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T.K.E Operator Based Symmetrical Fault Detection During Power Swing using Three Phase Active Power

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Abstract:
In distance relay, PSB function is provided to block the relays in order to mitigate the maloperation during the swing. Unblocking of the relay function is performed whenever fault occurred during the swing. Symmetrical fault detection is a complex task due to balancing phenomenon similarly like power swing. In this paper, a novel technique is proposed for detection of symmetrical faults during power swing based on Teager Kaiser Energy (T.K.E) operator using three phase active power. T.K.E operator is obtained by taking the difference between the square of the present Nth sample and the product of previous and future Nth sample of the instantaneous three phase active power signal. Performance evaluation of the proposed technique is studied on 400 kV, 50 Hz double circuit power system network by considering different fault events like variation of the fault resistance, fault distance, fault inception time and power angles. The results were compared with few existing techniques shows that efficacy of the proposed method. The entire algorithm is implemented in MATLAB environment.

Keywords: Distance relays; Power swing; Symmetrical fault; Three phase active power; Teager Kaiser Energy (T.K.E) operator.

I. INTRODUCTION

Power system is a big network consisting of equipment like alternators, transformers, transmission lines and protective devices like relays. Different anomalous situation occur in the power systems network leads to damage of the equipment and distress operation of the power system may continue for cascading failures of entire system, results blackout. Power system faults, sudden change in load, line switching, generator disconnection and loss of excitation are the reasons for occurrence of power swing [1]. Apparent impedance seen by the distance relay during power swing operation may enter into its operating characteristics causes unwanted tripping. To avoid mal-operation, a power swing blocking (PSB) function is provided to block the relay and whenever a fault occurred during swing an unblocking PSB scheme is implemented to clear the fault as quickly as possible with high of selectivity. Asymmetrical fault detection during power swing is easy to implement due to availability of zero sequences & negative sequence components and they clearly examine the unbalancing. But symmetrical fault detection during power swing is still challenging issue because of its symmetry. Power swing & symmetrical fault are both balanced phenomenon and also non availability of zero & negative sequence components therefore detection of symmetrical fault is difficult. Several researchers are focusing on developing many algorithms to overcome the complications of detecting symmetrical fault during power swing condition and they are listed in [3]-[11]. This paper presents a novel technique to detect symmetrical fault during power swing based on Teager Kaiser Energy (T.K.E) operator. T.K.E is calculated using three phase instantaneous active power signal by taking the difference between square of the present Nth sample and the product of previous and future Nth sample value. The proposed method is tested on 400 kV, 50 Hz double circuit power system network by considering different fault events like variation of fault resistance, fault distance, fault inception time and power angles. The results were compared with few existing techniques shows that efficacy of the proposed method. Section-II describe brief review on performance of existing methods and section-III presents the explanation of proposed method along with simulated results and conclusions are followed by in section-IV.

II. REVIEW ON EXISTING METHODS

Many schemes have been developed from past years to enhance the difficulties available in symmetrical fault detection. Some methods were briefly explained and simulated to examine the performance. Those methods were listed below.

a) Rate of change of Impedance method [2]
b) Swing centre Voltage method [2]
c) Three phase instantaneous Active power based method[9]

A. Rate of change of impedance method [2].

In this method, a power swing blocking scheme is developed by calculating the rate of change of impedance in order to distinguish a fault from a power swing. Firstly the measured voltage and current signals are used to find fundamental phasor quantities by discrete flourier transform (DFT) prior to rate of change of positive sequence impedance estimation. Fault detection criteria is developed by rate of impedance change seen by the distance relay is done by providing timer to measure the duration of the impedance locus as it travels. If the measured impedance enters into the pre-determined zone-1 setting impedance then give signal to timer on. If the timer expires then relay declares the event a system fault. Otherwise, if the impedance crosses the zone-1 setting of impedance characteristics before expire of timer, is said to be power swing.

