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# Variance Index of DWT Based Symmetrical Fault during Power Swing

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**Abstract:** ***Distance relays are designed to operate reliably and secured manner, and are strictly obeyed to avoid mal-operation during stressed condition. To avoid these conditions, power swing blocking functions (PSB) is incorporated in the distance relay design. However, any kind of fault is initiated during swing, the PSB function should unblock it and provides trip signal to the circuit breakers (CB). Unsymmetrical fault cases were easily unblocked, but in the case of symmetrical fault during power swing condition is a difficult task for relay unblocking due to balanced phenomenon. Variance indexes of discrete wavelet transform (VIDWT) based symmetrical fault detection during power swing is presented in this paper. The method utilizes measured three-phase current signals from relay end. Initially, high frequency components are extracted from three-phase current signals using DWT. Next, variance index is estimated for the details coefficients of current signals helps to discriminate the symmetrical fault from swing event. To validate the response of the proposed technique, a 400 kV, 50 Hz single machine infinite bus system is considered and simulated in the MATLAB / SIMULINK platform. Different critical cases such as fault inception time, slip frequency, fault resistance and fault location were considered for the simulation and comparative assessment. From the results, it examines that the proposed method is more efficient as compared to other available methods.***

**Keywords:** Distance relay, Transmission lines, Three-phase current signal, Symmetrical fault, Power swing, Wavelet transform, Variance estimation.

## 1. Introduction

In a power systems, network, powerful swings are exhibited due to transpiring of events like line outages by switching or fault events, removal of generators, integration and expunction of an immense load direct to rapid vicissitudes in between voltage and current [1]. Distance relays are designed to operate whenever quantified load impedance may enter into operating zone characteristics. During swing phenomenon, relay gives an unwanted tripping operation to the circuit breakers (CB). In order to evade this issue, power swing blocking function (PSB) is implanted in the relay design which initiates to block the relay operation. But, the fault occurs during power swing condition then the relay unblocks and provide tripping signal to CB for clearing the fault [2]. Unsymmetrical fault are facilely be identified by the relay during swing phenomenon due to availability of zero/negative sequence components. During symmetrical fault situation it becomes more arduous by absences of zero and negative sequence components respectively. Ergo, symmetrical fault detection during power swing is still a tough task.

Several techniques have been implemented over the years to mitigate the quandary with symmetrical faults detection during the power swing issue. A Wavelet predicated approach is presented in [3] to dependably and expeditious detecting any fault during power swing. Higher sampling frequency is needed. Reference [4] proposes an expeditious unblocking scheme by rate of change of three-phase active and reactive puissance. Symmetrical fault detection during power swing is achieved by the extraction of decaying dc components of current wave form in [5]. But this method depends on the connection between fault and DC decay components, but cannot be utilized in unconnected scheme. A expeditious symmetrical fault detection approach is proposed utilizing travelling wave predicated method in [6]. It requires a modal transformation in integration with WT. Utilizing S-transform and PNN amalgamated approach is developed in [7]. However, these schemes require an astronomical immense number of training data set.

Mathematical morphology (M.M) techniques is utilized to discriminate the swing from fault event is given in [8]. This methods need a felicitous cull in design of structure element and applicability in authentic time applications is arduous. In [9], a method predicated on the frequency component of instantaneous three phase active power is presented. To extract the fundamental frequency component by FFT analysis leads to capable of detecting the symmetrical fault within one cycle. A differential power predicated approach developed in [10] utilizing auto regression technique. It requires an abundance of simulation tribulations for cull of regression parameter ‘k’. To discriminate fault from swing and in additament to swing relegation is presented in [11] by wavelet singular entropy. Transient monitor index predicated approach utilizing current signal is presented in [12] to differentiate fault and swing. Parks transformation predicated fault detection is developed to mitigate the symmetrical fault detection issue during power swing in [13]. Teager Kaiser energy operator is utilized to discriminating fault from swing with negative sequence currents is presented in [14]. It is capable of differentiating both symmetrical and unsymmetrical fault with the avail of energies estimated from zero sequence voltages but, fails it effect with variation of threshold.

