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Araştırma Makalesi/Research Article

Detection of Power Disturbances using Emprical Mode Decomposition and Hilbert Transform

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Abstract- **This paper presents a new method based emprical mode decomposition and hilbert transform for detection of power quality disturbances. Hilbert Huang Transform HHT, which was suggested by Huang and improved by Flandrin and his group, is a new signal processing method. The analysis of nonlinear and non stationary signals can use HHT. In this paper, the recorded disturbances signals are decomposed into Intrinsic Mode Functions using the Emprical Mode Decomposition. The frequency and amplitude of power disturbances are obtained of IMF components by using Hilbert Transform HT. The clear success of EMD in defining envelope variations of a sinusoidal waveform has been the main motivation for the adoption of EMD in analysis of power disturbance signals. Simulations are performed over waveforms including voltage harmonics, voltage sag and swell. The waveforms are selected as pure sinusoids. Simulation results show that the suggested methodology can effectively detect different power disturbances.**

Key Words- **Power Disturbance, Emprical Mode Decomposition, Voltage Harmonics, Hilbert Huang Transform.**

I. INTRODUCTION

Power quality analysis is the foundation of fault diagnosis and protection for power system. Transient signal would generate when faults occur in the high voltage transmission lines and electrical equipment. Power quality topic in a power system include different types of PQ disturbances such as voltage harmonics, voltage sag, voltage swell, voltage flickers, fluctuation, transients, sag with harmonics, swell with harmonics[1].For the purpose of develop power quality, the resources and causes of such disturbances must be known before proper reducing precaution can be taken. However, for the purpose of determine the causes and resources of disturbances, it is significant to detect and localize them.

The conventional power quality detection methods are as follows: Fast Fourier transform (FFT) [2-4]. FFT has various advantages, for example, easy calculation, wide implementation and dependable computing. So it is widely used, but its sufficiency is restricted to stationary signals only. But is powerless to analyze nonlinear and non-stationary signal. As an development to FFT technique, the short-time FT (STFT)[5,6] and the Wavelet Transform (WT)[7-9] have been recorded. STFT performs satisfactorily for stationary signals whose properties do not change in time. For non-stationary signals, the STFT does not track the signal dynamics properly due to the limitations of a fixed window width. A wavelet is a function localized in both time and frequency. Furthermore, wavelets are band-limited, i.e. they are composed of not one but a relatively limited range of frequencies. WT has been shown to be proper for the analysis of non stationary signals. The main disadvantage of wavelet transform is its reduced performance under noisy situation.

Several authors have presented different methods [10-12] that always try to model all information into a set of feature from where decision making becomes easier and more certain than the traditional methods for the detection of power quality disturbances in recent years. HHT has the quality to detect some features of power quality disturbances [13]. EMD is non rational and adaptive, with basic functions derived fully from the data. The computation of EMD does not require any previously known value of the signal. As a result, EMD is especially proper to nonlinear and non-stationary signals, such as power quality disturbances.

EMD and HT are mainly used to analyze the nonlinear and non-stationary signal [14-16]. HHT represents the signal being analyzed in the time-frequency domain by combining the empirical mode decomposition (EMD) with Hilbert transform. This paper proposes a method based Empirical Mode Decomposition and Hilbert Transform, to detect and analyze voltage harmonics, voltage swell and voltage sag. In this method, after the decomposition of the original signal through the transform, components that carry similar

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oscillatory characteristics are automatically bundled to the same decomposition level by the Empirical Mode Decomposition, enabling the envelope component to exhibit itself for voltage harmonic, swell and sag detection. Once the flicker or harmonic envelope band is detected, the Hilbert Transform is applied to the corresponding IMF component.

The rest of this paper is organized as follows, Section II and III formulate the emprical mode decomposition and hilbert transform, Section IV describes mathematical model of power disturbances. Section V gives the results of simulation. Conculusions are given in Section VI.

II. EMPRICAL MODE DECOMPOSITION

The core step of the overall HHT is called the Emprical Mode Decomposition, which was developed by Norden E. Huang and his colleagues in 1998. EMD separates a time series into a finite number of its individual characteristic oscillations. The essence of EMD is to identify the intrinsic oscillatory modes by their characteristic time scales in the data and then decompose the data accordingly. Each series is named intrinsic mode function (IMF), which gives prominence to the different local character of original data. In order to define a meaningful instantaneous frequency (IF), each IMF has to satisfy the following two conditions [15]:

1) The number of extreme point and the number of the zero points must be equal or differ by at most one,

2) The mean of the envelope of the local maximum and the envelope of local minimum value must be zero.

