Fault Detection in Power System Using the Hilbert-Huang Transform

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***Abstract*—The Hilbert-Huang Transform (HHT) is used for time-frequency analysis of non-stationary and non-linear signals, e.g., power signals. In this paper, we propose a fault detection method for electric power system using the HHT. The presented numerical example shows the implementation of HHT on unsymmetrical phase voltages to detect the occurrence time of a single line to ground fault at a particular phase in the power system. The HHT is shown to be an effective method for detecting fault due to its ability of estimating the instants at which the frequency of signal changes abruptly.**

Keywords: Hilbert-Huang transform, intrinsic mode function (IMF), power quality signal disturbances, unsymmetrical fault

I. Introduction

The smart grid is an advanced electricity infrastructure that uses technologies such as sensors, communications, monitoring and automation to enhance the efficiency and reliability of the power system [1]. It will help power utility companies to detect and fix the outages more quickly. The traditional electricity meters can be replaced by smart meters which involve real-time sensors to provide power quality monitoring and power outage notification.

The current power grid comprises of subsystems classified as generation, transmission and distribution. The supervisory control and data acquisition (SCADA) system used in existing power grid provides limited control over electricity generation functions and the distribution network [2]. It cannot facilitate real-time monitoring and control of power systems. Distribution automation is limited due to the lack of communication between the grid and its control centres. Since most of the power outages and signal disturbances are originated in distribution network, the automation of distribution systems becomes important to develop smart grid.

Signal analysis is indispensable to detect and classify power signal disturbances and faults, which is a fundamental feature of advanced distribution automation. The technique of Fourier Transform is prominent for signal analysis due to its effectiveness and simplicity. However, there are few considerable limitations of Fourier transform. The signal to be analyzed must be linear and stationary, otherwise the resulting Fourier spectrum will not have much physical sense. In the power grid, most of the signals are non-stationary and non-linear. The frequency components of signal to be analyzed often change with time. Therefore, the Fourier transform cannot be applied to analyze such signals.

Wavelet transform is another potential signal processing tool which is orthogonal, local and adaptive. Though it is capable of analyzing non-stationary and nonlinear signals, it also has limitations. For example, energy leakage, interference terms and border distortion occur while applying wavelet transform [3]. These may generate undesirable spikes over the frequency scale and produce misleading results. Non-stationary signal processing technique also includes short time Fourier transform (STFT). However, its performance is affected by the chosen window size. A larger window size is inappropriate for fast time-varying signals while a smaller window size decreases the frequency resolution.

To avoid the aforementioned limitations of existing signal analysis techniques, Hilbert-Huang transform (HHT) has been proposed for non-stationary and non-linear signal analysis [2], [4]. First, using empirical mode decomposition (EMD), it decomposes the signal into signals with single meaningful instantaneous frequencies called intrinsic mode functions (IMF) as described in section II. It then generates a HHT spectrum which shows the energy-frequency-time distribution of signal. From this distribution,

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we can localize any event on its occurring time and instantaneous frequency. Although HHT is a promising tool, it also has a major drawback. EMD in particular, described in [2], is unable to separate frequency components lying within an octave [5]. Moreover, there can be a significant frequency overlap between adjacent IMFs called mode mixing [6]. The low-energy components may get masked by the higher ones during EMD processing. Considering its application in the fault detection, it will give accurate results as there is a significant deviation in frequency of power signal during the fault. In what follows, we describe a detailed description of application of HHT in detecting fault of any type, symmetrical or unsymmetrical.

The rest of the paper is organized as follows. While in Section II, we introduce Hilbert-Huang Transform and Instantaneous frequency calculation method, in Section III we provide simulation set up. In Section IV, we provide application of HHT for fault detection. Finally Section V concludes the paper.

II. Hilbert-Huang Transform

The Hilbert-Huang Transform uses EMD, an adaptive algorithm to decompose the nonstationary signal into Intrinsic Mode Functions and then applies Hilbert Transform to IMFs to obtain instantaneous frequency data [2].

A. Empirical Mode Decomposition

A signal $x(t)$ can be decomposed as a linear combination of IMFs using the EMD algorithm as follows:

1) Generate the upper and lower envelope of signal connecting local maxima and local minima respectively using spline interpolation.
2) Find the mean m_1(t) of the two envelopes at each instant and subtract it from the original signal.
$$a_1(t) = x(t) - m_1(t)$$
3) Apply steps 1) and 2) on a_1(t) to get
$$a_2(t) = a_1(t) - m_2(t)$$
and keep on repeating to find
$$a_k(t) = a_{k-1}(t) - m_k(t)$$
for $k = 3, 4, \cdots$ until the following standard deviation is smaller than 0.3 and label a_k(t) as first IMF, say b_1(t).
$$SD = \sum_{t=0}^{T} \frac{|a_{k-1}(t) - a_k(t)|^2}{a_{k-1}^2(t)}$$
4) Subtract b_1(t) from $x(t)$ to get r_1(t)
$$r_1(t) = x(t) - b_1(t)$$
and apply all above steps on r_1(t) to obtain second IMF b_2(t) and r_2(t).
5) Keep on finding subsequent IMFs until r_i(t) where $i > 1$ becomes monotonic. Thus, $x(t)$ can be written as
$$x(t) = \sum_{j=0}^{i} b_j(t) + r_i(t)$$

