A Low Frequency Oscillation Disturbance Source Positioning Method Based on Oscillation Phase Difference

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Abstract. In the face of voltage sag which causes power quality problems, combined with the common short circuit fault types in power system, how to locate disturbance source quickly and accurately is an important problem in low frequency oscillation monitoring and control. The mechanism of the disturbance source affecting the unit in the network is analyzed. A low frequency oscillation source location method based on oscillation phase difference is proposed. Firstly, the electrical data of the dominant oscillation mode are extracted by empirical mode decomposition, then the oscillatory phase with physical meaning is calculated by Hilbert transform. According to the network information criterion, the location of the disturbance source can be traced, according to the power plant. The ground information criterion can check the specific disturbance source unit. The principle of the method is clear, only one electrical quantity is needed to participate in the calculation.

1. introduction
With the wide application of new power electronic equipment in power system, power quality has become the focus of attention of all departments. Among them, the production equipment failure caused by voltage sag brings huge economic losses to the production of enterprises. Low frequency oscillation has become an important problem threatening the safe and stable operation of power grid. In the already low frequency oscillation accidents, there are both weak damping and even negative damping free oscillations due to insufficient damping of the system and forced power oscillations due to persistent periodic small disturbances. The essence of the low frequency oscillation is the relative motion between the rotor of the generator, and the oscillation frequency and the oscillation phase difference between the rotors are fixed. Under the influence of the relative oscillation of the rotor, the same frequency oscillation will occur in the line power, bus voltage and frequency. Where the disturbance source is not excised, the oscillation will persist and may diffuse leading to system instability. After the low frequency oscillation occurs, the first problem is to locate the disturbance source quickly and accurately. Disturbance source on-line identification based on measured data of wide area measurement system (wide area measurement system, WAMS) is a hot research topic in low frequency oscillation monitoring and control. The consistency of energy consumption and damping
torque of the generator is proved, and a kind of meter is proposed. The practical method of calculating energy flow reduces the transient energy component and determines the oscillation source according to the energy consumption or generation, based on the WAMS dynamic information of the key lines, different levels of network cutting set are constructed, and the cutting set of oscillation energy outflow is judged as the oscillation source, and the disturbance source is accurately located to the control system of the generator by the method of torque decomposition. The empirical mode spatiotemporal filtering function is used to extract the dominant component of the required electrical quantity, and the disturbance source is automatically identified based on the empirical mode energy trend function. Current phasor measurement units (phasor measurement unit, PMU) in power systems It is very important to study the location method of disturbance source based on local information. Oscillation is a kind of physical phenomenon which exists widely in nature, and its essence is a form of energy propagation. In the physical oscillation, along the propagation direction of the oscillation wave, there is a certain phase difference in the oscillation of each prime element, and the prime element near the wave source is ahead of the prime element away from the wave source in phase. The low frequency oscillation of power system is also a kind of physical oscillation, the disturbance source unit is equivalent to the wave source, it is active oscillation, the non-disturbance source unit is equivalent to the mass element around the wave source, they are affected by the disturbance source and passively vibrate Swing. In this paper, oscillation phase distribution of each point in the power network during low frequency oscillation, and proposes a low frequency oscillation source location method based on oscillation phase difference. Hilbert-Huang transform (HHT) is used to process the oscillation data and calculate the instantaneous oscillation phase of each point accurately. This method can realize the location of disturbance source by only one electrical quantity, which is simpler and more intuitive than the existing method. Through the simulation analysis of Huazhong Power Grid, the effectiveness of this method is verified.