B. Swing Center Voltage (SCV) method[2].

Swing-centre voltage (SCV) is defined as the voltage at the location of a two-source equivalent system where the voltage value is zero when the angles between the two sources are 180 degrees apart.

$$SCV=|V_S|.\cos\varphi \qquad (1)$$

Where $|V_S|$ is the magnitude of locally measured voltage, and φ is the angle difference between Vs and the local current. For fault detection criteria, estimate the rate of change of the SCV will provides the information for discriminating the fault event from power swing. The rates of change of SCV values are drastically high during fault and very less during power swing condition.

C. Three Phase Instantaneous Active Power Method[9].

Symmetrical fault detection during power swing is developed based on frequency components of an instantaneous three-phase active power. During a power swing, the instantaneous three-phase active power profile has a frequency component of slip frequency whereas after the fault inception time, a damping power-frequency component (50 or 60 Hz) will be created. Based on these features and apply fast Fourier transform (FFT) analysis, to extract the fundamental phasors which helps in detecting symmetrical faults. This method claims to detect the fault quickly within one power cycle. The entire algorithm is explained in the flow chart as shown in figure.1.

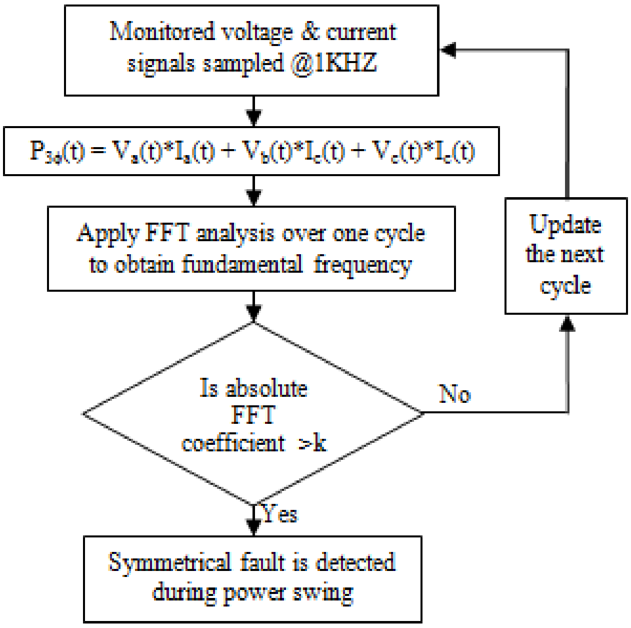

Figure.1. Flow chart for three phase instantaneous active power

III. PROPOSED METHOD

In this paper a new method is developed to detect a symmetrical fault during power swing based on teager kasier energy (T.K.E) operator. Three-phase instantaneous active power is used as input signal for calculation of energy using teager kaiser energy operator technique. The procedure is recently is discussed in [11] by using negative sequences currentsfor calculation of energy. In order to discriminate fault from power swing the algorithm uses three phase power signal. Three phase instantaneous active power is calculated using equation.2.

$$P_{3\phi}(t) = V_a(t)*I_a(t) + V_b(t)*I_c(t) + V_c(t)*I_c(t) \qquad (2)$$

Where V and I are the monitored three-phase voltage and current signals from the relay point. Teager Kaiser Energy is calculated by considering by taking difference between square of the present Nth sample and the product of previous and future of Nth sample for three phase power is given in equation.3.Teager Kaiser Energy operator is

$$TEO(P) = ((P(N)^2-(P(N-1)*P(N+1)) \qquad (3)$$

Where P is the instantaneous power calculated from measured voltage and current signals and N is the sample. The entire detection algorithm is explained by a flow chart in figure.2.

