A New Detection Technique for Distance Protection during Power Swings

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Abstract: - This paper presents a new detection technique based on the derivative of the line reactive power as seen by the relay to prevent distance relay mal-operation during power swings. This proposed technique overcomes the shortcoming of conventional power swing detector (PSD) by removing the pre-defined R-X diagram. The conventional PSD has the difficulty in obtaining the timer setting at pre-defined R-X diagram due to varying cycle of power swings. To illustrate the effectiveness of the proposed detector, the studies have been conducted on the IEEE 39 bus test system using the PSS/E software. The results show the effectiveness of the proposed detection technique to distinguish the fault, fault clearance and power swing in order to activate the correct relay trip signals during power swing.

Key-Words: - distance relay, line reactive power, power swing detector (PSD), power swings, fault, fault clearance

1 Introduction
Power swings occur following a system disturbance such as load changes and fault clearance. When a power swing occurs, a change appears in the relative phase angle between two groups of generators [1-3]. As consequences, the measured apparent impedance is oscillating during power swing and it may initiate the distance relay to send false trip signals due to low measured impedance during power swing.

Many techniques have been introduced to block the trip signals during power swing by a number of researchers [4-9]. Jonsson and Dalder [4] have introduced the negative sequence current magnitude and the derivative of current angle to dictate the relay operation during fault and power swings. This technique is very fast by sending the blocking signals in 10ms according to the test conducted on the Nordic 32 lines system. Although the results were promising in blocking false trip signals during power swing, the possibility of false trip signals during fault clearance was noted. The combination of waveform of swing center’s voltage (WSCV) and synthetic negative sequence vector (SNSV) has been utilized to block the tripping signals during power swing [5]. The technique seems to be rigorous in discriminating power swing and high fault resistance for protection purposes. However, it requires two computationally heavy steps of derivative operation for WSCV. There is also a time delay of about 30-40 ms before a power swing blocking scheme can be activated and hence the method is relatively slow as compared to the technique of ref. 4.

A technique based on Vcosθ has been introduced by Su et al. [6]. The technique takes 30-50 ms to activate a power swing blocking scheme. However, further testing is needed in larger power systems before the existing technique can be deployed to the relay. The derivative of real power and reactive power has been integrated to develop an unblocking scheme for distance protection during symmetrical faults in power systems [7-8]. This technique is very complicated and computationally inefficient since it requires instantaneous product of voltage, current and angle to obtain the real and reactive powers. The unblocking scheme sends the trip signals after 30 ms in the event of a fault. A more advanced technique using adaptive neuro fuzzy system has been developed to block the relay trip signals during power swings [9]. However, no justification has been done on Zone 3 relay operation setting considering that this zone is the most vulnerable zone during power swings. In addition, the relay response time is more than 40 ms which is very slow as compared to techniques developed by Jonsson and Daaider, Shaohua et al., Su et al., Xiangning et al. and Lin et al. [4-8].

In this paper, a new detection approach by using the derivative of the line reactive power has been proposed to block false tripping signals during power swings. The proposed detector has been tested on the IEEE 39 bus system. A comparison with the technique in [4] is also made to ascertain the validity of the proposed approach.
2 Formulation of New detector during Power Swing

The fundamental behavior of the line reactive power immediately before and after a three phase fault can be explained by using a simple power system shown Fig. 1.

\[ Z_{\text{line}} = R_{\text{line}} + jX_{\text{line}} \]
\[ Z_{\text{load}} = R_{\text{load}} + jX_{\text{load}} \]

The proposed criterion is based on the fact that most of the reactive power during a fault is consumed by the line reactance. The derivation of the criteria is shown below;

\[ S_s = V_s^* I_s^* \]
\[ = V_s \left( \frac{V_s}{Z_{\text{line}} + Z_{\text{load}}} \right)^* \]
\[ = \frac{|V_s|^2}{Z_{\text{line}} + Z_{\text{load}}} \]  \hspace{1cm} (1)

By using the Kirchoff Voltage Law (KVL), the voltage at bus \( V_s \) can be written as;

\[ V_s = V_{\text{line}} + V_{\text{load}} \]  \hspace{1cm} (2)

Substituting (2) into (1), equation (1) becomes;

\[ S_s = \frac{|V_{\text{line}} + V_{\text{load}}|^2}{Z_{\text{line}} + Z_{\text{load}}} \]  \hspace{1cm} (3)

