A New Power Swing Detection Scheme for Distance Relay Operations

Ahmad Farid Bin Abidin, Azah Mohamed, Hussain Shareef

Abstract**—**This paper presents a new detection scheme based on the derivative of the line reactive power as seen by a relay to prevent distance relay mal-operation during power swings. This proposed scheme 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 simulation were 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 between a fault, fault clearance and power swing in order to activate the correct relay trip signals during power swings**.**

Keywords**—**distance relay, line reactive power, power swing detector (PSD), power swings

I. Introduction

Power oscillation which is inherent to power systems may result from any event such as line switching, short circuit faults, generator tripping or load shedding. During power oscillation, the measured apparent impedance, Z_a at relay location may decrease and it could enter the relay tripping zone. For this situation, the relay needs to make a proper justification either to activate the tripping signals or to block the tripping signals. Power oscillation can be classified into two type, which is, stable swing and unstable swing [1,2]. During stable swing, tripping actions should be avoided at all costs [2]. 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.

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.Many techniques have been introduced to block the trip signals during power swing. One of the earliest techniques is the using of a negative sequence current magnitude and a derivative of current angle to dictate the relay operation during fault and power swings [4]. 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. A combination of waveform of swing center's voltage (WSCV) and synthetic negative sequence vector 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 in [4].

A technique based on Vcosθ was introduced in which the technique takes 30-50 ms to activate a power swing blocking scheme [6]. However, further testing is needed in larger power systems before the existing technique can be deployed to a distance 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 other techniques [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.

II. DISTANCE PROTECTION DURING TRANSIENT INSTABILITY

Transient stability is the ability of the system to withstand contingencies by surviving the transient conditions to acceptable steady-state operation [10-11]. It deals with the effect of large and sudden disturbances such as the occurrence of a fault, the sudden outage of a line or the sudden application or removal of loads [12]. The fundamental phenomena appearing in a power system in case of transient instability are power oscillations. Generally, power oscillations can be divided into three different categories [1];

i. Local plant mode oscillations or inter machine oscillations with a frequency range of 0.7 - 2 Hz (6 Hz),
ii. Inter-area oscillations, where groups of generators are swinging against each other in the frequency range of 0.4 - 0.7 Hz
iii. Large sub-systems oscillating against each other where the swinging frequency usually is in the order of 0.1 - 0.3 Hz.

Power oscillations may be the source of incorrect distance protection behavior as the cycle times of the oscillations are in the same time range as the timer settings of the distance protection. The two machine system in Fig. 1 is used to analyze the performance of distance protection during power oscillations [4]. By studying the apparent impedance as seen by a relay located at bus a, the different transfer angles the effect of power oscillations can be examined. The analysis made in this section is similar to the one given by Kundur in [1].

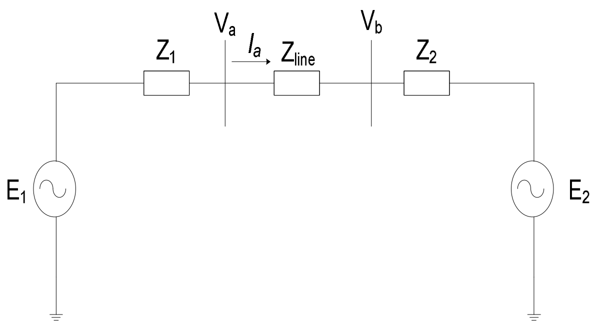

Fig. 1 Simple two machine power system

In Fig. 1, E_1 and E_2 are the internal voltages of the machines and Z_1 and Z_2 are the transient impedance. E_2 is assumed to be the reference phasor and θ represents as the transmission angle. As the transferred real power increases, this angle becomes larger. The relation between transferred power, P_2 and transmission angle, θ is described by the equation below,

$$S_2 = E_2 I_2^* \qquad (1)$$

$$S_2 = E_2 (E_1 - E_2/Z_T)^* \qquad (2)$$

where $Z_T = Z_{Line} + Z_1 + Z_2$

$$S_2 = E_2 (E_1 \cos\theta - E_2 \sin\theta - E_2/Z_T)^* \qquad (3)$$

At transmission lines since the reactance component is more dominant as compare to the resistance component, then, equation (2) becomes,

$$S_2 = E_2 (E_1 \cos\theta - jE_2 \sin\theta - E_2/jX_T)^* \qquad (4)$$

where $Z_T \approx jX_T$

By expanding equation (3), we get,

$$S_2 = (E_1 E_2 \sin\theta / X_T) + j(E_1 E_2 \cos\theta + E_2^2 / jX_T) \qquad (5)$$

