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Superimposed TMI Based Symmetrical Fault Detection during Power Swing

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Abstract: ***Distance relays are mal-operated during power swing condition as they are blocked in that period. Though, a fault occurs they must be unblocked to clear the fault event with high degree of reliability. This paper presents an incipient technique for symmetrical fault detection during power swing using superimposed based transient monitor index (TMI) currents. In this regard, initially transient monitor index (TMI) currents are estimated by taking difference between the predicted current samples regenerated from the dynamic phasors and the actual sample values, helps to distinguish the fault from the power swing condition [12]. To obtain robust discrimination between faults and swing the algorithm is further implemented by processing TMI values into superimposed TMI values. Simulation results are carried out in MATLAB environment by considering different fault situations and results designate how the inhibitions of subsisting methods are overcome by the proposed method.***

Keywords: Distance relay; Power swing; Symmetrical faults; Superimposed currents, transient monitor function.

1. Introduction

In power systems network, power swings are engendered due to occurrences of events like line outages by switching or fault events, any generator detachments, additament and expunction of immense load leads to abrupt transmutations in between voltage and current [1]. Distance relays tripping operations are designed whenever a quantified apparent impedance may enter into operating zone characteristics. These relays are operated causing an unwanted tripping of transmission lines during swing phenomenon. Hence, a power swing blocking (PSB) function is provided in distance relay to avoid unwanted trippings [2]. However, if a fault occurs during the power swing, it should be detected and the unblocking function be activated to clear the fault as anon as possible. Tripping operation are clearly identified in the case of unsymmetrical faults since zero sequence and/or negative sequence components are available and unblocking schemes can be effectively implemented. But, symmetrical fault detection during power swing is a complicated task. Due to absences of zero and negative sequence components respectively.

Several techniques have been implemented over the years to mitigate the problem with symmetrical faults detection during the power swing issue. A Wavelet based approach is presented in [3] to reliably and quickly detect any fault during power swing. This method requires high sampling frequency. Reference [4] introduce a fast unblocking scheme is rate of change of three-phase active and reactive power. The decaying dc components of current wave form present during fault is extracted by Prony method for detection in [5]. But this method depends on relationship between fault and DC decay components but cannot be utilized in standalone scheme.

A travelling wave based fast symmetrical fault detection approach is proposed in [6].It needs modal transformation in addition with WT. Using S-transform and PNN combined approach is developed in [7]. However, these schemes require large number of training data set. Mathematical morphology technique is used to discriminate the fault from power swing is presented in [8]. This methods require proper selection in design of structure element and it is difficult to use in real time applications. In [9], a method based on the frequency component of instantaneous three phase active power is presented. This technique uses fundamental frequency component by FFT analysis and also capable of detecting the symmetrical fault within one cycle. A differential power based approach is developed in [10].Selection of appropriate parameter 'k' in regression method requires lot of simulation trials. A wavelet singular entropy scheme is adopted to discriminate fault from swing and in addition to swing classification [11]. Transient monitor index based approach using current signal is presented in [12] to discriminate fault from swing. Parks transformation based fault detection is developed to mitigate the symmetrical fault detection issue during power swing in [13].

In this paper a new approach is proposed to overcome the above limitations. The technique uses currents signals from local end measurements are fed to estimate the transient monitor index values and prior to application of superimposed technique. The proposed method is tested on 400-kV ,50 Hz a SMIB double-circuit transmission system which is simulated in MATLAB environment for various fault conditions during the power swing such as fault resistance, fault inception times, power angles and fault distances. The method is evaluated and the performance results are presented on a comparative basis. Results indicate that the proposed method is fast, reliable.

Section-II of this paper describes proposed methods. Section-III presents the simulation results and conclusion are followed by Section-IV.

