Fault Detection on Transmission Line Using TMI Values

Pavan Kumar Chintha[1], Nazeer Shaik[2], Kumarraja .A[3]

[1]PG Scholar, EEE department, S.R.K.R Engineering College, Bhimavaram, India

[2]Assistant Professor, EEE department, S.R.K.R Engineering College, Bhimavaram, India

[3]Assistant Professor, EEE department, S.R.K.R Engineering college, Bhimavaram, India

Abstract: ***Transmission lines are incessantly disturbed with any kind of temporary or permanent faults, leads to effect of system stability and reliability. In order to avoid this issue, well operated distance relays are needed to be designed. Generally, Relay will provide accurate information for circuit breakers operation during occurrence of any kind of fault. Faults in transmission lines be detected first for immediate removal of fault to protect the system and then ensue to classify the type of fault by the relay. This paper introduces a new scheme for fault detection and classification on transmission line using Transient monitor index method. The proposed method calculates transient monitor index values from measured currents signals from one end information. These index values will discriminate the fault from normal event within a short duration and also classify the nature of the fault. The performance of the proposed method is studied on 500kV, 50Hz two terminal transmission system under MATLAB/SIMULINK environment. Different critical faults and non-fault events were simulated and the results show that the proposed method gives more accurate and faster response than other existing methods.***

Keywords: Three-phase current signals, Transient monitor index, unsymmetrical faults, symmetrical faults, critical events

1. Introduction

In power system, transmission lines are one whose probability of occurring faults is more due to its lengthy nature and expose to the atmospheric conditions. Transmission lines transfer bulk amount of power so we have to protect it from the fault events to achieve continuous reliable power supply to the consumers. Therefore, a proper fault detection schemes is adopted in the relay operation to provide accurate tripping signal to the circuit breakers. Later, Fault classification is necessary to be done in order to quick repair of faulted line and get back into service for maintaining system reliability [1]. Several researchers are focused to develop fault detection and classifications techniques on transmission line [2-12] over the years. In [2], differential protection scheme is proposed to detect the fault and classify the type of fault. This scheme needs measurement of both end information. A transmission line fault detection and classification using alienation coefficient technique is given in [3]. But computational burden is high. Travelling wave-based fault detection and classification on transmission line using wavelet transform technique in [4]. This technique helps in extraction of fault transient happened between fault points to relay point. But it needs high sampling rate. Reference [5], presents fault detection and faulty phase identification for series compensated double line circuit transmission network. This method uses discrete wavelet transform for obtaining transient information. But it requires proper selection of mother wavelet and high sampling rate. In [6] Fourier transform based approach is proposed to detect and classify the fault using current signals. But it fails to operate system parameter variations. A novel distance protection scheme is used for the protection of the long transmission lines given in [7]. This method operates based on the measured electrical quantities at the reference point obtained from Bergeron model in frequency domain. This scheme has an advantage of high resistance tolerance ability but computational burden is high. Wavelet energy entropy scheme is proposed to detect and classify the fault on transmission line in [8]. In [9], a new protection scheme is introduced on short transmission line in which the data considered by the relay from the both ends. But for the long transmission line this method was not suitable. Sample - sample method is proposed in [10], uses a simple consecutive sample difference is followed. Cycle-cycle method is given in [11] which uses difference of two samples over distance of one cycle information. A moving sum approach is proposed in [12], it uses average sum of current samples over one cycle of data. The methods [10-12] are considered to evaluate the performance in different scenarios and identify the available limitations among them.

To mitigate the limitation observed from existing approaches as mentioned above is overcome by the proposed method in this paper. A novel approach is developed in order to detect the fault initiated on transmission lines using transient monitor index (TMI) values. Enumerated three phase current signals are subjected to estimate the differential currents phasors and were proceeding to find the TMI index values over every cycle of data in a recursive manner. Performance of the proposed method is evaluated on 500 kV, 50Hz two terminal transmission system using MATLAB/SIMULINK environment. Different fault and non-fault situations by considering variation of fault resistance, fault locations, fault type, Inception time, change in load, system frequencies. Results indicate that the proposed method gives robust performance and also made comparative report with few existing techniques like sample-sample method [10] for detection cycle-cycle approach [11] moving-sum approach[12] all the fault conditions were performed on the transmission line using these techniques

Section-II gives the concise explication of existing approaches along with limitations, section-III demonstrate the proposed method and simulation results and discussion were presented in section-IV. Finally, Conclusion are given in section-V.

