ISSN 2229-5518

Improving the Detection of Power Quality Events in Real-Time Electrical Voltage Waveform Using a Multi-detector Approach

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Abstract— Reliable and uninterrupted power supply is the main goal of power industries; however, the continually changing load demand often leads to power quality (PQ) events which impose severe problems towards end-users or utilities. Accurate and timely detection of these PQ events is very essential for corrective measures. In this paper, a multi-detector scheme termed joint triggering point detection (JTPD) is proposed with a view to achieving a more accurate PQ event detection in a real-time voltage waveform. The JTPD combines the advantage of the cumulative sum (CUSUM) algorithm for the statistical distribution of a signal waveform and the discrete wavelet transform (DWT) for change-point detection. The detection rate performance of the proposed JTPD scheme is compared with each of cumulative sum (CUSUM) and discrete wavelet transform (DWT) schemes; and the results show that the proposed JTPD scheme outperforms both CUSUM and DWT.

Index Terms— Power quality, voltage waveform, real-time voltage signal, joint triggering point detection

1 Introduction

The demand vis-à-vis growth of power supply has tremendously increased all over the world. For the economic development and industrialization of any society or country, efficient and reliable electricity supply is the key; however, the power industry is faced with the problem of power quality (PQ) distortion (or events). In Nigeria, most consumers of electricity nowadays complain about short lifespan of their home appliances, which is as a result of the poor quality of power supplied. Some PQ analyses have been made to address these problems but most of the proposed solutions are evaluated on synthetic signals [1],[2].

Voltage swell is an increase to 1.1-1.8 p.u in root mean square (RMS) voltage or current magnitude at the line frequency for duration from 0.5 cycles to 1 minute. Swells are usually associated with system fault conditions, lightning strikes and introduction of heavy loads, which could cause damage to power supply equipment [3],[4],[5]. Voltage dip (or sag) refers to a decrease to 0.1 – 0.9 p.u in RMS voltage or current magnitude at the line frequency for duration from 0.5 cycles to 1 minute [6],[7],[8]). Sag may cause data processing and control equipment to suffer from data loss and extended downtime.

Voltage interruption occurs when the supply voltage or load current decreases to less than 0.1 p.u for a period of time exceeding 1 minute. It causes equipment failures and control malfunctions.

Santoso *et al.* in [9] presented electric power quality disturbances detection using wavelet transform analysis for short and fast transient disturbances. Liang, *et al.* [10] presented a tool that can be used to evaluate power quality problems, which is based on wavelet decomposition technique. The wavelet technique used placed a higher emphasis on transient events instead of a general study of various disturbances. Bollen *et al*. [11] investigated the use of root mean squared (RMS) approach for the detection of voltage dip events on three phase voltage waveform. Voltage magnitude variations are quantified by the RMS voltage calculated over a 200-ms window. He *et al*. [12] presented a triggering point detection approach to PQ monitoring in smart grids based on change-point detection theory with unknown parameters. A sequential CUSUM scheme was developed with the aim of providing quick and accurate detection of the occurrence of PQ event in real-time.

This paper proposes joint triggering point detection (JTPD) for the detection of voltage PQ events in the power supply to some selected home appliances (laptop and TV).

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2 Modelling

2.1Real-Time Voltage Signal

The CUSUM, DWT and JTPD schemes were experimented on the real-time voltage signal waveforms at 220V, 50 Hz supplied to the home appliances. Power quality (PQ) analyzer "FLUKE 435" [13] was used to acquire voltage and frequency data for the purpose of detecting and identifying the PQ events in the voltage waveform. Data was directly acquired using the FLUKE 435 connected between an electrical appliance and the distribution system. This was carried out in three different environments having different load distributions. The environments are campus, residential area and saw-mill area. FLUKE 435 samples the input signal at a sampling rate of 200 kilo-samples-per-second (200 kS/sec). The FLUKE 435 gives the numbers of voltage dips, swells and interruptions measured from the supply to each of the appliances.

