveals application in numerous areas of energy structures. Strategies to hit upon voltage Sag encompass the root imply square (rms), fourier rework, and Height voltage detection techniques. The hassle with those techniques Is they use a windowing method and might therefore be too Slow when carried out to discover voltage sags for mitigation since they Use historic facts. Latest work within the area of sign processing has Led to an algorithm that can extract a nonstationary sinusoidal signal out of a given multi-aspect input signal. The algorithm is able to estimating the amplitude, segment and frequency. On this paper, the algorithm is as compared to existing techniques of sag Detection.

Keywords: Mitigation, nonlinear filter, power quality (PQ), sags.

I. INTRODUCTION

The Power exceptional has been the point of interest of significant research In current years. Voltage sags, mainly, can reason expensive downtime. Voltage sags are defined as a lower in root Imply rectangular (rms) voltage on the power frequency for intervals From zero.5 cycles to one min [1]. The period of a voltage sag is the Time measured from the moment the rms voltage drops underneath 0.Nine pu of nominal voltage to while it rises above zero.9 pu of nom- Inal voltage. It is consequently viable for sags of brief duration to reason issues in a few touchy equipment. Voltage sag can be due to switching operations associated with a brief disconnection of supply, the float of inrush currents related to the beginning of motor loads or the Waft of fault currents. Those activities may emanate from the customers gadget or from the public deliver network. Lightning strikes can purpose momentary sags. Voltage swells are quick increases in rms voltage that once in a while accompany voltage sags.They seem at the unfaulted section of a 3 phase circuit that has evolved a 1 phase brief circuit.Various answers have been proposed to mitigate sags. An Instance is a dynamic voltage restorer (dvr) where the simple Precept is to inject a voltage in series with the deliver whilst a Fault is detected. Figure 1 indicates a wide review of the mitigating System.

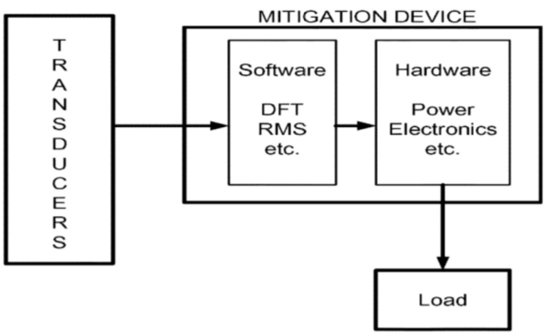

Figure 1. Broad overview of sag mitigation.

Two techniques to enhance journey-through functionality consist of:

- ✓ enhancing hardware performance;
- ✓ improving sag detection time.

A whole lot of the research in current years has centered on the hard-Ware performance of mitigation devices [2]–[4]. Typically, the Rms technique is used to detect the sag before mitigation is initi- Ated. The drawback of this technique is that a window of his-

Torical data has to be received, processed after which handiest can a Mitigation sign be despatched to the hardware. Obstacles associated with the rms technique are discussed in [5], [6]. The authors Use a low skip filter and instant reactive strength concept to extract the sag. This is complicated for implementation in a virtual Sign processor or micro-controller. A technique for determining The begin and end time of a sag the usage of wavelets is provided in [7].

That is done to affirm proper breaker operation after the sag has Happened. The goal of this paper is to provide a way for fast sag detection through the usage of a nonlinear adaptive filter. The clear out Has the ability to song the amplitude of the sag in actual time. This would have applications in mitigation. The paper is organized as follows: section ii gives existing techniques of sag Detection. In phase iii, a description of a new algorithm is Offered. The experimental setup for laboratory simulation is Shown in segment iv. The set of rules is as compared to current

Techniques in section v. The impact of point on wave, fee Of alternate, frequency and magnitude deviations is discussed in Sections vi–ix. Case research in section x affirm the advan- Tages of the brand new set of rules.