2. Proposed Method

In order to mitigate the symmetrical fault issue during swing an superimposed based transient monitor index current technique is proposed. Firstly, monitored current signals are processed into TMI algorithm [12] to estimate the TMI index values and then prior to application of superimposed technique. A brief explanation about the proposed methodology is as follows.

a) Transient monitor Index estimation

Generally transient monitor function method is clearly explained in [12]. Pristine sinusoidal input results in zero value for TM because the estimated phasor is precisely equal to the input. However, during pure power swing, the signal could be defined as

$$S(n) = a(n).\cos(n.\theta_1 + \emptyset)\ , a(n) = A.\cos(n.\theta_2) \quad (1)$$

Where θ_2 is sample per swing frequency, and A is the amplitude of the envelope of the signal. Therefore, during power swing, the first column of t_n is obtained as

$$t_n = \left(1 - \frac{2}{N}\ .\cos(0\ .\theta_1)\right).S(0) + \left(-\frac{2}{N}.\cos(1\ .\theta_1)\right).S(1)+ ..+\left(-\frac{2}{N}.\cos(N-1).\theta_1\right).S(N-1) \approx 0. \quad (2)$$

Concerning equation (2), results approximately zero because the variation of amplitude is negligible during low frequency oscillation:

$$a(0) \approx a(1) \approx \cdots \approx a(N-1) \quad (3)$$

In spite of fault occurred during power swing, the phasor estimation process to the input signal is computed as

$$S_{(n)} = \begin{cases} S_{s\omega}(n) = a(n)\ .\cos(n.\theta_1 + \emptyset) n < n_f \\ a_{(n)} = A\ .\cos(n.\theta_1) \\ S_{f_a}(n) = a(n)\ .\cos(n\ .\theta_1 + \emptyset) n > n_f \\ a_{(n)} = B\ .exp(n.\omega) \end{cases} \quad (4)$$

Where n_f is the starting sample of a fault, B is the amplitude, and ω = exp $(-\Delta t/\tau)$. When the first sample of the fault is observed in the data window, t is not equipollent to zero anymore, because the last inserted sample is conspicuously different from the others.

$$a(0) \approx a(1) \approx \cdots \neq a(N-1) \quad (5)$$

Existences of TMI values can enhance reliability of the fault detection method by showing clear discrimination between the power swing and fault events. To obtain this, phasor should be estimated more accurately during power swing. A dynamic phasor concept is introduced to evaluate the amplitude and phase of the voltage/current signal during a power swing, A sinusoidal quantity with variable amplitude and phase is defined as

$$S(n) = a(n).\cos\left(n.\theta_1 + \emptyset(n)\right) \quad (6)$$

Where$a(n)$ and $\emptyset(n)$are the variable amplitude and phase of the signal respectively and $p(n)$ is the dynamic phasor expressed as

$$p(n) = a(n)..exp\left(j\ .\emptyset(n)\right) \quad (7)$$

Using second order taylor series the signal $p(n)$is used to approximate dynamicaround t=0 is given by

$$p(n) = p_{0+}p_1\ .n + p_2\ .n^2$$

$$p_0 = p^{(0)}, p_1 = p'(0), p_2 = p''(0)/2 \quad (8)$$

According to the equations and for N samples of the signal in (15), the discrete time signal $\{S(n); n = 0,1, \ldots\ldots, N-1\}$in terms of its Taylor-Fourier coefficients $(P = [P_2, P_1, P_0, P_0^*, P_1^*, P_2^*]^T$) is extracted as

$$S = B.P \quad (9)$$

Here matrix B is in the basic form with the difference that it contains first and second derivative of dynamic phasor. These coefficients are calculated by least square method as

$$\hat{P} = (B^H.B)^{-1}.B^H.S \quad (10)$$

The difference between input and recomputed sample data, calculated from the dynamic phasor estimates, is considered as the error of estimation process

$$t = S - \hat{S} = (1 - B.(B^H.B)^{-1}.B^H).S \quad (11)$$

$$BB = \begin{bmatrix} 1-c_{11} & \ldots & c_{1N}\cos(N-1)\theta \\ c_{21}\cos\theta & \ldots & c_{2N}\cos(N-2)\theta \\ \vdots & \vdots\vdots\vdots & \vdots \\ c_{N1}\cos(N-1)\theta & \ldots & 1-c_{NN} \end{bmatrix} \quad (12)$$

