Multiresolution Analysis and Standard MRA Curve for Analysis of Power Quality Disturbances

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Abstract—

This paper presents the use of multi-resolution analysis and STD_MRA curve for detection and classification of power quality disturbance events. The power quality disturbance waveforms were generated using Matlab programming and taking actual loading conditions in case study. In the first step the programmed disturbances were detected and classified. A case study was held at Urse substation near pune for getting actual power quality disturbances. Urse substation has industrial as well as residential load. A Simulink model was developed and all the necessary data from case study was feed in the Simulink model. These actual disturbances were detected and classified in second step. A comparative study is done between both the observations in this paper. The disturbances mainly included were sag, swell, harmonics, sag with harmonics and swell with harmonics. Multi-resolution analysis was used for detection and classification of disturbances.

Keywords— power quality, wavelet transform, Std_MRA curve

I. INTRODUCTION

In our modern power system the power quality becomes a major issue. The various power quality disturbances such as sag swell, harmonics sag and swell with harmonics can cause major damage to the power system. So it is necessary that the quality of power must be improved. For that the causes of disturbances and various sources of disturbances must be determined in order to take proper mitigation action. While determining these disturbances one must have ability to detect and classify the various power quality disturbances. Modern power system consists of mainly generation, transmission, and distribution system. In these each system there are various equipments which mainly consist of power electronics devices.These devices are susceptible to the various power quality disturbances. For example, a voltage sag lasting for hundredth of second can reset programmable logic controllers in an assembly line [1]. It is not a desirable thing because cost due to this phenomenon is very high. So to avoid these types of losses analysis and mitigation of power quality disturbances are necessary. The power quality disturbances waveform identification is very complicated work because it involves a broad range of disturbance classes. So there is a need of a reliable technique for monitoring the disturbances. To monitor power quality disturbances there are several methods are used like Fourier transform, short time Fourier transform[2][3]. Alexander presented a technique based on Kalman filter to categorize power quality events [4]. In these various methods the wavelet transform is the best method suited for power quality disturbance detection [5]. Fourier transform can't track the system dynamics properly because it can be applied only to the steady state phenomenon and it can't analyze the signal in both time and frequency domain. Whereas short time Fourier transform is not suitable for non stationary signals due to the limitations of a fixed window width. Thus STFT can't be used to analyze transient signals consisting both low and high frequency component. On the other hand wavelet transform is the best suited transform to analyze the signal in both time and frequency domain [6]. It provides the unique framework for monitoring the power quality problem. Recent advances in the wavelet transforms provide a powerful tool for power quality analysis [7].

A. Wavelet Transform

It is one of the signal processing technique which has the ability to analyze the signal in both time and frequency domain. It can be used on both stationary as well as non stationary signal. The signal can be accurately reproduced with the wavelet analysis using small number of components [8]. The analyzing wavelets are called as Mother Wavelet and the transformed version are called as Daughter wavelet. The "mother wavelet" determines the shape of the components of the decomposed signals. There are many types of wavelets such as Harr (H), Daubechies 4 (D4), Daubechies 8 (D8), Coiflet 3 (C3), Symmlet 8 (S8), and so on. A particular type of wavelet is selected depending on the particular type of application. It has been proved that Daubechies family of mother wavelet has good efficiency in power quality events [9].

B. Multiresolution Analysis

Wavelet functions and scaling functions are used to decompose the signal and construct the signal at different resolution level in multi-resolution analysis

[10]. In which wavelet function is used to generate detail version of decomposed signal and the scaling function is used to generate approximated version of decomposed signal. This can be represented by following mathematical equation:

$$f(t) = \sum_k C_0(k)\varphi(t-k) + \sum_k \sum_{j=0}^{j-1} d_j(k) 2^{\frac{j}{2}} \ \gamma(2^j t - k) \quad (1)$$

Where C_0 is the '0' level scaling coefficient and d_j is the wavelet coefficient at scale j. $\varphi(t)$ is the scaling function and $\gamma(t)$ is the wavelet function and k is the translation coefficient. The translated and scaled version of the wavelet will build a time frequency picture of decomposed signal. Multi-resolution analysis is used to get the localization property in time for any transient phenomenon and the partitioning property of the signal energy at different frequency bands.

In this paper, a novel approach for power quality disturbance detection and localization is presented based on the multi-resolution analysis in discrete wavelet transform. Further the standard multi-resolution analysis curve is used for the classification of the disturbances viz sag, swell, harmonics, sag with harmonics and swell with harmonics.