II. METHODS OF SAG DETECTION

There are many methods used to measure and detect sags Among these are:

A. RMS Voltage and current measurements are regularly expressed in rms Values [6]. The sag is detected after records for a window duration Has been processed. The rms voltage is expressed as

$$V_i^{\mathrm{rms}} = \sqrt{\frac{1}{N}\sum_{j=1}^{i+N-1} V_j^2} \qquad (2.1)$$

Where is the samples per cycle of the essential, is the pattern of the recorded voltage waveform and is the ith Sample of the calculated rms voltage. Is behind schedule relative To the section voltage by means of n-1 pattern factors because of the n-pattern Window utilized in (2.1). If the pattern rate is such that n isn't an integer, rounding it off will produce some errors, but remains Suited. The begin and drop time of the sag may be described in Some of approaches depending on the chosen rms voltage thresholds. The start time is taken as the first factor of whilst drops under 0.9 pu. To locate the end time, look for an c programming language wherein drops beneath zero.Nine pu for as a minimum half of a cycle. The recuperation

Time is then chosen because the first factor on this c language. Because the Rms voltage is in impact a moving average calculated the usage of a

One-cycle window, there can be a lag of up to 1 cycle from the time the voltage simply begins or clears and the time that the rms price falls underneath the given threshold [6].

B. Peak Voltage

The peak voltage (pv) can also be used to report voltage sags. The subsequent equation can be used to calculate voltage sags:

$$V_{\mathrm{peak}} = \max\ V(t-\tau)| \quad 0 < \tau < t \qquad (2.2)$$

In which v(t) is the sampled waveform and t is an integer of one Half cycle. For each sample, the maximum of absolutely the price of the voltage over the preceding half cycle is calculated.

C. Fourier

When harmonics are to be calculated, it is most desirable to apply one approach for sag and harmonic calculation. In square Form, the discrete fourier rework (dft) is [8]

$$f(t) = C_0 + \sum_{n=1}^{\infty}(b_n + ja_n)\sin(n\omega t + \varphi_n) \quad ($$

where

$$a_n = \frac{2}{NK}\sum_{j=1}^{j=NK} f\left(\frac{j-1}{S}\right) \times \cos\left(\omega \times \frac{j-1}{S} \times n\right) \quad ($$

$$b_n = \frac{2}{NK}\sum_{j=1}^{j=NK} f\left(\frac{j-1}{S}\right) \times \sin\left(\omega \times \frac{j-1}{S} \times n\right) \quad ($$

$$C_0 = \frac{1}{NK}\sum_{j=1}^{j=NK} f\left(\frac{j-1}{s}\right) \quad ($$

$$\varphi_n = \arctan\left(\frac{a_n}{b_n}\right). \quad ($$

D. Missing Voltage Technique

The lacking voltage is described because the difference among the desired instantaneous voltage and the real instant one [6].

$$V_{\mathrm{pll}}(t) = A\sin(\omega t - \phi_a) \qquad (2.8)$$
$$V_{\mathrm{sag}}(t) = B\sin(\omega t - \phi_b). \qquad (2.9)$$

A section-locked loop (pll) is needed that locks onto the presag voltage magnitude, phase and frequency. The disturbed waveshape is referred to as $V_{sag}(t)$

$$m(t) = R\sin(\omega t - \psi) \qquad (2.10)$$

m(t) gives the instantaneous deviation from the known waveform , where

$$R = \sqrt{A^2 + B^2 - 2AB\cos(\phi_b - \phi_a)} \qquad (2.11)$$

$$\tan\psi = \frac{A\sin\phi_a - B\sin\phi_b}{A\cos\phi_a - B\sin\phi_b}. \qquad (2.12)$$

In [6], this technique has been proven to be superior to the rms approach for sag evaluation where segment attitude jumps arise. It is based

On the belief that the machine frequency is constant at some stage in

The sag. The technique calls for the rms technique to decide the amplitude of the presag and sag voltages and , respectively. This technique is suitable for sag evaluation rather than detection.

The motive for that is that the sag amplitude is not known Until after the event.