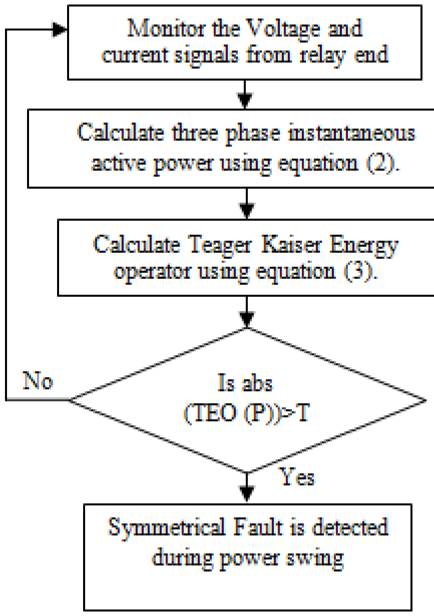

Figure.2. Flow chart for proposed method

IV. SIMULATION RESULTS

A double-circuit transmission system shown in fig.3 is considered for verifying the proposed method. Simulation is done using MATLAB/ SIMULINK. The system data are provided in Appendix. A fault is created in line-2 (symmetrical or asymmetrical) at point F which is cleared after 0.1 sec by the opening of breakers B3 and B4.As a result, the distance relay R1 in line-1 experiences a power swing. Any fault in line-1 during the swing has to be detected by relay R1.The proposed method to detect the symmetrical fault during power swing is tested in line-1 for various fault situations like fault resistances, fault inception times, fault distance and power angles. Simulation results indicate the accuracy of the proposed technique and also show the comparative assessment with existing techniques [2] & [9].

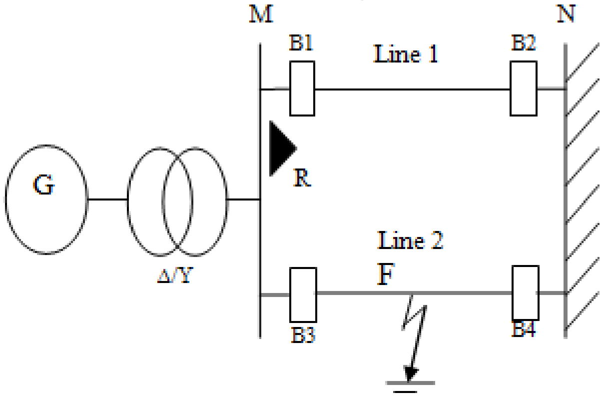

Figure.3.A 400 kV, 50 Hz double circuit transmission system

A. Variation of Power angle

Consider a three phase fault in line-1 at 50kms from relay with a fault resistance of 10 ohms and fault inception at 2.5secwith a power angle variation of 30 degrees. The following figures show the voltage and current signals measured by the relay R1 during power swing and fault detection indices of existing methods and proposed methods respectively.

