Research on Location and Recognition Method of Voltage Sag Disturbance

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Abstract. The accurate positioning of the voltage sag disturbance source relative to the monitoring point helps to clarify the responsibilities of both parties. This paper proposes a brand-new single-frequency cross S-transform perturbation power positioning method for locating voltage sag disturbance sources. First, the voltage and current signals collected at the monitoring point are transformed into a single fundamental frequency S to obtain a complex vector of the fundamental frequency of the voltage and current; then, the complex vector of the voltage and current fundamental frequency is subjected to a single fundamental frequency cross S transformation. The module extracts the instantaneous apparent power, and then obtains the instantaneous apparent disturbance power; finally, the disturbance power criterion is used to locate the source of the voltage sag disturbance. Through analyzing and judging the monitoring point of the problem caused by short circuit fault, the result proves the accuracy and effectiveness of the proposed method.

1. Introduction

Voltage stability refers to the power system's ability to maintain voltage stability, which can be divided into static voltage stability and transient voltage stability. Among them, static voltage stability refers to the voltage instability caused by the continuous increase of load [1]. Transient voltage stability refers to the phenomenon of bus voltage drop caused by system failure [2]. With the development of the electricity market, the pricing of energy according to quality has become the future development trend; and, with the increase of load-side sensitive equipment such as computers, frequency conversion speed control devices, programmable logic controllers [3], such equipment loses voltage Stability is extremely sensitive. When it is interfered, it may not only cause the failure of the device itself, but even endanger the operation safety of the entire system. Therefore, it is of great significance to achieve fast and accurate voltage stable disturbance source positioning to restore the voltage to a reasonable range as soon as possible and ensure that the power quality meets the safe operation requirements of equipment and systems [4-6].

This paper analyzes various positioning methods and identification methods of voltage sag disturbance sources in detail, and compares their characteristics. At present, more mature voltage sag disturbance source positioning methods include methods based on disturbance power and disturbance
2. The disturbance power and energy method to locate the disturbance source

When a disturbance occurs, the difference between the total three-phase power and the total three-phase power that the system should have without disturbance is defined as the disturbance power (DP) \[7,8\]. When the system is without disturbance, the disturbance power value is always close to zero (due to the presence of noise, it is not completely equal to zero). It can be seen that when the disturbance power exceeds the set threshold, it is considered that disturbance has occurred in the system. The integral of the disturbance power is the disturbance energy (DE).

\[
DP = p(t)_f - p(t)_{ss}
\]  
\[
DE = \int DP(t) dt
\]

DP is the difference between the instantaneous power \(P(t)_f\) and \(P(t)_{ss}\) transmitted during the disturbance and during the steady state, DE is the integral of DP during the disturbance.

When a voltage sag occurs in the system, it can be seen that energy flows from other loads to the fault point. Therefore, the location of the disturbance source can be achieved by analyzing the instantaneous energy change at a certain point in the power grid. A power quality monitor is installed at the outlet end of the substation, which can record three-phase voltage and current \[9\]. According to the voltage and current data recorded at the monitoring point, the change of the three-phase instantaneous power flowing through the monitoring point can be calculated \[10\]. Three-phase instantaneous power:

\[
p(t) = u_a(t)i_a(t) + u_b(t)i_b(t) + u_c(t)i_c(t)
\]

Define the difference between the three-phase instantaneous power when the voltage sag occurs in the system and the three-phase instantaneous power at the steady state as the disturbance power:

\[
P_D(t) = p_d(t) - p_s(t)
\]

Where \(d\) is the disturbance; \(s\) is the steady state \[11\]. When the system is in steady state, the instantaneous power is an approximate constant, and \(P_0=0\) at this time. When \(P_0=0\), it means that the instantaneous power of the system has changed, that is, the system has some disturbance. Define \(W_D\) as the value that integrates \(P_D\), which is:

\[
W_D(T) = \int_0^T P_D(t) dt
\]

\(W_D(T)\) can characterize the instantaneous energy change at the monitoring point. When the system is in steady state, \(W_D(T)\) is approximately 0. If \(W_D(T)<0\), the disturbance source is upstream of the detection device; if \(W_D(T)>0\), the disturbance source is downstream of the detection device. By analyzing the value of \(W_D(T)\), the position of the disturbance source relative to the monitoring device can be determined.

3. Usage of S changes to identify disturbance sources

The S transform is a reversible time-frequency analysis method based on short-time Fourier transform and wavelet transform. Suppose the signal \(h(t) \in L^2(R)\), where \(L^2(R)\) represents the square integrable space on the real domain, then the one-dimensional continuous S transform of \(h(t)\) to \(S(\tau, f)\) can be defined as follows:
In equations (6) and (7): $t$ is time; $f$ is frequency; $w(t, f)$ is a Gaussian window function; $\tau$ is the center of the Gaussian window. Using the convolution theorem, there are:

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) w(t - \tau, f) e^{-j2\pi ft} dt$$

(6)

$$w(t - \tau, f) = \sqrt{\frac{1}{2\pi}} e^{-\frac{f^2(t-\tau)^2}{2}}$$

(7)

In the formula: $H(\alpha + f)$ is obtained by translation of the Fourier transform $H(f)$ of the signal $h(t)$; $\alpha$ is the representation of the variable $\tau$ in the frequency domain in the time domain.