III. DESCRIPTION OF THE DETECTION ALGORITHM

Allow represent a voltage signal in which denotes the superimposed disturbance or noise. For strength gadget operation, Parameters , and are functions of time

$$v(t) = \sum_{i=0}^{\infty} V_i \sin(\omega t + \phi) + n(t). \qquad (3.1)$$

In the case of electricity systems, this feature is typically continuous

And almost periodic. A sinusoidal aspect of this feature is

$$s(t) = V_s\sin(\omega t + \delta_s) \qquad (3.2)$$

Where in is the amplitude, the frequency (in rad/s), and is the segment perspective. All through electricity machine operation, parameters

, and range with time relying on load changes and Faults. For sag evaluation and detection,

The essential parameters of challenge consist of:

- sag importance;
- duration;
- phase perspective jump.

A sag is detected whilst goes underneath 0.9 p.U of the declared voltage. Permit be the manifold containing all sinusoidal signals

$$M = \{V(t)\sin(\omega(t)t + \delta(t))\} \qquad (3.3)$$

where

$$V(t) \in [V_{\min}, V_{\max}], \omega(t) \in [\omega_{\min}, \omega_{\max}], \delta(t) \in [\delta_{\min}, \delta_{\max}]. \qquad (3.4)$$

Therefore ,

$$\Im(t) = [V(t), \omega(t), d(t)]^T \qquad (3.5)$$

is the vector of parameters that belong to the parameter space

$$\vartheta = [V, \omega, \delta]^T \qquad (3.6)$$

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

$$s(t, \Im(t)) = V(t)\sin(\omega(t)t + d(t)). \qquad (3.7)$$

To extract a certain sinusoidal component of , the solution has to be an optimum that minimizes the distance function

$$\Im_{\rm opt} = \arg \min_{\Im(t)\in\vartheta} d[s(t, \Im(t)), v(t)]. \qquad (3.8)$$

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 dis-

tance function is d used

$$d^2(t, \Im(t)) = [v(t) - s(t, \Im(t)]^2 \underline{\underline{\Delta}} e(t)^2. \qquad (3.9)$$

The cost function is defined as

$$J(\Im(t), t) \underline{\Delta} d^2(t, \Im(t)). \qquad (3.10)$$

Although the cost function is not quadratic, the parameter vector

is estimated using the gradient decent method

$$\frac{d\Im(t)}{dt} = -\mu \frac{\partial[J(t, \Im(t))]}{\partial\Im(t)}. \qquad (3.11)$$

The estimated parameter vector is denoted by

$$\hat{\Im}(t) = [\hat{V}(t), \hat{\omega}(t), \hat{\delta}(t)]^T. \qquad (3.12)$$

A complete mathematical proof is presented in [11]. The governing set of equations for the algorithm is

$$\dot{V} = k_1 e \sin\phi \qquad (3.13)$$
$$\dot{\omega} = k_2 e V \cos\phi \qquad (3.14)$$
$$\dot{\phi} = k_3 e A \cos\phi + \omega \qquad (3.15)$$
$$s(t) = V \sin\phi \qquad (3.16)$$
$$e(t) = v(t) - s(t) \qquad (3.17)$$

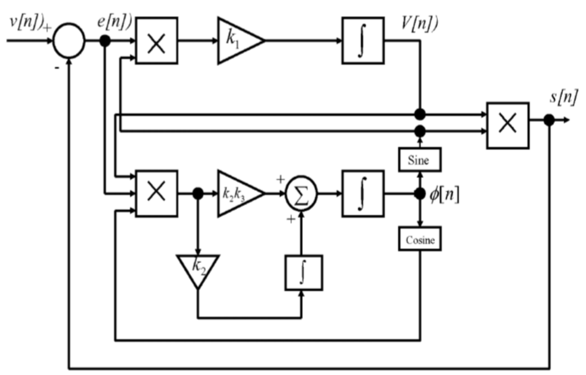

Fig. 2. Block diagram representation of the algorithm [9].

