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A new wide area information based power system out-of-step oscillation detecting and oscillation center tracking scheme

Yanxia Zhang, Shuai Zhang *, Gaopeng Meng

Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, China

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ABSTRACT

A new out-of-step oscillation detecting and oscillation center tracking scheme based on the wide area information obtained from phasor measurement units (PMU) is proposed in this paper. In this scheme, the out-of-step oscillation is detected by the change rate of phase angle difference between bus voltage and system current, and the oscillation center tracking is completed by analyzing the phase angle relation between terminal bus voltages of electrical components and the system current. The scheme is easy to implement, and the tracking result is not affected by the changes of system structure and operation modes. Even in the complicated situations that the impedances of the whole system are nonuniform and the equivalent system potential amplitudes are not equal, it can still work well. The simulation results on PSCAD prove it is efficient. Utilizing the tracking results, a new out-of-step splitting criterion is given with which the splitting section can be determined dynamically according to the real-time operation state of power system.

1. Introduction

When a power grid suffers a big disturbance, the rotor angular velocities of generators change due to the imbalance between input power and output power. If the power grid can not obtain a new steady running state, the out-of-step oscillation occurs. The consequence of out-of-step oscillation is disastrous for power systems [1,2]. As the last defense line to guarantee the safe and stable operation of power grid, the out-of-step splitting protection is significant [3], while the out-of-step oscillation detection and the oscillation center tracking are two important steps that should be done in out-of-step splitting protection.

The existing out-of-step splitting schemes are based on local measurements. These schemes judge whether out-of-step oscillation occurs in power system by indirectly reacting to the change of power angle and they are not adaptable in the situations of oscillation center drifting. The apparent impedance based out-of-step splitting scheme distinguish between short circuit and oscillation by means of the apparent impedance trajectory [4,5]. If the trajectory moves through the setting impedance area slowly, the out-of-step oscillation is judged. When it is used on the transmission line with large number of intermediate loads, the setting process is very complicated [6]. In the apparent impedance angle based out-of-step splitting principle [7], the out-of-step oscillation is detected by observing the time sequence of impedance angle variation and the oscillation center is determined using the minimum value of measured impedance. Because the reactive power pass through the zero-axis with multiple swings when an out-of-step oscillation occurs, the principle may bring time sequence judgment error, which results in mal-operation or refused operation of protection [8]. The splitting principle utilizing frequency characteristic are introduced in [9]. The out-of-step oscillation is judged and the oscillation center is determined according to the difference of the voltage frequency and current frequency on both sides of the oscillation center, which is not affected by the system structure and the operation mode but over-reliance on the frequency measurement accuracy. Considering the conversion of system kinetic energy and potential energy, the branch energy based splitting method is proposed in [10]. By evaluating the potential energy of the cutset consisting of unstable branches, the splitting section and splitting time are determined without coherency grouping of generators. But it is established under the precondition that the oscillation center position is fixed, it cannot be well applied to the real systems in which the oscillation center drifts during oscillation process. The splitting method based on $u\cos\varphi$ can capture the time point at which the out-of-step oscillation center voltage amplitude decreases to zero, but it can't lock the position where the out-of-step oscillation center is located [11].

* Corresponding author.
E-mail address: spritstronger@126.com (S. Zhang).

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PMU provides a new platform for real-time out-of-step splitting protection [12,13] and some progresses have been achieved. The factors leading to drifting of the out-of-step oscillation center are studied in [14]. Ref. [15] analyses the oscillation center drifting regularity under complicated scenes and an oscillation center locating method is given. It uses the measured impedance phase angle at buses to decide which line the oscillation center locates. An oscillation center tracking method is proposed in [16]. Through analyzing the phase relationship between bus voltages and line voltage difference, the position of oscillation center is tracked in real time. In literature [17], an out-of-step center locating method is illustrated. In out-of-step oscillation process, the power system is divided into two areas according to the different variation characteristics of bus voltage phase angles. The out-of-step center is located at the connecting line of different areas. In this paper, an out-of-step oscillation detecting criterion is presented based on the change rate of phase angle difference between bus voltage and system current. Moreover, a novel oscillation center tracking method and its application in out-of-step splitting protection are introduced. With the aid of the phase relationship between system current and bus voltages, the position of the oscillation center is calculated quickly to form the oscillation center tracking curve and the system is split when the voltage amplitude of oscillation center decreases to 0. The method is not affected by the changes of system structure and operate modes. This paper is organized as follows. In Section 2, the out-of-step detecting criterion is given with an equivalent two-terminal system. In Section 3, how to use the phase relationship between system current and bus voltages to get the lowest voltage amplitude point is discussed firstly, and then a novel oscillation center tracking method is proposed. In Section 4, one application of the proposed oscillation center tracking method in out-of-step splitting protection is illustrated. In Section 5, the simulation results of *IEEE39* system verify the effectiveness of the proposed scheme in meshed multi terminal systems.

2. Out-of-step oscillation detection

An equivalent two-terminal system is displayed in Fig. 1. Three assumptions are given below.