The block diagram for the proposed JTPD scheme for PQ event detection is shown in Figure 1. The input electrical signal waveform is acquired by a measuring device. The measuring device propagates the voltage signal waveform to the analog-to-digital (A/D) converter which converts the continuous-time voltage waveform into discrete-time voltage waveform for digital signal processing. The output of the A/D conversion is then passed to a wavelet filter to remove the noise in the signal. The filtered signal waveform is then passed to the JTPD scheme where the triggering points of the occurrence of PQ events are detected. Since multiple events could be present in the input signal waveform, the signal waveform is then segmented and each segment represents the duration of an event.

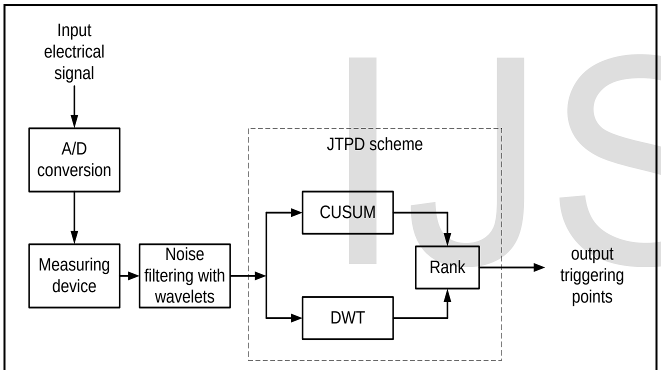

Fig. 1. Proposed JTPD scheme for PQ event

2.2 Joint Triggering Point Detection (JTPD) Scheme

The developed JTPD method consists of the combination of the CUSUM and DWT algorithms. The CUSUM method computes the sample-by-sample log-likelihood ratio (LLR) of the signal waveform by utilizing both the instantaneous and statistical information of the signal waveform. An event is detected at a point where the CUSUM value is greater than or equal to a threshold value. On the other hand, the DWT detection method involves decomposing the signal waveform to extract the detail coefficients from the signal; and these details contain the frequency components that can reveal disturbance in the signal. The outputs of the CUSUM and DWT are passed to a modified least-square (MLS) operator given by Equation (3.19). Every triggering point supplied by CUSUM (x) is compared with every other triggering point supplied by DWT (y) using the MLS operator. If the MLS value is greater than 10^{-3} threshold, then the point is rejected; however, if the value is less than or equals to 10^{-3}, the point is accepted and the minimum between x and y is taken as the triggering point.

$$MLS = \frac{(x-y)^2}{10^6} \qquad (1)$$

The flow chart of the proposed JTPD scheme is shown in Figure 2.

