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A New PMU Based Power Swing Detector to Enhance Reliability of Distance Relay

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SUMMARY

Power grid protection aim is to make the generation, transmission and distribution of electrical energy as safe as possible from the effects of equipment failures. The operational security of the power system depends on the successful operation of the thousands of relays that protect power elements and hence protect the whole system against cascading failures. Thus, the failure of a relay to operate as intended may place at risk the entire power system and its elements.

In conventional transmission line protection, a distance relay is used to provide the primary as well as backup protection. The voltage and current phasors measurement needed by the distance relay for determining the impedance may be affected by the power disturbances such as power swing. Consequently, this power swing may cause mal-operation of Zone three distance relays which in turn may affect on the reliability of the whole protective scheme. The mal-operation of this relay is generally due to not only unnecessary tripping during power swing that reduces the security of protection system and hence its reliability but also unnecessary blocking when symmetrical fault occurs accompanying a power swing. This latter action may affect on a dependability of the relay and hence its reliability.

Many techniques have been developed to mitigate these effects and hence improve the relay reliability. One of the earliest techniques is the using of a negative sequence current magnitude and a derivative of current angle. This technique is very fast and its test results were promising in blocking false trip signals during power swing but when it is associated only with unsymmetrical faults. A combination of waveform of swing center's voltage (WSCV) and synthetic negative vector has been also utilized to block the tripping signals during power swing. The technique seems to be rigorous indiscriminating power swing and high fault resistance. However, it requires two computationally heavy steps of derivative operation. 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.

In order to improve the reliability of the relay, this work proposes a new scheme based on power swing detector using Phasor Measurement Units (PMUs). In addition to the local phasors information, the proposed scheme requires remote phasors information from different locations, which can be provided at high speed by PMUs. These measurements are used for calculating the power and the difference in phase voltages angles that may be used for detecting power swing and distinguishing it from the fault. This detector will not block relay when the power swing associated with any fault types. The MHO relay including power swing detector has been implemented using Simulink block set and S-function. To validate the present work, the performance of developed relay has been tested by signals generated by power network Simulink model running under different conditions. The test results show that this relay provides good discrimination between the transient high currents and the fault current.

KEYWORDS

Protection System, Distance relay, Reliability, PMU, Power Swing detector, Blocking Protection Function, symmetrical or asymmetrical faults.

1.INTRODUCTION

Power grid protection aim is to make the generation, transmission and distribution of electrical energy as safe as possible from the effects of equipment failures and events that place the power system at risk. When the faults occur in such power grid, protection systems are designed to isolate only a faulted part of the power grid, and leave the healthy parts of the system connected in order to ensure the continuity of the power supply. Disturbances include transient loss of synchronism called power swing may affect on transmission line relays and protection scheme in various ways. Some relays such as overcurrent, directional overcurrent and distance relays may respond to the variations of voltage and currents and their phase angle relationship. In fact, some of the above relays may even operate for stable power swings for which the power system should recover and remain stable [1]. A major cause of this mal-operation (false trip) is due to the relative long time delay for fault clearance of zone three backup relays. In order to overcome the drawbacks of these traditional relaying systems, many techniques have been developed such as a blinder that blocks the relay to operate during the power swing [2].

The mal-operation of this relay is generally due to not only unnecessary tripping during power swing that reduces the security of protection system and hence its reliability but also unnecessary blocking when fault occurs accompanying a power swing. This latter action may affect on a dependability of the relay and hence its reliability.

Many techniques have been developed to unblock the operation of the relay during power swing associated with fault condition. One of the earliest techniques is the using of a negative sequence current magnitude and a derivative of current angle [3]. This technique is very fast and its test results were promising in blocking false trip signals during power swing, but the possibility of false trip signals during symmetrical fault clearance has been noticed. A combination of waveform of swing center's voltage (WSCV) and synthetic negative vector has been utilized to block the tripping signals during power swing [4]. The technique seems to be rigorous indiscriminating 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 [3].

A technique based on Vcos (δ) was introduced in which the technique takes 30-50 ms to activate a power swing blocking scheme [5]. However, further testing is needed in larger power systems before the existing technique can be deployed to a distance relay. A more advanced technique using adaptive Neuro-fuzzy system has been developed to block the relay trip signals during power swings [6]. 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 [1, 4, 5, 7].