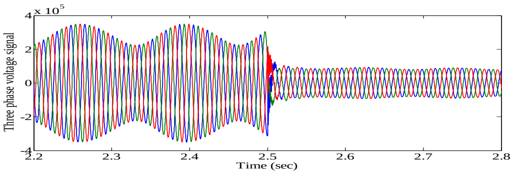

Figure.4.a. Three phase voltage signals measured at relay R

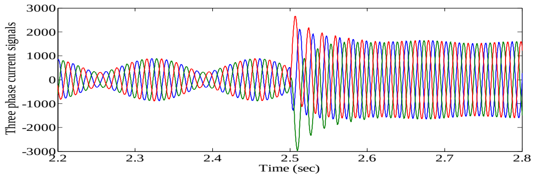

Figure.4.b. Three phase current signals measured at relay R

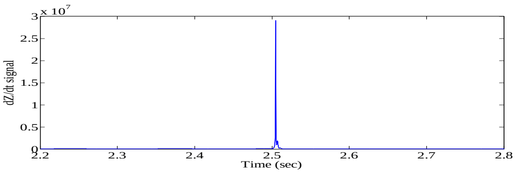

Figure.4.c. Rate of change of impedance method

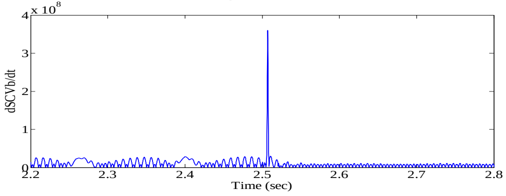

Figure.4.d. Rate of change of SCV method for phase-A

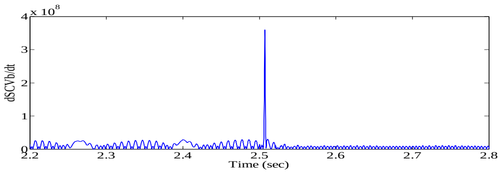

Figure.4.e. Rate of change of SCV method for phase-B

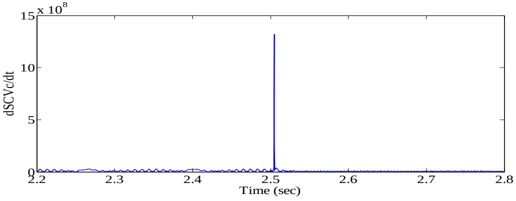

Figure.4.f. Rate of change of SCV method for phase-C

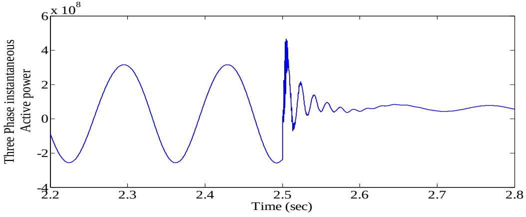

Figure.4.g. Three phase instantaneous active power signal

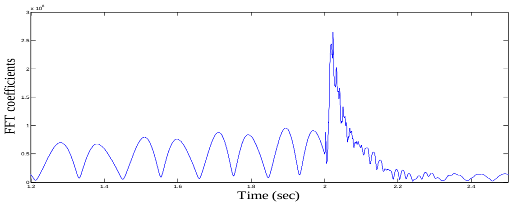

Figure.4.h. FFT coefficients of three phase instantaneous active power signal

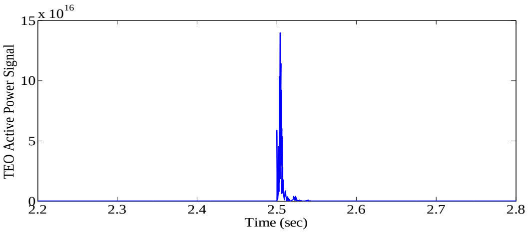

Figure.4.i. T.K.E Operator of three phase instantneous active power signal

In this case, the rate of change of impedance method, SCV method, three phase instantaneous active power method &proposed method are able to detect symmetrical fault during power swing with detection time is 0.8 ms, 18.8 ms, 1.6 ms and 0.5ms after fault inception respectively. Few simulattion case studies are presented in Table.I by varying different power angles.

Table.1. Variation of power angle

Results for detecting a symmetrical fault during power swing (From 0^0 to 180^0power angle variation).						
S. No.	***δ (Deg.)***	***Fault inception time (s)***	***Detection time for Existing Methods (ms)***			
			dZ/dt [2]	***SCV [2]***	***ITPAP [8]***	***Proposed Method***
1	30	2.50	0.8	18.8	1.60	0.5
2	60	3.00	1.0	2.9	1.60	0.8
3	120	3.50	2.6	5.5	16.1	1.0
4	90	3.50	5.2	2.1	16.1	1.3
5	150	2.50	Fail	Fail	17.7	1.3
6	30	2.50	1.8	18.8	1.30	0.8
7	150	3.00	Fail	Fail	2.30	1.0
8	30	3.50	2.3	5.5	1.30	1.3
9	90	3.00	1.8	4.4	16.9	0.5
10	120	2.50	1.6	Fail	2.60	1.6

B. Variation of Fault Resistance

Consider a three phase fault in line-1 at 150kms from relay with a fault resistance of 25 ohms, power angle variation of 120 degrees and fault inception at 3 sec. The following figures show the voltage and current signals measured by the relay R1 during power swing and fault detection indices of existing methods and proposed methods respectively.

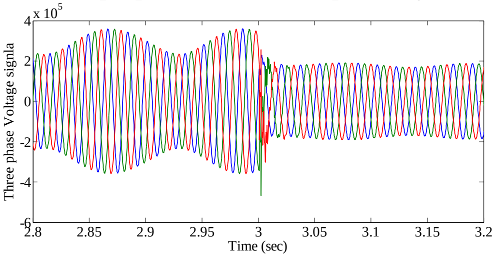

Figure.5.a.Three phase voltage signals measured at relay R

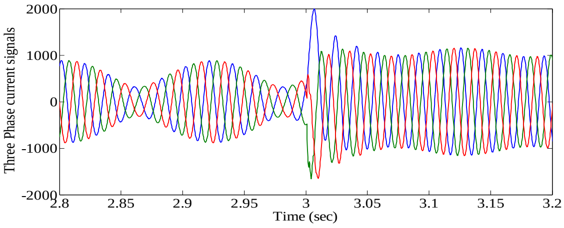

Figure.5.b. Three phase current signals measured at relay R

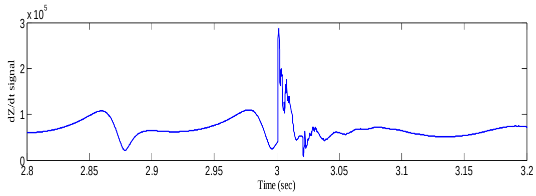

Figure.5.c.Rate of change of impedance method

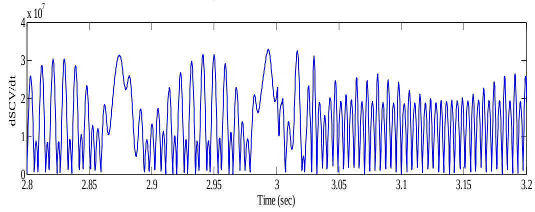

Figure.5.d.Rate of change of SCV method for phase-A

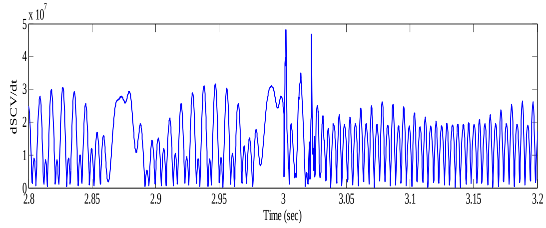

Figure.5.e.Rate of change of SCV method for phase-B

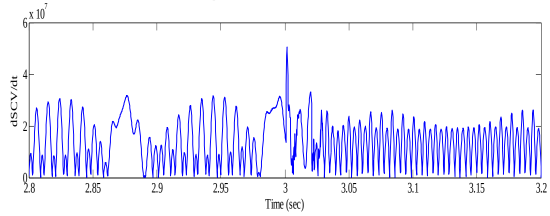

Figure.5.f.Rate of change of SCV method for phase-C

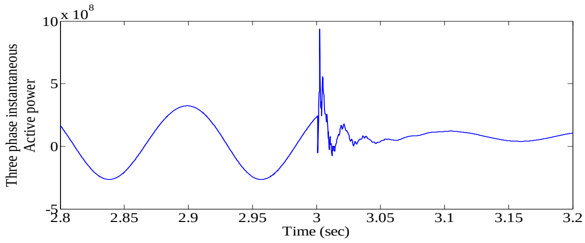

Figure.5.g. Three phase instantaneous Active power signal

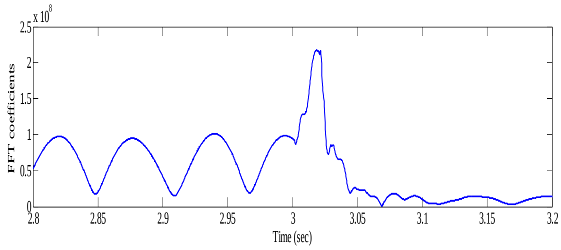

Figure.5.h. FFT coefficients of three phase instantaneous active power signal

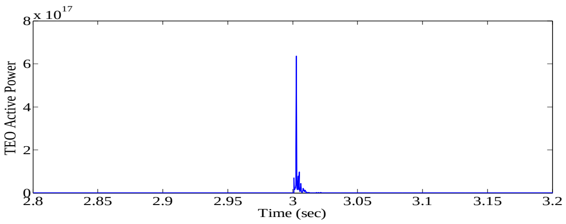

Figure.5.i.T.K.E Operator of three phase instantneous active power signal

In this case, the rate of change of impedance method, SCV method are failed to detect the fault. But three phase instantaneous active power method &proposed method are able to detect symmetrical fault during power swing with detection time are 2.3 ms and 1.0 ms after fault inception respectively. Few simulation case studies are presented in Table.II by varying different fault resistance.