Therefore the first array of t is obtained as

$$t_n = (1 - c_{11}\ .\cos(0.\theta_1)).S(0) + (-C_{12}\ .\cos(1.\theta_1)).S(1) + \cdots + (-c_{1N}\ .\cos((N-1)\ .\theta_1)).S(N-1) \approx 0 \quad (13)$$

Where $c_{ij}\{i,j \in 1,2, \ldots N\}$ are constant parameters. The accuracy of phasor estimation obtained by dynamic phasor is higher than static one due to consideration of first and second derivatives of the phasor.

Therefore TM is calculated by

$$TM = \sum_{n=r-N}^{n=r} |t_n| \quad (14)$$

The result of equation.14 shows approximately zero during power swing compared fault period. Performance of TMI index is evaluated under three-phase fault during power swing. Current signal is considered as input signal because its TM is higher than voltage.

b) Superimposed

A dynamic transition from normal system condition to an abnormal system condition occurs when a fault is incepted in the transmission line. The protective unit will observe this change from processing either voltage or current signal of the system. The fault current signal will differ from steady state current signal as fault current is consisting of superimposed [ ].Superimposed 'S_k' can be obtained from the expression

$$S_k = \sum_{y=k}^{k+N} i_{a(y)} - \sum_{y=k}^{k+N} i_{a(y-N)} \quad (15)$$

Where 'y' is sample number variable, 'k' is the recent sample number and 'N' is the number of samples per cycle. A fault will be registered if

$$s_k > T \quad (16)$$

Where, 'T' is the threshold value. During normal operation, the frequency may deviate from its fundamental value and it may lead to a false detection, either threshold has to be increased which is a compromise or an adaptive window scheme can be used to prevent this false detection. At a sampling frequency of 1 kHz the window length has been fixed at one cycle (20 samples) corresponding to a frequency of 50 Hz. The proposed scheme is developed by processing TM index values of current signal is feed to the superimposed technique. The method results shows high accuracy and robustness in discriminate between the fault and power swing condition. Exhaustive simulation is carried out to validate the proposed method is presented in the next section.

3. Simulation Results

A double-circuit transmission system shown in fig.1 is considered for verifying the proposed fault detection method. Simulation is done using MATLAB/SIMULINK and system data are provided in Appendix. A sampling frequency of 1 KHz is used for voltage and current signals.

A power swing is generated in line-1 by clearing a fault (symmetrical or unsymmetrical fault) in line-2 at point F by the opening of breakers B3 and B4. The relay R of line-1 is blocked to avoid unwanted tripping of line-1 due to power swing. Now, if there is a symmetrical fault in line-1 during power swing the relay R is unblocked by using the above technique. The efficacy of the proposed method is verified by creating several symmetrical fault situations with varying fault resistance, fault inception time, fault resistance and power angles. The following representative cases indicate the accuracy of the proposed method when compared to two other recent methods proposed in references [7] & [8].

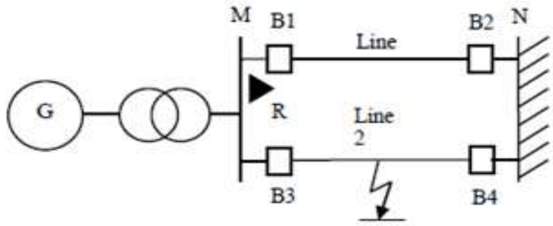

Figure 3: The 400kv double circuit line transmission system

a) Stable swing case ($\delta = 60^0$)

Consider a three phase-ground(LLLG) fault on the double circuit line as shown in figure.6 at a distance of 140km with fault inception angle $\delta=60^0$ and fault resistance R=0.01Ω.