II. PROPOSED METHOD ON PROGRAMMED WAVEFORMS

Proposed method is mainly divided into three steps as generation of power quality disturbances using Matlab programming. Those disturbances are applied to the wavelet transform for analysis and then classification of that detected signal using standard multi-resolution analysis curve is done.

A. Waveform Generation

In this proposed method 5 power quality disturbances were considered viz, sag, swell, harmonics, sag with harmonics and swell with harmonics. For comparison purpose sine wave was also generated. These disturbance waveforms were generated by using Matlab programming. For this programming the logic used is as follows.

- Sine wave was generated by using formula (2). The time span of this wave was 0 to 1 sec.

$$f(t) = A\sin(2\pi f t) \quad (2)$$

  Where 'A' is amplitude and 'f' is system frequency.
- For generating sag waveform, the time span was divided into 3 parts viz 0 to 0.5 sec, 0.5 to 0.6 sec, and 0.6 to 1 sec. For first time interval i.e. between 0 to 0.5sec the waveform was generated using sine formula. For next time interval i.e. between 0.5 to 0.6 sec the amplitude A_1 was subtracted from amplitude A as follows,

$$f(t) = A\sin(2\pi f t) - A_1 \sin(2\pi f t) \quad (3)$$

  And again for next time interval i.e. between 0.6 to 1 sec waveform was generated using sine formula. So that for interval 0.5 to 0.6 sec sag was generated.
- For generating swell waveform again time span was divided same as sag waveform. The only change was that the time interval between 0.5 to 0.6 sec the amplitude A_1 was added as follows,

$$f(t) = A\sin(2\pi f t) + A_1\, Sin\,(2\pi f t) \quad (4)$$

- For generating harmonics waveform the various frequency components were added in sine waveform as follows,

$$f(t) = A\sin(2\pi f t) + A_1 \sin\{2\pi(3f)t\} + A_2 \sin\{2\pi(5f)t\} + A_3 \sin\{2\pi(7f)t\}$$

$$+A_3 \sin\{2\pi(11f)t\} .. and\ so\ on \quad (5)$$

- For generating sag with harmonics waveform, time was again divided into three parts. In the time span of 0 to 0.5 sec normal harmonic waveform was generated as per formula (5). In the time span of 0.5 to 0.6 sec the amplitude A was lowered by 30%. And again in the time span of 0.6 to 1 normal waveform with harmonics was generated. So the sag was generated for the time span of 0.5 to 0.6 sec in the normal harmonics waveform.
- For generating swell with harmonics waveform just increased the amplitude A by 30% in the time span of 0.5 to 0.6 sec. remaining procedure was same as that of sag with harmonics.

These generated waveforms were loaded in wavelet toolbox for detection and then after classification is done.

B. Detection of Power Quality Disturbances

The waveforms of sine, sag, swell, harmonics, sag with harmonics and swell with harmonics were loaded to the wavelet toolbox. Daubechies 5 was used as mother wavelet. Five level decomposition of Db5 wavelet was used for analysis. The following results were observed.

Fig.1 shows the decomposition of sine wave at level 5 of Db5. As it was a pure sine wave, no disturbance was detected. Fig.2 shows the decomposition of sag waveform at level 5 of Db4. The sag was detected at second level of decomposition. Similarly fig.3, fig.4, fig.5, fig.6 shows the decomposition of swell waveform, harmonic waveform, sag with harmonic waveform and swell with harmonic waveform at level 5 of Db5 respectively. Simultaneously the values of standard deviations were noted at each decomposition level from statistics block in wavelet toolbox.