The dynamics of the algorithm offers a notch clear out within the experience that it extracts (i.E., we could bypass) one particular sinusoidal component and rejects all other additives including noise. It's miles adaptive inside the feel that the notch filter incorporates variations of the traits of the desired output over the years. The middle frequency of such an adaptive notch filter is targeted by means of the initial situation of frequency . It is within the form of the easy blocks appropriate for schematic software program development gear. Numerically, a probable manner of writing the set of equations governing the prevailing set of rules in discrete shape, which can be without problems utilized in any programming language, is

$$V(n+1) = V[n] + 2T_s k_1 e[n]\sin(f[n]) \qquad (3.18)$$
$$\omega(n+1) = \omega(n) + 2T_s k_2 e[n] V[n]\cos(f[n]) \qquad (3.19)$$
$$f(n+1) = f[n] + 2T_s\omega[n] + 2T_s^2 k_2 k_3 e[n] V[n]\cos(f[n]) \qquad (3.20)$$
$$s(n) = V[n]\sin(f[n]) \qquad (3.21)$$
$$e(n) = v[n] - s[n]. \qquad (3.22)$$

First order approximation for derivatives is assumed in deriving these equations; in other phrases, the time derivative of a typical quantity is approximated by in discrete shape. Is the sampling time and is the time index. An implementation of this device is proven in fig. 2 with 3 integrators for 3 kingdom variables. In phrases of the engineering overall performance of the gadget, this indicates that the output of the system will approach a sinusoidal issue of the enter signal . Moreover, time variations of parameters in are tolerated by way of the gadget. One issue that needs to be considered when using the algorithm is the placing

of its parameters , and . The values of the parameters, and determine the convergence pace as opposed to error compromise.Fig.3 shows the convergence of the set of rules to a periodic orbit within the frequency area. Balance of the set of rules hasbeen proved in [9]. Fig. 4 suggests the convergence of the algorithm in the time area. In contrast to the fourier-based totally strategies in which only estimates of the amplitude and consistent section are computed, the essential thing itself is immediately generated and is available in actual time. That is because of the fact that the set of rules instantly generates the total segment rather than [10].

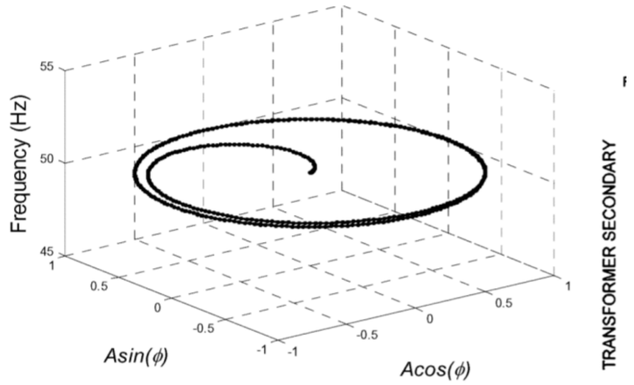

Fig. 3. Convergence of algorithm to a periodic orbit in the frequency domain.

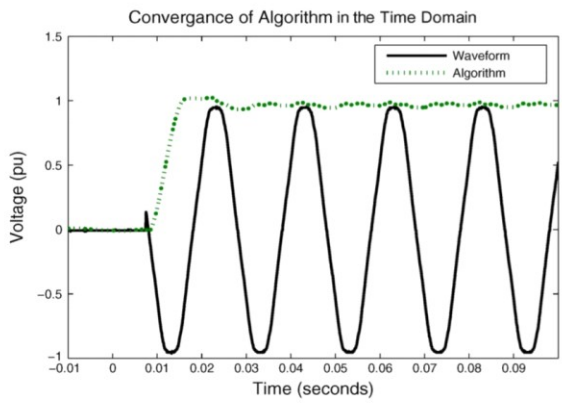

Fig. 4. Experimental results showing the convergence of the algorithm in the
time domain.