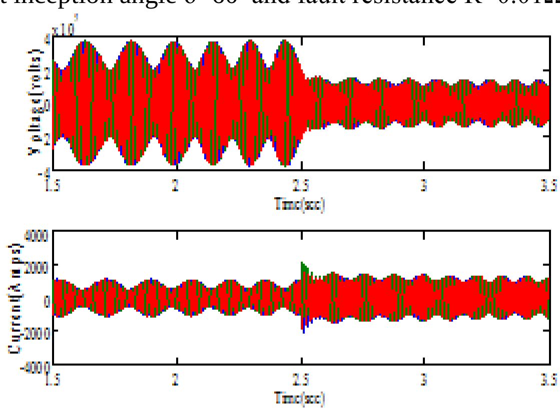

Figure 4 (a): Three phase instantaneous voltage and current at fault inception 2.5 sec

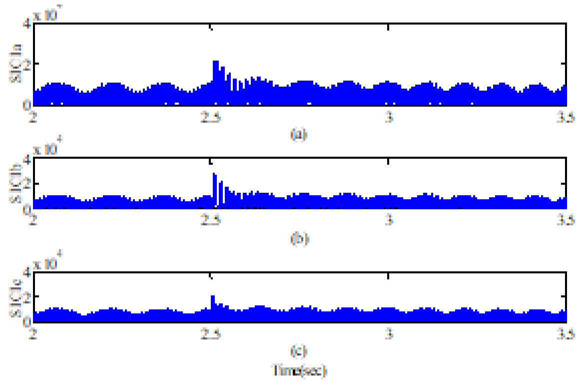

Figure 4 (b): Superimposed Currents all phases at fault inception 2.5 sec

b) Unstable swing case ($\delta = 120^0$)

Consider a three phase-ground (LLLG) fault at a distance of 140km with fault inception angle $\delta=120^0$ and fault resistance R=0.01Ω.

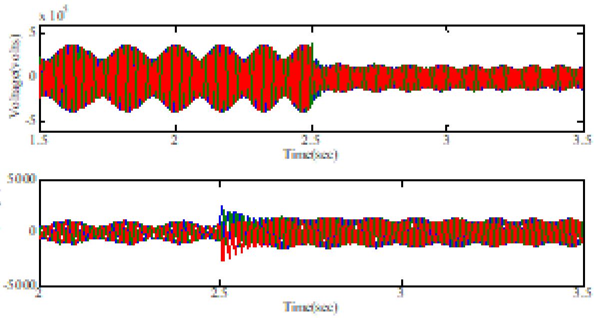

Figure 5 (a): Three phase instantaneous voltage and current at fault inception 2.5 sec

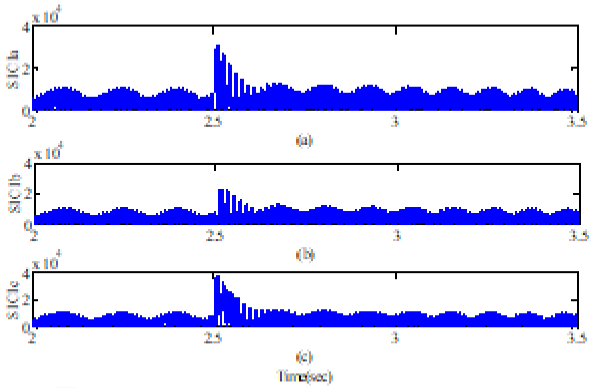

Figure 5 (b): Superimposed Currents all phases at fault inception 2.5 sec

c) Low resistance variation during stable swing

Consider a three phase-ground (LLLG) fault at a distance of 100km with fault inception angle $\delta=60^0$ and fault resistance R=0.01Ω.

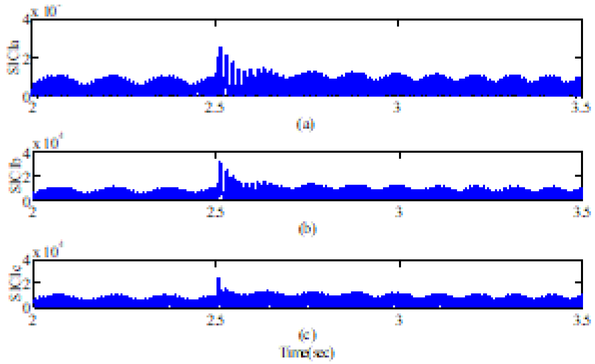

Figure 6: Superimposed Currents all phases at fault inception 2.5 sec

d) Low resistance variation during Unstable swing

Consider a three phase-ground (LLLG) fault at a distance of 100km with fault inception angle δ=60^0 and fault resistance R=0.01Ω.

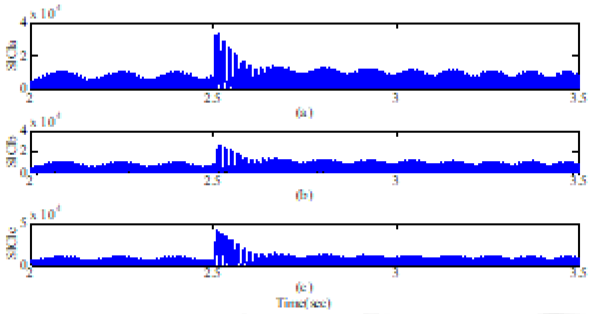

Figure 20: Superimposed Currents all phases at fault inception 2.5 sec

e) High resistance variation during stable swing

Consider a three phase-ground (LLLG) fault at a distance of 100km with fault inception angle δ=60^0 and fault resistance R=100Ω.

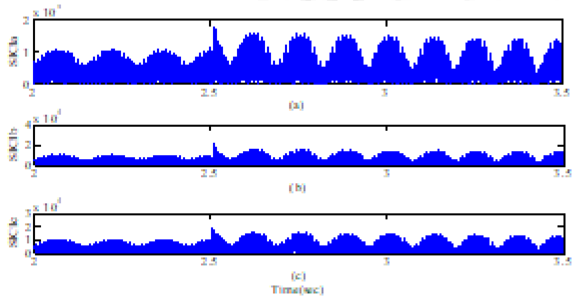

Figure 21: Superimposed Currents all phases at fault inception 2.5 sec

f) High resistance variation during unstable swing

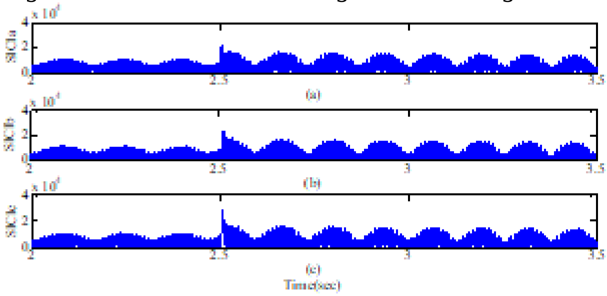

Figure 22: Superimposed Currents all phases at fault inception 2.5 sec

Consider a three phase-ground (LLLG) fault at a distance of 100km with fault inception angle δ=120^0 and fault resistance R=100Ω.

g) Close-in-fault during stable swing

Consider a three phase-ground (LLLG) fault at a distance of 20km with fault inception angle δ=60^0 and fault resistance R=0.01Ω.

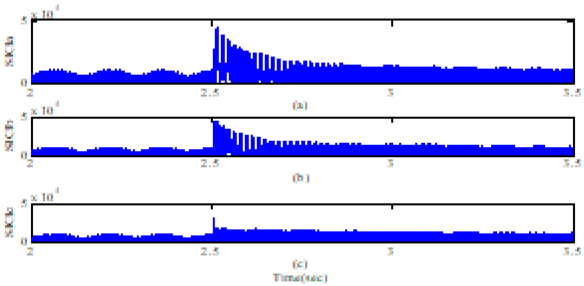

Figure 23: Superimposed Currents all phases at fault inception 2.5 sec

h) Close-in-fault during unstable swing

Consider a three phase-ground (LLLG) fault at a distance of 20km with fault inception angle δ=120^0 and fault resistance R=0.01Ω.

