Feature Extraction of Low Frequency Oscillation in Power System Using Hilbert-Huang Transform

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Abstract **– Power system oscillation is one of the phenomena that can cause problem in power system that can even lead to outage. Using data of phasor sifting in power system available through Phasor Measurement Unit (PMU) implementation, power system oscillations could be observed directly. However, to predict the condition of power system, the recorded phasor data need to be processed to obtain the quantitative measures. In this paper, important parameters are extracted by applying Hilbert Huang Transform (HHT) to phasor signal taken from PMU. The stable and oscillation condition are determined by the parameters that show the increasing power of each frequency over period of time. Validation is conducted by using simulation data that represents characteristic of PMU data.**

Keywords **– Hilbert-Huang Transform, Phasor Measurement Unit, Power System Oscillation, Instantaneous Power, Stable Signal.**

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1. Introduction

Phasor as one of power system parameters now could be monitored by using phasor measurement unit (PMU) which has been developed by [1]. The observed phasor could be used by wide area monitoring system to estimate the power system condition [2], [3]. The obtained phasor data still possess errors due to measurement instrument accuracy and deficiency in PMU specifications [4], [5]. Nevertheless, the discrepancy between two voltage phases angle from two PMU which is placed in different substation could be used for analysis which has been shown by [4].

With the growth of load demand, capacity and length growth of transmission line, operation of power system is facing a new problem such as low frequency oscillations. These oscillations could be undamped and arise to potentially create unstable system operation that could lead to a black out of power system network. Therefore, this undamped oscillation in power system should be detected and utilized to estimate the final result of this phenomena. The range frequency of this oscillations is 0.1 to 2 Hz [6] which could be monitored using recorded data of voltage phase angle taken from PMU in two different substations. This recorded data should be processed to determine the existence of low frequency oscillation.

The method that usually has been used to study power system oscillation is modal analysis [7] which requires power system network model in detailed form. The model is linearized around specific operating point [8]. To obtain the detailed model of power system is not easy and modal analysis is slow. Furthermore, many parameters such as power system structure, power system operating point and others that determine the existence of the oscillation is changed over the time which makes modal analysis could not be used to monitor the oscillation in real time. Many research has been conducted to evaluate oscillation in power system using various method. [9,10] use some algorithm to monitor voltage stability in the system. [11,12,13] use digital signal processing to help identification of oscillation and [14] use artificial intelligent to do the same task. However, [15] shows that Hilbert-Huang Transform (HHT) method could assess the oscillation accurately in non-stationary signal.

This paper presents the parameter extraction by applying HHT that could be used to recognize the low frequency oscillation in power system. The parameter is extracted using the proposed algorithm. The study used simulation data that represent PMU data characteristic to be processed by HHT. For comparison, both stable and unstable condition in the power system will be simulated. This paper is arranged as follow: section 2 provides HHT algorithm with EMD, the PMU data that is used for simulation and the proposed method is also given, while section 3 provides the result and discussion. In the last section, conclusion of this research is presented.

2. Research Method

2.1. Hilbert-Huang Transform

Hilbert–Huang transform (HHT) is the empirical mode decomposition method (EMD) which express the complicated signal data as a set of finite intrinsic mode functions (IMF) that used Hilbert transforms for further processing. Important feature of the original signal contained in the resulted IMF is identified by EMD. Each of the IMFs, which are the summation of all forms of the low-frequency signal *s(t),* must meet the criteria [16]:

- The total number of zero-crossings and the total number of extremes must either differ at most by one or equal the dataset.
- The envelope which is outlined by the local minima is zero at any point and the average value of the envelope is outlined by the local maxima.