Considering the relation between apparent power, real power and reactive power which is give by,

$$S_2 = P_2 + jQ_2 \qquad (6)$$

Hence, the real part of equation (5) can be written as,

$$P_2 = |E_1||E_2| \sin\theta / X_T \qquad (7)$$

From (7), the transmission angle, θ is described as,

$$\theta = \sin^{-1}(X_T P_2 / |E_1||E_2|) \qquad (8)$$

The measured apparent impedance seen by the a relay at the bus a, Z_a during a power swing can be derived by considering the following equation,

$$I_a = (E_1\angle\theta - E_2\angle 0)/(Z_{line} + Z_1 + Z_2) \qquad (9)$$

$$V_a = E_1\angle\theta - I_a Z_1 \qquad (10)$$

$$Z_a = V_a / I_a = (E_1\angle\theta / E_1\angle\theta - E_2\angle 0) Z_T - Z_1 \qquad (11)$$

where

V_a :Voltage at bus a,
I_a : Current flowing from bus a to bus b

For the case of $E_1 = E_2$, the impedance becomes,

$$Z_a = (Z_T / 1\angle\theta - 1\angle 0) - Z_1 \qquad (12)$$

Simplifying (12) further, we get,

$$Z_a = ((Z_T/2) - Z_1) - j((Z_T/2)\cot(\theta/2)) \qquad (13)$$

For a stable swing, θ increase gradually until a maximum value is reached, where the trajectory shifts direction and

θ decreases until a minimum value is reached, where the trajectory ones again shifts direction. This sequence of events is repeated until the oscillations are damped out. If the trajectory of θ reaches beyond the angle of 180 degrees, the swing can be considered unstable.

The fluctuations of voltage and current in case of power swings make it difficult for the relay to discriminate between 3-phase faults and power swings. Impedance calculations based on these measurement quantities suggest similar conditions as under system faults. Thus, the swing impedance trajectory may enter the relay operating zone or even the instantaneous impedance zone of distance relays as shown in Fig. 2.

During stable swings, the swing impedance trajectory returns to the actual load impedance locused. Thus, all distance relays in the power system subject to swings need to be securely blocked for the time the swing impedance remains within the distance relay characteristic in order not to disrupt the power system integrity.

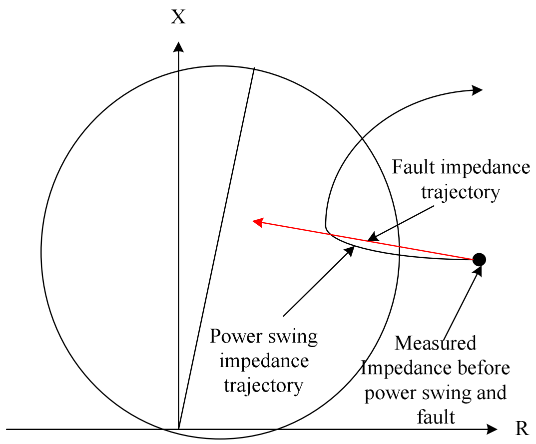

Fig. 2 The swing impedance trajectory entering the relay operating zone

III. Conventional Power Swing Detector

The most conventional method used for Power Swing Detectors (PSD) is based on the transition time through a blocking impedance area in the RX-diagram. Basically, the method uses the feature that the movement of the apparent impedance during power swings is slow as compared to its movement for short circuit faults. Fig. 3 shows the characteristics of Power Swing Detector (PSD) schemes using line detector.

The swing impedance moving along its trajectory needs some time to travel through the two blinders shown in Fig.3. Its trajectory speed is slow compared to the sudden impedance jump when faults occur. At the instant of faults, the impedance jumps instantly from load to fault impedance.

The conventional power swing detection is based on the time Δt that elapses as the traveling swing impedance trajectory enters and leaves two thresholds (circles or blinders). If the times, the swing impedance requires to pass through the two impedance set points is longer than a set time Δt, the swing detector will block the distance relay's tripping signals.