When performing S-transform on the signal, it is necessary to calculate the fast Fourier transform (FFT) of the Gaussian window at each frequency point. The calculation process is cumbersome and the calculation amount is large. When analyzing the voltage drop signal, only the relevant vector information of the fundamental frequency $f_0$ needs to be extracted, so the single fundamental frequency S transform (SFST) simplified by the S transform can be defined as follows:

$$S(\tau, f_0) = \int_{-\infty}^{\infty} h(t) w(t - \tau, f_0) e^{-j2\pi ft} dt$$

(9)

$$w(t - \tau, f_0) = \sqrt{\frac{f_0}{2\pi}} e^{-\frac{f_0^2(t-\tau)^2}{2}}$$

(10)

It can be seen that the signal obtained after the single fundamental frequency S transform is a one-dimensional complex vector. The calculation process of the single fundamental frequency S transform is shown in Figure 1.

![Figure 1 SFST calculation process](image)

P(k) in Figure 1 is the discrete form of the sampled signal p(t), which is obtained by fast Fourier transform to obtain p(m); after shifting p(m) by $n_0$, P(m+$n_0$) is obtained; G(k) is the discrete form of the Gaussian window, and the FFT corresponding to the fundamental frequency is G($n_0$,m); multiply G($n_0$,m) and P(m+$n_0$), and then find the fast Fourier The inverse fast Fourier transform (IFFT) can obtain the fundamental frequency voltage and current complex vector $S_0(kT,n_0)$.

4. SFCST-based voltage drop disturbance source positioning method

4.1. SFCST principle

The single fundamental frequency cross S transform of voltage and current signals [12] is defined as:

$$CrossST (\tau, f_0) = S_i(\tau, f_0) \{S_v(\tau, f_0)\}^\dagger$$

(11)
Where: $S_u(\tau, f_0)$ is the SFST transformation of voltage; $S_i(\tau, f_0)$ is the SFST transformation of current; $\{S_i(\tau, f_0)\}^*$ is the conjugate of $S_i(\tau, f_0)$.

Because the modulus of the single fundamental frequency S transform of the voltage and current signal has a direct correspondence with the amplitude of the signal, the instantaneous apparent power of the signal can be obtained after modulo the equation (13). To simplify the formula, let $CrossST(\tau, f_0)$ be $CST(\tau, f_0)$. Then the discrete form of the single fundamental cross S-transform is:

$$\{\tau, f_0\} = \frac{1}{N^2} \sum_{n_1=1}^{N} \sum_{n_2=1}^{N} S_n \left( kT, n_0 \right) \left( S_n \left( kT, n_0 \right) \right)^*$$

(12)

4.2. SFCST-based voltage sag disturbance source location method

The formula for calculating instantaneous apparent power using SFCST is:

$$S = \left| CST_u(\tau, f_0) \right| = \left| S_u \left( kT, n_0 \right) \left( S_i \left( kT, n_0 \right) \right)^* \right|$$

(13)

The disturbance apparent power $DS$ calculated by SFCST is:

$$DS = S_D - S_S$$

(14)

In the formula: $S_D$ is the instantaneous apparent power; $S_S$ is the steady-state three-phase instantaneous apparent power, which is an approximate constant.

Due to the presence of transient disturbances, the instantaneous apparent power $S_D$ cannot be equal to the steady-state three-phase instantaneous apparent power $S_S$. According to equation (14), $DS$ is not zero. Therefore, the following perturbation power positioning method criterion is adopted:

1) If $DS > 0$, the disturbance source is located downstream of the monitoring point;
2) If $DS < 0$, the disturbance source is located upstream of the monitoring point.

5. Simulation

In practical applications, common voltage drops are caused by short-circuit faults. This study models and simulates the voltage drop situation, and uses SFCST and the disturbance power positioning method to locate the disturbance source. Finally, the accuracy of the method is verified by judging whether the positioning result is consistent with the actual situation.

The three-phase short-circuit fault system is simulated. When a three-phase short-circuit fault occurs in the system, the current and voltage waveforms at the phase A drop at monitoring points M1 and M2, the fundamental voltage and current waveforms via SFCST, and the disturbance power waveforms are shown in Figures 2. It can be seen from Figure 2 that $DS > 0$ at M1, and according to the criterion of the disturbance power positioning method, the disturbance source occurs downstream of point M1.
6. Conclusion

In this study, SFCST is used to calculate the instantaneous apparent power, the fundamental frequency voltage and current complex vector are directly used, and the instantaneous apparent power can be obtained after the cross S transformation, and then the disturbance power method is used to locate the voltage sag disturbance source, which is the disturbance Source positioning provides a new idea. Since the single fundamental frequency S transform only needs to calculate the fundamental frequency vector relative to the S transform, the calculation amount is greatly reduced, the calculation speed is improved, and it is convenient for real-time application.

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