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An Enhanced Symmetrical Fault Detection during Power Swing/Angular Instability using Park's Transformation

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Abstract

Power systems are subjected to a wide range of small or large disturbances during operating conditions. Power system disturbances such as line switching, generator disconnection and sudden removal of faults causes oscillations in an electrical machine rotor angles that can result in severe power swings. Depending on the protection controls, the system may remain stable or unstable and it may result in loss of synchronism. In recent years, distance relay finds difficulty between symmetrical fault and power swing which causes undesired tripping of the transmission line is the foremost reason for blackout. This paper proposes a new method Park's Transformation and Fast Fourier Transform which are used to discriminate between the three phase fault and power swing and also to protect the backup zone of distance relay. This method is verified for normal and abnormal conditions with different load angles and different fault locations in IEEE 6-bus system are simulated in MATLAB/ Simulink. The Simulation results show the capability to avoid unwanted tripping decision of relay quickly and precisely.

Keywords: *Distance Relay, Power Swing, Symmetrical fault, Park's transformation, Fast Fourier Transform.*

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1. Introduction

In power systems, power swings are created during short circuit faults, line switching, generator disconnection and large load changes leading to large variations in voltage, current and power. A major concern over backup zone mal-operation in case of primary protection failure of distance relay has been raised throughout the world. Distance relay is vulnerable to sense the impedance presented to it during a power swing as a three phase fault, unless it is prevented from blocking the power swing. Distance relay elements prone to operate during stable or transient power swings. A Power Swing Block (PSB) function is available in modern relays to prevent unsolicited relay element operation. The main function of PSB is to distinguish between faults and power swings and block distance or other relay elements from operating during a power swing. Faults that arise during a power swing must be detected and cleared with a high degree of selectivity and dependability [1]. Power swings are deviations in power flow that happen when the internal voltages of generators at dissimilar locations of the power system slip relative to each other. Large power swings, stable or unstable, can origin undesirable distance relay element operations at different power system network locations, which can exaggerate the power-system disturbance and cause for major power blackouts. During a fault, the apparent impedance trajectory falls inside the operating zone and as a result, the trip signal will be initiated by the distance relay. The problem of the existing methods is that the threshold setting of distance relay operating zones is to differentiate the three phase fault and power swing. Ahmad Farid Abidin et al., [2] proposed a new method established on S-transform and Probabilistic neural network to detect unstable swings during distance relay operation. Behnam Mahamedi et al., [3] presented a new method to detect symmetrical faults for the duration of a power swing based on the damping frequency component of 50 Hz or 60 Hz created on instantaneous three-phase active power within one cycle. Brahma [4] proposed a wavelet transform of time based analysis approach to detect any fault during power swing quickly. Chengzong et al., [5] introduced a wavelet transform for identification of detecting three phase

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fault and power swing. In the devastating event of 30/31 July 2012, several interconnecting lines had tripped on severe transient conditions like power Swing and load encroachment. [7]. Saeed Lotfifard et al., [8] described a Prony method to extract the decaying dc components of current wave during fault. Song et al., [9] introduced a novel algorithm using frequency deviation of voltage for identifying stable and unstable swing.

2. Proposed Method

The proposed method is based on Park's transformation algorithm that is used to evaluation the dynamic phasor of the voltage and current signal and also to provision of backup zone of distance relay. This method is used to differentiate between the three phase fault and power swing. The proposed Symmetrical fault detection during power swing algorithm monitors the three phase voltage and current signals using Park's transformation and Fast Fourier Transform.

2.1. Park's Transformation

The three phase voltage sampled signals are converted into (dq) direct and quadrature component signals using Park's transformation and is given by equation (1).

