Abstract—Distance relays are blocked during power swings as they are prone to mal-operate in that period. However, if a fault occurs during a power swing, the distance relay must be unblocked to clear the fault with a high degree of reliability. This paper presents a new technique for symmetrical fault detection during power swing using park’s transformation. Park’s transformation theory is applied to convert the three phase voltage and current signals into two signals of direct and quadrature components (d-q). A sample to sample moving window comparison is used for finding power coefficients from voltage and current components of d-q signals. The proposed method is evaluated by comparing with two recently developed approaches. Simulation results are carried out in MATLAB environment by considering different fault situations and results indicate how the limitations of existing methods are overcome by the proposed method.

Keywords—Distance relay; Power swing; Symmetrical faults; Park’s transformation.

I. INTRODUCTION

In power systems, power swings are created during faults, line switching, generator disconnection and large load changes leading to large variations in voltage and current [1]. The apparent impedance seen by a distance relay during power swing may enter its operating zone, causing unwanted tripping of transmission lines. Hence, a power swing blocking (PSB) function is used to avoid tripping of distance relays during power swing [2]. However, if a fault occurs during the power swing, it should be detected and the unblocking function be invoked to clear the fault as soon as possible. In case of unsymmetrical faults a zero sequence and/or negative sequence current component based unblocking can be effectively implemented. But, a symmetrical fault detection during power swing is a complicated task.

Several techniques have been developed over the years to detect symmetrical faults during the power swing. A Wavelet-based approach is presented by Brahma [3] to reliably and quickly detect any fault during power swing.

Reference [4] proposed a fast unblocking scheme on the basis of change rates of three-phase active and reactive power. In reference [5], the decaying dc components of current wave form present during fault is extracted by Prony method for detection. A travelling wave based fast symmetrical fault detection approach is proposed by Pang and Kezunovic [6].

In reference [7], a method based on the frequency component of instantaneous three phase active power is presented. This technique claims to be capable of detecting the symmetrical fault within one cycle based on fundamental frequency component by using FFT analysis. A differential power based fault detection technique in which differential power is calculated by comparing actual and predicted samples of both voltage and current signals is proposed in [8].

Performance studies of the above two methods using digital simulation revealed certain limitations. The three phase instantaneous active power based method fails to detect symmetrical fault during swing for power angle variation of (≥ 45°). In case of differential power based method, more than one cycle time is required for detecting close-in faults. Also, the above two methods fail to detect the symmetrical fault during power swing for far end faults. In this paper a new technique is proposed for symmetrical fault detection during power swing to overcome the above limitations.

The proposed technique uses park’s transformation to obtain a set of power coefficients. The Power coefficients are calculated by multiplying the voltage and currents coefficients of d-q signals obtained by parks transformation of three phase voltage and current signals into two signals of direct and quadrature components (d-q). The proposed method is tested on 400-kV 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 an a comparative basis. Results indicate that the proposed method is fast, reliable and able to overcome certain limitations of the earlier methods given in references [7] & [8].

Section-II of this paper describes proposed methods. Section-III presents the simulation results and conclusion are given in Section-IV.
II. PROPOSED METHOD

The proposed technique to detect a symmetrical fault during power swing is based on park’s transformation theory. By using the Park’s transformation, the monitored three phase voltage and current signals are transformed into two signals of d-q components. A sample to sample moving window comparison is applied to d-q components of voltage and current signals to obtain the voltage and current coefficients. Then, a set of two power coefficients are found from these V, I coefficients. These power coefficients are used as indices for symmetrical faults during power swing. In the following a brief explanation of park’s transformation is given followed by its application in the proposed technique.

A. Park’s transformation

Park’s transformation is generally studied in synchronous machine analysis. The synchronous machine consists of three phase windings on the stator and three windings on the rotor, namely a main field winding along the direct axis and two fictitious short circuited damper windings, one each along the direct (d) and quadrature (q) axis respectively. The convention of the d-axis leading the q axis is adopted in this paper[9]. A coupled circuit view point of the six windings indicate that the differential equations involve time varying coefficients. It is universal to adopt the well-known park’s transformation which converts the three stator windings into two equivalent fictitious windings called the d-axis and q-axis windings, moving synchronously with the rotor as shown in figure1.

\[
\begin{bmatrix}
V_d \\
V_q
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
\cos(\Phi) & \cos(\Phi - \frac{2\pi}{3}) & \cos(\Phi + \frac{2\pi}{3}) \\
\sin(\Phi) & -\sin(\Phi - \frac{2\pi}{3}) & -\sin(\Phi + \frac{2\pi}{3})
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]

... (1)

Where \(V_a, V_b, V_c\) represents the three phase voltage signals and \(V_d, V_q\) are direct and quadrature axis components. Similarly three phase current signals \(I_a, I_b, I_c\) can be transformed.