The steps to carry out the EMD process are as follows[15].

a. The mean envelope of $x(t)$ signal $m(t)$ is obtained from the mean of upper and lower envelopes
b. A new signal $h_1(t)$ is obtained from subtracting mean envelope from $x(t)$:
c. If $h_1(t)$ does not satisfy IMF properties, the first 2 steps are applied on $h_1(t)$. This is called the sifting process. If the mean envelope signal satisfies the IMF properties, recursion is stopped and a IMF component $c_1(t)$ is obtained. The mean signal and the mean-subtracted signal are updated as in Eq.1:

$$\begin{aligned} m_{k-1}(t) &= \left[u_{k-1}(t)+v_{k-1}(t)\right]/\,2 \\ h_k(t) &= h_{k-1}(t)-m_{k-1}(t) \end{aligned} \tag{1}$$

d. The first IMF component, $c_1(t)$, is subtracted from the original data and its residue signal $r_1(t)$ is obtained from Eq. 2:

$$\begin{aligned} c_1(t) &= h_k(t) \\ r_1(t) &= x(t)-c_1(t) \end{aligned} \tag{2}$$

In our case, $c_1(t)$ shows the highest frequency component in voltage signal. The residual signal, $r_1(t)$, still has oscillatory components. Consequently, a new elimination process is started and iterated until $r_n(t)$ becomes a non-oscillating function. Finally the remaining $m(t)$ signal is called as residue signal $(r_n(t)=r_{n-1}(t)-c_n(t))$. At the end of the EMD process the signal $x(t)$ can be exactly reconstructed using a linear combination as in Eq. 3:

$$x(t)=r_n(t)+\sum_{j=1}^{n} c_j(t) \tag{3}$$

III. HILBERT TRANSFORM

The Hilbert transform of continuous signal $x(t)$ can be expressed as follows[15]:

$$y_j(t) = \frac{1}{\pi} P \left\{ \int_{-\infty}^{\infty} \frac{c_j(\tau)}{t-\tau} d\tau \right\} \tag{4}$$

where P is the Cauchy principal value. From above definition a complex data series $z_j(t)$ is constructed. Then a new data set $y_j(t)$ for each IMF component $c_j(t)$ is obtained from Eq. 5:

$$z_j(t) = c_j(t) + i \cdot y_j(t) = a_j(t) e^{i\theta_j(t)} \tag{5}$$

Using the above equation amplitude, phase and instantenous frequency can be calculated as Eq. 6. The resultant $a_j(t)$ and $\omega_j(t)$ values are varying as a function of time.

$$\begin{aligned} a_j(t) &= \sqrt{c_j^2(t) + y_j^2(t)} \\ \theta_j(t) &= \tan^{-1}\left\{ \frac{y_j(t)}{c_j(t)} \right\} \\ \omega_j(t) &= \frac{d\theta_j(t)}{dt} \end{aligned} \tag{6}$$

IV. MATHEMATICAL MODEL OF POWER DISTURBANCES

The harmonic signal is:

$$u(t) = A_0 \cos(2\pi f_0 t) + \sum_{i=3,5}^{n} A_i \cos(2\pi(m_i f_0)t) \tag{7}$$

Where A_0 is the amplitude of main signal, f_0 is main frequency, $m_i f_0$ is i. the harmonic frequency, A_i is the amplitude of i. harmonic signal.

Voltage swell is denoted by a sudden raise of voltage amplitude from its nominal value for several cycles. Voltage sag is denoted by a sudden drop of voltage amplitude from its nominal value for several cycles The voltage swell and sag signals are given:

$$u(t) = \left\{ \begin{array}{r} A_0 \cos(2\pi f_0 t)(t_0 \le t \le t_1) \\ (t_2 \le t \le t_3) \\ \\ A_1 \cos(2\pi f_0 t)(t_1 \le t \le t_2) \end{array} \right\} \tag{8}$$

where f_0 is main frequency , A_0, A_1 amplitude. A_1 is selected as 1.05 p.u. if t is between $(t_1 \le t \le t_2)$, other times amplitude A_0 is selected 1 p.u. for voltage swell signal. A_1 is selected as 0.9 p.u. if t is between $(t_1 \le t \le t_2)$, other times amplitude A_0 is selected 1 p.u. for voltage sag signal.

