Discrimination of Power Quality Events using Power Modal Signal

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Abstract-Power utility companies strive to provide their customers anuninterrupted power supply with sinusoidal voltage of constant magnitude. However, achieving this objective has become an uphill task as number and size of non-linear and poor power factor loads like adjustable speed-drives, computer power supplies, furnaces and traction drives are increasing apace. At the same time deregulation in power industry has fuelled the demand for high quality power. So, the frequent Power Quality disturbances must be detected in order to carry out the mitigation action. The purpose of this work is to propose the signal processing based approach to classify the Power Quality events. Sliding window technique is used here to calculate the RMS value of voltage sag, voltage swell and voltage interruption. Power modal signal is generated for the classification of power quality event by using statistical parameters such as kurtosis, maximum, standard deviation and variance.

Keywords: Power Quality Events, Sliding Window Technique, RMS, Standard Deviation.

I Introduction

Quality of power is nothing but the interaction of electrical power with electrical equipment(Electrical power can be classified as of good quality when an equipment operates correctly and reliably without getting damaged. Whereas if the equipment malfunctions or get damaged the during the normal use the power supply is said to be poor. In the developmental phase of the electrical power system the main concern of the electrical engineers was to keep the lights on. Engineers designed the power systems to deal with the power outages. They strived the prevent the frequency deviation from 50Hz after outages[12]. The main concern of the consumers until 1960s was continuity of the supply or the reliability of the supply. However, consumers these days ask not only for the reliability but also the quality of the power supply[13]. Voltage sags has been the main topic of concern relating to the power quality among the suppliers, customers and the manufacturers.With rise in use of the highly sophisticated electronics and microelectronic processors in variety of equipments like computer terminals, programmable logic controllers and diagnostic systems the demand for the quality power has been steadily increasing [4].Of late, most of the modern loads whether on industrial

or domestic scale are inverter based such as adjustable-speed drives (ASDs), air conditioner, voltage controlled power supplies etc. Owing to the usage of sensitive load, the efficiency, energy saving, and high controllability can be increased. The increment can cause the electrical disturbances. The missing voltage technique can be used to evaluate the voltage disturbance by comparing the RMS and voltage missing voltage algorithm. The statistical approach is used in [3] for Fast Online Detection of Fault-Induces Voltage Dips. In Voltage sag detection- A survey''[4]many methods have been introduced to measure and voltage sags. Among these are RMS Value

The increment can cause the electric power disturbances . The disturbances can stimulate the sensitive equipment damage and are costly to repair. The cost of repair causes severe financial losses.The voltage sag is the most frequently occurring power quality disturbance as compared to the voltage swell. Voltage sags account for the highest percentage of equipment interruptions, i.e. 31%. Voltage sags are also major power quality problem that contributes to nuisance tripping and malfunction of sensitive equipment in industrial processes.The impact of voltage disturbances on sensitive equipment has called for focus on detection of them [8]. While detecting the sag and swell the important parameter is its detection time. While in quantification of voltage sag and swell, the most important parameters are magnitude and duration.Much of the research in recent years has focused to improve the power quality. By using sliding window algorithm for the detection of sag and swell, andby measuring updated RMS voltage, every sample is developed[1].Evaluation, Peak Value Evaluation, Missing Voltage technique and Hysteresis Voltage Control technique. In this paper we have proposed the signal processing based approach for classification of Power Quality events. A Sliding Window algorithm is proposed to calculate RMS ofthe signal and statistical parameters are used to classify the power quality events. The paper is organized as follows:The PQ disturbances are in section II. The Sliding Window Technique algorithm in section III. The experimental setup is presented in section IV and section V contains the resultand discussion of PQ investigations. Finally, some conclusions are summarized in section VI.