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

where,

V_a(k), V_b (k) and V_c (k) represents the three phase voltage signals

I_a(k), I_b (k) and I_c(k) represents the three phase voltage signals

V_d(k) and V_q(k) are direct and quadrature axis components of voltage signals

I_d (k) and I_q (k) are direct and quadrature axis components of current signals

After calculating the direct and quadrature components of voltage and current signals, the 'C' coefficients of direct and quadrature are calculated by using moving data window samples with the new samples using equations (2), (3), (4) and (5).

$$C_{vd}(k) = V_d(k) - V_d(k-1) \quad (2)$$

$$C_{vq}(k) = V_q(k) - V_q(k-1) \quad (3)$$

$$C_{id}(k) = I_d(k) - I_d(k-1) \quad (4)$$

$$C_{iq}(k) = I_q(k) - I_q(k-1) \quad (5)$$

Now the power coefficients are obtained by multiplying these 'C' coefficients of voltage and current components of direct and quadrature axes are given by equations (6) and (7).

For direct axis components is

$$C_{pd}(k) = C_{vd}(k) * C_{id}(k) \quad (6)$$

For quadrature axis components is

$$C_{pq}(k) = C_{vq}(k) * C_{iq}(k) \quad (7)$$

During power swing C_{pd} (k) and C_{pq} (k) values are not quite zero and it is considered under symmetrical fault condition. The detection criterion is, if C_{pd} (k) or C_{pq} (k) is greater than the threshold 'T' then the symmetrical fault is detected [6] during swing.

2.2. Fast Fourier Transform

Fast Fourier Transform (FFT) is an efficient algorithm to speed up the Discrete Fourier Transform (DFT) calculation by reducing the number of multiplications and additions required. It requires only complex multiplications. The FFT equation can be defined by the following equations (8) and (9).

$$X_s = \frac{2}{N}\sum_{k=0}^{N-1} x_k \sin(\frac{2\pi}{N}k) \tag{8}$$

$$X_c = \frac{2}{N}\sum_{k=0}^{N-1} x_k \cos(\frac{2\pi}{N}k) \tag{9}$$

where,

$X_s = V_s = I_s$ are real component of fundamental voltage and current phasor.
$X_c = V_c = I_c$ are imaginary component of fundamental voltage and current phasor.
N is number of samples per period of fundamental cycle.

2.3. Computation of Apparent Impedance

The main objective of the digital distance relaying of transmission lines is to determine the phasor representations of the voltage and current signals from their sampled values and then to calculate the apparent impedance of the line from the relay location to the fault point in order to determine whether the fault lies within the protective zone or not.

The calculations of the apparent impedance of the test system have a prospective of discriminating the different zones of protection. The time step methodology for different protection zones allows the present modern relays closest to the significant fault to activate first. If they fail to operate, the relay located at the isolated terminals in the transmission line that see the similar fault as in primary protection zone 2. If zone 2 relay fails to operate, the relay located further away from the faulted line in the power system will work next with the backup protection zone reach setting of the power system.

Knowing V_s, V_c, I_c, I_s, the magnitudes (rms values) and phase angles of the fundamental frequency voltage and current phasors are given by equations (10), (11), (12) and (13).

$$V = \sqrt{(V_s^2 + V_c^2)} \tag{10}$$

$$I = \sqrt{(I_s^2 + I_c^2)} \tag{11}$$

$$\emptyset_v = \tan^{-1} {V_c}/{V_S} \tag{12}$$

$$\emptyset_i = \tan^{-1} I_c/I_s \tag{13}$$

When the signal is chosen for a given fault, the ratio of the voltage to current gives the apparent impedance of the line.

The apparent impedance is then given by the equation (14).

$$Z = \frac{V}{I} = \frac{|V|}{|I|} * \frac{\emptyset_v}{\emptyset_i} \tag{14}$$

The complete symmetrical fault detection during power swing algorithm procedure is given in the flow chart in the Figure (1).