V. SIMULATIONS

Simulations are performed in MATLAB. Voltage harmonics, voltage swell and voltage sag signal are tested for the method mentioned above. For all the identified samples the amplitude of voltage signal is normalized to unity. Voltage waveform sampling frequency is taken as 10kHz. In order to detect voltage harmonics , voltage swell and voltage sag, Hilbert transform is used after the envelope signal is obtained.

A. Analysis of Voltage Harmonics

The voltage expression contains 3. and 5. harmonic component is shown.

$$u(t) = 5\cos(2\pi 50t) + 1.5\cos(2\pi 150t)\left\{0 \le t \le 0.2\right\}$$

$$5\cos(2\pi 50t) + 1\cos(2\pi 250t)\left\{0.2 \le t \le 0.5\right\}$$

The simulated voltage harmonic signal consists of a 50 Hz component with amplitude 5 p.u. and 150 Hz component with magnitude 1.5 p.u. from 0 - 0.2 sec and a 50Hz component with amplitude 5 p.u. plus a 250 Hz component with magnitude 1 p.u. from 0.2 - 0.5 sec. is shown Fig. 1. $u(t)$ was decomposed into its components (IMFs) using the EMD process. Fig. 2 shows the results IMF when the EMD is applied to the $u(t)$.

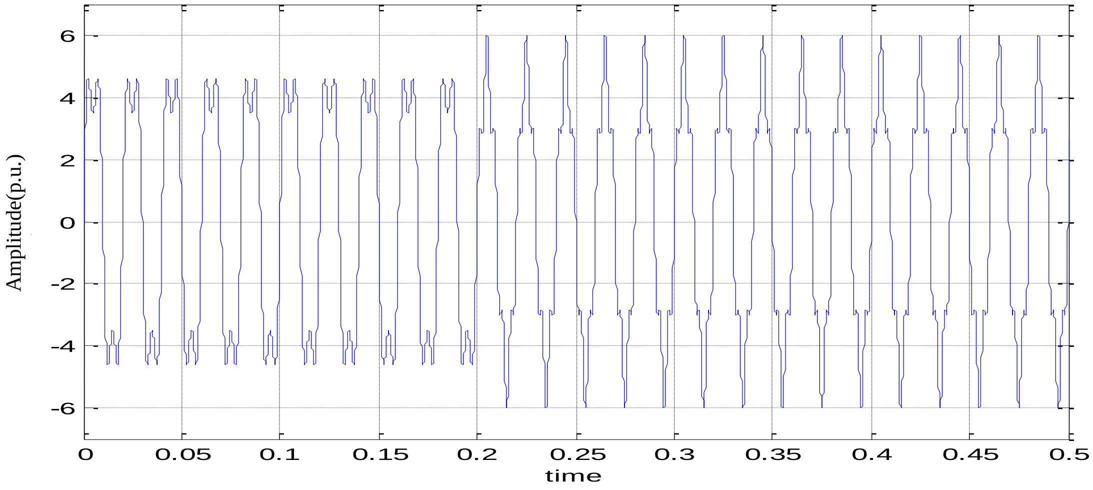


Figure 1. Voltage harmonics signal

According to Fig.2, IMF1 includes two harmonic components, and IMF2 is main component. The harmonics and main component are separated from the signal according to the results of decomposition. Then, using Hilbert transform to all of IMF component, the amplitudes and frequencies of IMF1 component include respectively 1.5pu, 1pu and 150Hz, 250Hz, and the boundaries of these frequencies and amplitudes are clearly shown in figure 3 and 4.