Based on the relay setting procedure, if the inner line is not passed, the device declares a stable swing while in case the inner line or circle is penetrated after the timer has expired; the device signals an unstable swing. However, depending on the system configuration nearby the relay, this solution may not be acceptable with respect to line length, fault clearing, load discrimination and the nature of possible power swings.

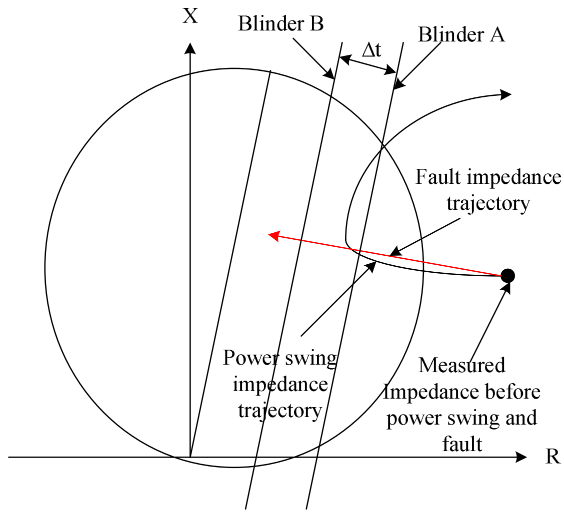

Fig. 3 Two Line Blinders PSD

IV. Formulation of New Detector During Power Swing

The fundamental behavior of a line reactive power immediately before and after a three phase fault can be explained by using a simple power system shown Fig. 4.

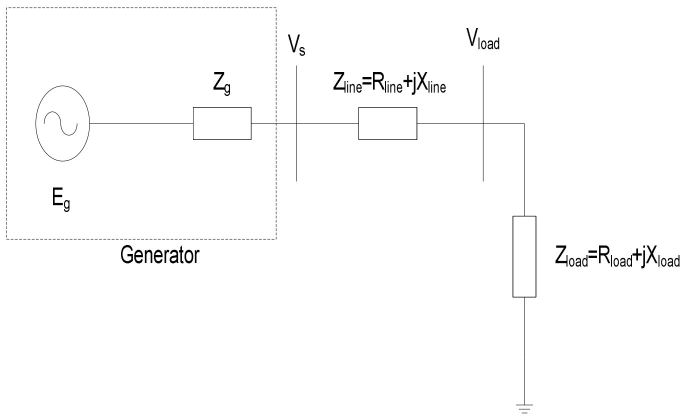

Fig. 4 A simple power system model

The proposed criterion is based on the fact that most of the reactive power during a fault is consumed by the line reactance. Initially, the input power to the system is defined as,

$$S_s = V_s I_s^* \qquad (14)$$

The current, I_s is given by,

$$I_s = V_s / (Z_{line} + Z_{load}) \qquad (15)$$

Substituting (15) into (14), we get,

$$S_s = V_s (V_s / (Z_{line} + Z_{load}))^*$$

$$= |V_s|^2 / (Z_{line} + Z_{load}) \qquad (16)$$

By using the Kirchoff Voltage Law , the voltage V_s can be written as;

$$V_s = V_{line} + V_{load} \qquad (17)$$

Substituting (17) into (16), we get;

$$S_s = |V_{line} + V_{load}|^2 / (Z_{line} + Z_{load}) \qquad (18)$$

Then, the line impedance, Z_{line} of the power system is be represented as,

$$Z_{line} = R_{line} + jX_{line} \qquad (19)$$

The resistive component, R_{line} at transmission lines is very small and hence it is neglected. Thus, equation (19) becomes,

$$Z_{line} = jX_{line} \qquad (20)$$

Substituting (20) into (19), we get,

$$S_s = \frac{|V_{line} + V_{load}|^2}{jX_{line} + Z_{load}} \qquad (21)$$

where,

S_s : apparent power at sending end
V_s : nominal voltage at sending end
I_s : current flow at the line
Z_{line} : line impedance
R_{line} : line resistance
X_{line} : reactance of the line
Z_{load} : load impedance
V_{line} : line voltage
V_{load} : load voltage
S_{load} : apparent power of the load
P_{load} : real power of the load
Q_{load} : reactive power of the load
S_{line} : apparent power of the line
P_{line} : real power of the line
Q_{line} : reactive power of the line