IV. EXPERIMENTAL SETUP

For experimental trying out of the performance of the algorithm, a voltage sag generator became required that is able to generating sags of various magnitudes and period.

Fig. 5 shows the experimental setup that changed into arranged to conduct the experiments. A transformer turned into used with two output voltages. The primary output was set to a 100% rated voltage. The 2D output become set to the required sag significance price. It has faucets that can be set from 40 v to 400 v in steps of 40 v. A tms320f240 processor changed into used to log statistics and transfer solid kingdom relays very speedy among the 2 outputs to gain the desired sag magnitude and period. When trying out the performance for fee of exchange, a cascaded configuration became used. A resistor bank changed into used as a load.

V. APPLICATION TO SAG AND SWELL DETECTION

In an effort to determine if the algorithm is appropriate to detection, it needs to be in comparison with strategies currently used.

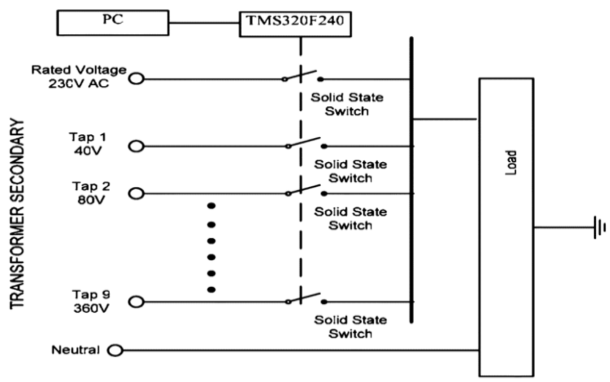

Fig. 5. Experimental setup of the system for lab testing.

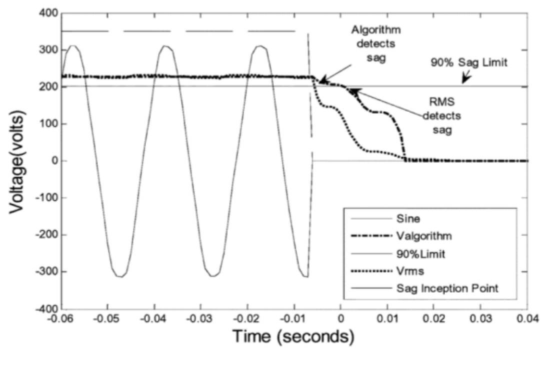

Fig. 6. Experimental results comparing rms and algorithm. In this phase, the set of rules is in comparison to the rms, peak voltage and fourier rework. Sag/swell detection time from hereon

Refers back to the time distinction from sag/swell inception factor until detection.

A. Sag Detection

1) one-cycle going for walks rms and algorithm: to normalize the facts for assessment, the algorithm is divided via . For the test, sag down to 0% changed into generated. The software deliver frequency of 50 Hz is used and a low sampling frequency of 20 samples per cycles became used. Fig. 6 indicates the sag inception factor, the rms, and the algorithm.

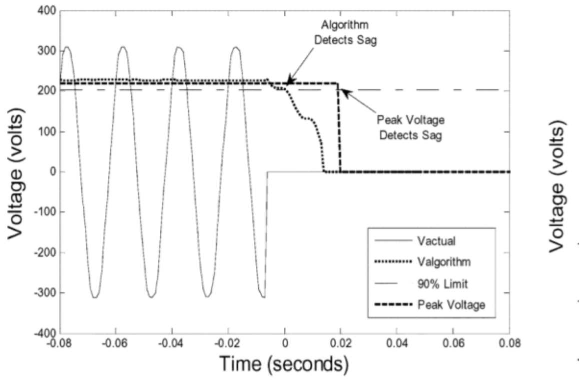

Fig. 7. Experimental results comparing PV and algorithm.