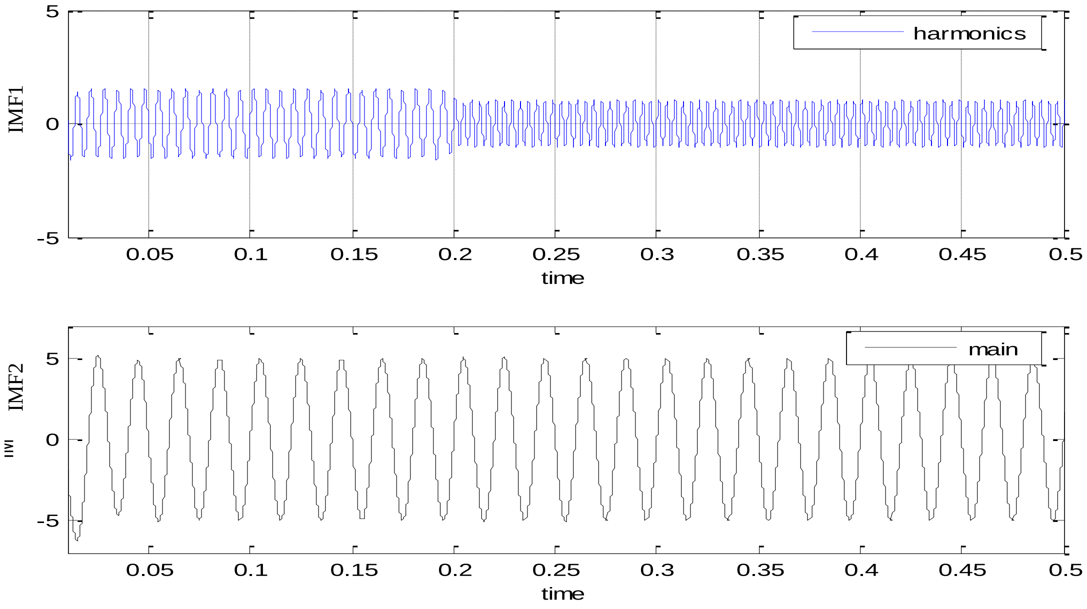


Figure 2. IMF components obtained result of EMD

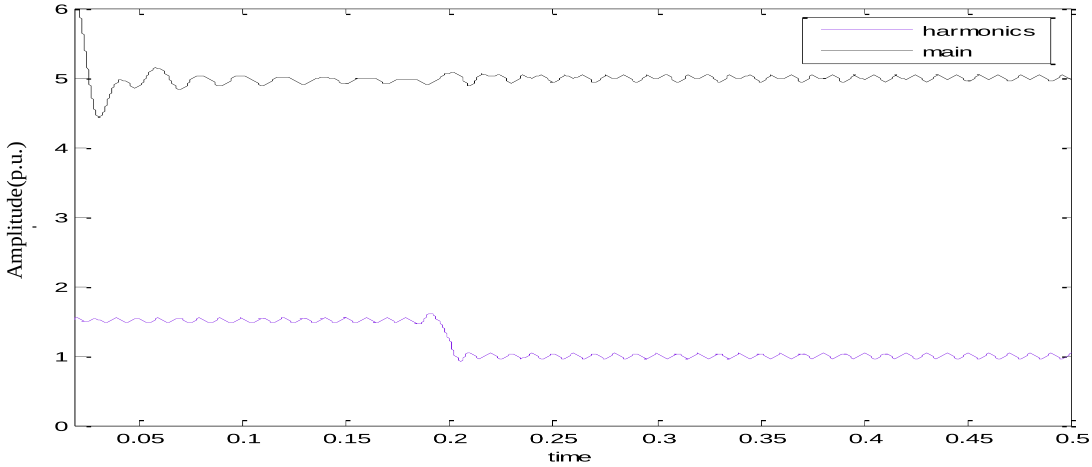


Figure 3. Amplitudes obtained from result of HT

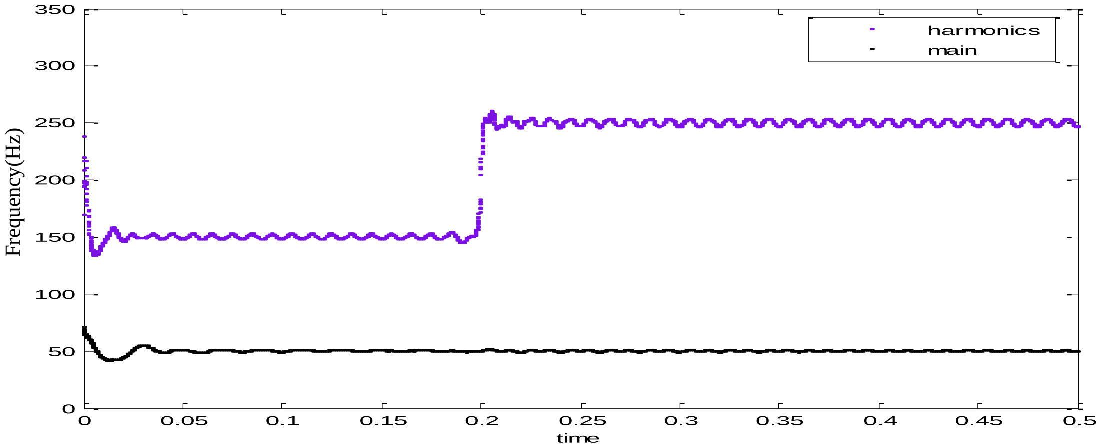


Figure 4. Frequencies obtained from result of HT

B. Analysis of Voltage Swell

The overall expression of voltage swell waveforms is given.