From Fig. 4, the apparent power of the system is composed of the combined apparent power of transmission line and load, which is given by,

$$S_s = S_{line} + S_{load}$$

$$= P_{line} + jQ_{line} + P_{load} + jQ_{load} \qquad (22)$$

Assuming that $P_{line} << Q_{line}$ equation (22) then is written as,

$$S_s = jQ_{line} + P_{load} + jQ_{load} \qquad (23)$$

During a power swing, the load impedance is significantly larger than the line impedance, that is,

$$Z_{line} << jZ_{load} \qquad (24)$$

The simplified apparent power at the sending end, $S_s^{'}$ can be written as

$$S_s^{'} = |V_{load}|^2 / Z_{load} = P_{load} + jQ_{load} \qquad (25)$$

Based on the above equation, the corresponding power system model during power swing is further simplified as shown in Fig. 5.

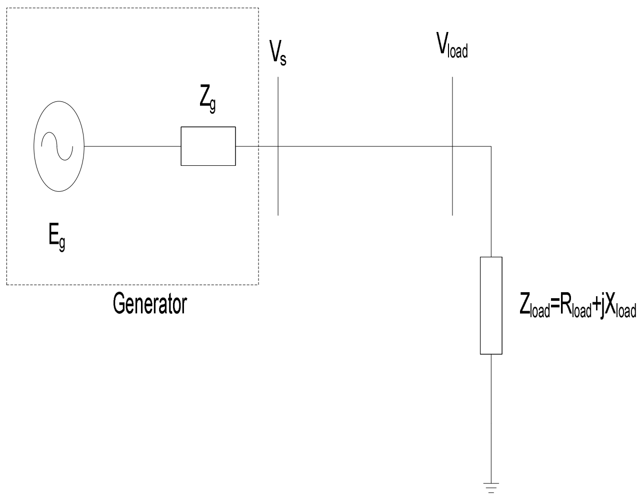

Fig. 5 The simplified power system model during power swing

By subtracting (25) from (23), value of line reactive power is,

$$jQ_{line} = 0 \tag{26}$$

Based on equation (26), it can be deduced that during power swing, no reactive power is consumed by the line.
Unlike the case of power swing, the line impedance during a fault is very large compared to the load impedance and $V_{line} \approx V_s$. Thus, equation (21) becomes,

$$S_s = \left|V_{line}\right|^2 \Big/ jX_{line} \tag{27}$$

Thus, during a fault, the line reactive power changes significantly during a fault. Equations (26) and (27) show that the line reactive power is abruptly changing from 0 to S_s .

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, dQline/dt to discriminate between a fault and a power swing so that the relay operates only due to a fault.

V. Test Results

Large figures and tables may span both columns. Place figure captions below the figures; place table titles above the tables. If your figure has two parts, include the labels “(a)” and “(b)” as part of the artwork. This section describes the simulations and tests that have been performed in order to study the behavior of the proposed detector under power swing conditions. 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 18 loads and 36 lines as shown in Fig. 6.