All local minima and maxima is identified to be connected by a cubic spline line to form the lower and upper envelopes respectively. All data should be covered by the lower and upper envelopes. The resulted EMD should be the sum of several $c_i(t)$ which is the component of IMF and a residue component *r* as in (1).

$$s(t) = \sum_{i=1}^{n} c_i(t) + r \quad (1)$$

(2) describes the transform for any continuous time signal of *X(t)* by applying the Hilbert transform to each IMF component.

$$Y(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{X(t)}{t - T} dt \quad (2)$$

Multiple conjugate pairs of *X(t)* and *Y(t)* is used in (3) to analyze the signal by comparison.

$$Z(t) = X(t) + jY(t) = a(t)e^{j\theta(t)} \quad (3)$$

Where the instantaneous amplitude is represented by *a(t)* in (4), the phase is *θ(t)* is in (5) and the function of instantaneous frequency is in (6).

$$a(t) = \sqrt{X^2(t) + Y^2(t)} \quad (4)$$

$$\theta(t) = arctan \frac{Y(t)}{X(t)} \quad (5)$$

$$f(t) = \frac{1}{2\pi} \frac{d\theta(t)}{dt} \quad (6)$$

(7) is the result of low-frequency signal analysis function for each IMF by employing Hilbert transform which shows instantaneous frequency along with instantaneous amplitude of each IMF.

$$Z_i(t) = c_i(t) + j\tilde{c_i}(t) = a_i(t)e^{j\theta_i(t)} \quad (7)$$

2.2. Simulated PMU Data

The obtained PMU data will be processed using HHT in real time condition. For analysis, simulated data of power system which has been treated to resemble PMU data is used for processing. Each PMU data has interval of 40 milliseconds. The simulated data represents a low frequency oscillation signal in power system network which is displayed in Figure 1.

Another simulated data is also created to represent the stable signal data for comparison which is shown in Figure 2. and Figure 3. All signal is simulated from one event of power system disturbance.

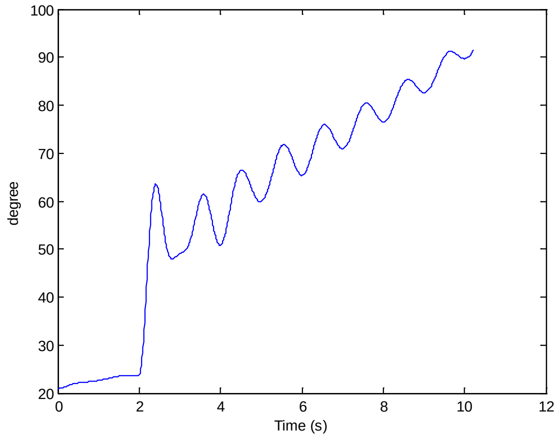


Figure 1. Low frequency oscillation signal

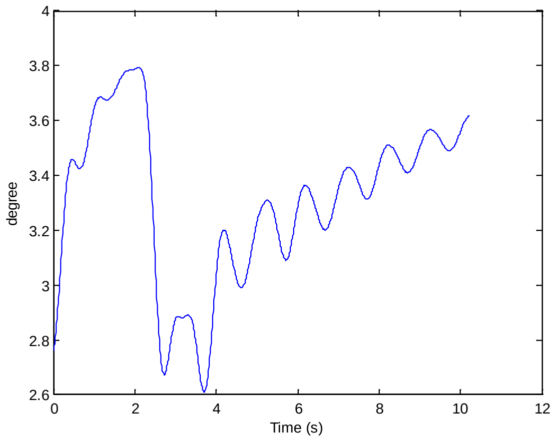


Figure 2. 1st stable signal

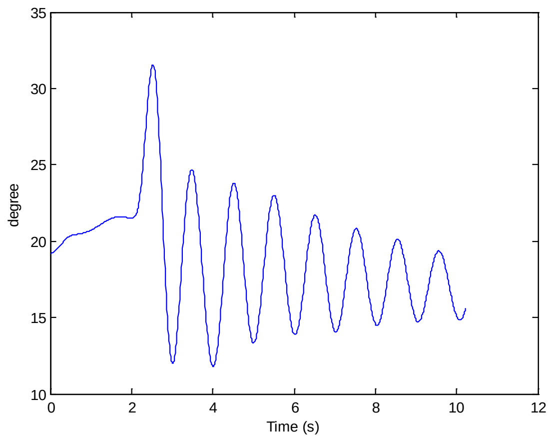


Figure 3. 2nd stable signal

Both of low frequency signal and stable signal are divided into 3 segments where the interval of each segment is 2.56 seconds. HHT is applied to each segment and Figure 4., Figure 5. and Figure 6. represent the resulting IMF of low frequency oscillation signal from all segments.

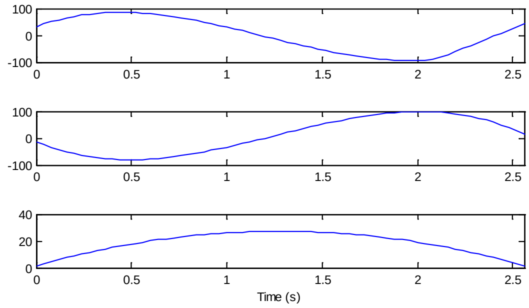


Figure 4. IMF of the first segment of low frequency oscillation signal

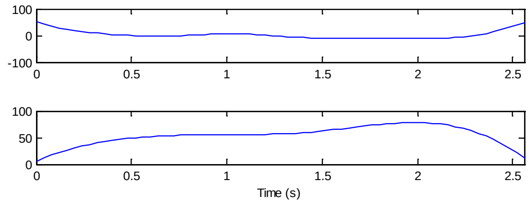


Figure 5. IMF of the second segment of low frequency oscillation signal

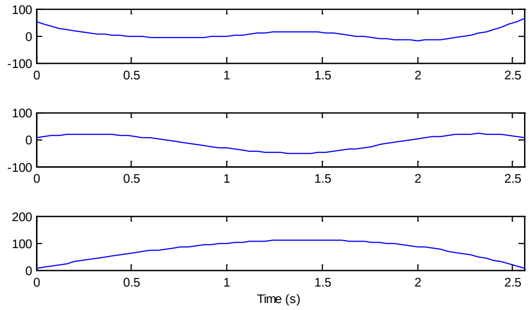


Figure 6. IMF of the third segment of low frequency oscillation signal

2.3. Proposed Method

Using typical discrete time signal variable x_n with a finite window of $1 \leq n \leq N$ and the length of the signal sampled is $x_n = x(n\Delta t)$ for a total measurement period $T = N\Delta t$, a single estimated power spectral density could be written in (8).

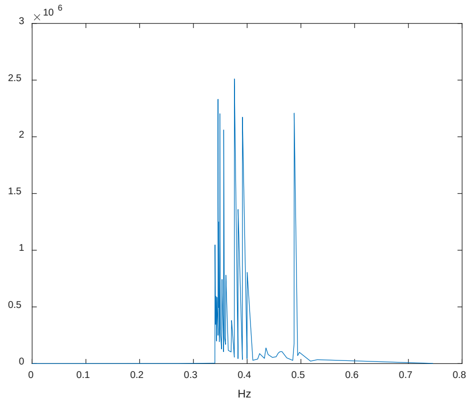
$$\tilde{S}_{xx}(\omega) = \frac{(\Delta t)^2}{T} \left| \sum_{n=1}^{N} x_n e^{-i\omega n \Delta t} \right|^2 \tag{8}$$

With the assumption that using only the power of a single measurement in Δt time, the instantaneous power of each instantaneous frequency of all IMF could be proposed in (9) with n as the number of instantaneous amplitude with the same instantaneous frequency resulted from HHT.

$$\tilde{S}_i(\omega) = \frac{2\pi\Delta t}{\Delta\omega(t)} \sum_{i=0}^{n} \left| a_i(t) e^{-j\theta_i(t)} \right|^2 \quad (9)$$

By comparing the power of each instantaneous frequency in each IMF, the resulting power of each frequency of all IMFs of each segment is shown in Figure 7., Figure 8. and Figure 9. The procedure is repeated for stable signal data in Figure 2. and Figure 3.

a.



b.
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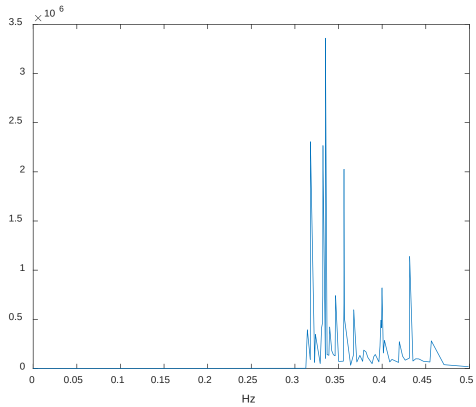


c.

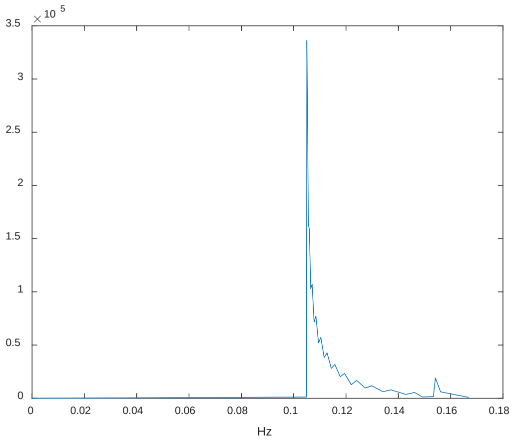
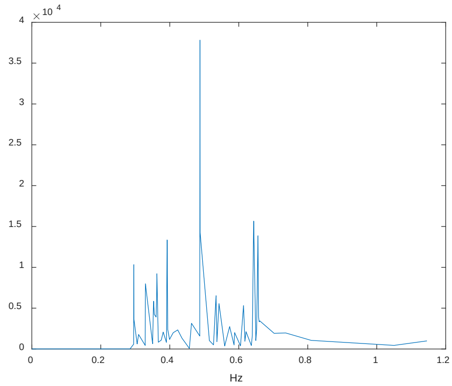


Figure 7. The power of each IMF of the first segment of low frequency oscillation signal in frequency domain

a.



b.

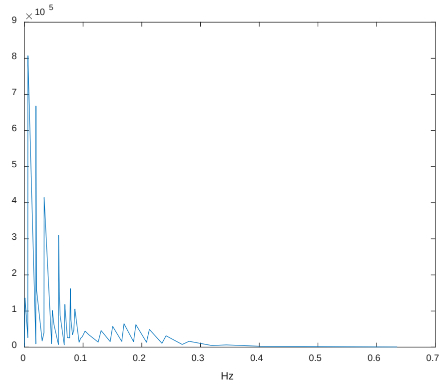
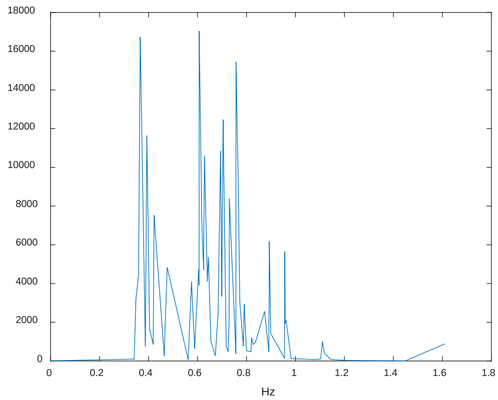
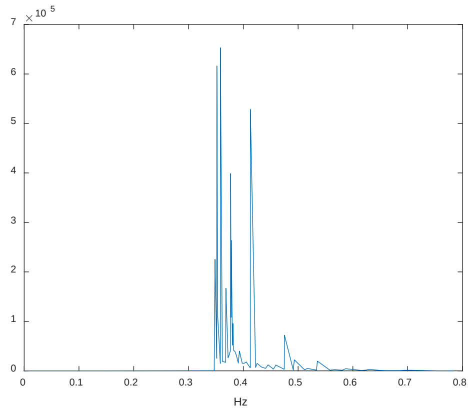


Figure 8. The power of each IMF of the second segment of low frequency oscillation signal in frequency domain

a.



b.



c.

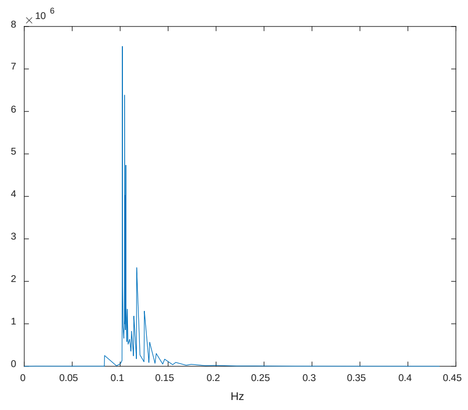


Figure 9. The power of each IMF of the third segment of low frequency oscillation signal in frequency domain

Each of the peaks from signal in Figure 7., Figure 8. and Figure 9. is listed and collected based on the nearest frequency. The frequency which has the increased power of peak signal from segment 1 to segment 2 and segment 2 to segment 3 is selected.

3. Results and Discussion

By comparing the power peak of each IMF of low frequency oscillation signal segments in frequency domain, the frequency which shows the increased power from the first segment to the last segment is in the range of 0.1298 – 0.1308 Hz which is shown in Table 1.

Table 1. The Frequency of Increasing Power in Low Frequency Oscillation Signal

Frequency (Hz)	Power (dB)	Segment
0.129851811	4.06795045	1
0.130689771	4.662565882	2
0.130758432	5.752019656	3

Table 1. shows that there are more than 14% increase of power from segment 1 to segment 2 and more than 23% increase from segment 2 to segment 3. However, there is reduction of power in both frequencies from segment 1 to segment 2.

Although the signal in Figure 2. is defined as stable signal, there is still frequency which shows that the increased power from the first segment to the last segment is in the range of 0.1077 – 0.1085 Hz and 0.1124 – 0.1128 Hz which is shown in Table 2. However, there are only 1.32% increase of power from segment 1 to segment 2 and 12.54% increase of power from segment 2 to segment 3 in the frequency of 0.1077 – 0.1085 Hz. Moreover, there is only 0.82% increase of power from segment 1 to segment 2 and 9.82% increase of power from segment 2 to segment 3 in the frequency of 0.1124 – 0.1128 Hz. Therefore, although the signal is defined as a stable signal, it will become unstable or low frequency oscillation will appear if there is no action taken in power system to compensate the change.

Table 2. The Frequency of Increasing Power in Figure 2. Stable Signal

Frequency (Hz)	Power (dB)	Segment
0.108494251	4.82174	0
0.107686036	4.88525	1
0.10820334	5.49787	2
0.112763632	4.56445	0
0.112565383	4.60186	1
0.112444845	5.05364	2

Stable signal in Figure 3. doesn’t have the frequency which shows the increased power from the first segment to the last segment. Therefore, the proposed method could differentiate between the stable condition and the low oscillation condition. Moreover, the method could be used to determine whether the condition will go toward oscillation or not since if there is a slightly increased power of frequency which means that the signal is not damped. For identifying the undamped frequency using this method in real-time data taken from PMU needs more study. However, comparing the computation time of this research method with results from [14], the time required to compute using this method is less than 8 seconds which is still faster than Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) method in [14].

4. Conclusion

To find out the existence of low frequency oscillation in power system, the parameter that is extracted from phasor signal using HHT could be used. This parameter is the increased power of specific frequency. If the power of this frequency is increased consistently and very high, then this frequency is undamped and the system could be in the oscillation condition. However, if the power of the frequency is increased slightly then the power system will be in oscillation condition if there is no action taken to compensate the changing. If there is no increased power from the phasor signal, then the system could be in stable condition.

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