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An Adaptive Method for Detecting Faults During Power Swing in Distance Relays Based on Short Fourier Transform

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Abstract

Reliable discrimination between a fault and a power swing is essential to prevent distance-relay maloperation in transmission networks. This study proposes an adaptive short-time Fourier transform (ASTFT) method that detects faults by tracking the spectral energy of line-current signals. Unlike conventional STFT, the proposed method adjusts the analysis-window width according to the instantaneous-frequency behaviour and the local stationarity interval of the signal. A wider window is retained during normal operation and power swings to improve frequency resolution, whereas a narrower window is selected when rapid spectral changes indicate a fault, thereby improving time resolution. The method is evaluated through PSCAD/EMTDC and MATLAB simulations on a standard power-system network. The reported studies cover swing frequencies from 0.5 to 5 Hz, different fault inception times and locations, fault resistances, symmetrical three-phase faults, and an asymmetrical phase-to-phase-to-ground fault. At a sampling rate of 2.5 kHz, the method detects the investigated faults with short delays; one reported case is detected in 14 ms. The article also reports an average detection-time improvement of approximately 15% over classical STFT and detection times below 20 ms. The results indicate that adaptive time-frequency resolution can improve fault discrimination during power swings while limiting unwanted relay operation during switching disturbances.

Keywords

Distance relay, power swing, adaptive short-time fourier transform, ASTFT, Spectral energy, Fault detection.

1. Introduction

Power swings may follow severe disturbances, sudden load changes, or generator outages. During a swing, the apparent impedance observed by a distance relay can move through its operating characteristics and resemble the impedance trajectory associated with a fault. If the relay cannot distinguish these conditions, it may trip unnecessarily or remain blocked during a genuine fault. Reliable fault detection during power swings is therefore an important requirement for dependable transmission-line protection.

Previous approaches have used waveform asymmetry, wavelet analysis, instantaneous-frequency features, RMS current, statistical indicators, phasor quantities, adaptive protection, and intelligent classifiers. Wavelet-based methods provide multi-resolution analysis and have been used to separate power swings from faults [1–3]. Instantaneous-frequency and current-based methods offer alternative detection features [4–6], while statistical and phasor-based techniques have also been investigated [7-8]. Adaptive distance protection has been studied to reduce the risk of relay maloperation under power swings [9-10]. Nevertheless, a fixed time-frequency window cannot simultaneously provide high frequency resolution during slowly varying conditions and high time resolution at the abrupt onset of a fault. More computationally demanding approaches may also be less attractive for time-critical protection.

The contribution of the present work is an ASTFT-based detection scheme in which the analysis-window width is adapted using the estimated instantaneous frequency and its local stationarity interval. The resulting spectral energy is used as the fault-detection indicator. The method is evaluated for a range of swing frequencies, fault types, fault inception instants, and switching disturbances, and its detection delay is compared with that of conventional STFT.

2. Methodology

The proposed method analyses the frequency content of the measured line current. Its central premise is that a fault introduces abrupt waveform changes and additional high-frequency content, whereas a power swing produces a comparatively gradual evolution of the current signal. Consequently, the spectral energy associated with a fault is

expected to rise above the level observed during normal operation or a power swing. The relay calculates the time-varying spectrum using ASTFT and evaluates its energy against a selected threshold. When the energy exceeds the threshold, a fault is declared; otherwise, the relay remains blocked to avoid an inappropriate trip. Figure 1 illustrates the frequency spectrum of the current signal during a power swing.

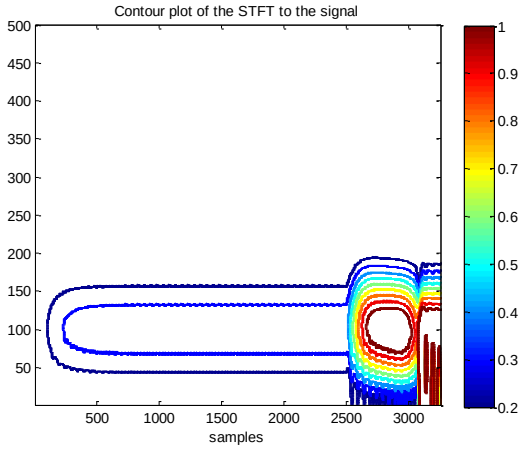


Figure 1. The frequency spectrum of the current signal during a power swing

The adaptive window is determined from the instantaneous-frequency trajectory. The local stationarity interval is defined by assessing how much the instantaneous frequency changes over a time interval. When the frequency slope remains sufficiently small, the signal can be treated as locally quasi-stationary and a longer analysis window can be used. The window is shortened when the signal exhibits rapid frequency variation. This produces the intended compromise: relatively wide windows during normal operation and power swings provide improved frequency resolution, while narrow windows around fault inception provide improved time resolution.