In order to improve both security and dependability and hence the reliability of the relay, this work proposes a new scheme based on power swing detector using Phasor Measurement Units (PMUs) [8, 9]. In addition to the local phasors information, the proposed scheme requires remote phasors information from different locations for power swing detection, which can be provided at high speed by PMUs. These measurements are used for calculating the apparent power absorbed by power line and the difference in phase angles of voltages that may be used for detecting power swings and faults. Hence, the proposed scheme blocks tripping signal during the power swing and unblocks it during fault condition. The detector has been tested using the two machine system model. A comparison with the conventional technique is also made to validate of the proposed approach.

2. DISTANCE PROTECTION DURING POWER SWING

Generally, two machine system model as shown in Fig.1 is used to analyze the performance of distance protection during power swings [4, 7, 8]. By studying the apparent impedance as seen by a relay located at bus S, the different transfer angles and the effect of power oscillations can be examined. In Fig. 1, $\mathbf{V_S}$ and $\mathbf{V_R}$ are the voltages at sending point and receiving point respectively, and $\mathbf{Z_T}$ is the impedance of the transmission line where the reactance of the two sources is very small which can be neglected.

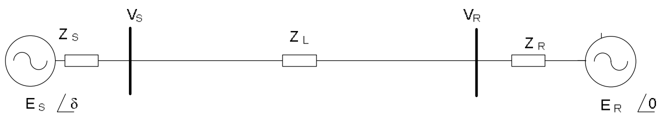

Fig.1 Two Machine model.

$\mathbf{V}_R$ is assumed to be the reference phasor and δ represents the transmission line angle. The relationship between transferred power $\mathbf{S}_R$ to the receiver and δ is described as follows,

$$\mathbf{S}_R = \mathbf{V}_R \times \mathbf{I}_L^* \tag{1.a}$$

Or,

$$\mathbf{S}_R = \mathbf{V}_R\,((\mathbf{V}_S - \mathbf{V}_R)/\mathbf{Z}_T)^* \tag{1.b}$$

For transmission lines, since the reactance component is more dominant compared to the resistance component,$\mathbf{Z}_T \approx jX_T$, then, Eq.(1) becomes,

$$\mathbf{S}_R = \left(\frac{V_R V_S \, Sin\delta}{X_T}\right) + j\,\frac{(V_R V_S \, Cos\delta - V_R^2)}{X_T} \tag{2}$$

In the same manner, the transferred power at the sending point can be obtained,

$$\mathbf{S}_S = \left(\frac{V_R V_S \, Sin\delta}{X_T}\right) + j\,\frac{(V_R^2 - V_R V_S \, Cos\delta)}{X_T} \tag{3}$$

Hence, the differential power that may be absorbed by transmission line using Eqs (2) and (3) can be obtained as follows,

$$\Delta\mathbf{S} = \mathbf{S}_S - \mathbf{S}_R = j\,\frac{2(V_R^2 - V_R V_S \, Cos\delta)}{X_T} \tag{4}$$

It can be noted that the absorbed power by line is dependent on the angle and the reactance of the line X_T.

We can compute other quantities used in power-swing detection functions and see their dependence on system impedances. Assuming that $\mathbf{V}_S = \mathbf{V}_R = \mathbf{V}$, the following quantities used for power swing detection are as follows:

$$\text{Impedance:} \quad Z = \frac{V}{I} = \frac{x_T}{2}\text{Cos}\left(\frac{\delta}{2}\right) \tag{5}$$

$$\text{Rate of change of Z:} \ \frac{dZ}{dt} = -\frac{X_T}{2}\left(\frac{1}{1-\cos(\delta)}\right)\frac{d\delta}{dt} \tag{6}$$

It can be observed that most of them are dependent on the impedance X_T.

Faults are permanent compared to power swings that are slow events and disappear after a short period. This fact is used in the distance relay to distinguish between short circuit faults and power swings [10].