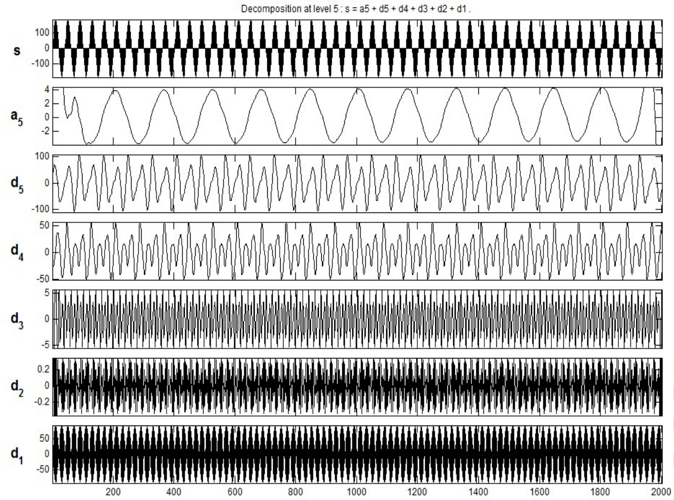

Fig.1: Decomposition of Sine wave at level 5

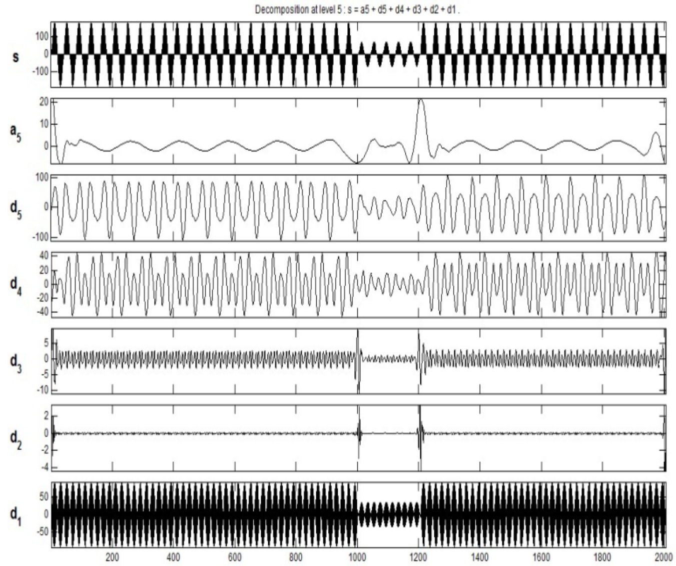

Fig.2: Decomposition of Sag waveform at level 5

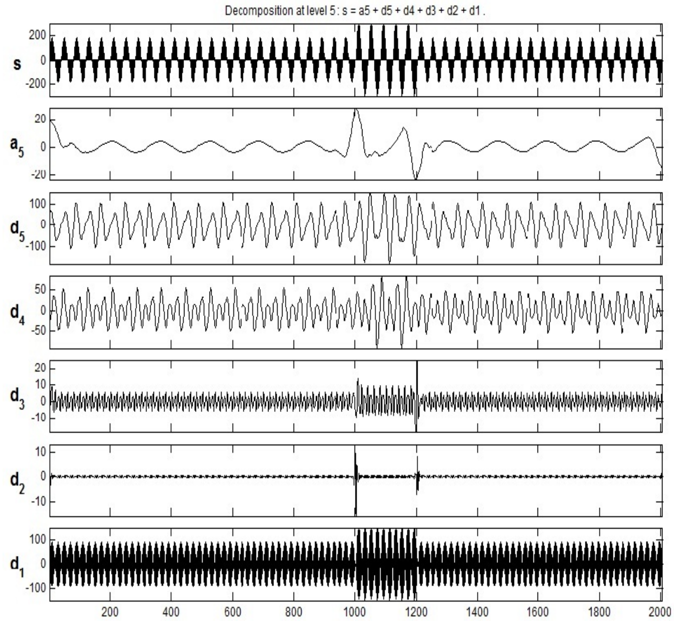

Fig.3: Decomposition of Swell waveform

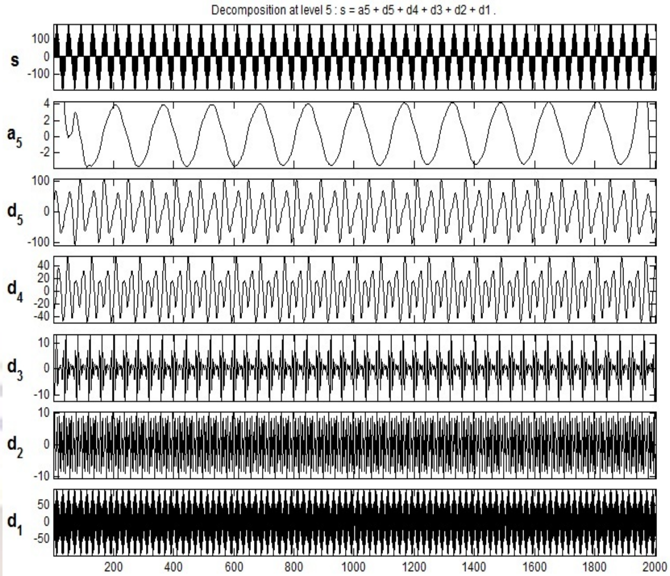

Fig.4: Decomposition of Harmonics Waveform

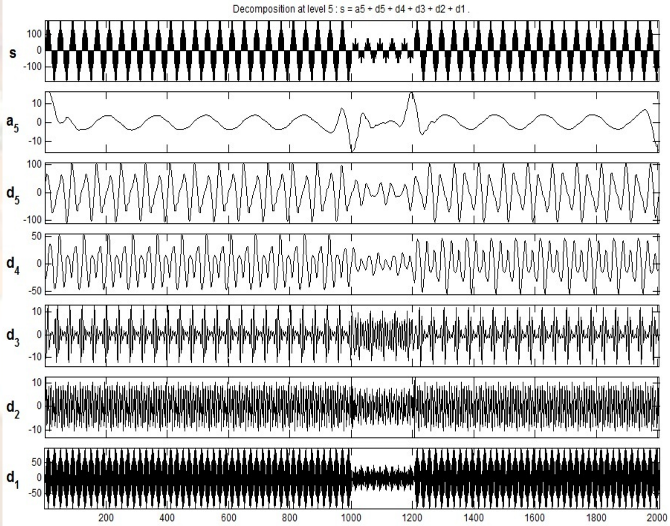

Fig.5: Decomposition of sag with harmonics waveform

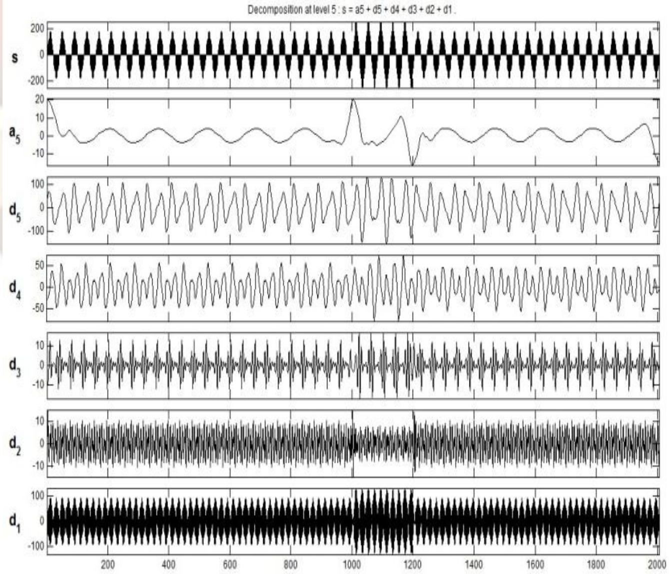

Fig.6: Decomposition of Swell with Harmonics Waveform

C. Classification of Programmed Power Quality Events

The energy of the power quality disturbance at various levels varies depending on the type of the disturbance. For a normal sinusoidal waveform, the standard deviation value is equal to the energy of the signal (as the mean is zero). Hence, the standard deviation value of the various levels of multi-resolution analysis can give us a comparative indication of any disturbance present within power signal. So the Standard MRA curve is used for classification of various disturbances. The X axis of the Standard MRA curve represents various decomposition levels and Y axis represents Standard deviation values.Fig.7 shows the classified output of the sag and swell disturbances using STD_MRA curve taking sine wave as a reference.Fig.8 shows the classified output of the Harmonics, sag with harmonics and swell with harmonics taking sine wave as a reference.

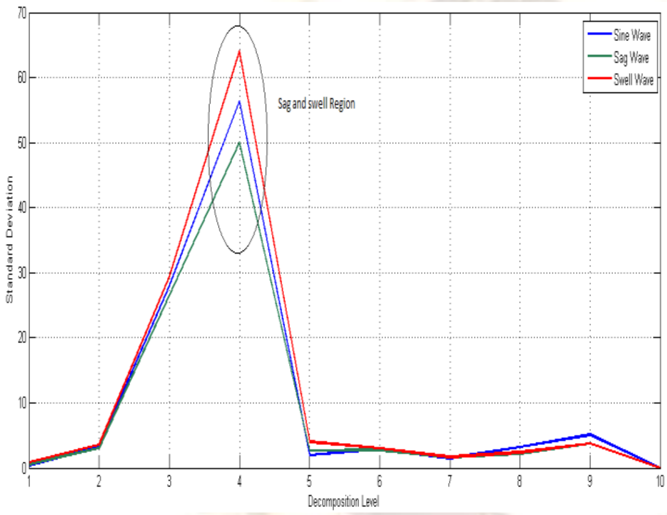

Fig.7: Classification of sag and swell wave w.r.t sine wave

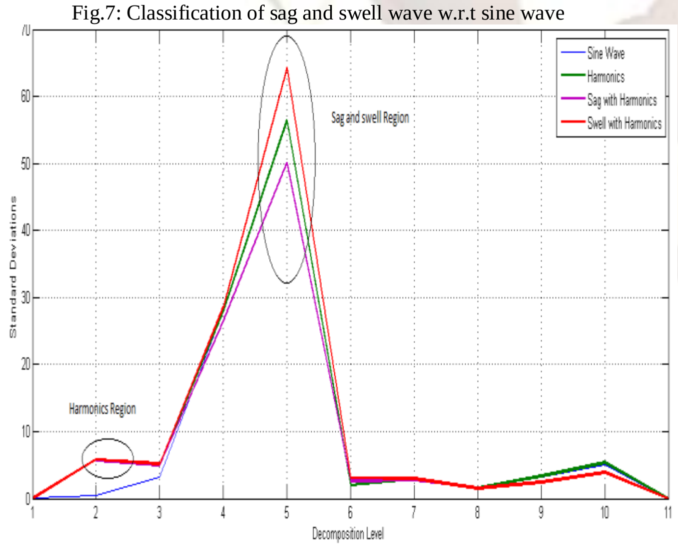

Fig.8: Classification of Harmonics, Sag with Harmonics and Swell with Harmonics w.r.t Sine wave.

III. CASE STUDY

A case study was held at Urse substation near Pune for getting actual power quality disturbances. Urse substation had industrial and residential load at the time of case study. A Simulink model was developed and all the necessary data from case study was feed in the Simulink model shown in fig.9.The necessary data from case study is shown in table no.1.

TABLE I

Sr.No.	Source Parameters	
1.	Phase to phase RMS voltage (KV)	222
2.	Frequency (Hz)	50
3.	3 phase short circuit level at base voltage (MVA)	50
4.	Base Voltage (KV)	22
5.	X/R ratio	4.429

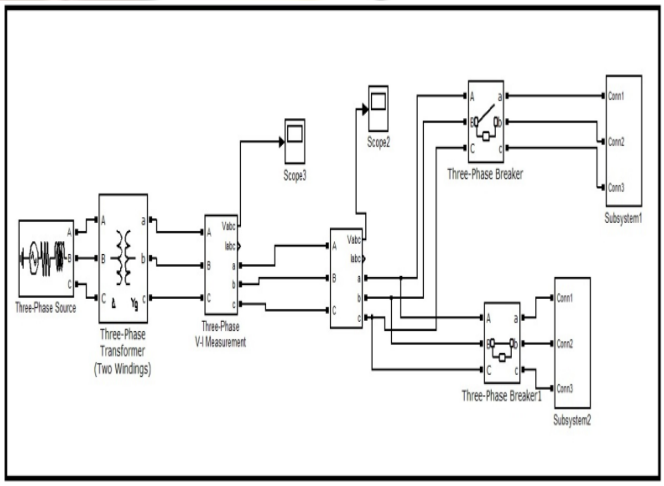

Fig.9: Simulink model for case study

TABLE II

Sr. No.	Transformer Parameters	
1.	Winding 1 connection	Delta
2.	Winding 2 connection	Yg
3.	Nominal Power (MVA)	50
4.	Winding 1 Voltage (KV)	222
5.	Winding 2 Voltage (KV)	22

A. Detection of Disturbances

The disturbance waveforms were generated in the simulink model with the data of case study. These waveforms were loaded into wavelet toolbox for the analysis procedure. The results of detection of sine wave, sag wave, swell wave, harmonics wave, sag with harmonics wave and swell with harmonics wave are observed in fig 10, fig 11, fig 12, fig 13, fig 14 and fig 15 respectively.