1. $\dot{E}_M$ rotates counterclockwise around $\dot{E}_N$. The equivalent potential amplitudes E_M and E_N may differ from each other and $\rho = E_M/E_N$. The frequency $f_{\dot{E}_M}$ of $\dot{E}_M$ is greater than the frequency $f_{\dot{E}_N}$ of $\dot{E}_N$.
2. The influence of frequency variation on electrical component impedances is ignored. Z_{AB}, Z_{BC}, Z_{CD} are the line impedances and Z_M, Z_N are the impedances of equivalent systems M and N respectively. Their impedance angles $\varphi_{AB}, \varphi_{BC}, \varphi_{CD}, \varphi_M$ and φ_N might be different. The impedance angle of $Z_\Sigma = Z_M + Z_{AB} + Z_{BC} + Z_{CD} + Z_N$ is φ_Σ.
3. The bus voltages and the system current can be obtained from PMUs.

When the system out-of-step oscillates, the phase angle difference δ between $\dot{E}_M$ and $\dot{E}_N$ varies from 0° to 360° periodically, which causes the phase angle difference between the bus voltage and system current changes within the range of 0° and 360° too. The following analyzes the change characteristic of this phase angle difference utilizing the coordinate transformation proposed in [17]. In original coordinate system, the Eq. (1) is satisfied.

$$\begin{cases} \dot{E}_{MN} = \dot{E}_M - \dot{E}_N \\ \dot{E}_N = E_N\angle 0^\circ \\ \dot{U}_D = \dot{E}_N + \frac{Z_N}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M}\dot{E}_{MN} \\ \dots \\ \dot{U}_A = \dot{E}_N + \frac{Z_N+Z_{CD}+Z_{BC}+Z_{AB}}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M}\dot{E}_{MN} \\ \dot{E}_M = \dot{E}_N + \frac{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M}\dot{E}_{MN} \end{cases} \tag{1}$$

If two sides of formula (1) are divided by $\dot{E}_{MN}$, the formula (2) can be written.

$$\begin{cases} \dot{U}_{D'N'} = \dot{U}_{D'} - \dot{E}_{N'} = \frac{Z_N}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M} \\ \dots \\ \dot{U}_{A'N'} = \dot{U}_{A'} - \dot{E}_{N'} = \frac{Z_N+Z_{CD}+Z_{BC}+Z_{AB}}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M} \\ \dot{E}_{M'N'} = \dot{E}_{M'} - \dot{E}_{N'} = \frac{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M}{Z_N+Z_{CD}+Z_{BC}+Z_{AB}+Z_M} \end{cases} \tag{2}$$

The conversion formula (2) makes all bus voltage phasors in original coordinate system are rotated λ to the delay direction and makes all phasor amplitudes are reduced $1/L$ times as Fig. 2 displays, where λ is the phase angle of $\dot{E}_{MN}$, and L is the amplitude of $\dot{E}_{MN}$. Because all of the phasors are rotated λ, the phase angle difference among phasors does not change before and after transformation, which makes this coordinate transformation owns conformal property. After the coordinate of N' is set to (0, 0), all of the phasor ends of converted bus voltage M', A', B', C', D' can be determined according to (2), and $\dot{U}_{D'N'} \dots \dot{U}_{A'N'}, \dot{E}_{M'N'}$ are fixed phasors, while the converted power network neutral point O' is drifting. In [17], the trajectory of O' is derived as

$$\begin{array}{ll} \left(x + \frac{\rho^2}{1-\rho^2}\right)^2 + y^2 = \left(\frac{\rho}{1-\rho^2}\right)^2 & if \quad \rho \neq 1 \\ x = \frac{1}{2} & if \quad \rho = 1 \end{array} \tag{3}$$

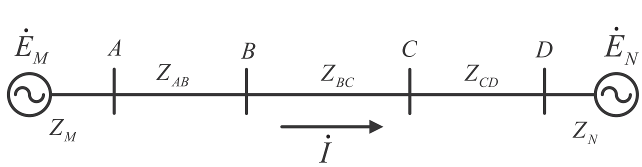

Fig. 1. Equivalent two-terminal power system.

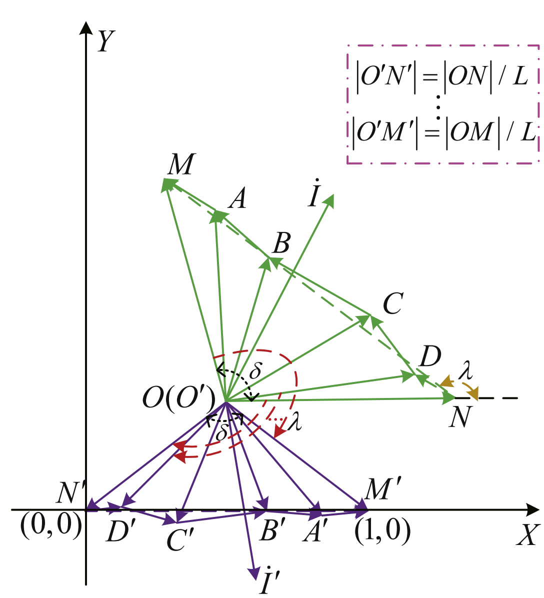

Fig. 2. Coordinate transformation process.