Traditional impedance-based characteristics for detecting power swings on the transmission network are shown in Fig.2. All of these methods involve measuring apparent impedance and introducing a time delay between two measuring elements.

The impedance measurement is typically a phase-phase impedance, where all three phase-phase loops are required for operation, or it is positive-sequence impedance.

A timer is started when the apparent impedance enters the characteristic as illustrated in Fig.2. If the apparent impedance remains between the inner and outer characteristics for the set time delay, the Power Swing Block (PSB) element operates and selected distance element zones are blocked from operation for a period of time. A timer determines if the change in impedance is due to a fault or a power swing. If it is an unstable power swing, then one can select tripping on the way into the characteristic or on the way out of the characteristic. Selection of tripping on the way in or on the way out is determined from numerous stability studies and the ability of the circuit breakers to isolate the circuit with a significant voltage angle across the breaker [6].

3. POWER SWING DETECTOR ALGORITHM

Two PMUs are used for measuring phase-currents and phase-voltages at both ends of the transmission line [8]. These values are received every 20 ms. On the base of these measurements, an angle difference δ and apparent power S absorbed by line are calculated and used in the developed algorithm for detecting the power swing and distinguishing it from the fault.

The proposed algorithm whose flow chart shown in Fig.3 is explained by the following steps:

1. Measured data by PMUs is read by Matlab program in S-function block
2. First array at steady state, at t =0, is assumed to give stable values. Stable angle is calculated and the threshold apparent power is set.The algorithm uses these values as reference values for some of the IF-THEN statements to be able to determine changes in the network.
3. Angle and apparent power are calculated at each time step and then filtered using a moving average filter.

4. The algorithm creates vectors for complex current, voltage and impedance. From these vectors, it calculates new vectors with phase angle and apparent power for all time steps.

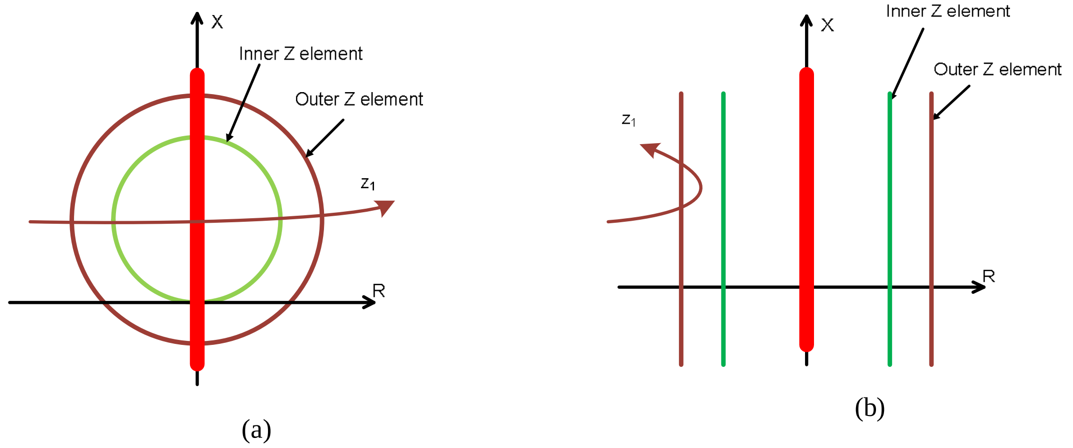

Figure 2 Different power swing protection schemes: (a) Double blinder, power swing characteristic, (b) Offset mho, power swing characteristic.

4. IF statement for change in angle is not detected go back to step 4, otherwise go to next step.
5. An IF statement compares values with each other or with threshold values, the outcome can be either Yes or No. If Yes go back to step 4, otherwise go to next step.
6. Activate the power swing block function (Block)

In the step 6, the computed electrical apparent power (S) absorbed by line will be checked if its rate of change is smalldue to the power swing only; the distance relay will be blocked. Otherwise, if the change of the apparent is large orthe apparent power is higher than the threshold value due tothe fault, the distance relay should not be blocked.