B. Calculation of Instantaneous Frequency

Hilbert Transform is performed on each IMF component to obtain instantaneous frequency data. Hilbert Transform $y(t)$ of any signal $x(t)$ is computed as:

$$y(t) = \frac{P}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{t - \tau} d(\tau) \qquad (1)$$

where P is Cauchy principal value. The analytic signal of $x(t)$ called $z(t)$ is then defined as follows

$$z(t) = x(t) + iy(t) = a(t)e^{i\phi t}. \qquad (2)$$

The phase of $z(t)$ can be expressed as follows

$$\phi(t) = \arctan \frac{y(t)}{x(t)}. \qquad (3)$$

Now the instantaneous frequency ω(t) of each IMF component is given as

$$\omega(t) = \frac{d\phi}{dt}. \qquad (4)$$

Thus, for signal with multiple instantaneous frequencies at a given time, HHT decomposes it into a superposition of monocomponent IMFs via EMD and then creates its time-frequency distribution by evaluating the $\omega(t)$ of each IMF.

III. Simulation of unsymmetrical fault in Matlab Simulink

A. Development of Model

To simulate electrical power systems in MATLAB Simulink, the library called SimPowerSystems provides the models of all power system components such as three-phase source, multi-winding transformer, three-phase RLC load [7]. The model shown in Fig. 1 is designed for the simulation of various types of faults in the transmission lines. The powergui block in Fig. 1 is set as discrete to discretize the electrical system for a solution at fixed time step of

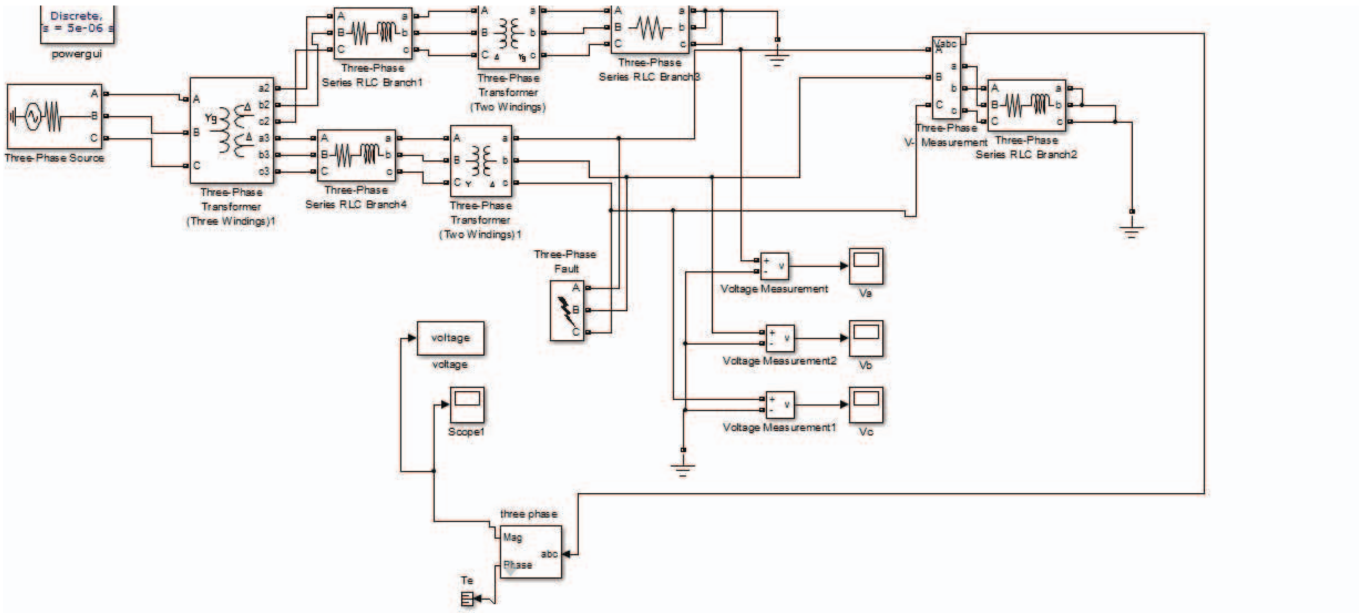

Fig. 1: Simulink model to generate fault in power system.

5 microseconds. The three-phase fault block implements a three-phase circuit breaker where the opening and closing times are externally specified to be 0.05 second and 0.1 second respectively with simulation stop time kept at 0.18 second. To program a single line to ground fault at phase A, the parameter “Phase A Fault” is selected with ground resistance equal to 0.001 ohms. The parameters of three-phase fault block can be easily changed to generate symmetrical fault, double line to ground fault or line-to-line fault.