In discrete-time implementation, the instantaneous-frequency slope is evaluated at successive samples. The local stationarity length is then obtained from the condition imposed on this slope, and the Gaussian-window width is updated accordingly. The adaptive window is inserted into the short-time Fourier transform to obtain ASTFT. For each time index, the spectral-energy measure is calculated from the squared magnitude of the ASTFT coefficients over the analysed frequency bins. A threshold is selected so that the energy increase caused by a fault is distinguished from the energy variations associated with power swings and switching events. The source article identifies the threshold as an important design parameter but does not provide a universal numerical threshold applicable to all networks.

3. Discussion and Results

The method was tested on a standard power-system network in PSCAD/EMTDC, with signal processing and evaluation also reported in MATLAB. The simulated transmission line is rated at 400 kV and 50 Hz and has a length of 300 km. A disturbance initiates the power swing, after which a fault is applied to the same line. The rotor angle before the swing is reported as 70°. Current and voltage sampling is performed using phase A at 2.5 kHz, corresponding to 50 samples per power-frequency cycle. To examine dependence on fault inception time, simulations are repeated at different instants separated by 2 ms.

The investigated swing-frequency range is 0.5–5 Hz. The reported spectral-energy traces show that the energy during normal operation and power swings remains below the energy reached at fault inception. This separation allows a suitable threshold to discriminate between the two operating conditions. The study further reports that the detection delay is below 1.5 power-frequency cycles for the tested cases. In the three-phase fault scenario with a 3 Hz swing, the reported detection delay is 46 samples. For the 1 Hz and 5 Hz swing cases, the reported delays are 43 samples. These results support the use of the adaptive window to capture the rapid spectral change associated with fault inception.

The method was also examined for an asymmetrical B–C–G fault during a 2 Hz power swing. With the fault applied at 1.23 s, the detection is reported at 1.244 s. At 2.5 kHz, this corresponds to a 14 ms delay; the article also reports a delay of 35 samples for this case. A further scenario combines the same type of fault with resistive-load switching and capacitor switching. Load switching occurs at 1.10 s, capacitor switching at 1.15 s, and the fault at 1.23 s. The fault is detected at 1.244 s, again with a reported delay of 14 ms. The algorithm does not confuse these switching events with the fault in this test.

Table 1 summarizes selected numerical cases reported in the article. The values are reproduced from the source and are not additional simulations.

Table 1. Selected reported fault-detection cases

Test condition	Swing frequency	Fault / event timing	Reported delay
Three-phase fault	3 Hz	Swing at 1.00 s; fault at 1.35 s	46 samples
Three-phase fault	1 Hz	Swing at 1.00 s; fault at 1.47 s	43 samples
Three-phase fault	5 Hz	Swing at 1.00 s; fault at 1.40 s	43 samples
B–C–G fault	2 Hz	Fault at 1.23 s; detected at 1.244 s	35 samples (14 ms)
B–C–G fault with switching	Not specified	Load: 1.10 s; capacitor: 1.15 s; fault: 1.23 s	35 samples (14 ms)

The comparison with conventional STFT is based on the different time-frequency resolution offered by the two methods. A fixed-width STFT window preserves the same resolution trade-off throughout the record. ASTFT, in contrast, changes the window width as the signal evolves, allowing a narrower window near the fault and therefore a timelier indication. The article reports an average detection-time improvement of about 15% relative to classical STFT, with detection times below 20 ms. Its comparative table also characterizes the proposed method as having moderate computational complexity, moderate processing demand, and suitability for real-time use. These are simulation-based findings; the paper does not present hardware-in-the-loop or field-test validation. The practical performance will depend on threshold selection, sampling, noise, and the behavior of the protected network.

4. Conclusions

This extended abstract has described a current-signal-based fault-detection method for distance relays exposed to power swings. The proposed ASTFT adapts the Gaussian analysis window using instantaneous-frequency behavior and local stationarity, and uses the resulting spectral energy as the decision variable. The reported PSCAD/EMTDC and MATLAB studies cover swing frequencies between 0.5 and 5 Hz, symmetrical and asymmetrical faults, different fault inception conditions, and switching disturbances. The selected cases include a 14 ms detection delay, while the article reports an average improvement of approximately 15% over conventional STFT.

An important implementation advantage is that the detection decision is based on current sampling, potentially reducing measurement and hardware requirements compared with approaches that also require voltage measurements. The findings support further consideration of adaptive time-frequency analysis in distance-relay protection. However, the results should be interpreted within the scope of the reported numerical studies. Before practical deployment, the threshold and window adaptation should be tested across a broader range of network configurations, measurement noise, instrument-transformer effects, and real-time hardware.

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