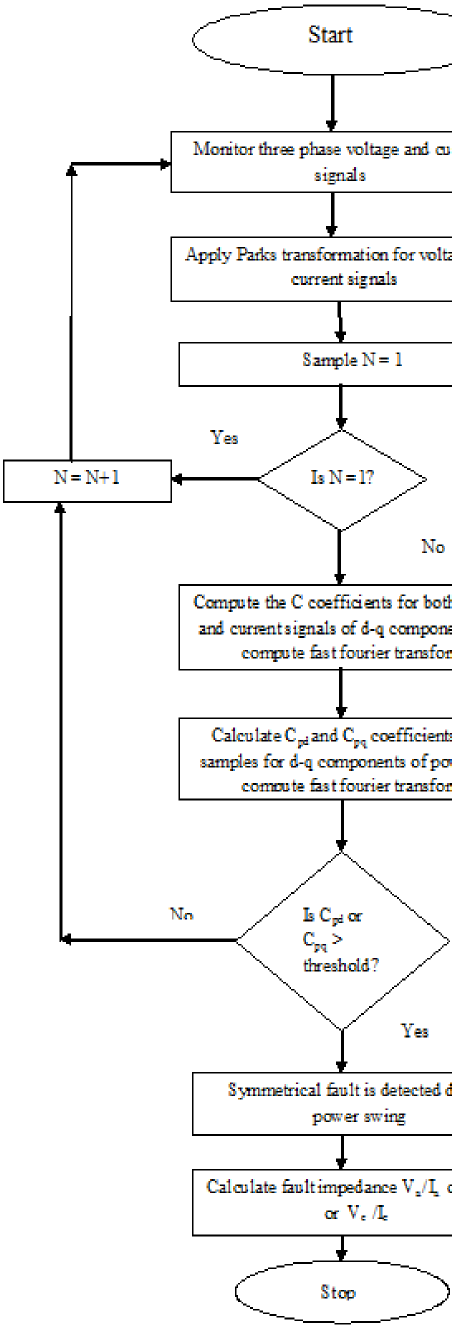


Figure 1. Flowchart for Fault Discrimination from Power Swing Condition

3. Simulation of the Proposed Method

The proposed Symmetrical fault detection during power swing technique uses Park's transformation and Fast Fourier Transform to discriminate three phase fault and power swing. It is simulated in IEEE 6- bus system using MATLAB/Simulink tool and is shown in the Figure (2).

The IEEE-6 bus system is simulated as per the generator, transformer, line, synchronous compensator and load datas. The test system is established under normal and abnormal condition with different load angles, different fault locations and different swing frequencies.

