A Comparative Assessment of the Single-Criterion Methods

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ABSTRACT:
Disturbances and faults cause power swing in the power system. Under these dynamic conditions, the power swing blocking (PSB) function prevents the misoperation of the distance relay. However, if a fault occurs during power swing, the relay must be unblocked and let it trip. In other words, the relay should be capable of detecting faults during power swing. The power swing phenomenon involves all three-phases of power system and thus, the detection of the symmetrical faults in this situation is great complexity. In this paper, single-criterion methods for the symmetrical fault detection during power swing are implemented and their performances in different situations including fault location, fault inception time, fault resistance and the angle difference between two buses at the ends of transmission line, are evaluated and compared with respect to speed and accuracy.

KEYWORDS: Fault Detection, Distance Relay, Power Swing Blocking Function.

1. INTRODUCTION
Under steady state conditions, the generated and consumed active and reactive power are balanced and power systems operate near to their nominal frequency. A sudden disturbance such as fault, heavy loaded line switching and a large generation outage cause oscillation in machine rotor angles and can result in large fluctuations of power flow between sending and receiving ends of transmission lines. In such situation, the impedance seen by distance relay may move into the protection zones and the relay misoperates which can result in spread blackout [1-4].

Generally, the distance relay under dynamic conditions such as the power swing should not send trip signal. Thus, the power swing blocking (PSB) function is embedded in new generation of these relays. The main purpose of the PSB function is to discriminate between the faults from the power swing and block the relays from sending unintended trips during the power swing. The most common measure for classifying the power swing from the faults is the rate of change of apparent impedance calculated at the point of the relay.

In terms of the reliability indices of the distance protection, if a fault (both symmetrical and unsymmetrical) occurs during power swing, the relay must be unblocked and let it trip [1] and [5-6]. In this regard, the power swing phenomenon involves three-phases of power system and thus, the detection of the symmetrical faults unlike the unsymmetrical faults, in this situation is great complexity. In other words, using increasing of negative and zero sequence components, the unsymmetrical faults detection during the power swing is easily provided.

Many schemes based on different techniques have been proposed to solve this problem. These methods can be divided into two categories, single-criterion and multi-criteria, from the point of view using one or more criteria. The most important techniques of single-criterion can be seen in Fig. 1. The main purpose of this study is to provide a comparative assessment of these techniques. First method, fault detection method based on DC component of fault current [7], [8]. Another method uses frequency components of instantaneous three-phase active power to identify fault during power swing [9]. In third method, fault detection will be done by measuring the positive sequence of impedance and applying the wavelet transform on it [10], [11]. Finally, negative sequence component-based approach, using the factor of current unblocks the distance relay [12].

This paper is organized as follows: section two briefly introduces the conceptual considerations including the slip frequency of power swing, the amount of negative sequence component and the DC component of current, speed and accurately identify the fault and the

Fig. 1. Single-criterion methods for detecting fault during power swing.
2. CONCEPTUAL CONSIDERATIONS

Power swing and three-phase fault include each three-phase in the power system. For this reason, identification of the symmetrical fault is more complicated than unsymmetrical fault. In other words, the amount of negative and zero sequence components in symmetrical fault is much less than unsymmetrical fault. Another issue is fault resistance. Whatever the resistance of the fault be more, the fault detection becomes more difficult. Fault location is also effective on fault identification. As well as speed and accurateness of fault identification is very important, too. Whatever speed and accuracy is higher, lower electrical and mechanical pressure is applied to electrical equipment.

3. SYSTEM MODELING

In order to evaluate the performance of the different fault identification method, a power system shown in Fig. 2 is simulated using PSCAD / EMTDC with the system details are provided in Appendix 1. A three-phase fault is created at the middle of Line-2 at 0.6 s and cleared by opening breakers B3 and B4. This causes a power swing condition in Line-1. Then relay is blocked by the PSB function. Under this condition, another fault at Line-1 in 4.5 s for a second time occurs. This fault should be cleared by circuit breakers B1 and B2. So under this condition, distance relay should be unblocked by anticipated methods of identification and sends the interrupted command.

4. SINGLE-CRITERION METHODS

In this section four methods of symmetrical fault identification during power swing are introduced.

4.1. DC Component of Fault Currents

The basic idea of proposed method is using the transient DC component of the fault current waveform. In this method, first, the DC component of each phase current is extracted. Then the DC components are compared with the threshold and if each of which is greater than the threshold, it means that fault occurred and relay sends the trip command. In other words, if values of the DC component in all three-phases are less than the threshold, the relay will remain lock [7], [8].