II. PQ DISTURBANCES

The PQ events are commonly identified in the system by set of waveforms, this waveform may observe, calculated and classified by the test equipment. IEEE Standard 1159-1995 defines various PQ disturbances. The extracted data of PQ events are used to classify them by various parameters

Voltage Sag:

Voltage sag as defined by IEEE Standard 1159-1995, IEEE recommended practice for monitoring electric power quality, is a decrease in root mean square (RMS) voltage at the power frequency for durations from 0.5 cycles to 1 minute [8]. Typical magnitudes

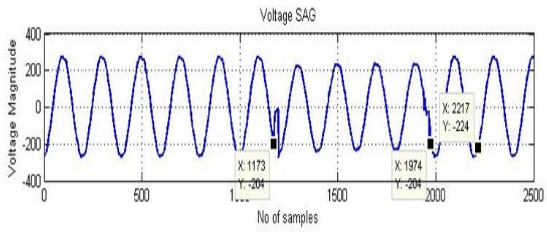

Fig. 1: Voltage sag event

Voltage Swell:

Voltage swell as defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is an increase in root mean square (RMS) voltage at the power frequency for durations from 0.5 cycles to 1 minute [8]. Typical magnitudes are between 1.1 and 1.8 pu.

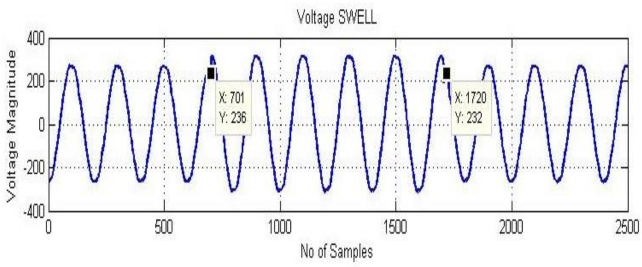

Fig.2 : Voltage swell event

Interruption:

An interruptionoccurs when the supply voltage decreases to less than 0.1 pu for a period of time not exceeding 1 min. Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The interruptions are measured by their duration since the voltage magnitude is always less than 10% of nominal. The duration of an interruption due to a fault on the utility system is determined by utility protective devices and the particular event that is causing the fault.

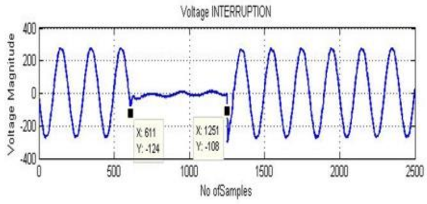

Fig.3: Interruption event

III METHODOLOGY

RMS by Sliding Window Technique:

The most common processing tool for voltage measurement in power systems is the calculation of the Root Mean Square (RMS) value. The most important standards related to the measurement of power quality disturbances are, at present, IEC Standard 61000-4-30 and IEEE Standard.1159-1995. Both propose the use of RMS value of voltage supplies for voltage sag and swell detection. Root Mean Square (RMS) value of a signal can be used effectively to detect voltage sags and swell. Voltage and current measurements are often expressed in RMS values [2]. As voltage sags are initially recorded as sampled points in time, the RMS voltage will have to be calculated from the sampled time domain voltages. This is done by following equation (1):

$$V^{RMS}(i) = \sqrt{\frac{1}{N}\sum_{j=1}^{i+N-1} V^2(j)} \tag{1}$$

Where,

N is Number of the samples per cycle

V (j) is j^{th} *sample of the recorded voltage waveform*

$V^{RMS}(i)$ *is* i^{th} *sample of the calculated RMS voltage*

During the occurrence of sag, the RMS value drops below the nominal value. This drop is proportional to the level of sag. Similarly, during a swell, the RMS value exceeds the nominal RMS value by an amount proportional to the level of swell. The sag and swell are the non stationary event. Thus there is a need to reset the algorithm after the occurrence of sag or swell. This can be overcome by calculating the RMS value over a moving window encompassing a fixed number of samples.