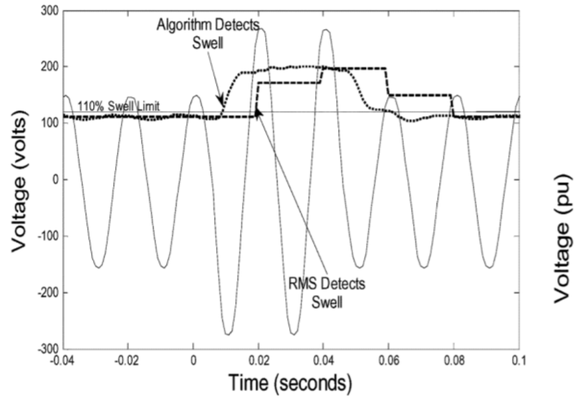

Fig. 8. Experimental results comparing the rms and algorithm for swell.

The set of rules detects the sag In 2 ms and the rms in 9 ms. The difference in detection time between the two methods is 7 ms.

2) peak voltage technique and set of rules for sag detection:

Fig. 7 indicates the performance of the peak voltage technique when compared to the algorithm. The set of rules detects the sag in

2 ms and the height voltage approach in 20 ms. That consequences in a difference in sag detection time of 18 ms. For waveforms with a excessive noise content material, it was located that the error associated with the height voltage approach is very excessive.

B. Detecting a Swell

A voltage swell is most usually caused by a line-to-ground fault on a poly-section transmission line or feeder. A voltage swell can also be caused by eliminating a massive load or by using switching in

Capacitor bank this is too massive for the winning situations. Failure to restriction a swell can bring about damage to strength system and quit use gadget. So far, handiest comparisons were made for voltage sag detection. The set of rules may be used to isolate device while the declared voltage will increase above predefined thresholds.

1) rms and algorithm for swell detection: fig. Eight shows a evaluation of the set of rules towards the rms for detecting a swell in actual time. The difference in detection time from the swell inception factor is 17 ms.

2) peak voltage and algorithm for swell detection: fig. 9 shows a assessment of the algorithm and peak voltage detecting a swell in real time. The distinction in detection time from swell inception is 17 ms.

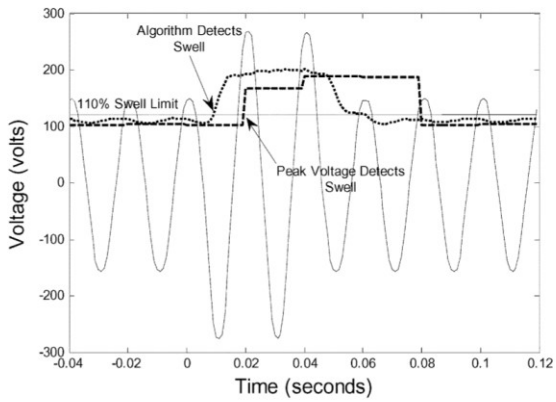

Fig. 9. Experimental results comparing the PV and algorithm for swell.

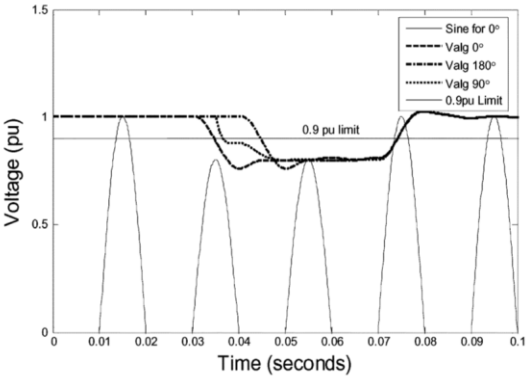

Fig. 10. Influence of point on wave for sag detection.

VI. INFLUENCE OF POINT ON WAVE

The factor on wave is the on the spot at the sinusoid when a dis- Turbance starts. In exercise, one cannot control the point on Wave whilst a fault occurs. Therefore for a sinusoidal waveform, The point-on-wave is minimal close to the 0-crossing location and Maximum near the peak fee of a waveform. For simulations Provided in this phase, matlab simulink is used as the com- Putational tool.