$$u(t) = 1.0\cos(2\pi 50t)\begin{Bmatrix} 0 \le t \le 5 \\ 5.5 \le t \le 10 \end{Bmatrix}$$

$$1.05\cos(2\pi 50t)\{5 \le t \le 5.5\}$$

where the parameters are chosen as follows: amplitude is 1 p.u. if t is between $0 \le t \le 5$ and $5.5 \le t \le 10$, other amplitude is 1.05 p.u., frequency 50 Hz. Again, Hilbert transform is applied to IMF1 component and voltage swell amplitude and frequency are obtained. The voltage swell results are shown in Figure 5(a) and 5(b), respectively.

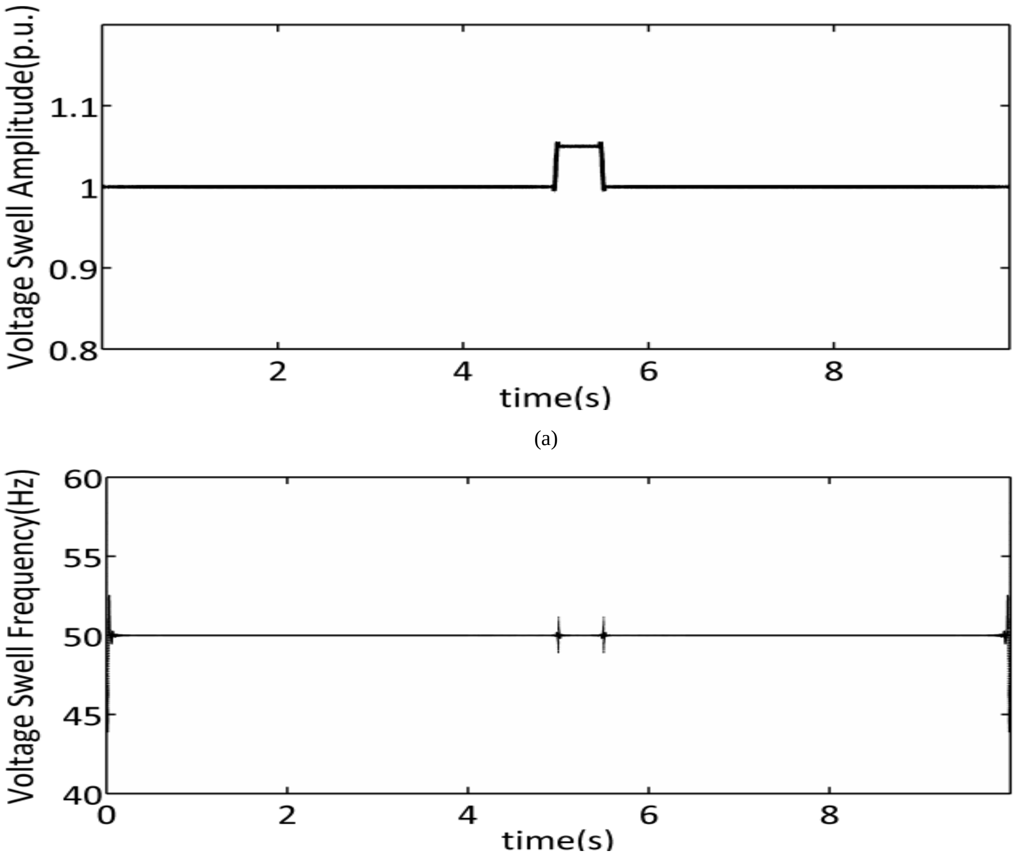
C. Analysis of Voltage Sag

The overall expression of a voltage sag waveform, is given.