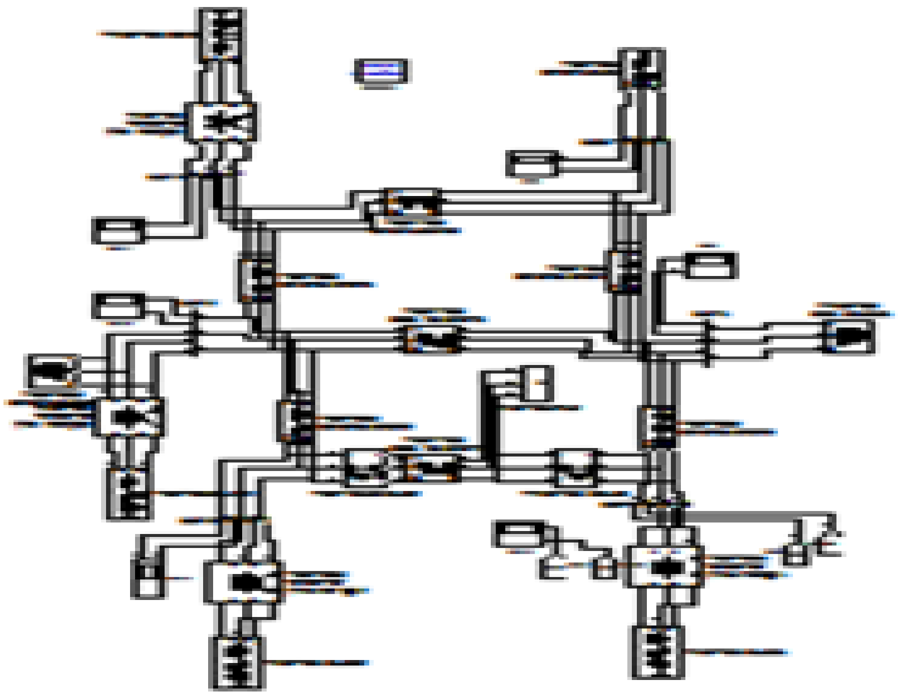


Figure 2. Simulation Diagram of IEEE 6-Bus System of the proposed method

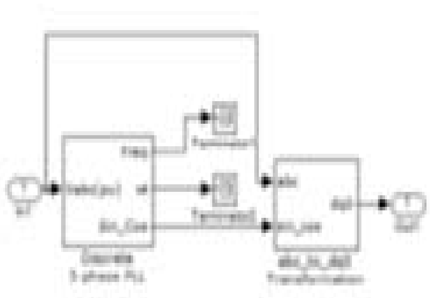


Figure 3. Simulation Diagram of Park's transformation

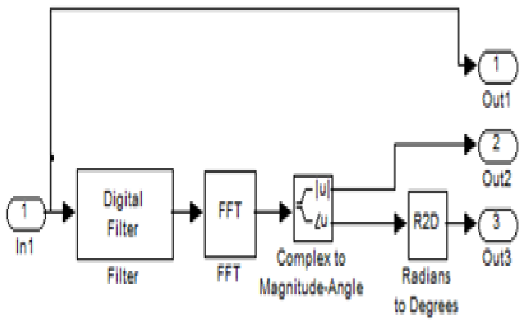


Figure 4. Simulation Diagram of Fast Fourier transformation

The Discrete three Phase Locked Loop (PLL) can be used to synchronize on three-phase sinusoidal signals. Park's transformation is used for calculating three phase components into direct and quadrature components are shown in Figure (3).

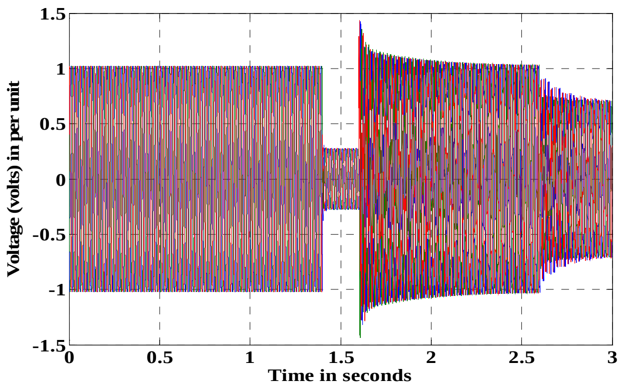
The low pass filter is designed using Filter Design and Analysis (FDA) tool for both the voltage and current signals. The Hamming window is designed with a leakage factor of about 0.04% and side- lobe attenuation of about 355.8 decibels. The FFT block is shown in the Figure (4) computes the Fast Fourier transform each row of a sample for an N- dimensional input array. When the input length is greater than the FFT length, it gives the FFT output.

4. Simulation Results and discussions under Abnormal Conditions

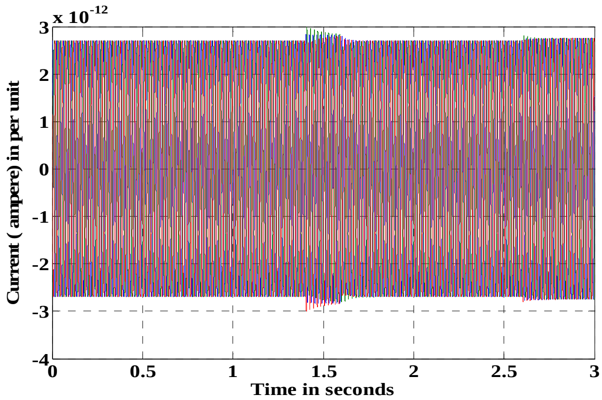
The test system is simulated under abnormal conditions with the dissimilar fault resistances, different load angles and different fault locations.