The the line impedance, \( Z_{\text{line}} \) can be represented as;

\[ Z_{\text{line}} = R_{\text{line}} + jX_{\text{line}} \]

Where the resistive component, \( R_{\text{line}} \) is very small and hence it can be neglected. Thus, equation (3) becomes;

\[ S_s \approx \frac{|V_{\text{line}} + V_{\text{load}}|^2}{jX_{\text{line}} + Z_{\text{load}}} \]  \hspace{1cm} (4)

where,
\[ S_s: \text{Apparent power at sending end} \]
\[ V_s: \text{Nominal voltage at sending end} \]
\[ I_s: \text{Current flow at the line} \]

From Fig. 1, the apparent power of the system is composed of the combined apparent power at transmission line and load which is given by;

\[ S_s = S_{\text{line}} + S_{\text{load}} \]
\[ = P_{\text{line}} + jQ_{\text{line}} + P_{\text{load}} + jQ_{\text{load}} \]  \hspace{1cm} (5)

where,
\[ S_{\text{load}}: \text{Apparent power of the load} \]
\[ P_{\text{load}}: \text{Real power of the load} \]
\[ Q_{\text{load}}: \text{Reactive power of the load} \]
\[ S_{\text{line}}: \text{Apparent power of the line} \]
\[ P_{\text{Line}}: \text{Real power of the line} \]
\[ Q_{\text{Line}}: \text{Reactive power of the line} \]

At transmission lines, reactive power is very large as compared to real power, thus, we can assume that;

\[ |S_{\text{Line}}| \approx |Q_{\text{Line}}| \]

Simplifying equation (5), we get,

\[ S_s = jQ_{\text{line}} + P_{\text{load}} + jQ_{\text{load}} \]  \hspace{1cm} (6)

During a power swing, the load impedance is significantly larger than the line impedance. This relation can be formulated as;

\[ Z_{\text{line}} \ll Z_{\text{load}} \]  \hspace{1cm} (7)

Thus, by assuming \( Z_{\text{line}} \ll Z_{\text{load}} \) and \( V_{\text{load}} \approx V_s \), equation (1) can be further simplified as;

\[ S_s \approx \frac{|V_{\text{load}}|^2}{Z_{\text{load}}} = P_{\text{load}} + jQ_{\text{load}} \]  \hspace{1cm} (8)

Using similar assumption as in equation (7), we can assume that the reactive power of the line, \( Q_{\text{Line}} \) is;

\[ jQ_{\text{Line}} \approx 0 \]  \hspace{1cm} (9)

Unlike the case of power swing, the line impedance during a fault is very large compared to the load impedance and \( V_{\text{line}} \approx V_s \). Thus, equation (1) becomes,

\[ S_s \approx \frac{|V_{\text{line}}|^2}{jX_{\text{line}}} = jQ_{\text{Line}} \]  \hspace{1cm} (10)

This proves that the line reactive power change significantly during a fault. Equations (9) and (10) show
that the line reactive power is abruptly changing from 0 to $|S_q|$. This feature can be used as a detection criterion for distance relay operation to avoid triggering of false tripping signal due to power swing. Based on this criterion, it is possible to propose the use of rate of change of the line reactive power, $dQ_{\text{line}}/dt$ to discriminate between a fault and a power swing so that the relay operates only due to a fault.

3 Simulation Results

The proposed detector is studied on the IEEE 39 bus test system by using the commercial PSS/E software version 31. The test system consists of 10 generators and 18 loads as shown in Fig. 3.

Fig. 3  The IEEE 39 bust test system

Five different fault cases have been considered to generate the power swing condition as described below:
Case 1: Three phase fault at line between buses 5-8 from 1 to 1.15s, followed by fault clearance and line trip
Case 2: Three phase fault at line between buses 6-7 from 1 to 1.15s, followed by fault clearance and line trip.
Case 3: Three phase fault at bus 5 from 1 to 1.15s, followed by fault clearance and bus disconnect
Case 4: Three phase fault at bus 6 from 1 to 1.15s, followed by fault clearance and bus disconnect
Case 5: Three phase fault at bus 11 from 1 to 1.15s, followed by fault clearance and bus disconnect

From the above cases, 3 different relays have been identified to be operating falsely during power swings. The identified mal-operating relays on the basis of case studies are:
Case 1: Relay at bus 6
Case 2: Relay at bus 5
Case 3: Relay at bus 6
Case 4: Relay at bus 14
Case 5: Relay at bus 14

In order to justify the reliability of the proposed detector, another three phase faults need to be simulated during power swing occurrences. The locations of the entire faults are simulated at 200% of the distance relay protected zone. These entire faults are simulated at 3-3.05 second of the simulation time. Bus 6 active power variation during simulation is shown in Fig.4.