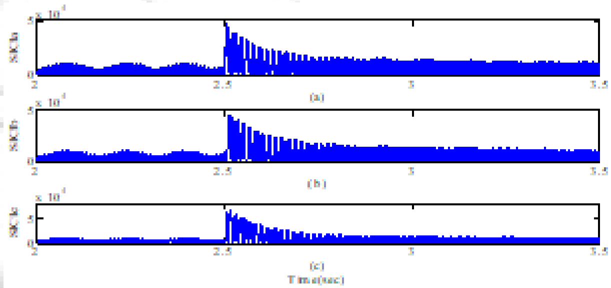

Figure 24: Superimposed Currents all phases at fault inception 2.5 sec

i) Far-end fault during stable swing

Consider a three phase-ground (LLLG) fault at a distance of 260km with fault inception angle δ=60^0 and fault resistance R=0.01Ω

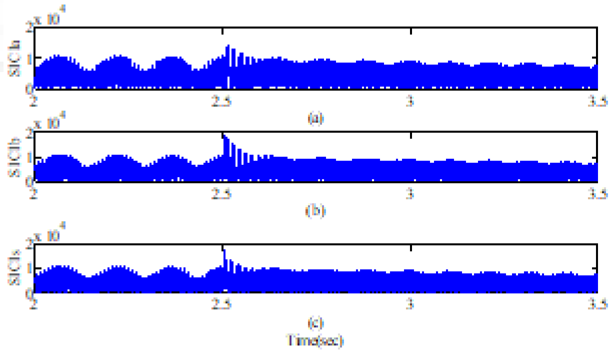

Figure 25: Superimposed Currents all phases at fault inception 2.5 sec

j) Far-end fault during unstable swing

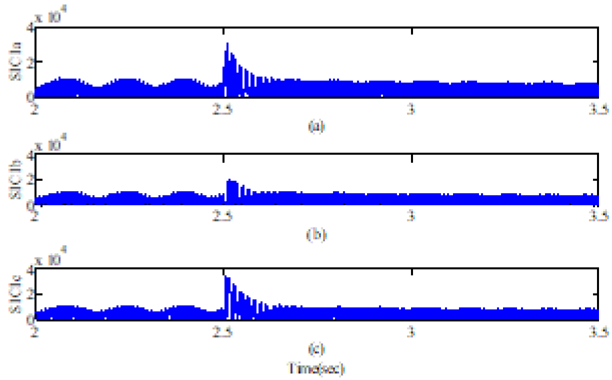

Figure 26: Superimposed Currents all phases at fault inception 2.5 sec

Consider a three phase-ground (LLLG) fault at a distance of 20km with fault inception angle δ=120^0 and fault resistance R=0.01Ω.

Results for detection a symmetrical fault during power swing using Superimposed TMI method

S.I No	Fault distance in (kms)	Power angle Δ (degrees)	Fault Resistance (ohms)	Fault inception time (sec)	TMI detection times (ms)
1	50	40	0.01	2.5	2.502
2	50	40	25.01	2.5	2.502
3	50	40	50.01	2.5	2.502
4	50	70	0.01	3.5	3.502
5	50	70	0.01	4	4.002
6	100	70	0.01	2	2.002
7	100	70	25.01	2	2.002
8	100	70	50.01	2	2.002
9	100	70	0.01	3.5	3.502
10	100	70	0.01	4	4.003
11	150	130	0.01	3	3.002
12	150	130	25.01	3	3.003
13	150	130	50.01	3	3.003
14	150	130	0.01	3.5	3.01
15	150	130	0.01	4	4.003
16	200	160	0.01	2.5	2.502
17	200	160	25.01	3	3.003
18	200	160	50.01	4	4.004
19	200	40	0.01	2.5	2.503
20	200	40	0.01	3	3.004

4. Conclusion

Symmetrical fault detection during power swing in transmission lines is a critical task. Several techniques developed earlier to detect such faults still face some drawbacks. In this paper, anincipient detection algorithm is implemented to detect a symmetrical fault during power swing. The algorithm is developed based on superimposed transient monitor current to differentiate between the fault and power swing. For validation of the proposed method, different fault locations, swing frequencies, and fault inception times (different) are examined during the power swing period.. Simulation results for various fault conditions indicate that the proposed method is capable of detecting symmetrical faults very quickly and reliably.