Table.2. Variation of Fault Resistance

Results for detecting a symmetrical fault during power swing (From 0^0 to 180^0power angle variation).						
S. No.	***Rf (Ohm.)***	***Fault inception time (s)***	***Detection time for Existing Methods (ms)***			
			dZ/dt [2]	***SCV [2]***	***ITPAP [8]***	***Proposed Method***
1	10	2.50	0.8	18.8	1.60	0.5
2	10	3.00	1.0	2.9	1.60	0.8
3	25	3.50	2.6	5.5	16.1	1.0
4	10	3.50	5.2	2.1	16.1	1.3
5	25	2.50	Fail	Fail	17.7	1.3
6	10	2.50	1.8	18.8	1.30	0.8
7	25	3.00	Fail	Fail	2.30	1.0
8	50	3.50	2.3	5.5	1.30	1.3
9	0.01	3.00	1.8	4.4	16.9	0.5
10	25	2.50	1.6	Fail	2.60	1.6

C. Variation of Fault distance

The proposed method is simulated under different fault distance variation to study the performance. In all the cases the methods gives accurate results and shows the efficacy from existing algorithms. Some cases are presented in Table-III.

Table.3. Variation of Fault distance

Results for detecting a symmetrical fault during power swing (From 0^0 to 180^0power angle variation).						
S. No.	***d (km.)***	***Fault inception time (s)***	***Detection time for Existing Methods (ms)***			
			dZ/dt [2]	***SCV [2]***	***ITPAP [8]***	***Proposed Method***
1	50	2.50	0.8	18.8	1.6	0.5
2	100	3.00	2.9	4.9	1.6	0.5
3	150	3.50	2.1	5.5	1.3	0.8
4	200	3.50	5.7	Fail	2.3	1.3
5	250	2.50	1.6	Fail	19.0	1.6
6	100	2.50	1.0	2.9	3.4	1.6
7	150	3.00	Fail	Fail	17.7	1.0
8	200	3.50	1.6	Fail	3.9	1.3
9	50	3.00	1.8	4.4	1.3	0.5
10	200	2.50	Fail	Fail	Fail	1.3

The effectiveness of the proposed methods is studied and made comparison with existing methods. Table-IV presents the overall comparative assessment report shows the robustness of proposed algorithm.

Table.4. Overall Performance Report of Proposed Methods

Performance comparison on existing methods					
S. No.	***Case Studies***	***dZ/dt [2]***	***SCV [2]***	***ITPAP [8]***	***Proposed Method***
1	Power Angle	Effected	Effected	Effected	Un-effected
2	Fault Resistance	Effected	Effected	Effected	Un-effected
3	Fault Distance	Effected	Effected	Effected	Un-effected
4	Sampling frequency	Less	Less	Less	Less
5	Detection times	> 1 cycle	> 1 cycle	< 1 cycle	< 1/2 cycle

V. CONCLUSION

In this paper, a robust technique is developed for detecting symmetrical faults during power swing is proposed. The technique is based on Teager Kaiser Energy (T.K.E) operator of instantaneous three phase power signal computed from the measured voltage and current signals at the relay point. The proposed technique based on teager kaiser energy operator of three phase instantaneous power is evaluated by considering several fault conditions. Simulations are carried out by varying fault distance, fault resistance, fault inception time and power angle. The performance of proposed method is compared with three existing methods of symmetrical fault detection [2] & [9].The overall performance report is presented in Table-IV shows efficacy of the algorithm. The performance of the algorithms is tested on 400 kV, 50 Hz double circuit system and implemented under MATLAB/SIMULINK environment.

APPENDIX-I

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 (Poitier 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 lengths:L1 & L2 (each) = 280 km;
Z_1 = 0.12 + j* 0.88 Ω /km; Z_0 = 0.309 + j*1.297 Ω/km;
C_1 = 1.0876 F/km; C_0 = 0.768 10 F/km;
Sampling frequency = 1 kHz.

VI. ACKNOWLEDGMENT

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