The widely-used moving-window RMSvalue is calculated for digitally recorded data. Each of the sampled components of one cycle of the waveform is squared individually and then summed together. Then, the square root of this sumis calculated and this single value is plotted. Since, a waveform disturbance is not stationary; the window is moved incrementally along the waveform. While there are several techniques commonly used, a continuous-time RMS waveform can be achieved by sliding the window one data point to the right and the oldest data (at the left of the window) is dropped astime progresses with each increment.

In Sliding Window Technique the sliding RMS mechanism to compute RMS of a signal, i.e. with a window size of N, this technique add the squared value of the new sample x(n) to the running total while deducting the squared value of the x(n - N) sample and then performing a square root to get the RMS value. This method works fine when a cycle's worth data in the signal under question lines up exactly with the length of the window.

Let the window length N = 200, frequency of the signal = 50 Hz & sampling frequency = 10000Hz. With the above settings, every set of 200 samples would have a cycle's worth data of the signal & the computation works fine. When the frequency of the signal deviates from 50Hz giving more or less number of samples in the same 200 samples window which throws off the accuracy of the sliding RMS algoritThis happens because the division by 200 to get the RMS, is no longer valid due to the fact that this particular cycle of the signal is getting complete before the end of the 200 samples window. However, the running squared total would already have the contributions from the previous samples which were divided by 200 while the samples of this cycle would require a different window length.In order to spend less processing time, a recursive alternative can be used. This provides a significant processing time saving when N is large. The flow chart for RMS algorithm is shown in Fig. 4.1.(flow chart)

Table: 1: Equipment Required For Experimental Setup

Experimental Setup:

Sr. No.	Name of Equipment	Specification
1	Single phase Transformer	1 Ph. 2KVA, 230V/230V, isolation transformer of 10V tapings
2	Solid State Mechanical Relay	Input supply of +12V DC, rating 230V/10A
3	Current Transformer (CT)	Input range :0.01Amp-5Amp AC, Output:400mV/A
4	Potential Transformer (PT)	TOOGOO(R)P4100 High Voltage Oscilloscope Probe 2KV 100: 1 100 MHz alligator clip Measuring tip
5	DigitalStorage Oscilloscope (DSO)	Tektronix TPS2014 Sample Rate1 GSa/s
6	Load (Single Phase)	Light load (linear and non linear) 140W
7	Personal Computer (PC)	4^{th} generation, i-3, windows 8. with MATLAB R2017a software

To study the performance of detection and classification method for most common PQ events such as voltage sag, voltage swell and voltage interruption the conditions are generated in the laboratories through tailor made experimentation setup. Desired voltage signals are captured through digital storage oscilloscope and processed to personal computer through the open choice desktop software. This chapter describes the hardware used during the experimentation in Fig.4 show the circuit diagram of the experimental setup used to generate the PQ disturbances and Table 1 show the all equipment required in the experimental setup with their specification in tabular form.

Fig.4 shows the experimental setup that used to conduct the experiment in laboratory for transient PQ event. The setup consist of single phase supply, single phase 2KVA, 230V/230V one to one tapping transformer having the taps steps of 10 V, tapings are set from 0 V to 230 V, single phase induction motor without pump (1Hp) as a load, Potential Transformer (PT), Current Transformer (CT), Digital Storage Oscilloscope (DSO), Personnel Computer (PC), switch and single phase capacitor of rating 1 KVAr. The capacitor switching is done to generate transient event. The voltage sag, swell and interruption events are generated by changing the taps of transformer with the help of Normally Open-Normally Close (NO-NC) switch. The solid state mechanical relay is also used to act as a tap changer so that the PQ events are simulated online. The relay has rating of 230V/10A and the operating coil of the relay is provided with the +12V DC supply. All events are recorded in DSO at sampling frequency of 10kHz and processed to personal computer through the open choice desktop software. Further the collected data in the form of sheet is loaded in the Matlab software. MATLAB R2017a software is used in the PC.