A. Sag

Fig. 10 suggests the set of rules monitoring 80% voltage sag at zero , 90 , and a hundred and eighty point on wave. Point on wave turned into simulated for Exceptional sag magnitudes. For the excellent state of affairs, a detection time Of 1ms become recorded. This corresponded to 20% sag at ninety factor On wave. Consequences from simulations display that detection time is Affected greater by way of sag value than point on wave. The worst Postpone time recorded became 4 ms (much less than sector cycle). This Corresponded to 80% sag at 180 factor on wave.

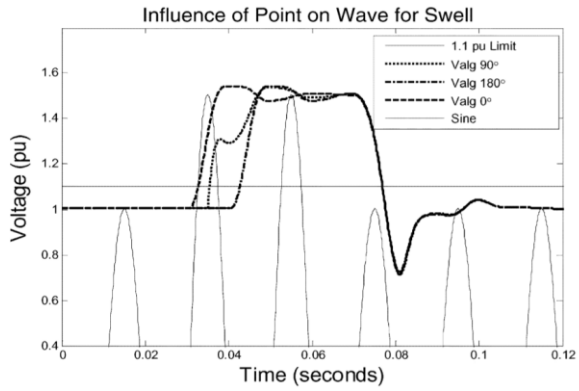

Fig. 11. Influence of point on wave on swell detection.

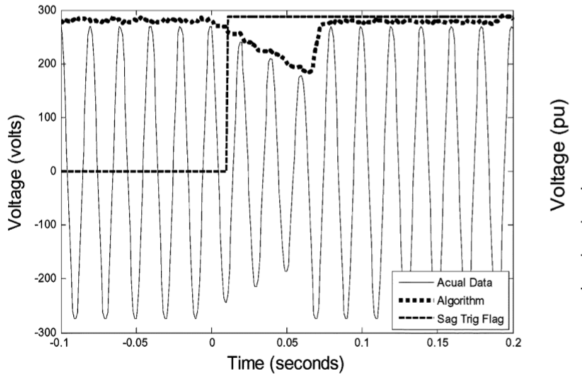

Fig. 12. Experimental results showing the influence of rate of change for a
small gradient.

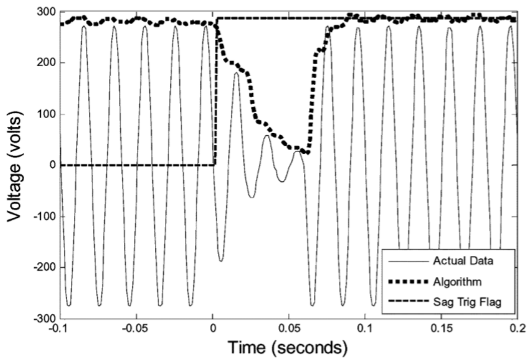

Fig. 13. Experimental results showing the influence of rate of change for large
gradient.

B. Swell

Fig. 11 suggests exams for factor on wave have an effect on on swell de- Tection for 150% voltage swell. The quality detection time of 1 ms corresponded to one 180% voltage swell and ninety point on wave

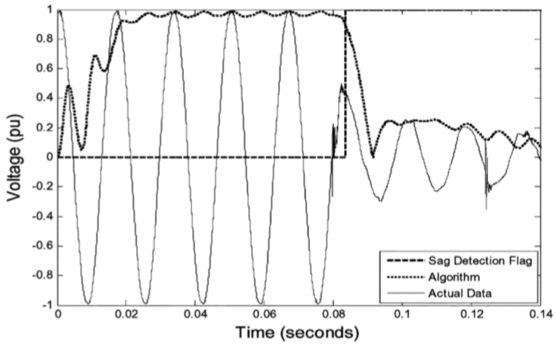

Fig. 14. Recorded voltage sag [11].