2. Disturbance Positioning Method

In a power network, the power emitted by any generator is a function of the phase angle difference between the electromotive force of the generator and the electromotive force phasor of other generators, namely:

\[ P_i = E_i^2 G_i + E_i \sum_{j} E_j |Y_{ij}| \sin(\delta_{ij} + \beta_{ij}) \]  

(1)

Formula: \( P_i \) is Electromagnetic power \( i \) for generators; \( E_i \), \( E_j \) is \( \text{r} \) the generator \( i \) and the electromotive force; \( Y_{ij} \) is Mutual admittance between \( i \) and \( j \) for generator electromotive force nodes; \( G_i \) is \( i \) self conductance for generators; \( |Y_{ij}| \) is For \( Y_{ij} \) modulus; \( n \) is total number of generators; \( \delta_{ij} \) is The angle between \( E_i \) and \( E_j \) phasor; \( \beta_{ij} = \arctan(G_{ij}/B_{ij}) \)

It can be seen from formula (1) that the active oscillation of the rotor of the disturbed source unit will affect the electromagnetic power of the disturbed unit, resulting in the torque imbalance of the rotor of the disturbed unit and forced oscillation. When the electromotive force angle of the disturbed source unit increases, the electromagnetic power of the disturbed unit will decrease, and its mechanical torque will be greater than the electromagnetic torque, so that the electromotive force angle of the disturbed unit will also begin to increase, and tend to keep the rotor angle difference of the two machines consistent with the initial value. In the process of oscillation, the rotor angle of the disturbed unit is always chasing the rotor angle of the disturbed source unit, and because of its rotor inertia, its oscillating phase lags behind the disturbed source unit. As in formula (1) contains the mutual admittance between nodes, so the electromagnetic power of a certain generator is mainly affected by the electromotive force phase angle of the unit near it. In the process of oscillation, the disturbance source mainly affects the unit at the proximal end, and then further affects the remote unit after the disturbance of the proximal unit. Along the propagation direction of the oscillation energy, the
oscillation phase of the unit rotor lags behind in turn. Under other conditions, the smaller the electrical distance between the units and the greater the synchronization force between the units, the smaller the oscillation phase difference.

3. Location Criteria of Disturbance Source

In conclusion, the following criteria can be used to locate the disturbance source:

1) power plant local information criterion: the phase of the rotor angle (frequency) oscillation of the source unit should be ahead of the phase of the voltage angle (frequency) of the voltage side of the boost variable high voltage;

2) network information criterion: for a transmission line connecting the disturbance source near and outside the network, the oscillation phase of the voltage angle (frequency) of the bus at one end of the near disturbance source will advance away from the oscillation phase of the voltage angle (frequency) of the bus at one end of the disturbance source. Oscillation phase difference is a quantity with direction. According to criterion 1, the disturbance source can be identified only power plant can be obtained to identify the disturbance source, and the specific disturbance source unit can still be accurately located when the network and other power plant information is missing. Suspicous area. During the low frequency oscillation process, the network structure mutation and other factors may cause the oscillation phase to be confused for a short time, and the data collected from the PMU often contain more interference signals. The above factors may affect the calculation results of oscillation phase in a short time, so it is difficult to ensure the accuracy of the results by comparing the oscillation phase at only a few moments. To accurately describe the overall phase relationship of two-point oscillations over a period of time, the oscillation phase difference is defined:

\[ \Delta \theta = \int_{t_1}^{t_2} (\theta_1 - \theta_2) dt \]  

the \( \theta_1 \) and \( \theta_2 \) in formula (2) are the rotor angle (frequency) and the voltage angle (frequency) oscillation phase on the boost variable high voltage side, respectively; for the network information criterion, the \( \theta_1 \) and \( \theta_2 \) in formula (2) are the voltage angle (frequency) oscillation phase of the bus on both sides; the \( t_1 \) and the \( t_2 \) are the starting and ending time of the calculation, respectively.