Fig. 4  Active power profile at bus 6

From Fig. 4, it is clearly observed that the first fault has been created at 1 second until 1.15 second which causes a power swing to appear after the fault clearance. Subsequently, a second fault which is located at 200% away of the relay boundary has been created at 3 second. During the simulation, the apparent impedance, $Z_a$ seen by distance relay at bus 6 is very low during the fault and power swing conditions. The apparent impedance or impedance trajectory enters the relay operating zone at both situations as shown in Fig. 5.

Fig. 5  The apparent impedance or impedance trajectory enters the relay operating zone during fault and power swing at relay bus 6

Once the apparent impedance, $Z_a$ enters the relay operating zone, the distance relay may send the trip...
signals to the breaker to clear the fault. However, during power swing, the trip signals should be blocked to avoid false tripping. The proposed additional detection criteria can be introduced in distance relay in order to avoid such undesirable relay operation.

3.1 Results of $ld\theta/dtl$

One of the fast techniques to discriminate a fault and a power swing employs the use of negative sequence current magnitude and the magnitude of derivative of current angle, $ld\theta/dtl$ [4]. However, identical values of $ld\theta/dtl$ may appear during fault and fault clearance as the increment of current angle is very substantial in both situations. The results in Fig. 6a and 6b show clearly the $ld\theta/dtl$ values of the affected relay during fault, fault clearance and power swing for each case study described before.

![Fig. 6a Result from $ld\theta/dtl$](image)

![Fig. 6b Result from $ld\theta/dtl$ (enlarge)](image)

As can be seen from Fig. 6a, the range of $ld\theta/dtl$ is approximately between 2,100 degree/second to 9,500 degree/second during the fault. The results of $ld\theta/dtl$ values during power swing are depicted in Fig. 6b, where the value of $ld\theta/dtl$ is between 9 degree/second to 45 degree/second. The results from both figures prove that the $ld\theta/dtl$ is very promising in distinguishing between a fault and a power swing. However, it can be noted that the $ld\theta/dtl$ values are not suitable to differentiate between fault and fault clearance as shown in Fig. 6a. From Fig. 6a, it can be deduced that, the value of $ld\theta/dtl$ is apparently in similar range for fault and fault clearance. The distance relay installed in these lines may send false trip signals during fault clearance operation.

3.2 Results of $dQline/dt$

The $dQline/dt$ is used as a new detector in order to enhance the capability of the relay to differentiate between a fault, power swing and fault clearance in power systems. Simulation results are displayed by plotting the $Qline$ and $dQline/dt$ profile at the effected line against time as shown in Fig. 7 and Fig. 8, respectively.

![Fig. 7 $Qline$ at at line between buses 6-11 which is associated to case 1](image)

![Fig. 8 $dQline/dt$ at the line between buses 6-11 which is associated to case 1](image)
The results in Fig. 9a and Fig. 9b shows that the magnitude of dQline/dt for the effected relay during fault, fault clearance and power swing for each relay that has been installed at the associated lines.

From the figures, it is clear that the range of dQline/dt for each case is significantly different during fault; fault clearance and power swing. The range of dQline/dt is between 60000 to 120000 Mvar/second, -90000 to -51000 Mvar/second and 20 to 320 Mvar/second for fault, fault clearance and power swing, respectively. The results prove that the proposed technique is able to differentiate the fault; the fault clearance and power swing, and improving the reliability of the relay operation as compared to the technique which has been proposed by Jonsson and Daadler [4].

4 Conclusion

The use of dQline/dt has been proposed as a new detection technique to block the distance relay trip signals during power swing. Time domain simulations were first carried out under the conditions of fault and power swing. The proposed detector has been tested to evaluate its effectiveness in differentiating the fault, power swing and fault clearance. The results show that the dQline/dt can effectively differentiate the fault, fault clearance and power swing unlike the use of ldl/dtl.

References: