Variance Index of Three Phase Instantaneous Power based Fault Detection during Power Swing

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Abstract: ***Distance relays are intended to operate reliably and secured manner, and are rigorously complied with to eschew mal-operation during stressed condition. To eschew these conditions, power swing blocking functions (PSB) is included in the distance relay design. But, any kind of fault is commencing during swing, the PSB function should unblock it and provides trip signal to the circuit breakers (CB). Unsymmetrical fault cases were facilely unblocked, except in the case of symmetrical fault during power swing condition is a difficult task for relay unblocking due to balanced phenomenon. Variance indexes of three phase instantaneous power signal (VITPIP) predicated symmetrical fault detection during power swing is presented in this paper. The method utilizes quantified three-phase voltage and current signals from relay end. Extraction of high frequency components of three-phase instantaneous power signals utilizing DWT. Subsequently, variance index is estimated for the details coefficients of power signals avails to discriminate the symmetrical fault from swing event. To validate the accuracy of the proposed technique, a 400 kV, 50 Hz single machine illimitable 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. The results, it illustrates that the proposed method is more efficient.***

Keywords: Distance relay, Transmission lines, Three-phase instantaneous power signal, Symmetrical fault, Power swing, Wavelet transform, Variance estimation

1. Introduction

Power system networks, power swings are occurred due to occurrences of the 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 intended to operate whenever computed load impedance may enter into operating zone characteristics. In swing phenomenon, relay furnishes an unwanted tripping operation to the circuit breakers (CB). In order to elude this condition, power swing blocking function (PSB) is fixed in the relay design which commence to block the relay operation. But, the fault occurs during power swing condition then the relay unblocks and offer tripping signal to CB in order to remove the fault [2].

Numerous techniques have been developed over the decades to mitigate the difficulty with faults detection during the power swing condition. A Wavelet predicated approach is presented in [3], Expeditious unblocking scheme by rate of change of three-phase active and reactive puissance [4], Decaying dc components of current parameters in [5]. Using travelling wave theory based approach in [6]. Combination of S-transform and PNN approach is developed in [7].

Mathematical morphology (M.M) techniques is utilized to discriminate the swing from fault event is given in [8]. 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. Wavelet singular entropy based [11], Transient monitor index method [12], Parks transformation based [13]. Teager Kaiser energy operator method [14]. The above mentioned [11-14] methods are capable of detecting fault from power swing.

In this paper present a robust incipient approach is proposed to overcome the above mentioned issue. Quantified voltage and current signals from relay end and were utilized for the estimation of three-phase instantaneous power signal. DWT is applied for the power signal to extract high frequency components. The wavelet coefficients are further proceeded to estimate the variance indices of three phase power 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 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 and assure 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 established to differentiate fault from power swing using variance index of three-phase instantaneous power approach. A 400 kV, 50 Hz double circuit transmission line SMIB test system is considered as shown in Fig.1 [10] for the evaluation of proposed method.

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

Initially the relay measures the three phase voltage and currents are measured continuously and estimate the positive sequence impedance. The measured impedance during stressed events may enter into the impedance zone trajectories and it will respond to mal-operate In order to evade this condition, the proposed algorithm will supervise the conventional distance relay operation by discriminating fault from power swing. Firstly the algorithm initializes to estimate the three-phase instantaneous power (TPIP) signal [9] using equation.1.

$$P_{3\phi}(t) = V_a(t)*I_a(t) + V_b(t)*I_c(t) + V_c(t)*I_c(t) \quad (1)$$

Where V and I are the monitored three-phase voltage and current signals from the relay point. Later the proposed algorithms engage with following steps are mentioned below.

a) Extraction of High frequency components using DWT
b) Assessment of variance index
c) Fault detection index

2.1 Extraction of High frequency components using DWT

DWT is a mathematical implement, 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 reiterated process is perpetuated to obtain different decomposition are kenned as level-1, level-2, etc. İn this work, only first level of detail coefficient (D1) are utilized, whereas it contains the high frequency transient information. The cull of mother wavelet withal plays a paramount role in the analysis and db-4 mother wavelet has been adopted in this paper [15]. DWT is defined by the equation.