4. SIMULATION RESULTS AND DISCUSSION

The experimental setup for testing distance relay together with the proposed power swing detector using Simulink model is illustrated in Fig.4. The power swing detector algorithm is implemented in S-function block. Digital filter based on Fourier Transform is used to extract the fundamental frequency phasors, voltages and currents [9]. The phasors for line voltages and currents are used to calculate the line impedances for comparison with the Mho characteristic of the Phase Distance Elements. Timers are simulated to ensure the required time coordination between the pickup and the operation of protection elements. The whole system integrating the Mho distance relay with the proposed power swing detector has been implemented in Simulink/MATLAB environment using both the power system block set and S-function block. To test its performance a power grid consists of power transmission line linking two sources where one of them acts as infinite bus is used.

After building this system using a hybrid approach, both Simulink block sets and S-functions, the simulation has been investigated for two cases under different conditions during 3.5 Sec.

Case 1: we have run the simulation under different conditions; normal situation, power swing and fault condition. The simulation starts under normal condition, after that a power swing is applied at t= 0.5 sec and finally a fault is introduced at 1 Sec.

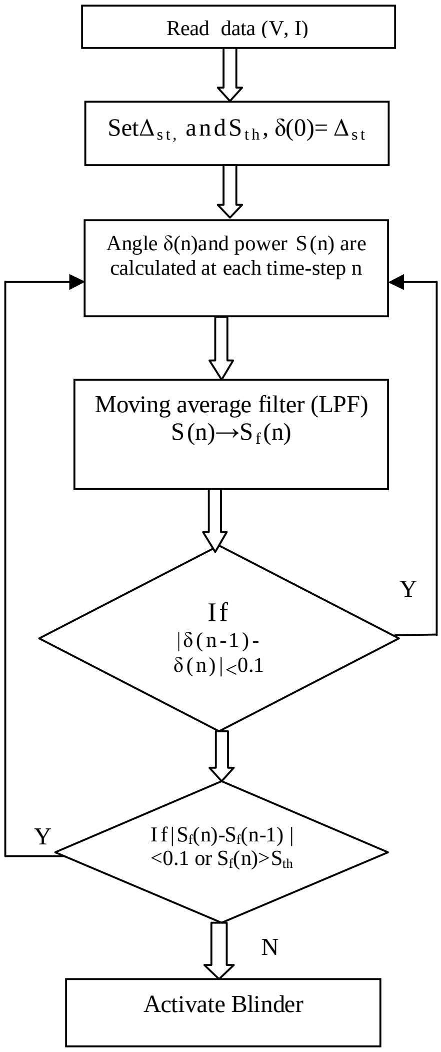

Figure 3. Flow chart of the power swing detector algorithm.

The obtained phase angle difference δ and the line absorbed power ΔS as function of time are shown in Figs.5 and 6 respectively. It can be noticed that their variations and dependencies verify Eq.(4).

Case 2: we have run the simulation under the same conditions for the same time as case 1. But, the distance relay integrating conventional power swing detector.

Figure 7 shows how the measured impedance enters the Mho distance relay characteristic during the fault. However, Fig.8 illustrates the output trip signals of the relay for both cases when the power swing event and the fault applied at 0.5 sec and 1 sec respectively. For the case where the conventional power swing detector is used, the relay of zone three will operate with a time delay of 0.2 sec after power swing event disappeared. However, for the situation when the proposed power swing detector is utilized, the relay trips just after the fault event occurs with time delay of 40 m Sec.