In this paper an incipient approach is proposed to surmount the challenging task. Quantified current signals from relay end utilized as a input signal. DWT is applied for the input signal to extract high frequency components. The wavelet coefficients are further proceeded to estimate the variance indices of three phase signal in order to discriminate fault from swing. The proposed method is tested on 400-kV ,50 Hz a SMIB double-circuit transmission system which is simulated in MATLAB environment for sundry 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 substructure. Results promise that the proposed method is expeditious, reliable basis. The paper organizes in the following sections as: section-II describes proposed methods. Section-III presents the simulation results and conclusion are followed by Section-IV.

## 2. Proposed methodology

The method is introduced to distinguish symmetrical fault from power swing using variance index of discrete wavelet transform based approach. A test system of 400 kV, 50 Hz double circuit transmission line predicated SMIB as shown in Fig.1 [10] is considered for the evaluation of proposed method.

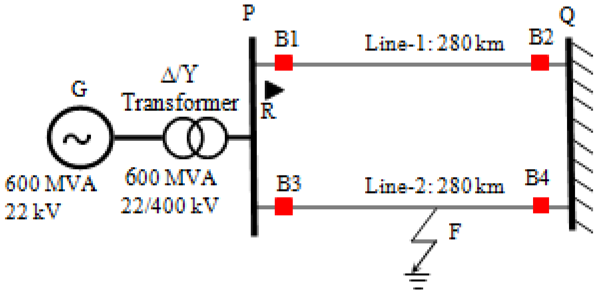

**Figure 1:** A 400-kV SMIB double circuit transmission line system

In the digital relay scheme, current vector are computed with help of discrete fourier transform (DFT) to perform indispensable computations. But during swing, accurate phasors are unable to estimate due to existence of different swing frequencies in the range 1-7 Hz. Therefore, estimation error of reliability index of any measured quantity will be decreased and mal-operates. To avoid such an ambiguous either advanced phasor estimation process can be applied to obtain phasor information otherwise lucky threshold will be culled so that the percentage of false detection can be reduced. To distinguish symmetrical fault from power swing the proposed algorithm mainly involves following steps are as follows

a) Discrete wavelet transforms.
b) Estimation of variance index.
c) Fault detection criteria.

### 2.1 Discrete Wavelet Transform (DWT)

DWT is a mathematical tool, which gives the information for both time and frequency information for a respective signal. It decomposes any given signal into approximation and detail coefficients called as first level of decomposition. Further approximations are decomposed into another set of approximation and detail coefficients and repeated process is continued to obtain different decomposition are known as level-1, level-2, etc. İn this work, only first level of detail coefficient (D1) are used, whereas it contains the high frequency transient information. The choice of mother wavelet also plays a significant role in the analysis and db-4 mother wavelet has been adopted in this paper [15]. DWT is defined by the equation.

$$W(t,k)=\sum_{t}\sum_{k}x(k)\frac{1}{\sqrt{2}}\Psi\left(\frac{n-k}{2}\right) \qquad (1)$$

where, Ψ (k) is the mother wavelet.

### 2.2. Estimation of Variance index

Variance estimation is used for practical problems in survey sampling. This estimation the deviation of a group of scores from the mean and also gives measurement how far each value in the dataset from the mean. Variance estimation is high, when the scores presents in the group of data are stretched out and small, if the data are spread closely around the mean [16]. Therefore variance coefficient is estimated by taking an average squared deviation of each number from its mean and then dividing by the number of values minus one. It can be expressed as follows.

$$V=\sum\frac{((x-\mu)^2}{N-1} \qquad (2)$$

$$\mu=\frac{1}{N}\sum_{i=1}^{n}A_i \qquad (3)$$

Where X denotes each value of dataset (current signal for each sample per cycle), μ denotes the arithmetic mean of the data given in equation.3.2, and N denotes the total number of data points for one cycle.