Appendix

The parameters of the 400-kV system used for simulation are given.

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'_d = 8 s, T''_{do} = 0.03 s,X_q = 1.76 p.u.,X''_q = 0.25 p.u.,
T''_{qo} = 0.03 s,R_a = 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:
Line length (each) = 280 km;
Z_1 = 0.12 0.88 /km;
Z_0 = 0.309 1.297 /km;
C_1 = 1.0876 F/km;
C_0 = 0.768 10 F/km;
Sampling frequency = 1 KHz.

References

[1] IEEE Power System Relaying Committee of the IEEE Power Eng. Soc.,Power swing and out-of-step considerations on transmission line. Rep.PSRCWGD6, Jul. 2005. [Online]. Available: http://www.pespsrc. org.

[2] P. Kundur, *Power System Stability and Control*. New York: McGrawHill, 1994, EPRI

[3] S. M. Brahma, ‘‘Distance relay with out-of-step blocking function using wavelet transform,’’ *IEEE Trans. Power Del.*, vol. 22, no. 3, pp.1360-- 1366, Jul. 2007.

[4] X. Lin, Y. Gao, and P. Liu, “A novel scheme to identify symmetrical faults occurring during power swings,” *IEEE Trans. Power Del.*, vol. 23, no. 1, pp. 73–78, Jan. 2008.

[5] Saeed Lotfifard, Jawad Faiz *and* Mladen Kezunovic, “Detection of Symmetrical Faults by Distance Relays During Power Swings”, *IEEE Trans. Power Del.*, vol.25, no. 1, pp. 81-87,January. 2010.

[6] Chengzong Pang and Mladen Kezunovic, “Fast Distance Relay Scheme for Detecting Symmetrical Fault During Power Swing”, *IEEE Trans.Power Del.*, vol.25, no. 4, pp. 2205-2212,October. 2010.

[7] Behnam Mahamedi, Jian Guo Zhu, ‘‘A Novel Approach to detect Symmetrical Faults Occurring During Power Swings by using Frequency Components of Instantaneous Three-Phase Active Power*”IEEE Trans. Power Del.*, vol.27, no. 3, pp. 1368-1375 , July. 2012.

[8] J.Gnaneswara Rao, A.K.Pradhan “Differential Power-Based Symmetrical Fault Detection during Power Swing” *IEEE Trans. Power Del.*, vol.27, no. 3, pp. 1557-1564,July. 2012.

[9] S. Gautam S.M. Brahma “Out-of-step blocking function in distance relay using Mathematical

morphology" IET *Trans. Power Del.*, vol.6, no. 4, pp. 1751-8687 , April. 2012.

[10] Behnam Mahamedi and Jian Guo Zhu, "A Novel Approach to Detect SymmetricalFaults Occurring during Power Swings byUsing Frequency Components of InstantaneousThreePhase Active Power"*IEEE Trans. PowerDel.*, vol.27, no. 3, pp. 5090-2806, June. 2017.

[11] A. P. Apostolov,D. Tholomier, S. H. Richards, "Superimposed Components Based Sub-cycle Protection of Transmission Lines"*IEEE Trans. Power Del.*, vol.27, no. 3, pp. 0-7803-8718-x, April. 2005.

[12] Jalal Khodaparast and Mojtaba Khederzadeh,"Three-Phase Fault Detection During Power Swing by Transient Monitor""*IEEE Trans. Power Del.*, vol.30, no. 5, pp. 2558-2565, November. 2014.

[13] Kumarraja Andanapalli and B.R.K.Varma"Park's Transformation based Symmetrical Fault Detection during Power Swing" Dept. of Electrical &Electronics Engineering, S. R. K. R. Engineering College."*IET Trans. Power Del.*, EISBN 978-4799-5141-3, May. 2015.