V RESULT AND DISSCUSSION

The power quality events such as voltage sag, swell and interruption are captured by experimental setup in the laboratory and the RMS values of voltage and current are calculated by using Sliding Window Technique. The detection of PQ events is done by Sliding Window technique and statistical parameter such as maximum, Standard Deviation, Kurtosis and Variance is used to classify them. For proper detection and classification number of samples and amplitude of the signal are taken same for all events.

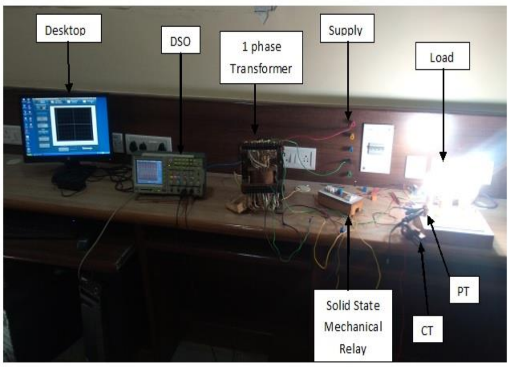

Fig.4: Experimental Setup

Generation of Power Modal Signal

In signal processing the number of power quality events studied with various calculating methods, from that various methods the sliding window technique gives much accurate results. By Sliding Window Technique the RMS values of the voltage and current signal to detect Power quality events, in this it is used for three Power quality events such as voltage sag, swell, and interruption.

Voltage Sag Event

The fig 5.(a) is voltage signal in which X axis shows number of samples and Y axis shows voltage magnitude with sag effect starting at point X=1182 and Y=-20 and at ending point X=1958 and Y=-28.

In fig 5.(b) by using sliding window technique the RMS signal of real time voltage sag signal is calculated and the voltage sag event is shown in below waveform.

In fig 5.(c) the power modal signal of voltage sag event is generated by multiplying voltage RMS and current RMS of the same signal.

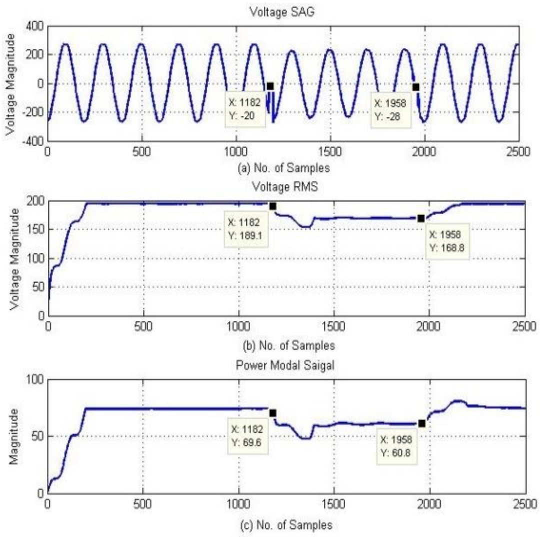

Fig. 5: Power modal signal of voltage sag event

Voltage Swell Event

The fig 6(a) is voltage signal in which X axis shows number of samples and Y axis shows voltage magnitude with swelling effect starting at point X=701 and Y=236 and at ending point X=1711 and Y=216.

In fig 6(b) by using sliding window technique the RMS signal of real time voltage swell signal is calculated and the voltage swelling event is shown in below waveform.