"Fig. 3," shows the amount of DC component of the three-phase currents when fault occurs during power swing. As shown in this figure, when the fault occurs at the 4.5 s, amount of DC component has significant value that fault can be detected by determining a threshold value.

4.2. Frequency Components of the Instantaneous Three-Phase Active Power

In this method, first, voltage and current signal of each phase is measured. Then the instantaneous three-phase active power calculated and analyzed using fast Fourier transform (FFT) to extract the fundamental
frequency component. Under power swing conditions, the fundamental component is small but after fault occurrence, its magnitude increases, rapidly. At this time, distance relay unlocked and trip. Fig. 4 illustrates a flowchart of the fault detection method. Fig. 5 shows the instantaneous three-phase active power signal and its FFT coefficient when three-phase fault occurs during power swing [9].

\[ \text{Instantaneous three-phase active power (MW)} \]

\[ \text{Fast Fourier Transform Coefficient (MW)} \]

Fig. 4. Flowchart of fault detection method during power swing by using frequency components of the instantaneous three-phase active power.

4.3. Using Wavelet Transform on Positive Sequence Impedance Seen by the Distance Relay

This method uses the wavelet transform coefficients of the impedance seen by the distance relay to identify fault during power swing. Sampling frequency required to perform this detection procedure is only 1 kHz that used in most digital relays.

In this method, the calculated impedance is analyzed based on wavelet transform with db4 as mother wavelet. Fault detection process is done by selecting a threshold for wavelet coefficients calculated at level 1[10], [11]. Fig. 6 shows the magnitude of positive sequence impedance and its wavelet coefficients of level 1. As can be seen, the wavelet coefficients has a substantial increase in the magnitude after the symmetrical three-phase fault inception which indicates the ability of the proposed idea in the three-phase fault detection during power swing.

4.4. Negative Sequence Component

Power swings and three-phase faults involve all three-phases of the power system. Though power swing is a balanced phenomenon, a small value of negative-sequence component of current is observed. In other words, the negative sequence component content is an insignificant amount. However, the negative sequence component increases when fault occurred during power swing. This property can be used for diagnosis symmetrical fault during the swing.

If the negative sequence component of current is further than specified threshold, it means fault occurred during power swing. But if the negative sequence component of current (a percentage of the current
principal component) is less than that threshold, show that the network is still in power swing condition [12]. Fig. 7 illustrates the three-phase current waveform and the negative sequence component of the current.

5. SIMULATION AND RESULTS
The most important factors that influence on the fault detection during power swing include:
- Fault distance to relay
- Fault inception time
- Fault resistance
- Angle difference between the sending and receiving ends of transmission line.

For this purpose, a variety of cases is simulated in Table 1. For example, if the three-phase fault occurs in the peak voltage or zero-voltage, the situation is different in the two cases, view point of fault detection.

Angle difference between the sending and receiving ends of transmission line is also another important factor in fault detection during power swing by four methods be expressed. Because changing of the angle difference between buses also changes the frequency of oscillation, so that whatever the angle difference approaches to 180 degrees, the oscillation frequency will increase.

Increasing of power swing frequency also becomes more difficult setting of threshold for fault detection. Because when the slip frequency of power swing increases during power swing, the output values of declared methods may be somewhat higher or equal to fault situation. In this situation, relay unlocks incorrectly and sends disconnection command.

Aforementioned methods need threshold determining for fault detection during power swing. Threshold determining depends on the equipment of power network and operating conditions of relays and so on. Therefore in this paper, 20 percent is considered for the DC component-based method. This means that if the percentage of the DC component for each of three-phases is more than 20%, the relay is unlocked and fault will be detected. The threshold is setting 10 MW for method based on instantaneous three-phase active power. If the fast Fourier transform of three-phase active power main components is more than 10 MW, the method identifies fault during power swing. The third method is based on wavelet transform coefficients of level 1 from the positive sequence impedance, which its threshold is considered 10 ohms. In addition, the threshold of the negative sequence component is

<table>
<thead>
<tr>
<th>Case</th>
<th>Fault distance to relay (km)</th>
<th>Fault inception time (s)</th>
<th>Fault resistance (ohm)</th>
<th>Angle difference between the bus M and N</th>
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appointed 40 A in negative sequence component-based technique. The current negative sequence is about 8% in normal conditions of power grid, but it increases to significant quantities when fault occurs.