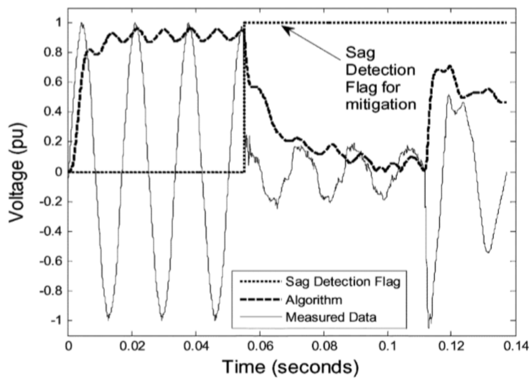

Fig. 15. Recorded voltage sag [11].

The worst detection time recorded was 5 ms. This corresponds to a 100 and 20% swell at 180 factor on wave.

VII. INFLUENCE OF RATE OF CHANGE

This phase assessments the algorithm for detection capacity for dif- Ferent charge of modifications. Fig. 12 suggests sag with a small gradient. The gradient was obtained via switching from rated voltage to 203, 180, 158, and one hundred thirty five v for one cycle (20 ms) every. A steeper Gradient turned into generated by using lowering the rated voltage to 203, 135, 42.5, and 22 V for as soon as cycle every. This is shown in fig. 13. In each cases, the set of rules is capable of tune the sag within 4 ms. Figs. 14 and 15 are area recorded voltage sags from [11].

VIII. SAG/SWELL MAGNITUDE INFLUENCE

From previous outcomes, it's miles glaring that sag significance has the Largest have an impact on on detection time. Fig. 16 shows the influence of sag/swell magnitude at the Algorithm. Results from the observe suggest that the algorithm Is capable of reply within 1 ms for deep sags and swells (i.E., Sags % and swells %). For other sags and swells, it Is able to respond within four ms. This is in line with mitigation Necessities since the sags and swells that require the quickest Reaction time are those with the largest value variant.

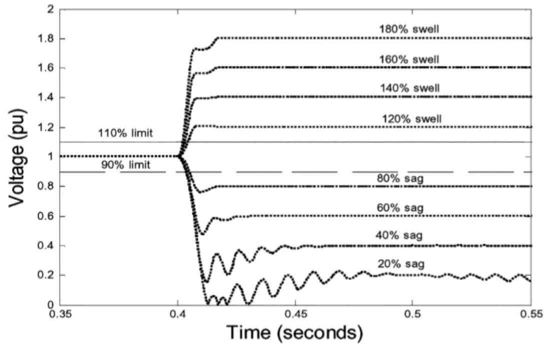

Fig. 16. Influence of sag/swell magnitude changes.

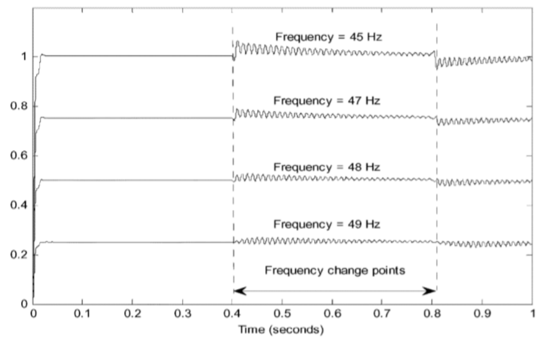

Fig. 17. Simulation showing the influence of a change in frequency.

VIII. CONCLUSION

A brand new algorithm has been supplied and implemented to the detec- Tion of sags in electricity structures. It has been as compared to current Techniques. This studies shows the potential of the set of rules to de- Tect voltage sag quicker than current methods. This has a dis- Tinct gain when mitigation is involved. Time saved can Be translated into reducing the aspect of misplaced electricity at some point of The sag. The set of rules may be similarly extended to voltage sag Evaluation. For evaluation, the set of rules offers the ability to calcupast due the amplitude, frequency and segment attitude jumps of the sag. The influence of point on wave, value and frequency vari- Ations has been investigated. It changed into located that sag value Has the best influence at the detection time. At worst case, It become shown that the proposed set of rules can discover voltage sag Within 4 ms

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