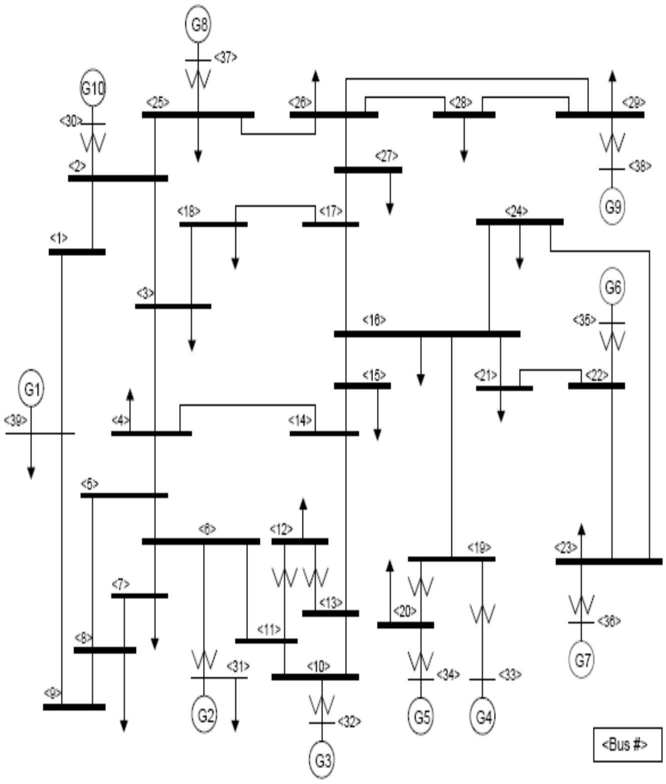

Fig. 6 The IEEE 39 bust test system

The IEEE 39 bus test data are constructed based on PSS/E format raw data. The 39-bus system has 10 generators GENROE and 10 exciter, ESDC1A type. The parameters of generators GENROE and exciter, ESDC1A type are tabulated in as shown Tables 1 and 2, respectively.

TABLE 1
THE PARAMETERS OF GENERATORS GENROE

Parameter	Value
T'do (> 0)	10.2
T"do (> 0)	0.03
T'qo (> 0)	1.5
T"qo (> 0)	0.04
Inertia H	4.2
Speed Damping D	0
Xd	1
Xq	0.69
X'd	0.31
X'q	0.31
X"d = X"q	0.2
Xl	0.125
S(1.0)	0
S(1.2)	0

TABLE 2
THE PARAMETERS OF EXCITER, ESDC1A TYPE

Parameter	Value
TR	0
KA	5
TA	0.06
TB	0
TC	0
VRMAX or zero	5
VRMIN	-5
KE or zero	-0.05
TE (> 0)	0.25
KF	0.04
TF1 (> 0)	1
0. Switch	0
E1	1.7
SE(E1)	0.5
E2	3
SE(E2)	2

A. Simulation Procedure

The dynamic simulation of a power system s using PSS/E software has three basic steps:

i. Construction of a set of differential equations describing the behavior of the physical system in general.
ii. Determination of a set of values of constant and variable parameters.
iii. Integration of the differential equations with the values determined in Step 2 as initial conditions.

The following procedure need to be fulfilled before conducting dynamic simulation.

i. Creating from scratch a RAW file using an already created RAW file.
ii. Running a successful load flow case and checking to ensure that all violations are resolved.
iii. Converting loads and generators in the saved load flow case (.sav) file.
iv. Creating a DYRE file.
v. Running the base case static load flow analysis.
vi. Running the dynamic analysis and plotting of results

Every dynamic simulation is based on a load flow case that provides the required transmission network data, load data, and generator positive sequence model. The set of files given in Table 3 are required to carry out load flow analysis and dynamic stability simulation by assessing PSS/ *psslf4* and PSS/E *pssds4* files, respectively. In addition, the converted version of the file *IEEE39bus_converted.sav* is used for performing dynamic stability studies.

TABLE 3
SET OF PSS/E FILES TO CARRY OUT LOAD FLOW AND DYNAMIC SIMULATION

File Name	Description
IEEE39bus.raw	Base case input data file
IEEE39bus_unconverted.sav	Main load flow solved case
IEEE39bus.sld	Single line diagram drawing datafile
IEEE39_stability.dyr	Base case Dynamic data file
IEEE39_converted.sav	Converted saved case file with loads and generators converted
IEEE39_basecase.snap	Base case snap shot file
IEEE39_event.snap	Base case event file
IEEE39_seq.snap	Base case sequence impedance file

For the purpose of conducting studies on power swing, five different fault cases with the following sequence of actions are implemented in the dynamic simulation as described below:

Case 1: Three phase fault at line connecting buses 5-8 from 1 to 1.15s, followed by fault clearance and line trip
Case 2: Three phase fault at line connecting 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 from the 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. The active power variation at bus 6 during simulation is shown in Fig.7.