4.1. Three Phase Fault with Load Angle 60^0

The test system is simulated under abnormal condition with a load angle of 60^0 and fault resistance of 0.01Ω. Figures 5(a) and 5(b) show the three phase voltage and current signals of the IEEE-6 bus system under power swing condition of load angle 60^0.



5(a)



5(b)

Figures 5(a) and 5(b). Three Phase Voltage and Current Signals under Symmetrical Fault with Load Angle of 60^0

The symmetrical fault is created in the transmission line (3-4) at 1.4 seconds and the fault is cleared at 1.6 seconds by opening the circuit breakers at both ends of the transmission line. This deliberate delay in fault clearance time acquaint with the power swing condition in both voltage and current signals.

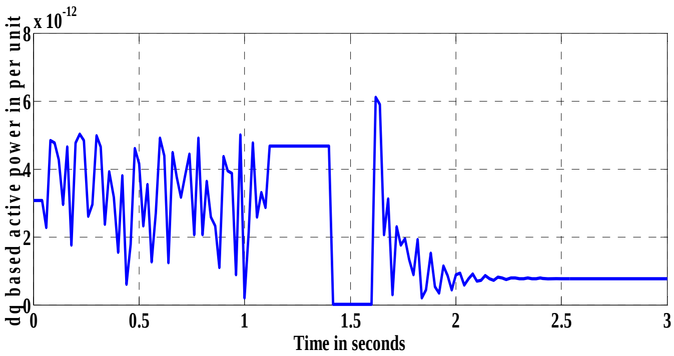


Figure 6. Output of dq Based Active Power under Symmetrical Fault with Load Angle of 60^0

During power swing condition, the fault period of 1.4 to 1.6 seconds has dq based active power is greater than its threshold value and then the symmetrical fault is detected and vice versa is presented in the Figure (6).

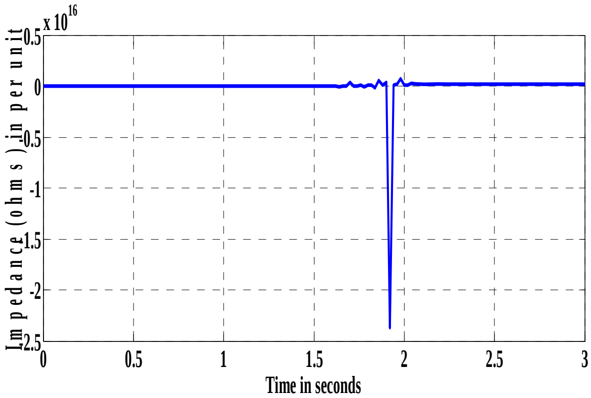
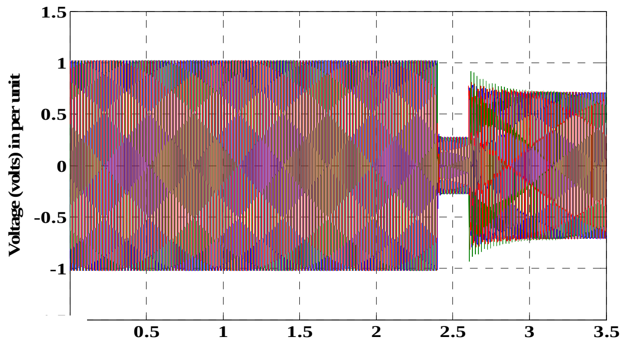


Figure 7. Impedance Plot of Symmetrical Fault with Load Angle of 60^0

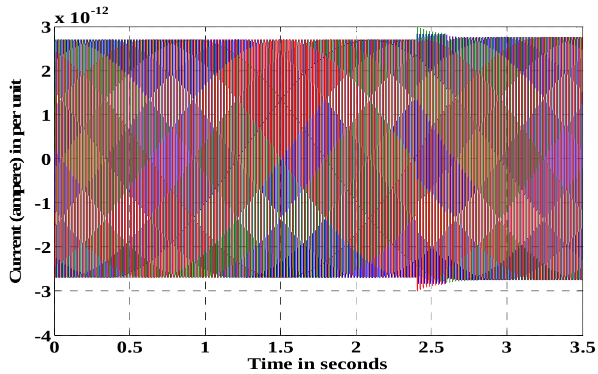
The impedance plot is plotted for the abnormal condition with swing frequency of 1 Hz and load angle of 60^0 is revealed in the Figure (7). The fault period from 1.4 to 1.6 seconds, the apparent impedance is low and impedance is high in non- fault period.