### 2.3. Fault detection criteria

The proposed algorithm will supervise the conventional distance relay algorithm and it will able to operate when fault exist during power swing only in order to unblock the PSB function. The algorithm initially, uses one cycle data of quantified three-phase current signals from the relay location are considered as input. DWT is applied to this input data for each individual phase current quantities for the extraction of high frequency and low frequency contents present in the input signal. Here, from daubiches family ‘dB4’ is selected for the decomposition process up to one level in order to obtain detail and approximation coefficients. Later, variance indexes are calculated with help of detail coefficients of three phase current signal using equation (2). This index calculation process is to be continued over entire signal in a recursive manner. These variance index values are drastically less value during swing phenomenon and high under symmetrical fault event. Based on this, an appropriate threshold is selected in order to discriminate the both the events. Threshold value is suggested based on the studies carried out under different critical events. The entire algorithm is clearly represented in the following flow chart as shown in figure.2.

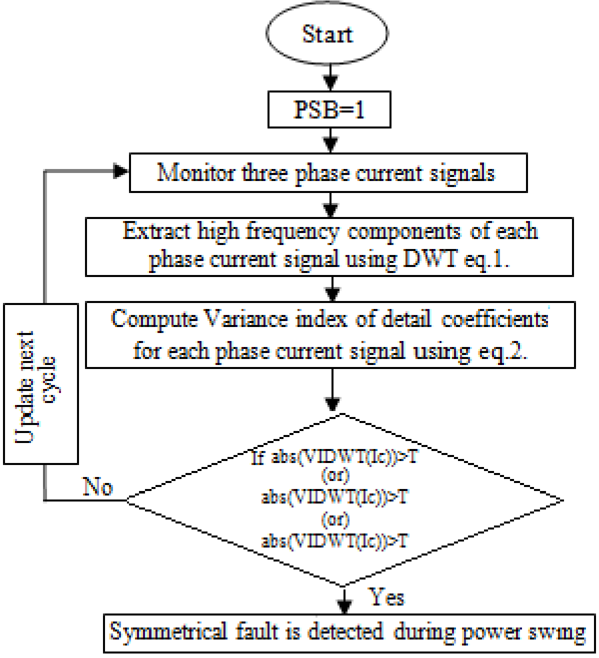

**Figure 2:** Proposed Algorithm

## 3. Simulation Results

A 400 kV, 50 Hz double-circuit transmission network shown in fig.1 is considered for verifying the proposed fault detection method. Simulation is carried out by MATLAB/SIMULINK software and system data is provided in Appendix. Sampling frequency of 1 KHz is considered to quantity the voltage and current signals from relay location. 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 ignore 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 utilizing the above technique. The efficacy of the proposed method is verified by engendering several symmetrical fault situations like fast swing, slow swing, close-in fault and far end fault at different inception angles the performance of the proposed method is verified.

### 3.1. Results for double circuit SMIB System

To evaluate the performance of the proposed method, let us consider a three phase fault in line-1 at 50kms from relay with a fault resistance of 10 ohms and fault inception at 2.5 & 2 sec respectively. The following subplots represents 3.a & 3.b indicate three phase voltages, fig.3.c & 3.d shows the three phase current signals measured from relay end respectively. The waveforms show variations during swing and fault condition for stable and unstable swing condition respectively.