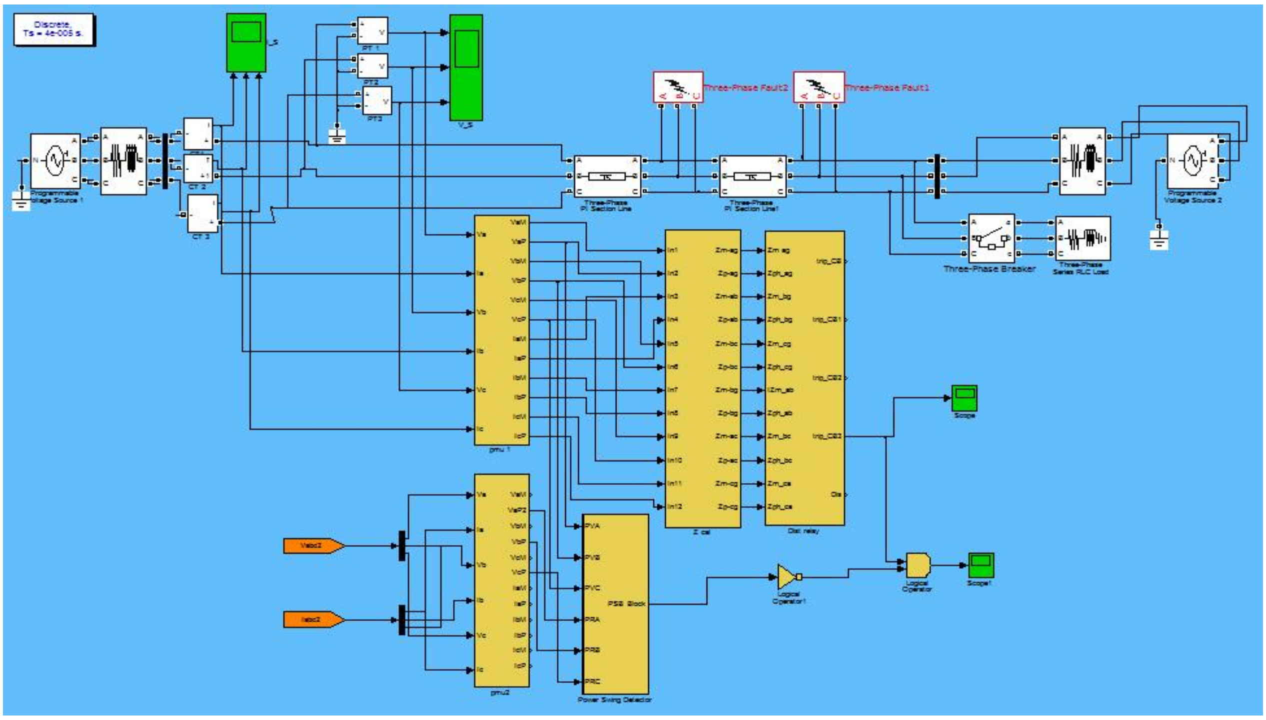

Figure 4. Test set up using power network Simulink model.

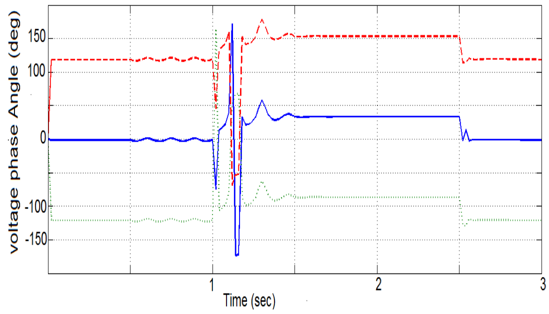

Figure 5. Voltage phase angle difference as function of time.

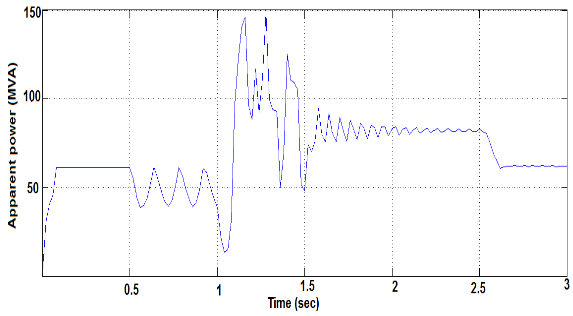

Figure 6. Apparent power absorbed by the line as function of time

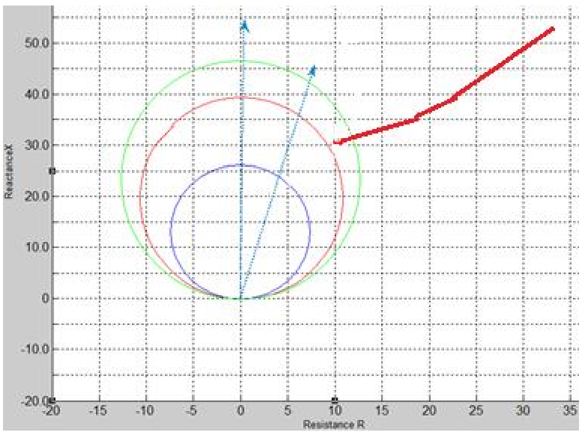

Figure 7. The Mho distance relay characteristic and the fault impedance.