B. Symmetrical Fault Detection during Power swing

The detection algorithm monitors the three phase voltage and current signals from the relay point of the protected line. The three phase voltage sampled signals are converted into direct and quadrature components signals using parks transformation as given below.

\[
\begin{bmatrix}
V_d(k) \\
V_q(k)
\end{bmatrix} = R_{dq} \begin{bmatrix}
V_a(k) \\
V_b(k) \\
V_c(k)
\end{bmatrix}
\]

... (2)

Where \(R_{dq}\) is given as

\[
R_{dq} = \frac{2}{3} \begin{bmatrix}
\cos(\Phi) & \cos(\Phi - \frac{2\pi}{3}) & \cos(\Phi + \frac{2\pi}{3}) \\
\sin(\Phi) & -\sin(\Phi - \frac{2\pi}{3}) & -\sin(\Phi + \frac{2\pi}{3})
\end{bmatrix}
\]

... (3)

In the above equations, \(k\) is the sample number and \(\Phi = k\omega \Delta t + \theta\), where \(\omega\) is the angular frequency, \(\Delta t\) is the sampling interval and \(\theta\) is the angle of \(V_d\). Assuming \(V_d\) and \(V_a\) signals are to be in phase, \(\theta\) becomes zero degrees. After calculating the direct and quadrature components of voltage signals, compute the ‘C’ coefficients of direct and quadrature by using moving data window with the new samples using equation 4.a & 4.b as given in reference [10].

\[C_{vd}(k) = V_d(k) - V_d(k - 1) \quad \cdots (4.a)\]

\[C_{vd}(k) = V_q(k) - V_q(k - 1) \quad \cdots (4.b)\]

A similar transformation is applied for current signals also to get the ‘C’ coefficients using equations 5.a & 5.b.

\[C_{id}(k) = I_d(k) - I_d(k - 1) \quad \cdots (5.a)\]

\[C_{id}(k) = I_q(k) - I_q(k - 1) \quad \cdots (5.b)\]

Now the power coefficients are obtained by multiplying these ‘C’ coefficients of voltage and current components of direct and quadrature as given by expression 6.a & 6.b.

For direct axis components

\[C_{pd}(k) = C_{vd}(k) * C_{id}(k) \quad \cdots (6.a)\]

For quadrature axis components

\[C_{pq}(k) = C_{vq}(k) * C_{iq}(k) \quad \cdots (6.b)\]

During power swing \(C_{pd}\) & \(C_{pq}\) values are almost zero and are significant under symmetrical fault condition. The detection criterion is, if \(C_{pd}\) or \(C_{pq}\) is greater than certain threshold ‘T’ then fault is detected during swing. The complete algorithm is given in the flow chart shown in

Fig. 1. Pictorial representation of synchronous machine
figure 2. The above procedure is tested with a simulated power system in the following section.

III. SIMULATION RESULTS

A double-circuit transmission system shown in fig.3 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 created 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].

Fig. 3. The 400kv double circuit line transmission system.

a) Three phase fault with power angle $\delta = 0$

Consider a three phase fault in line-1 at 50kms from relay with a fault resistance of 0.01ohms and fault inception at 2.5sec. The following figures (4.a and 4.b) show the voltage and current signals measured by the relay R during power swing.

Figures 4.c, 4.d, and 4.e. show the corresponding indices of three-phase instantaneous active power method, differential power based method and proposed method.
Table 1. show the detection times for the above fault situation and several other cases. Results are tabulated for different power angle variation of 0 to 90 degrees for different fault condition in table 1. It is clearly observed that the performance of the proposed methods is much better than the other two methods A & B given in references [7] & [8] respectively.

<table>
<thead>
<tr>
<th>S.I. no</th>
<th>Fault distance in (kms)</th>
<th>Fault resistance</th>
<th>Fault inception time (sec)</th>
<th>Detection times (ms) of methods</th>
<th>A</th>
<th>B</th>
<th>Proposed</th>
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b) Three phase fault at power angle $\delta = 90^\circ$

A three phase fault in line-1 at 240kms from relay $R$ with a fault resistance of 50 ohms at fault inception 3 sec is considered now.
In this case, the three phase instantaneous active power method (A) fails to detect, but the differential power based method (B) and the proposed method detected symmetrical fault in 2ms. Table II shows the performance of the proposed methods for several other cases when compared to the other two methods with power angle variation from δ = 90° to 180°.

TABLE II. DETECTION RESULTS FOR δ VARIATION FROM 90 TO 180 DEGREES

<table>
<thead>
<tr>
<th>S.I. no</th>
<th>δ</th>
<th>Fault distance in (kms)</th>
<th>Fault resistance</th>
<th>Fault inception time (sec)</th>
<th>Detection times (ms) of methods</th>
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<th>B</th>
<th>Proposed</th>
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<td>Fail</td>
<td>2.00</td>
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</table>

From the above results it can be observed that the method A. (Three phase instantaneous active power) fails in many cases when the power angle δ is greater than 45 degrees. In case of close-in faults (fault distance less than 20kms from the relay end), the detection time is much less than the time taken by the methods A & B. For far-end faults (fault distance greater than 250kms from relay end), the proposed method is able to detect fault effectively whereas the other two methods failed. In all the cases studied, the proposed algorithm based on Park’s transformation detected symmetrical fault during power swing very quickly well within a half cycle.

IV. 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, a new detection algorithm is implemented to detect a symmetrical fault during power swing and overcome some of the drawbacks. The algorithm is based on Park’s transformation where the transformation is used to calculate the power coefficients. The proposed method is evaluated by comparing with the performance of two recent methods. 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:
Generator: 600 MVA, 22 kV, 50 Hz, inertia constant 4.4 MW/MVA. \( X_c = 1.81 \) p.u., \( X''_d = 0.3 \) p.u., \( X''''_a = 0.23 \) p.u., \( T''_d = 8 \) s, \( T''''_d = 0.03 \) s, \( X_q = 1.76 \) p.u., \( X''''_q = 0.25 \) p.u., \( T''''_q = 0.03 \) s, \( R_d = 0.003 \) p.u., \( X_p \) (potier reactance) = 0.15 p.u.
Transformer: 600 MVA, 22/400 kV, 50 Hz. \( /Y, X = 0.163 \) p.u., \( X_{core} = 0.33 \) p.u., \( R_{core} = 0.00 \) 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