In fig 6(c) the power modal signal of voltage swell event is generated by multiplying voltage RMS and current RMS of the same signal. Fig. 6.1: Power modal signal of voltage swell event

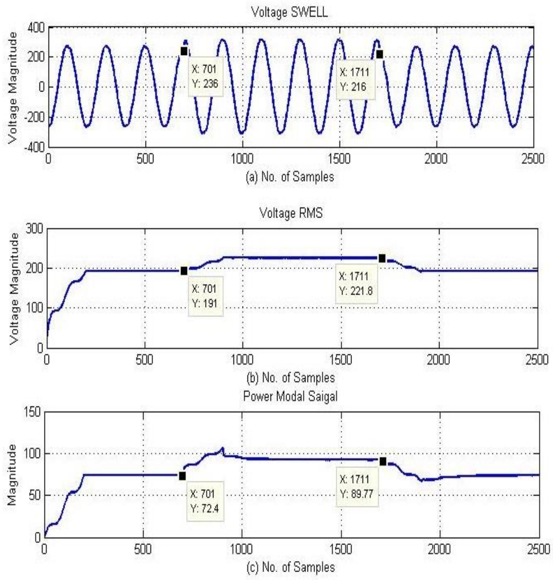

Fig. 6: Power modal signal of voltage swell event

Voltage Interruption Event

The fig 7(a) is voltage signal in which X axis shows number of samples and Y axis shows voltage magnitude with interruption effect starting at point X=611 and Y=-124 and at ending point X=1251 and Y=-108.

In fig 7(b) by using sliding window technique the RMS signal of real time voltage interruption signal is calculated and the voltage interruption event is shown in below waveform.

In fig 7(c) the power modal signal of voltage interruption event is generated by multiplying voltage RMS and current RMS of the same signal.

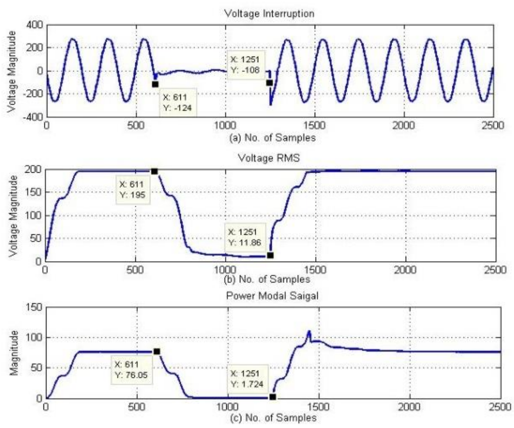

Fig.7: Power modal signal of voltage interruption event

Fig 8 shows the combined voltage RMS signal for all types of disturbances which we have taken i.e. voltage swell, voltage sag and voltage interruption.

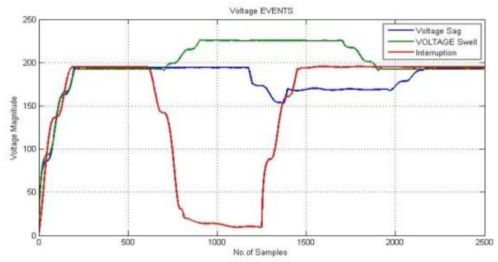

Fig.8: Voltage RMS signal of voltage sag, swell and interruption event

Table 2: Classification of Power Quality Events by Variance

Reading Number	Power Quality Events		
	Voltage Sag	Voltage Swell	Interruption
1	176.6612	286.504	1061.706
2	163.6764	301.1025	904.3593
3	163.413	284.7717	1312.464
4	169.7145	269.943	1141.738
5	169.7145	273.38	1191.57
6	158.3021	260.6999	1392.276
7	126.6064	266.4621	1089.931
8	155.7264	286.186	1218.549
9	154.3937	253.3378	1054.746

VII Conclusion

In this paper, the successful classification of power quality events such as voltage sag, voltage swell and voltage interruption through Sliding Window Technique is carried out for calculating RMS and generating the power modal signal. It observed that, the event can be classified at exact point on wave occurrence of it. The statistical parameters are calculated for the classification of Power quality events. The Variance is the only one successful parameter from four statistical parameter used to classify the power quality events and other parameters are not that much suitable to classify the power quality events.This method is very simple, easy to implement and faster, which requires only three samples for detection. The strength of algorithm is that it works on experimental setup data which consist of more noise and not as ideal as Simulink block model.

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