In order to a comparative assessment, the data obtained from the simulated cases in Table 1, is fed to each algorithm. The results can be seen in Table 2. These Results indicate that the DC component-based method can detect the fault during power swing for all cases except the 20th case.

Also according to the low percentage of three-phase DC component in cases 19, 23 and 24, it can be concluded that this method may be doesn’t identify fault during power swing when symmetrical three-phase fault with high resistance occurs at far from distance relay. So this method isn’t guarantee for these conditions. The time needed to detect fault based on this algorithm is about 12ms to 20ms.

Also, the method based on instantaneous three-phase active power can’t detect fault during power swing for 20th case but has acceptable performance for the rest of the cases. In case 20, high resistance fault occurs far from the distance relay after power swing (first fault in line-1) immediately, in addition angle difference between buses closes to 180 degrees.

According to achieved results for cases 5, 6, 21and 22, this method needs precision measurement devices to find threshold, in addition if low resistance fault occurs far from or closing to distance relay, fault may be undetectable. Method based on FFT of three-phase active power detects fault in ranged from 15ms to 20ms.

According to results from Table 2, it can be seen that the method based on wavelet transform of positive sequence impedance detects fault during power swing for all cases except two cases 18 and 20. By attention to the these cases, we can conclude that this procedure performs inappropriately when the angle difference between buses is close to the 180 degrees in the power system and fault occurs immediately after the power swing.

According to output values of cases that are very close to the threshold, it can be stated that this method greatly depends on the fault inception time and angle difference between the sending and receiving end of line. Thus, in these situations, performance of this method is not reliable and may not detect the fault. According to the results obtained from cases 2 and 4, it can be stated that the procedure performance is secure and assured for close-in faults. This method detects symmetrical three-phase fault in a time delay between 2ms to 5ms after fault inception.

The results of Table 2 shows that the method based on the negative sequence of current is not able to detect fault during power swing in cases 19, 20, 23 and 24. According to the specifications of cases described in Table 1, it can be concluded that the performance of the method is undesirable for symmetrical three-phase fault with high resistance occurs far from the distance relay. So it can be argued that this method has been highly dependent the fault resistance and fault distance from distance relay. In the other hand, the angle difference between two ends of line and fault inception time has no effect on its performance. Fault can be detected after 10ms to 12ms after fault inception.
6. CONCLUSION
In this paper, the single criterion methods to detect three-phase fault during the power swing phenomenon are investigated. Study results show the method using the DC component is very secure. The only problem with the scheme based on the DC component is filter selection to eliminate the impact of noise and other disturbances on the DC component. Fault detection method using fundamental component of the instantaneous three-phase active power, does not depend on the fault location and fault inception time. The only major problems of this fault detection procedure are its delays in fault detection and its dependence on the fault resistance during the swing. The algorithm based on wavelet transform of positive sequence impedance depends on mother wavelet. According to the simulation results, this method identifies fault during power swing with the highest speed in compared with other introduced methods. Fault identification method based on negative sequence component of current, is very much dependent on fault resistance and fault location. Moreover, accuracy of this method is influenced by power system equipment, such as capacitor banks and lightning arresters. Because these factors have created some negative sequence current that is effective on the negative sequence component of fault current during power swing.

7. APPENDIX
System data for SMIB:
Generator:
600 MVA, 22 kV, 50 Hz, inertia constant = 4.4 MW/MVA. X_d = 1.81 p.u., X'_d = 0.3 p.u., X''_d = 0.23 p.u., T''_q = 8 s, T'_q = 0.03 s, X_q = 1.76 p.u., X'_q = 0.25 p.u., T'_q = 0.03 s, R = 0.003 p.u., X_p(Potier reactance) = 0.15 p.u.
Transformer:
600 MVA, 22/400 kV, 50 Hz, Δ/Y, X = 0.163 p.u., X core = 0.33 p.u., R core = 0.0 p.u., P copper = 0.00177 p.u.
Transmission lines:
Length = 320 km.
Positive-sequence impedance = 0.12+j0.88 Ω/km.
Zero-sequence impedance = 0.309+j1.297 Ω/km.
Positive-sequence capacitive reactance = 487.723 × 10^3 Ω.km.
Zero-sequence capacitive reactance = 419.34 × 10^3 Ω.km.

REFERENCES