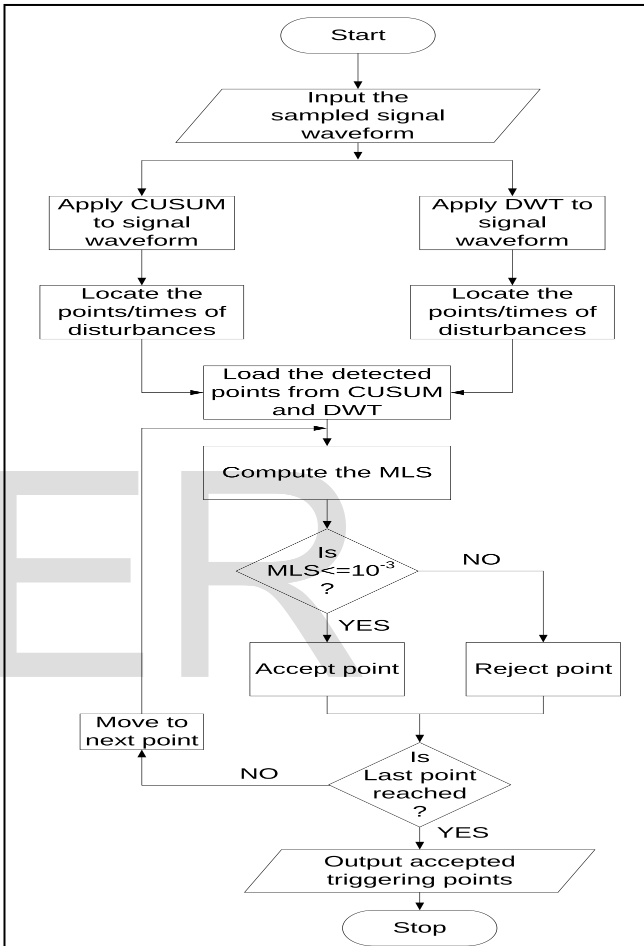

Fig. 2. JTPD Scheme

3 RESULT AND DISCUSSION

Table 1 presents the results of the number of PQ events detected in the voltage waveform supplied to the home appliances. For the residential area, the number of PQ events detected in the voltage waveform supplied to laptop by DWT, CUSUM, JTPD and FLUKE 435 are 3, 2, 3 and 3 respectively as shown in Figure 3. In the voltage waveform supplied to TV, DWT, CUSUM, JTPD and FLUKE 435 detected 8, 7, 13 and 13 events, respectively as shown in Figure 4. Using FLUKE 435 as benchmark, the detection rate for DWT, CUSUM and JTPD are 95%, 93% and 100%, respectively.

ISSN 2229-5518

For the campus area, the number of PQ events detected in the voltage supplied to laptop by DWT, CUSUM, JTPD and FLUKE 435 are 4, 5, 4 and 5, respectively as shown in Figure 5. In the voltage waveform supplied to TV, DWT, CUSUM, JTPD and FLUKE 435 detected 5, 8, 3 and 3 events, respectively as shown in Figure 6. The detection rate for DWT, CUSUM and JTPD are 99%, 95% and 99%, respectively.

For the saw-mill area, the number of PQ events detected in the voltage supplied to laptop by DWT, CUSUM, JTPD and FLUKE 435 are 14, 15, 13 and 13, respectively as shown in Figure 7. In the voltage waveform supplied to TV, DWT, CUSUM, JTPD and FLUKE 435 detected 13, 12, 11 and 12 events, respectively. The detection rate for DWT, CUSUM and JTPD are 98%, 98% and 99%, respectively as shown in Figure 8.

The mean detection rate for DWT, CUSUM and JTPD are 97.33%, 95.33% and 99.33%. This reveals that the proposed JTPD is able to reject false alarms by accepting triggering points that are common to both DWT and CUSUM while rejecting points with disparity. This helps to improve on the accuracy of the detection. However, this goes with a trade-off of processing time as more time is required to perform both the DWT and CUSUM. With the use of faster processors the problem of processing time could be eliminated while the accuracy is maintained.

Table 1. Comparison of the TPD schemes for PQ event detection in a residential area

Home Appliance	Number of PQ events detected			
	DWT	CUSUM	JTPD	FLUKE 435
Laptop	3	2	3	3
TV	8	7	13	13

Table 2. Comparison of the TPD schemes for PQ event detection on campus

Home Appliance	Number of PQ events detected			
	DWT	CUSUM	JTPD	FLUKE 435
Laptop	4	5	4	5
TV	5	8	3	3

Table 3. Comparison of the TPD schemes for PQ event detection in a sawmill area

Home Appliance	Number of PQ events detected			
	DWT	CUSUM	JTPD	FLUKE 435
Laptop	14	15	13	13
TV	13	12	11	12