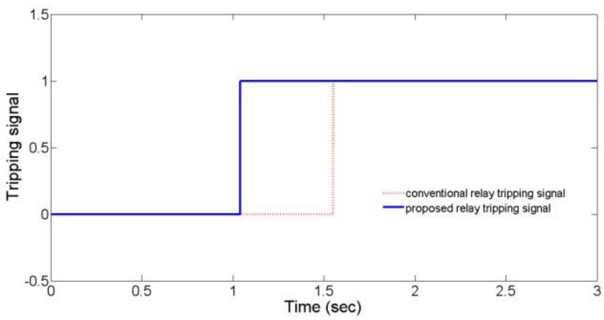

Figure 8.The output trip signal of the distance relay.

5.CONCLUSION

In this work, we have used a new scheme which is based on PMU for detecting the power swing and blocking the relay to trip during this condition. However, during the fault event accompanied with the power swing, the proposed detector unblocks the relay to trip. The complete MHO relay including this detector has been implemented using Simulink block set and S-function, and tested using a power network Simulink model. This proposed scheme has the following advantages: Firstly, the distance protection can be blocked reliably during power swings. When faults occur, the criterion can unblock the protection rapidly. It is superior to the conventional schemes based on local measurements. Secondly, this scheme can be implemented easily on PC based relay protection hardware using acquisition or DSP card.

Besides, the performance of the techniques employed to mitigate this unwanted action determines the reliability of this protective equipment because its behavior affects on various service conditions of power grid. Hence, the real-time power swings detector using PMUs is necessary and important to the safe and economic operation of smart power grids.

Moreover, the possibility to improve zone 3 protection system reliability while simultaneously decreasing clearance time can be achieved by using this new protection scheme as compared with reported data in [4, 10].

BIBLIOGRAPHY

[1] H.Bentarzi, A. Ouadi, M. Chafai and A. Zitouni, "Distance Protective System Performance Enhancement Using Optimized Digital Filter", (in Proc. CSECS '11, December 2011, pages 29-31).

[2] Mechraoui and D.W.P. Thomas, "A new blocking principle with phase and earth fault detection during fast power swings for distance protection", IEEETransactions on Power Delivery, (Vol. 10, No. 3, 1995, pages 1242-1248).

[3] M. Jonsson and J. Daalder, "A New Protection Scheme to Prevent Mal-Trips Due to Power Swings", IEEE/PES Transmission and Distrib., (Vol. 2, 2001, pages 724 – 729).

[4] 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, pages 73-77).

[5] 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, pages1836 – 1841).

[6] J. G. Rao and A. K. Pradhan," Differential Power-Based Symmetrical Fault Detection During Power Swing" , IEEE transactions on power delivery, (Vol. 27, NO. 3, 2012, pages 1557-1564).

[7] M.S.Sachdev and M. A. Baribeau, "A New Algorithm for Digital Impedance Relay", IEEE trans. Power Apparatus and systems, (Vol.98, 1979, pages 2232-2240).

[8] A.Ouadi, H. Bentarzi and J.C. Maun, " A new computer based phasor measurement unit framework" (Published Conference Proceedings style, IEEEexplorer), (in Proc. 6th Int. Conf. SSD'09, Djerba, Tunisia, 2009, pages1-6).

[9] A. Ouadi, H. Bentarzi and J. C. Maun, "Phasor Measurement Unit Reliability Enhancement Using Real-Time Digital Filter", International Journal of Circuits, Systems and Signal processing, (2011 pages 1-8).

[10] S. Lotfifard,, J. Faiz,and M. Kezunovic, " Detection of Symmetrical Faults by Distance Relays During Power Swings", IEEE transactions on power delivery, (Vol. 25, no. 1, , 2010, pages 81-87).