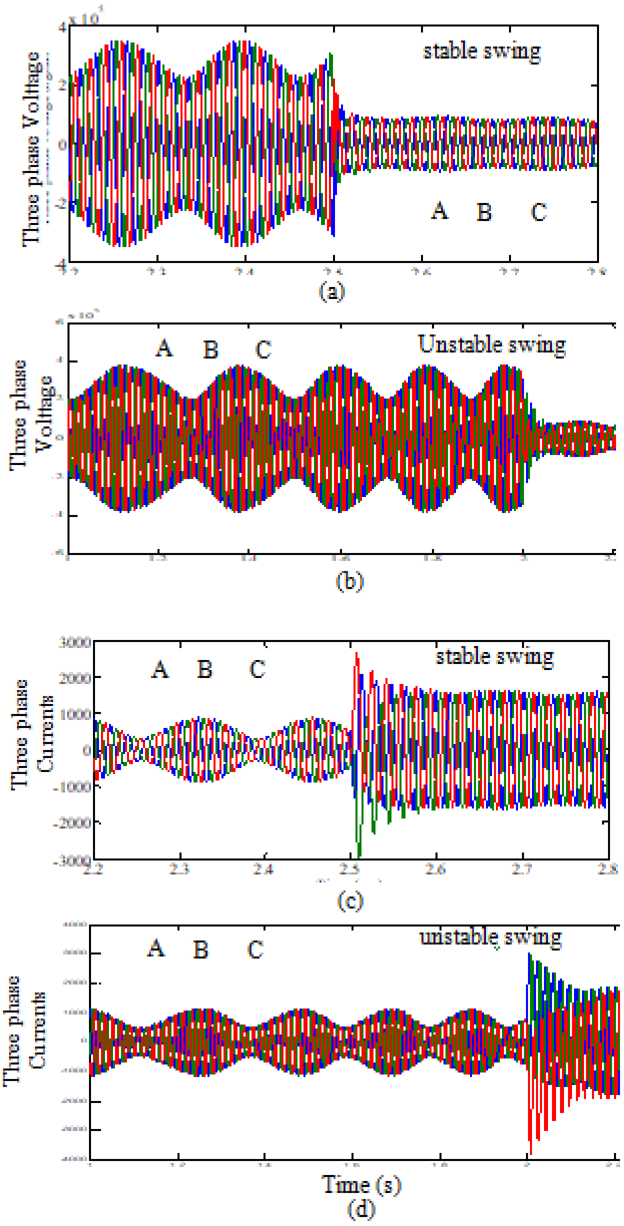

**Figure 3:** Waveform for symmetrical fault during stable & unstable power swing (a)- (b) Three phase voltage signal,(c)-(d) Three phase current signal

The proposed method is tested under various critical fault situations by changing the fault inception time, fault resistance, power angle variation. The figures (4)-(7) denotes the simulation results for different case studies with subplots for three phase current signals of VIDWT values under symmetrical faults during power swing condition respectively.

**Case-I:** Consider a three phase fault in line-1 at 260kms from relay with a fault resistance of 0.01ohms with power angle at $\delta=60^0$ and fault inception at 2.5sec.

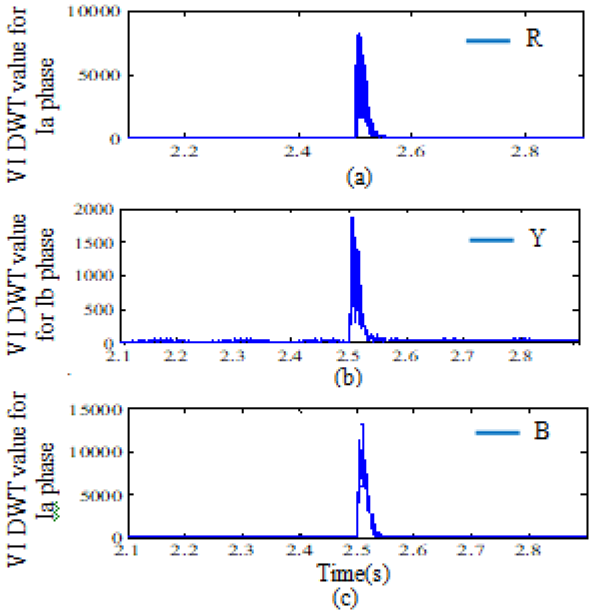

**Figure 4:** Result for proposed method

Figures 4.a, 4.b, and 4.c. show the corresponding indices of proposed method. The three subplots indicate that the values are very less during power swing phenomenon, whereas high with symmetrical fault condition. The method is able to detect within 6ms after the fault inception.