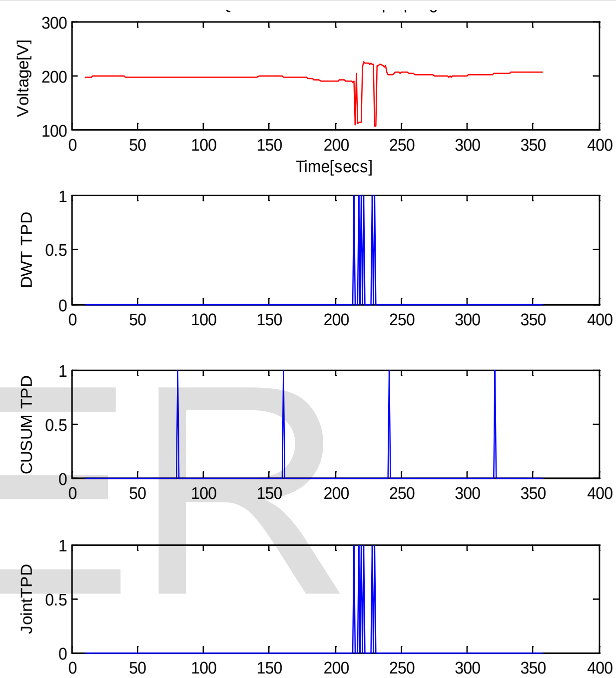

Fig. 3.Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the laptop of a residential area

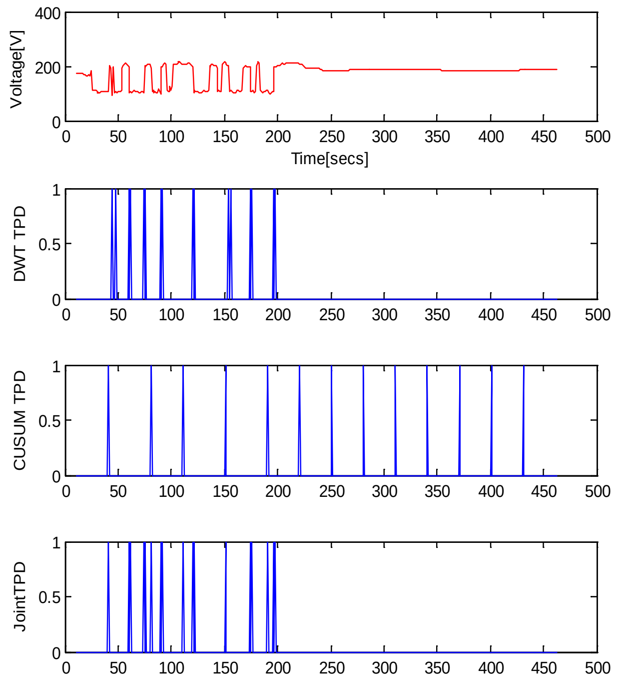

Fig. 4. Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the TV of a residential area