$$u(t) = 1.0\cos(2\pi 50t)\begin{Bmatrix} 0 \le t \le 5 \\ 5.5 \le t \le 10 \end{Bmatrix}$$

$$0.9\cos(2\pi 50t)\{5 \le t \le 5.5\}$$

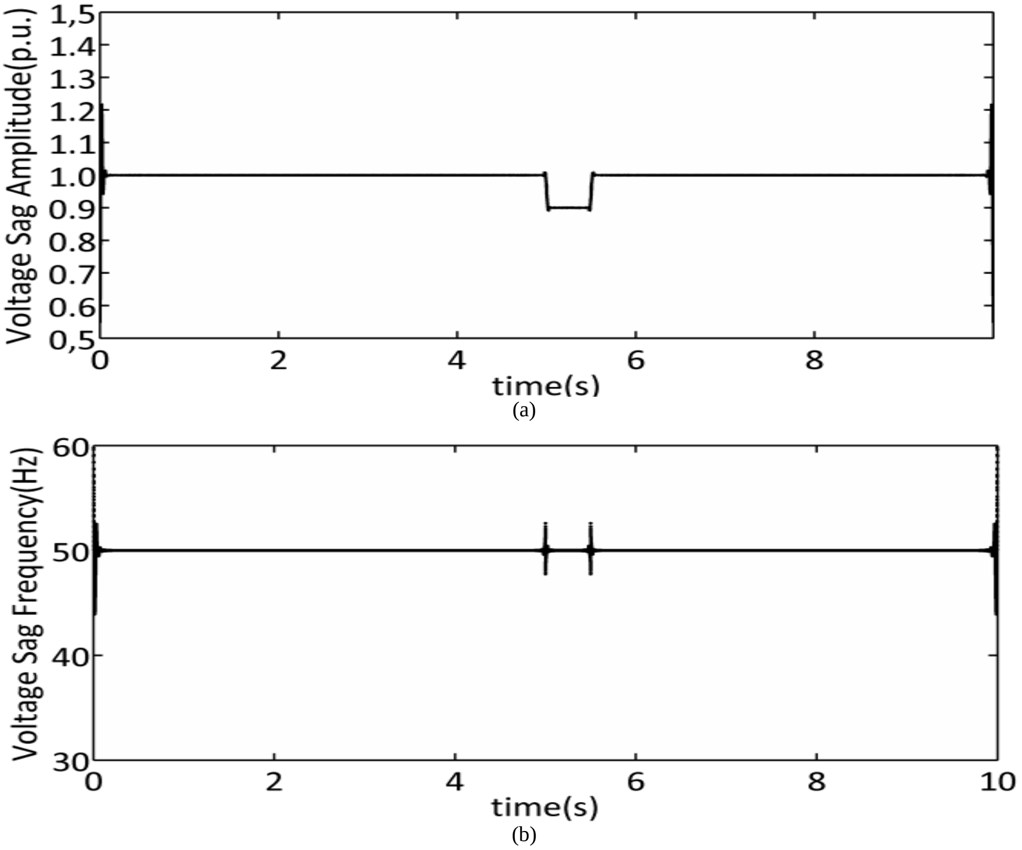
where the parameters are chosen as follows: amplitude is 1 p.u. if t is between $0 \le t \le 5$ and $5.5 \le t \le 10$, other amplitude is 0.9 p.u., frequency is 50 Hz. Again, Hilbert transform is applied to IMF1 component and voltage sag amplitude and frequency are obtained. The voltage swell results are shown in Figure 6(a) and 6(b), respectively.



(a)

(b)

Figure 5. HHT analysis of voltage swell signal



(a)

(b)

Figure 6. HHT analysis of voltage sag signal

VI. CONCLUSION

This paper applied the EMD and HT to detect the power disturbances signal. EMD is a novel technique that is capable of splitting signal components with different spectral characteristics. Despite this capability, it was not applied to the analysis of power quality disturbances. Firstly EMD process is applied to the voltage signal and the intrinsic mode function components are obtained. After obtaining the IMFs HT is applied to the first and second IMF components to detect the amplitudes and the frequencies of the voltage harmonics, voltage sag and voltage swell. The waveforms are selected as pure sinusoids. The simulation results show that EMD performs better than the time resolution and frequency resolution based methods that can be listed :

(1)The method is able to determine frequency and amplitude parameters of the harmonic, extremely accurately within the parametric range of interest.

(2)The method is capable to observe occurrence and the duration of disturbance very easily which gives a great advantage to quantification, unlike the classical methods.

(3) The method is able to detect the starting and ending time of voltage swell and voltage sag.

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