**Case-II:** Consider a three phase fault in line-1 at 50kms from relay with a fault resistance of 25 ohms with power angle at $\delta=120^0$ and fault inception at 3sec.

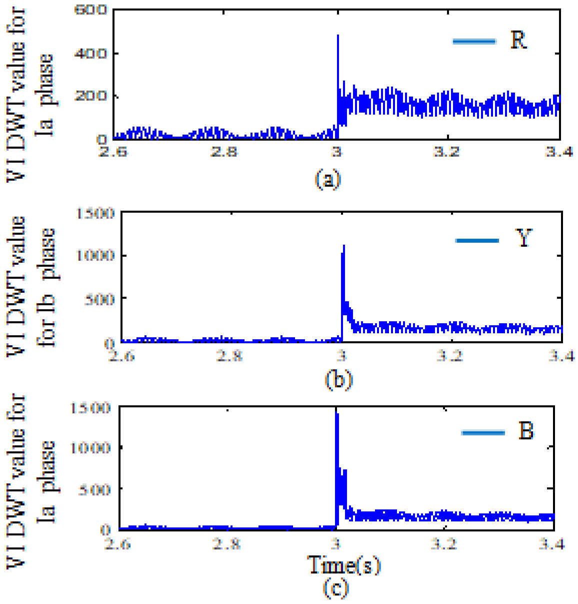

**Figure 5:** Result for proposed method

Figures 5.a, 5.b, and 5.c. show the corresponding indices of proposed method. Three subplots explores that the values are shows small during power swing phenomenon whereas drastically high with symmetrical fault condition. It clearly evident, that the method detects the fault within 7ms after inception.

**Case-III:** Consider a three phase fault in line-1 at 100kms from relay with a fault resistance of 50 ohms with power angle at $\delta=90^0$ and fault inception at 3.5sec.

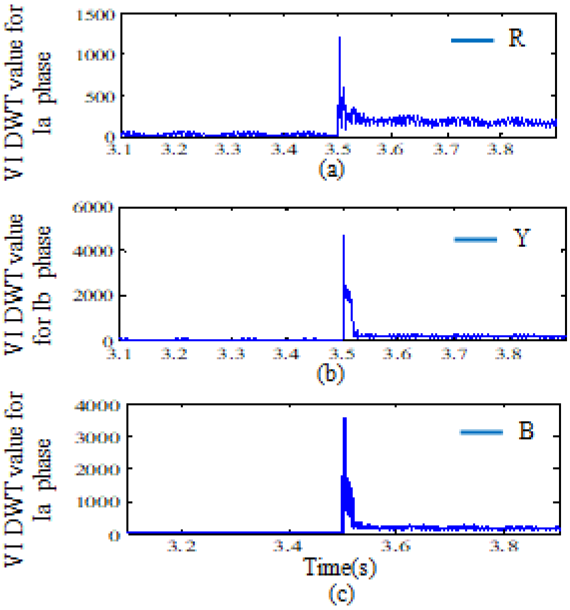

**Figure 6:** Result for proposed method

Figures 6.a, 6.b, and 6.c. show the corresponding indices of proposed method. The above subplots indicate that the values are very low during power swing phenomenon whereas enormously exceeds with symmetrical fault condition. The method is able to detect within 6ms after the fault inception

**Case-IV:** Consider a three phase fault in line-1 at 260kms from relay with a fault resistance of 0.01ohms with power angle at $\delta=150^0$ and fault inception at 3sec.