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

where, Ψ (k) is the mother wavelet.

2.2. Assessment of Variance index

Variance assessment is use for practical quandaries in survey sampling. This assessment the deviation of a group of scores from the mean and withal gives quantification 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 minute, if the data are spread proximately around the mean [16]. Consequently 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.

$$V = \sum \frac{((x-\mu)^2}{N-1} \quad (3)$$

$$\mu = \frac{1}{N} \sum_{i=1}^{n} A_i \quad (4)$$

Where X denotes each value of dataset (three-phase instantaneous power signal for each sample per cycle), μ denotes the arithmetic mean of the data given in equation.4, and N denotes the total number of data points for one cycle.

2.3. Fault detection index

The proposed algorithm will control the conventional distance relay algorithm and it will able to operate when fault subsist during power swing only in order to unblock the PSB function. The algorithm initially, uses one cycle data of quantified three-phase instantaneous power signals from the relay location are considered as input. DWT is applied to this input data for the extraction of high frequency and low frequency contents present in it. Here, from daubiches family 'dB4' is culled for the decomposition process up to one level in order to obtain detail and approximation coefficients by equation (2). Later, variance indexes are calculated with avail of detail coefficients of three phase current signal utilizing equation (3). This index calculation process is to be perpetuated over entire signal in a recursive manner. These variance index values are drastically less value during swing phenomenon and high under fault event.

Figure 2: Proposed Algorithm

Predicated on this, a congruous threshold is culled in order to discriminate the both the events. Threshold value is suggested predicated on the studies carried out under different critical events. The entire algorithm is pellucidly represented in the following flow chart as shown in figure.2.

3. Simulation Results

A single machine connected to infinite bus (SMIB) test system of 400 kV, 50 Hz double-circuit transmission network shown in fig.1 is considered to validate the proposed fault detection method. System data is provided in Appendix and simulations are done on MATLAB/ SIMULINK software. Sampling frequency of 1 KHz is

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considered to quantity the voltage and current signals from relay location. A power swing is engendering 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 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 assess 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 sec during stable power swing condition. The following sub figure 3.a, 3.b & 3.c indicates the three phase voltage, current and power signal respectively. In order to revise the fault during unstable power swing condition another simulated case is presented by fault initiated at 150kms from relay, fault resistance of 25 ohms at 120 degree power angle variation. The following subplots represents 4.a, 4.b & 4.c represents the three phase voltages, current and power signals measured from relay end respectively.

Figure 3: Fault during stable power swing (a) three phase voltages, (b) three phase currents & (c) power signal

The figure 5.a & 5.b denotes the fault detection index plot by using variance index of three-phase power method. The plots declares that the during swing phenomenon the index values are low during stable and unstable power swing condition and intrinsically high during fault. This index will clear discriminate the both the events. The proposed method is selected a proper threshold in order to detect fault from swing condition. Therefore, method is able to detect the fault within 3ms after the inception of fault during both stable and unstable power swing conditions.

The rest of the part of paper is need to elucidate the proposed method by conducting several cases are simulated and results were tabulated in the table. I.

Figure 4: Fault during unstable power swing (a) three phase voltages, (b) three phase currents & (c) power signal

Figure 5: Represents the proposed method fault index using Variance index of three phase active power (a) stable & (b) unstable power swing

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	2.5	60	100	3
2	10	2.5	60	50	2
3	0.01	3.0	60	230	4
4	25	3.0	120	150	3
5	25	3.5	20	100	4
6	25	3.5	120	180	3
7	0.01	2.5	30	120	4
8	25	2.5	30	230	4
9	50	2.5	30	120	3
10	0.01	3.5	70	100	3

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4. Conclusion

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 three-phase power 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 overall results show that the new technique of detecting 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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