4.2. Three Phase Fault with Load Angle 160^0

The test system is simulated under abnormal condition with a load angle of 160^0, swing frequency of 2 Hz and fault resistance of 0.01 Ω. Figures 8(a) and 8(b) show the three phase voltage and current signals of the IEEE-6 bus system under power swing condition of load angle 160^0.



8(a)



8(b)

Figure 8(a) and 8(b). Three Phase Voltage and Current Signals under Symmetrical Fault with Load Angle of 160^0

The symmetrical fault is created in the transmission line (3-4) at 2.4 seconds and the fault is cleared at 2.6 seconds by opening the circuit breakers at both ends of the transmission line. This intentional delay in fault clearance time introduces the power swing condition in both voltage and current signals.

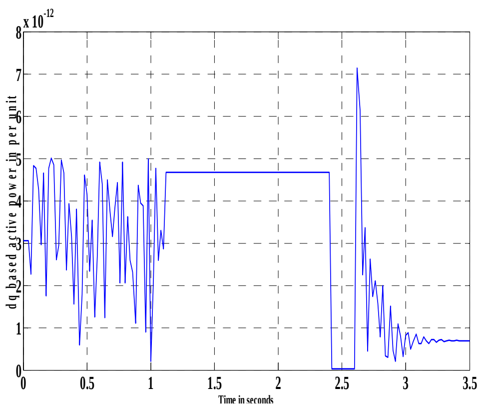


Figure 9. Output of dq Based Active Power under Symmetrical Fault with Load Angle of 160^0

During power swing condition, the fault period of 2.4 to 2.6 seconds has dq based active power is greater than its threshold value, then the symmetrical fault is detected and during non- fault period, it is lesser than its threshold value is shown in the Figure (9).

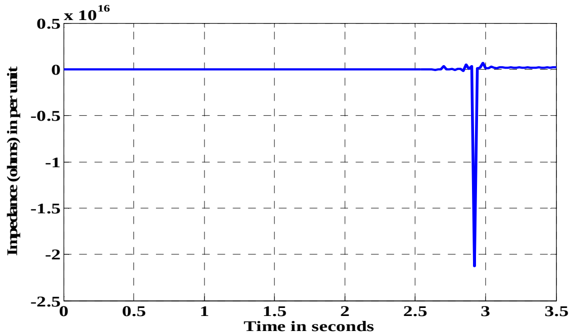


Figure 10. Impedance Plot of Symmetrical Fault with Load Angle of 160^0

The apparent impedance is given by the ratio of phase 'A' voltage to the phase 'A' current with respect to time. The impedance plot is plotted for the abnormal condition with swing frequency of 2 Hz and load angle of 160^0 is shown in the Figure (10). The fault period from 2.4 to 2.6 seconds, the apparent impedance is low and apparent impedance is high in non- fault period.

5. Conclusion

In this paper, the proposed method which uses Park's transformation besides with Fast Fourier Transform to discriminate the three phase fault from power swing condition is verified in the IEEE-6 bus system. Backup zone mal-operation may interrupt the smooth operation of the power system. The proposed threshold value setting is the most consistent threshold setting to maintain a sense of balance between the security and dependability of the modern relay decision during normal and power swing condition. For validation of the proposed method, certain investigations are carried on the test system under different fault locations, different swing frequencies and different fault inception times are examined during the power swing period. The Simulation results verify the innate potential of the proposed method to overwhelm the problem of symmetrical fault discrimination from power swing condition quickly and precisely to facilitate the right relay trip signals during stable and unstable power swings.

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