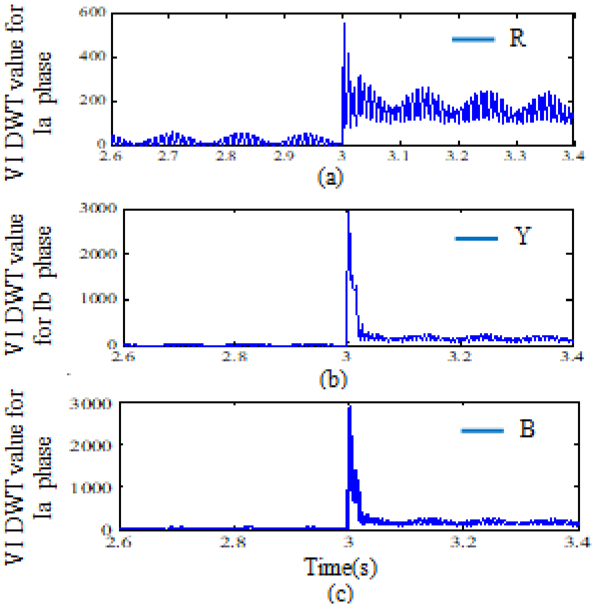

**Figure 7:** Result for proposed method

Figures 7.a, 7.b, and 7.c. show the corresponding indices of proposed method. The subplots indicate that the values are very less during power swing phenomenon whereas high with symmetrical fault condition. The method is able to detect within 6ms after the fault inception. Several cases are simulated and results were tabulated in the table. I.

**Table I:** Results for symmetrical fault during power swing on SMIB test system un compensated line

| *S.I. no* | *Rf (Ω)* | *FIT (s )* | *Power angle variation (δ) degrees* | *FD (km)* | *Proposed Method Detection Time (ms)* |
|---|---|---|---|---|---|
| 1 | 25.01 | 2.5 | 60 | 20 | 6 |
| 2 | 25.01 | 2.5 | 60 | 260 | 7 |
| 3 | 0.01 | 3.0 | 60 | 50 | 6 |
| 4 | 50.01 | 3.0 | 60 | 50 | 6 |
| 5 | 25.01 | 3.5 | 20 | 50 | 7 |
| 6 | 25.01 | 3.5 | 170 | 50 | 6 |
| 7 | 0.01 | 2.5 | 30 | 50 | 6 |
| 8 | 25.01 | 2.5 | 30 | 50 | 6 |
| 9 | 50.01 | 2.5 | 30 | 50 | 6 |
| 10 | 0.01 | 3.5 | 70 | 100 | 6 |

## 4. Comparative Assessment

As mentioned in the literature part that method-1 [9] three phase instantaneous active power method, method-2 [14] teager Kaiser energy based methods were considered for comparative assessment along with proposed algorithm. Typical simulated test cases were performed to appreciable of proposed algorithm on 400 kV double circuit SMIB system were shown below. Let us consider a simulated case on under unstable swing operation a three phase fault is created at line-1 at 2.5 s fault inception with fault distance of 250 km and fault resistance is 25 ohms taken. The corresponding comparative plot is shown in figure.8. The method -1 [9], method-2 [14] are represented in the subplots 8.a, 8.b & 8.c respectively and remaining subplots 8.e, 8.f & 8.g indicates the proposed one. Existing methods are mal-operates before fault inception during power swing based on their procedures, but the proposed one detects accurately within half cycle interval after fault inception. Few comparative test cases are presented in table. II and shows the robustness of the proposed method.

**Table II:** Comparative Assessment report

| *S. no* | *δ* | *Fault distance in (kms)* | *Fault resistance* | *Fault inception time (sec)* | *Detection times (ms) of methods* | | |
|---|---|---|---|---|---|---|---|
| | | | | | *[9]* | *[14]* | *Proposed* |
| 1 | 90 | 20 | 50 | 3.000 | Fail | Fail | 7.00 |
| 2 | 120 | 260 | 25 | 2.500 | 10.0 | 8.00 | 6.00 |
| 3 | 170 | 50 | 50 | 2.850 | 8.00 | Fail | 6.00 |
| 4 | 70 | 70 | 0.01 | 3.500 | Fail | 10.0 | 7.00 |
| 5 | 135 | 90 | 25 | 3.500 | 10 | 9.00 | 6.00 |
| 6 | 90 | 130 | 50 | 2.450 | Fail | 7.00 | 6.00 |
| 7 | 150 | 150 | 0.01 | 2.500 | 10 | 8.0 | 6.00 |
| 8 | 135 | 170 | 50 | 3.900 | Fail | 8.00 | 6.00 |
| 9 | 20 | 50 | 25 | 3.250 | Fail | 9.00 | 6.00 |
| 10 | 90 | 80 | 0.01 | 4.000 | 12 | 7.00 | 7.00 |
| 11 | 70 | 100 | 50 | 3.510 | Fail | Fail | 7.00 |
| 12 | 120 | 140 | 25 | 4.200 | 10 | 10.0 | 7.00 |
| 13 | 80 | 150 | 50 | 4.500 | Fail | 8.00 | 6.00 |
| 14 | 130 | 200 | 0.01 | 2.701 | Fail | Fail | 6.00 |
| 15 | 40 | 250 | 25 | 2.701 | Fail | Fail | 6.00 |