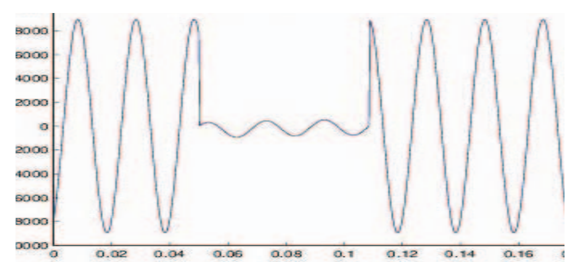

Fig. 2: Waveform of Phase A voltage from simulation.

B. Simulation Output

The phase voltages V_a, V_b and V_c of phase A, B and C respectively have been recorded using scope blocks in model as shown in Fig. 1. The waveform of phase A voltage in Fig. 2 shows a drop in voltage between the simulated fault time as contrary to the waveforms of phase B and C in Figures 3 and 4 respectively. This happened since we have model a single line to ground fault at phase A. When a line to ground fault occurs, there is voltage sag until operated by a protective electrical switchgear.

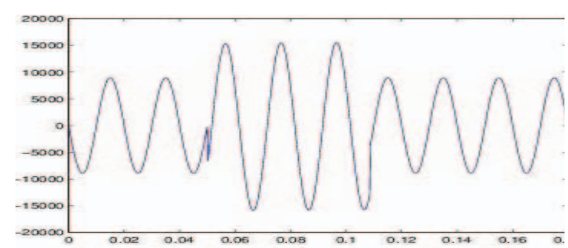

Fig. 3: Waveform of Phase B voltage from simulation.

IV. Application of Hilbert-Huang Transform in Detecting Fault

A fault in an electric power system is any failure which interferes with the normal flow of current. The faults are associated with abnormal change in current, voltage and frequency of the power system. HHT, when implemented on a signal, keeps track of its frequency components at each instant of time. It is applied individually on phase A, B and C voltages obtained from simulation and the respective time-frequency spectrums are shown in figures 5, 6 and 7. These clearly indicated the opening and closing time

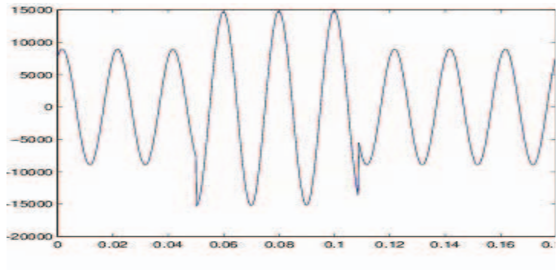

Fig. 4: Waveform of Phase C voltage from simulation.

of the three-phase fault breaker by showing spikes in the frequency. The most computation consuming step of HHT, referred to as EMD operation, generates some undesired frequency components in the low frequency region [3] and therefore, figures 5, 6 and 7 present undesired lines at the bottom of spectrum.

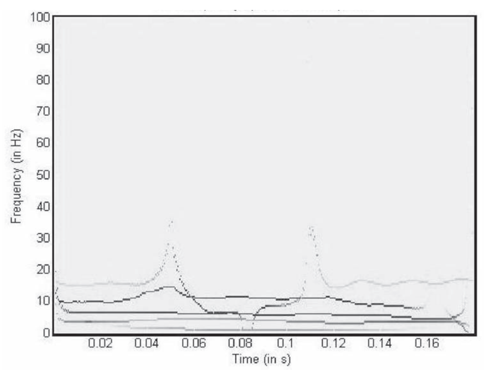

Fig. 5: Hilbert-Huang spectrum of phase A voltage.

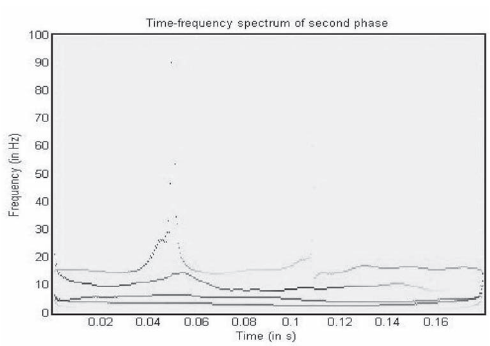

Fig. 6: Hilbert-Huang spectrum of phase B voltage.

V. Conclusion

In this paper, HHT has been presented for fault detection applications in power systems. The motivation for applying HHT was that the signals in power grid are non-stationary which means their frequency content varies with time. The proposed HHT method successfully detects the occurrence time of fault by showing significant deviation in time-frequency spectrum at the time when the fault occurs or the power system is restored after fault.

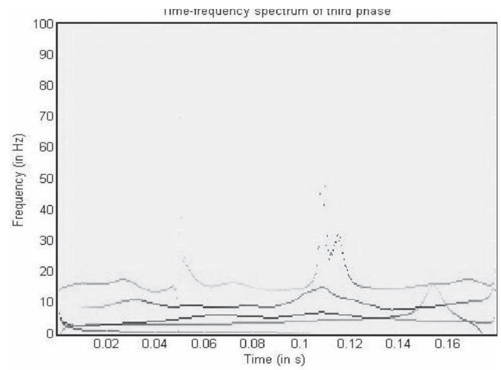

Fig. 7: Hilbert-Huang spectrum of phase C voltage.

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