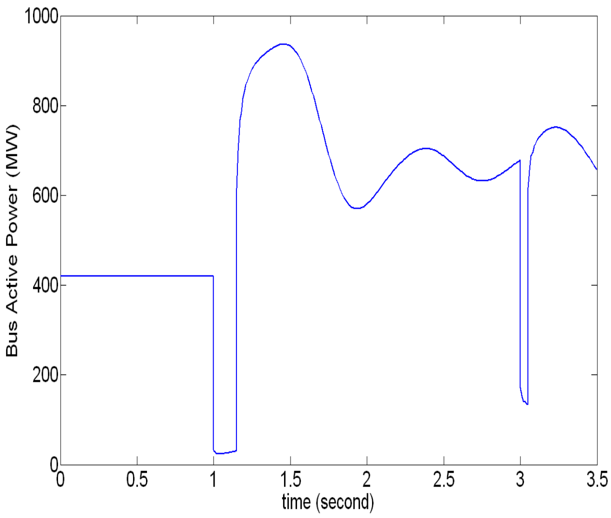

Fig. 7 Active power profile at bus 6

From Fig. 7, 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 the 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. 8.
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 is then introduced in distance relay in order to avoid such undesirable relay operation.

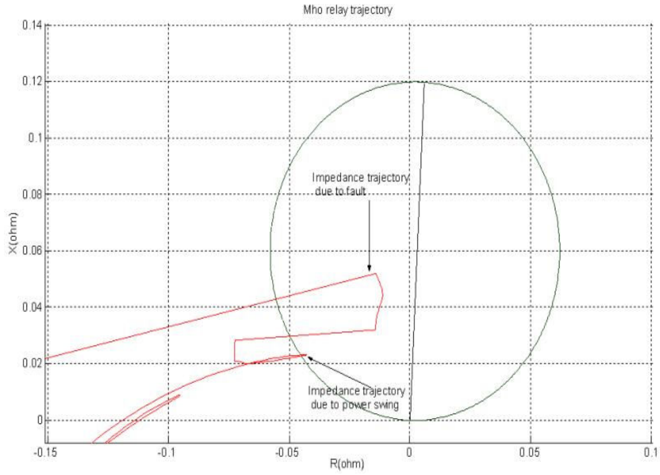

Fig. 8 The apparent impedance enters the relay operating zone during fault and power swing at relay bus 6

B. Results of |dθ/dt|

One of the fast detectors used to discriminate a fault and a power swing employs the use of negative sequence current magnitude and the magnitude of derivative of current angle, |dθ/dt| [4]. However, identical values of |dθ/dt| may appear during fault and fault clearance as the increment of current angle is very substantial in both situations. The results in Fig. 9 and 10 show clearly the |dθ/dt| values of the affected relay during fault, fault clearance and power swing for the case.

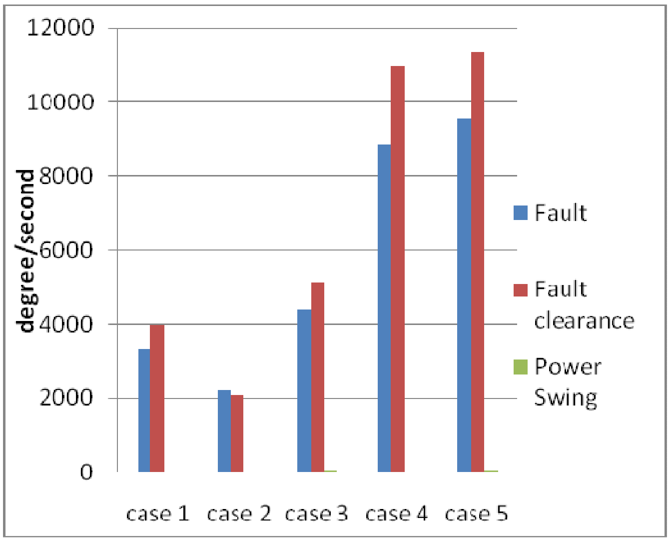

Fig. 9 Result of |dθ/dt|

As can be seen from Fig. 9, the range of |dθ/dt| is approximately between 2,100 degree/second to 9,500 degree/ second during the fault. The results of |dθ/dt| values during power swing are depicted in Fig. 10, where the value of |dθ/dt| is between 9 degree/second to 45 degree/second.