## 5. Conclusion

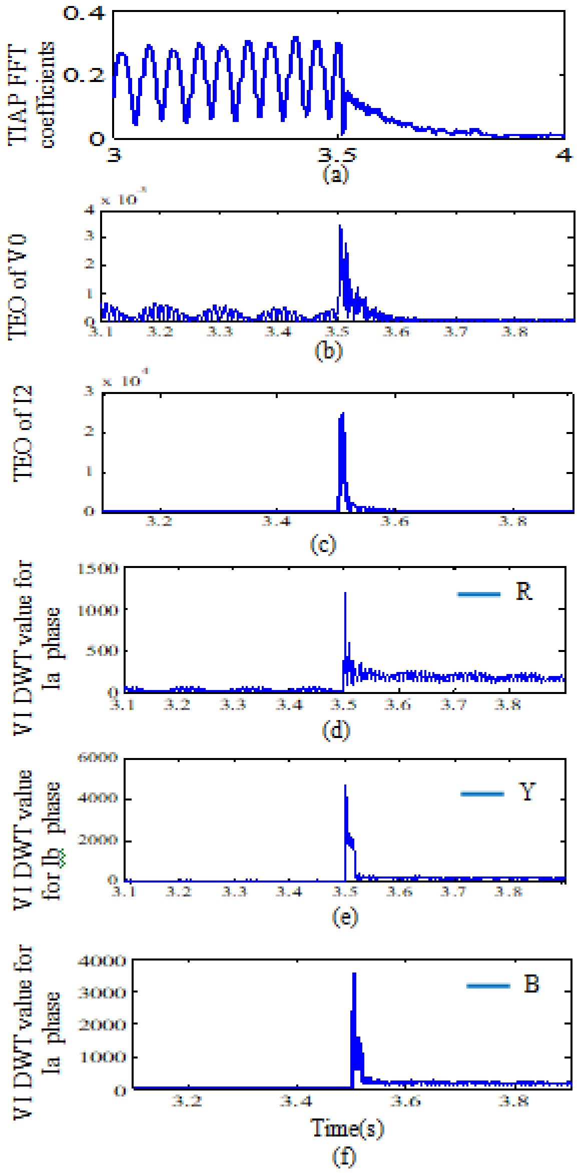

**Figure 8:** Result presents comparative assessment

Symmetrical fault detection during power swing in transmission lines is a critical task. Form the literature many techniques were developed earlier to detect such faults but still face some drawbacks. This paper presents a novel approach to mitigate this challenge using variance index of DWT based algorithm. For validation of the proposed method, different fault locations, swing frequencies, and fault inception times (different) are examined during the power swing period. The simulation results of the proposed technique are compared with three existing methods of symmetrical fault detection [9] & [14]. The overall results show that the new technique of detecting symmetrical faults during a power swing is a viable alternative for existing methods. The performance of the algorithms is tested on MATLAB/SIMULINK environment.

## Appendix-A

The parameters of the 400-kV system:
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, /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+j* 0.88 /km; $Z_0$= 0.309 + j*1.297 /km; $C_1$= 1.0876 F/km; $C_0$= 0.768 10 F/km; Sampling frequency = 1 KHz.
CT ratio : 600/5 A; P.T ratio: 400 kV/115 V

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