4. Calculation of Oscillation Phase Difference

4.1. Hilbert - Huang Transform

the power system is a nonlinear dynamic system. The oscillation data may contain multiple oscillation modes. The phase of this composite signal is of no physical significance. And in the process of oscillation, the steady-state frequency of the whole network often deviates from the rated frequency, and the oscillation curve of the voltage angle and frequency will be relative to the horizontal axis, so it is difficult to calculate the phase directly. Therefore, it is necessary to identify and decompose the oscillation data, extract the main oscillation mode and then calculate the phase. HHT consists of two parts, the first part is empirical mode decomposition (empirical mode decomposition, EMD) And the second part is the Hilbert Transform (Hilbert transform, HT). EMD is an adaptive signal time-frequency processing method, which can decompose complex signals into finite intrinsic mode function (intrinsic mode function, IMF) components and residual components, namely:

\[ x(t) = \sum_{i=1}^{n} IMF(i) + r(t) \]

the formula: \( x(t) \) is the original signal; \( r(t) \) is the residual component; and IMF (i) is the i intrinsic mode function.
Each IMF component must satisfy the following 2 conditions: (1) the number of extremum points and the number of zeros must be equal or at most difference 1 throughout the data segment; (2) at any time point, the mean of the envelope formed by the local maxima point and the envelope formed by the local minima point is 0, and the instantaneous phase of each IMF component has a clear physical meaning, taking its dominant component for Hilbert transformation. The real continuous signal $u(t)$ is transformed by Hilbert to obtain a conjugate signal $v(t)$, which is orthogonal to it.

$$v(t) = \frac{1}{\pi} \int_{-\infty}^{+\infty} \frac{u(t)}{t - \tau} d\tau \quad (4)$$

The original signal and the transformed signal can form a complex signal:

$$q(t) = u(t) + iv(t) \quad (5)$$

then $\theta(t) = \arctan \frac{v(t)}{u(t)}$ for the instantaneous phase of the original signal $u(t)$.

4.2. Calculation start time

At the start-up stage, the power grid has just been disturbed, the oscillation is not yet stable, and the phase may be more chaotic. Therefore, the calculation start time of Hilbert-Huang transform should be taken the disturbance occurs 1~2 cycles. Since the signal oscillates periodically, the oscillation phase obtained by Hilbert transform changes in the $-\pi$~$\pi$ cycle, and after the phase reaches the $\pi$, it is instantly reset to $-\pi$. In a short period of time after phase reset, the original leading signal will be smaller than the backward signal in the phase value. Therefore, improper selection of the calculation start time of the oscillation phase difference may result in the opposite calculation results. This method carries on the phase to the electrical distance close node bit difference calculation, so the position difference of the phase curve will not be too big. Take the reset point of one of the signals as the observation point, if another signal is reset near its left side, then take that observation point as the calculation starting point; if another signal is reset near its right side, take the reset point of another signal as the calculation starting point. To be able to calculate the total phase difference of multiple oscillation periods, the instantaneous phase takes a non-cyclic value, that is, after the $n$ return to $-\pi$, the data in the subsequent period are added two $n\pi$.

5. Simulation examples

The power quality simulation platform is built by using the power system dynamic real-time simulation software (DDRTS). The constructed simulation system structure is shown in figure 1. L1~L9 representing the line, S1L1~L9S5 representing the load. In order to monitor the whole line, the power quality monitoring points are placed at the first end of each line respectively, and the number is the same as the line.

![Figure 1 Topology for simulation systems](image-url)
The coverage matrix can be obtained according to Figure 1:

\[
A = \begin{bmatrix}
+1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
+1 & +1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
+1 & -1 & +1 & -1 & -1 & -1 & -1 & -1 & -1 \\
+1 & +1 & -1 & +1 & -1 & -1 & -1 & -1 & -1 \\
+1 & +1 & -1 & -1 & +1 & -1 & -1 & -1 & -1 \\
+1 & -1 & +1 & -1 & -1 & +1 & -1 & -1 & -1 \\
+1 & -1 & -1 & +1 & -1 & -1 & +1 & -1 & -1 \\
+1 & -1 & -1 & -1 & -1 & -1 & -1 & +1 & -1 \\
+1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & +1 \\
\end{bmatrix}
\]

If the disturbance occurs at the S9 of the load, and due to the existence of uncertain factors such as random interference, the disturbance direction judgment of the monitoring point 3 is wrong, then the disturbance direction matrix is:

\[
B_1 = (+1,-1,-1,-1,-1,-1,-1,-1,1)^T
\]

The vector of disturbance direction measure determined by the author's improved method is:

\[
B_2 = (0.109,-0.302,-1.144,-0.301,-0.299,-0.300,-0.325,2.455)^T
\]

using the perturbation measure localization method proposed by the author and only using the perturbation direction localization method, respectively, the perturbation localization calculation is carried out. The results are listed in Table 1. where, method 1 is to determine the location of the disturbance source only according to the perturbation direction; square 2 is to determine the location of the disturbance source according to the perturbation direction measure column vector.

It can be seen from Table 1 that there are multiple solutions when the location of the disturbance source is determined by method 1, that is, both line 1 and line 9 may be the branch where the disturbance source is located. At this time, the original power energy method can no longer make an accurate judgment. The improved method can accurately determine that the disturbance source is located in line 9.

| Line | Method 1 | Method 2 |
|------|----------|----------|
| L1   | 7        | 0.6254   |
| L2   | 5        | 0.0216   |
| L3   | 5        | -1.6618  |
| L4   | 3        | -0.5806  |
| L5   | 3        | -0.5806  |
| L6   | 1        | -0.5784  |
| L7   | 1        | -1.1784  |
| L8   | 3        | -2.3108  |
| L9   | 7        | 3.2474   |

6. Conclusion
In this paper, a low frequency oscillation source location method based on oscillation phase difference is proposed. Based on the simplified model of two-machine oscillation, the phase distribution of voltage angle and frequency oscillation phase of each point is proved. With the help of Hilbert-Huang transform, the instantaneous phase of the dominant oscillation mode can be calculated accurately. In order to avoid the sudden disturbance and the short-time disturbance of the data quality to the
oscillation phase, the oscillation phase relationship of the whole electric quantity is quantified by calculating the oscillation phase difference. The simulation results of Huazhong Power Grid show that this method is accurate and has engineering application value.

References

[1] Yang Jianfeng, Jiang Shuang, Shigeo. Recognition of Complex Power Quality Disturbance Based on Segmented Improved S Transform [J]. Power System Protection and Control , 2019, 47(09): 64-71

[2] Liu Tao, Wang Huihui, GE Lei Jiao, Wang Songsheng. Research on Compensation Strategy of Power Quality Integrated Regulator Based on FCS-MPC [J]. Power Grid Technology, 2019, 43(09): 3377-3384.

[3] Zhou Jin, Gao Yunpeng, Wu Cong, Gu Ting Yun, Xu Changbao, Lu Qiansu. Detection of disturbance based on improved wavelet threshold function and CEEMD power quality [J]. Journal of Electronic Measurement and Instruments, 2019, 33(01): 141-148.

[4] Xiao Sili, Hu Jie, Li Jianning. Detection and Analysis of Power Quality Based on Wavelet Transform [J]. Electricity and Energy, 2018, 39(02): 181-185.

[5] Xiao Sili, Hu Jie, Li Jianning. Detection and Analysis of Power Quality Based on Wavelet Transform [J]. Electricity and Energy, 2018, 39(02): 181-185.

[6] Wu Zhiyu, Zhu Yunfang, Hou Yishuang, Chen Weirong. Wavelet compression sensing method for power quality disturbance recognition [J]. Power Systems and Their Autochemistry, 2019, 31(05): 1-7.

[7] Wang Yan, Li Qunzhan, Zhou Fulin. A New Method [J.] for Detection of Transient Power Quality Disturbance Chinese Journal of Electrical Engineering, 2017, 37(24): 7121-7132 7426.

[8] Wang Yan, Li Qunzhan, Gao Jie. Adaptive Denoise Method for Power Quality Disturbance Signal J. Power System Automation, 2016, 40(23): 109-117.