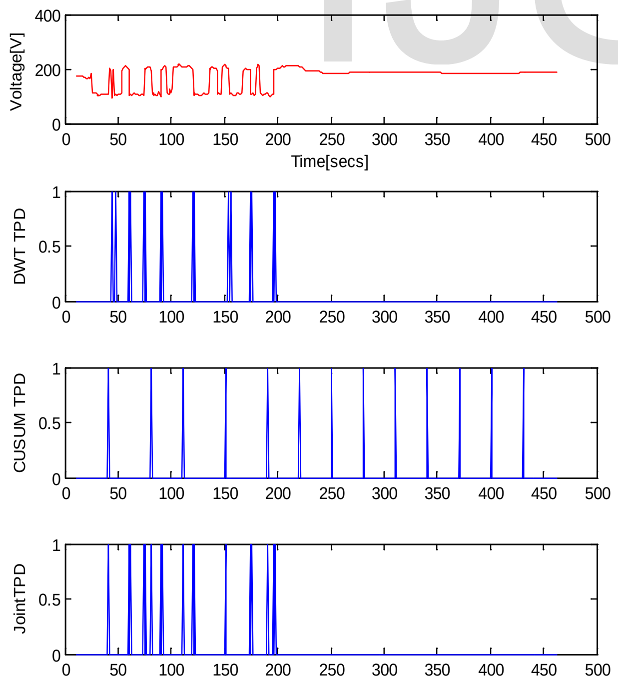

Fig. 5. Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the laptop on campus

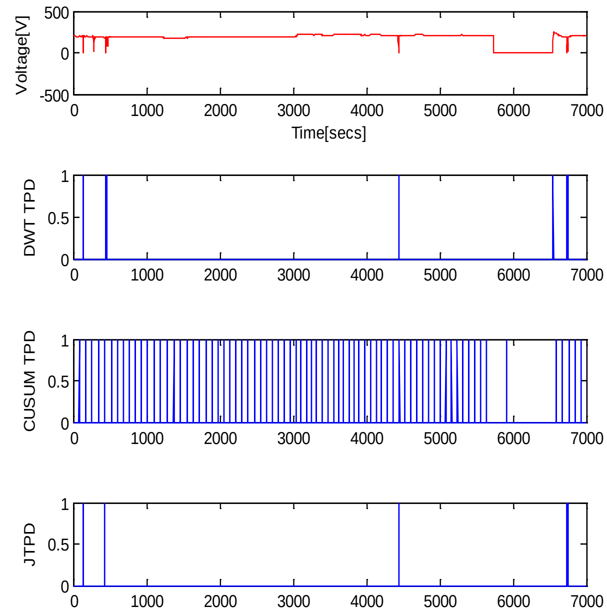

Fig. 6. Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the TV on campus

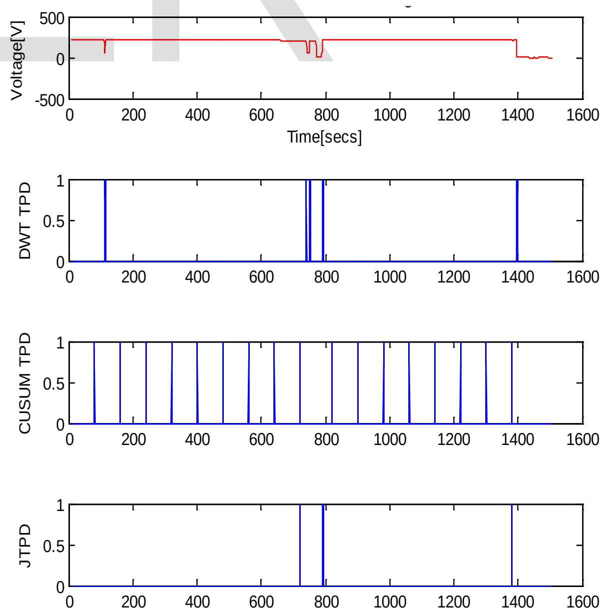

Fig. 7. Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the laptop at a sawmill

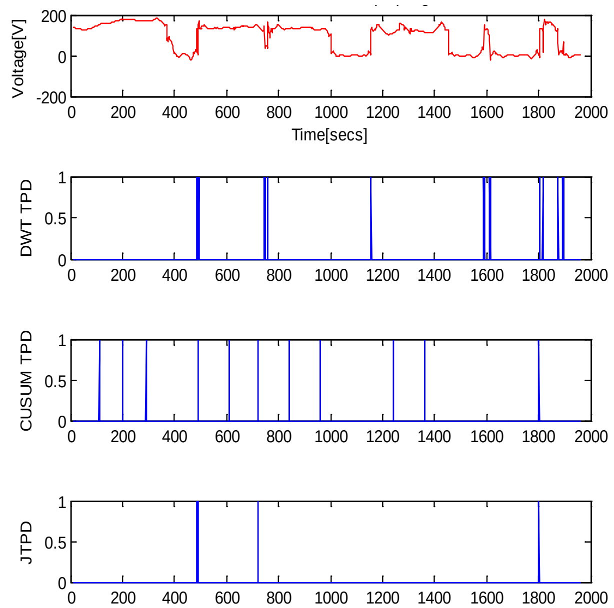

Fig. 8. Application of the TPD scheme for voltage dip event detection in the voltage signal waveform suuplied to the TV at a sawmill

4 Conclusion

In this paper, PQ event triggering-point detection in electrical voltage signals supplied to some home appliances using the CUSUM, DWT and the proposed JTPD schemes have been investigated, and the results benchmarked with the FLUKE 435 PQ analyzer. The detection rate performance reveals that the proposed JTPD scheme offers performance improvement for PQ event detection over both DWT and CUSUM. The JTPD achieves this by ranking the output of the CUSUM and the DWT schemes using a modified least square (MLS) operator to give more accurate triggering point detection.

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