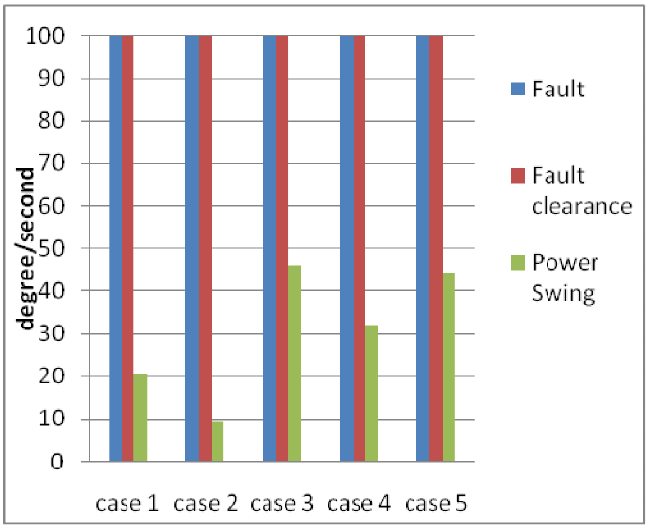

Fig. 10 Result of |dθ/dt| (enlarge)

The results from both figures prove that the |dθ/dt| is very promising in distinguishing between a fault and a power swing. However, it can be noted that the |dθ/dt| values are not suitable to differentiate between fault and fault clearance as shown in Fig. 9. From the figure, it can be deduced that, the value of |dθ/dt| 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.

VI. Conclusion

The use of dQ_{Line}/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 between a fault, power swing and fault clearance. The results show that the dQ_{Line}/dt can effectively differentiate the fault, fault clearance and power swing unlike the use of |dθ/dt|.

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References

[1] S. H. Horowitz, and A. G. Padke, Power System Relaying, John Wiley & Sons, Ltd, West Sussex, England, 2008 .

[2] S. Jiao, Z.Bo, W. Liu, Q.Yang, , New Principles to Detect Faults During Power Swing, *Seventh IEE Int. Conf. on Dev. in Power Syst. Protect. 2001,* pp.515 - 518 .

[3] P. Kundur, Power System Stability and Control McGraw-Hill, New York, 1993.

[4] M. Jonsson and J. Daalder, A New Protection Scheme to Prevent Mal-Trips Due to Power Swings, *IEEE/PES Transmission and Distrib. Conf. and Expo., Vol. 2, 2001*, pp. 724 – 729.

[5] X.Lin, Y. Gao and P.Liu, , A Fast Unblocking Scheme for Distance Protection to Identify Symmetrical Fault Occurring During Power Swings, *IEEE Trans. on Power Del., Vol 1, 2008*, pp. 73-77.

[6] B. Su,. X. Z. .Dong, Z.Q.Bo, Y.Z.Sun, B.R.J Caunce, D.Tholomier and A.Apostolov, Fast Detector of Symmetrical Fault During Power Swing for Distance Relay, *IEEE Power Eng. Soc. Gen. Meet.*, Vol. 2, 2005, pp.1836 – 1841.

[7] L.Xiangning, Z.Qing, L.Wenjun, W.Kecheng and W. Hanli, A Fast Unblocking Scheme for Distance Protection to Identify Symmetrical Fault Occurring During Power Swings, *IEEE Power Eng. Soc. Gen. Meet., 2006,* pp.1-8.

[8] H. K. Zadeh and Z. Li, A Novel Power Swing Blocking Scheme Using Adaptive Neuro-Fuzzy Inference System, *Electr. Power Syst. Research J., 2008*, vol. 78, pp. 1138-1146.

[9] P. M. Fonte and J. C. Quadrado, Stability Modelling of WECS for Power Generation, *WSEAS Trans. on Circuit and Syst., 2005*, vol. 3, pp. 1591-1596.

[10] S. Jalilzadeh and S.Jadid, Improvement of transient *stability by variation generator parameters and high speed fault clearing, WSEAS Trans. on Syst., 2005,* vol. 4, pp. 609-616

[11] V.G. Parkash, C. P. Singh and R. Dahiya, Transient Stability Improvement of SMIB With Unified Power Flow Controller, *2nd WSEAS Int. Conf. on Circuits, Systs., Signal and Telecommun. (CISST'08), 2008,* pp. 1155-1149.

[12] N. M. Hanoon, B.P.Kartik and O.M.Ahtiwash, A Neuro-Control Approach for Flexible AC Transmission Systems, , *WSEAS Trans. on Syst., 2004*, vol. 3, pp. 964-968

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