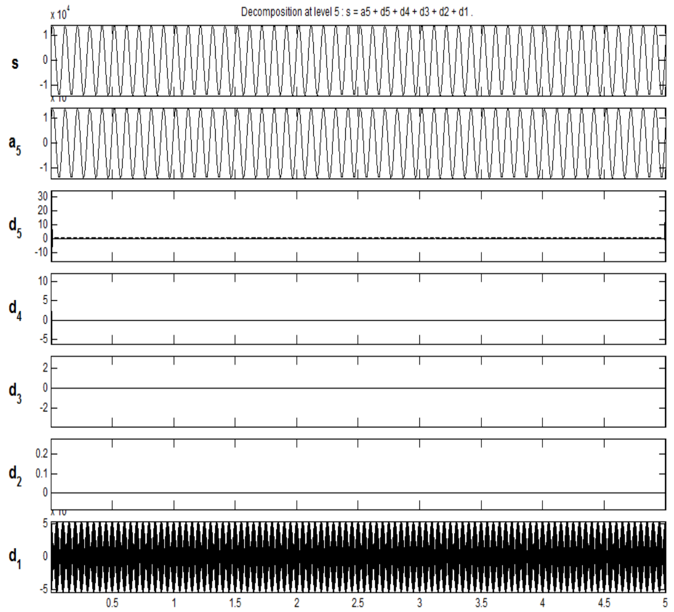

Fig.10. Decomposition of Sine wave at level 5 of Db5

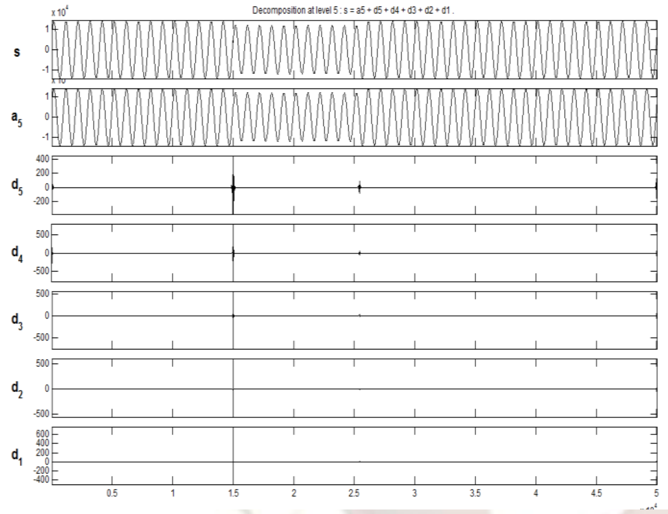

Fig.11: Decomposition of sag wave at level 5 of Db5

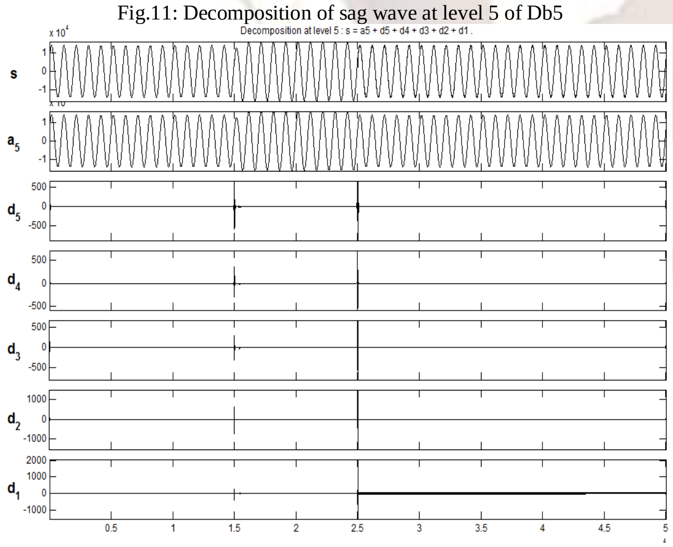

Fig.12: Decomposition of swell wave at level 5 of Db5

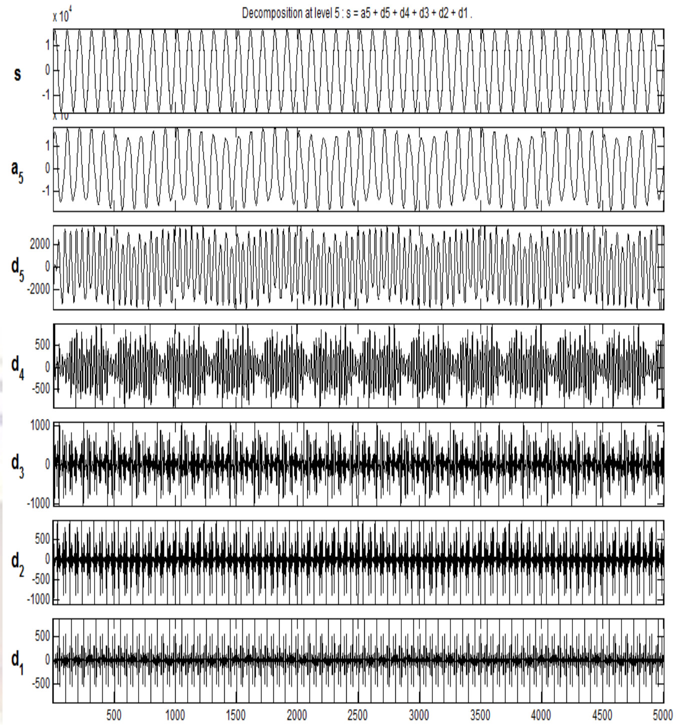

Fig.13: Decomposition of Harmonics wave at level 5 of Db5

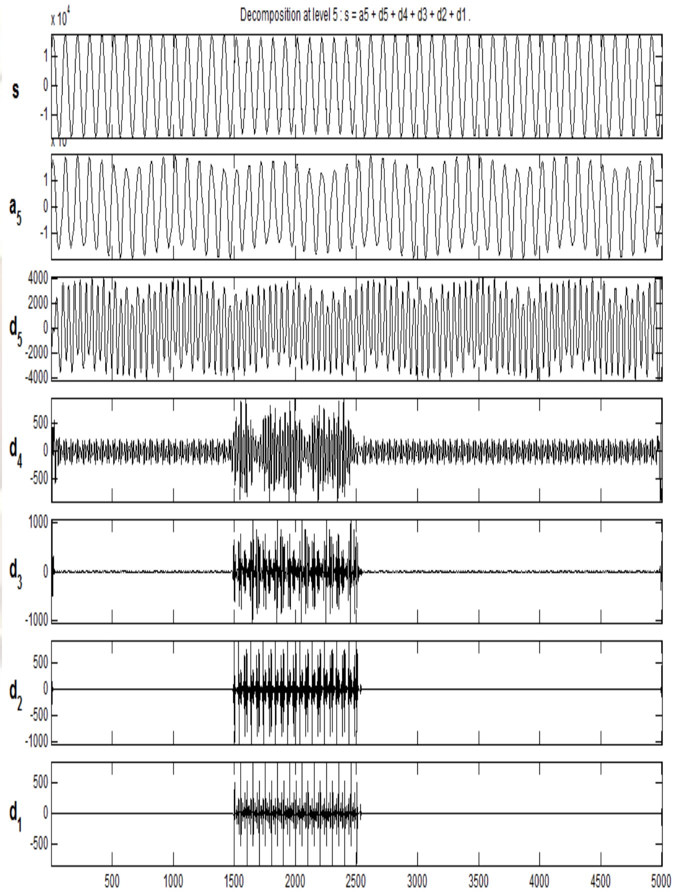

Fig.14: Decomposition of sag with harmonics at level 5 of Db5

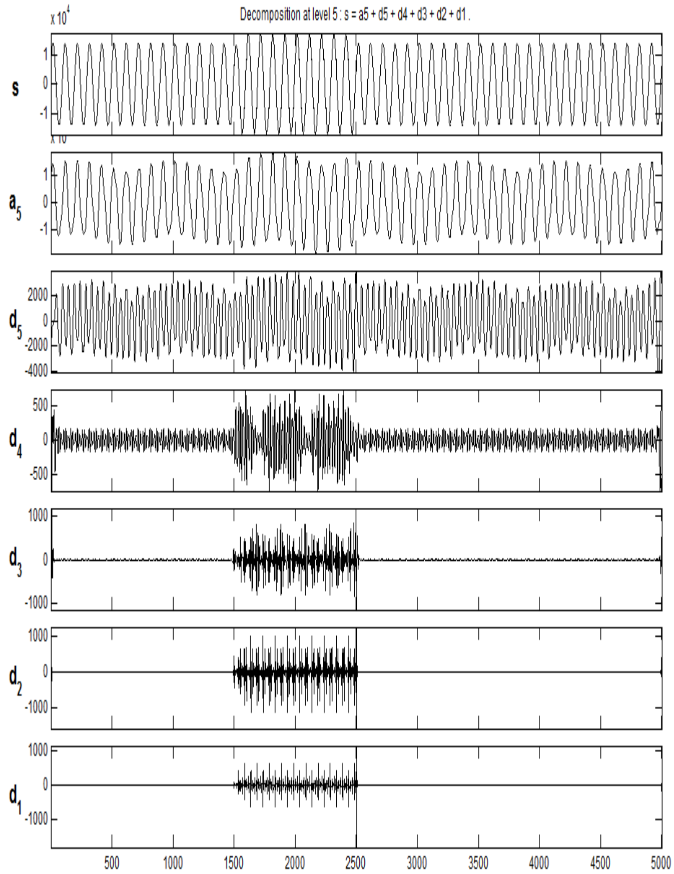

Fig.15: Decomposition of swell with harmonics at level 5 of Db5

From result of analysis it is clear that the sine wave analysis did not show any fluctuations whereas for disturbances the wave fluctuated at the starting and ending of disturbances. Sag and swell were detected in fifth level and sag and swell with harmonics were detected in first level of decomposition where as for programmed disturbances the satisfactory results were seen at the second decomposition level.

B. Classification of disturbances

Fig. 16 shows the classification results of sag swell with respect to sine wave. The maximum value of STD_MRA curve was increased for swell wave with respect to sine wave. The maximum value of MRA curve is decreased for sag wave with respect to the sine wave. Fig 17 shows the classification results of harmonic distortion as well as sag and swell with harmonic distortion. In fig.17 for harmonic distortion the lower left of curve is different than sine wave and the maximum value of MRA curve for sag and swell with harmonics are also decreased and increased respectively with respect to sine wave. Sag and swell zone as well as harmonics zone are mentioned in fig.17.

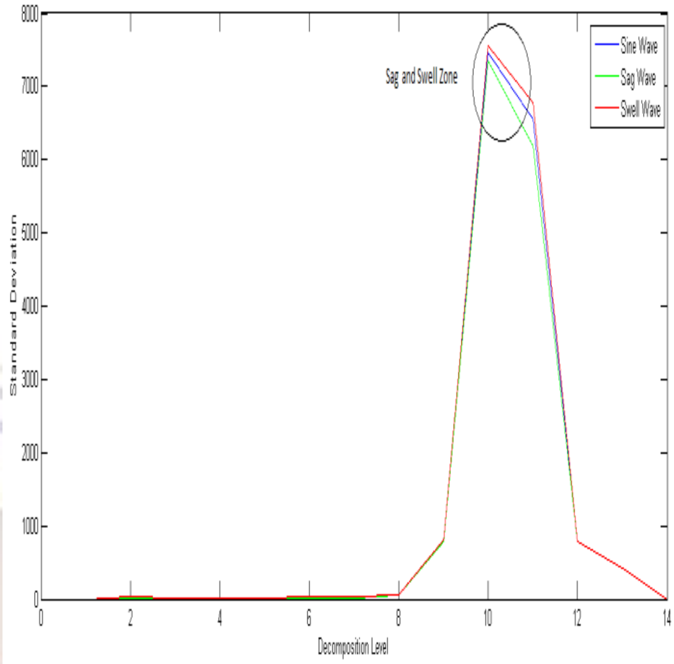

Fig.16: Classification of sag and swell wave w.r.t sine wave

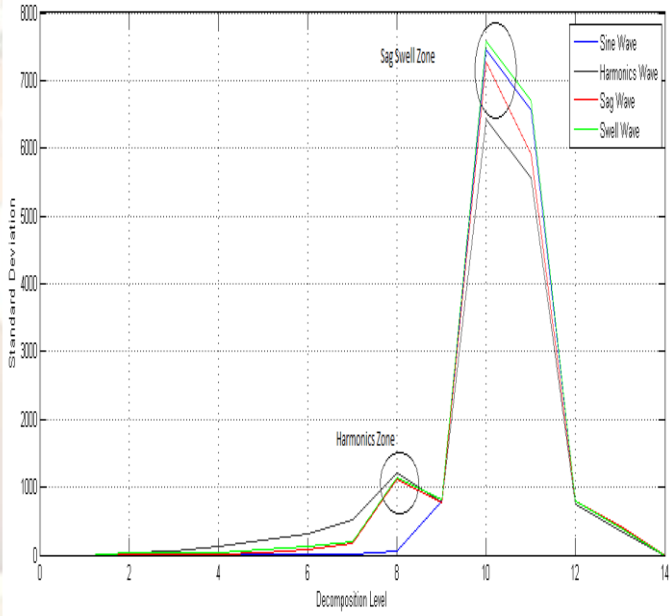

Fig.17: Classification of Harmonics, sag and swell with harmonics

IV. CONCLUSION

In this paper, a noble method for the detection and classification of power quality disturbances using wavelet transform and STD_MRA curve is presented. A case study results as well as programming results shows the only difference that the decomposition levels required for detection in both the cases are different. For programmed waveforms, the decomposition level required is two whereas for case study waveforms, the decomposition level required is up to five. In both the cases this method can accurately detect and classify the power quality disturbances mentioned.

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