2. Proposed methodology

Generally, relays read the samples of the voltage/current signals measured at the relaying point and within the case of fault occurrence; they trigger a series of protecting functions [6]. With the origination of a fault on transmission lines, the voltage and current signal waveform amendment considerably. Faults can be quickly detected by sensing these abnormal changes in the measured signal samples. Some standard techniques based on current signals are concisely given below.

2.1. Sample-sample method [10]

In this scheme the main objective is to detect the fault by comparing the present current sample at one point with the sample before it. During normal condition the difference between the two samples will be less as compared to the difference between the samples with fault condition. Based on this criterion of increased difference will helps to discriminate fault from normal event and it is clearly shown in figure.1.

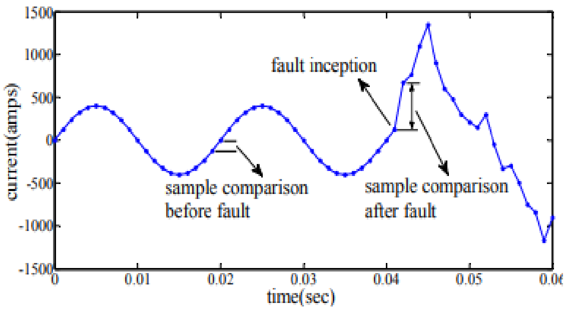

Figure 1: Sample-sample Approach

Mathematically,

$$Y(H) = |s(h) - s(h-1)| \quad (1)$$

where s(n) epitomizes sample value at the point n.

A fault is detected if

$$Y(H) > T1. \quad (2)$$

Where T1 is a threshold value and it is noticed from the above fig.1 that the inequality between the samples may not continuously satisfy eq. (2) in the faulted and now and then a load change may be concluded as a fault.

2.2. Cycle to cycle comparison method [11]

In this method, detect criteria is implemented by considering difference between the two samples which were separated by 360 degrees apart. This difference value of samples in the fault condition is higher than non- fault condition as shown in figure-2. The mathematical procedure is explained below with respective equations in order to detect the fault.

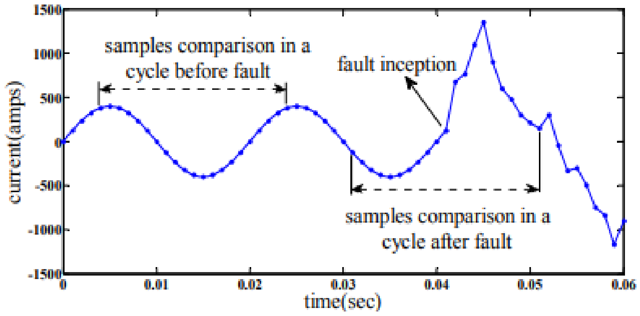

Figure 2: Cycle- cycle approach

Mathematically,

$$Z(H) = |s(h) - s(h-N+1)|. \quad (3)$$

where Y(H) is the index value of this method, s(h) denotes sample value at the point h and N is number of samples in a period.

A fault is detected if,

$$Z(H) > T2. \quad (4)$$

Here, 'T2' is defined with threshold value which helps in separation of fault from non-fault case.

2.3. Moving-sum approach [12]

A moving sum-based fault detection algorithm is proposed. This method takes the values of one power cycle information of current signals measured form relay end. These samples are proceeded to find the sum over the cycle of current samples to all phases individually. These obtained values will help to discriminate the fault from non-fault event based on the sum will be close enough to zero during the non-fault condition but, drastically high during the fault condition. The entire procedure is explained with relevant mathematical expression given below.
Statistically,

$$i_{sum}(h) = \sum_{i=h-N+1}^{h} i(l) \quad (5)$$

Where N is the window size.

A fault is detected if

$$|isum| > i_{Tr} \quad (6)$$

Where T_r is the threshold value separate the fault event from non-fault condition.

3. Proposed Method

This paper presents a novel approach to detect the fault on transmission lines using TMI index values. Firstly, monitored quantified current signal from relay end were proceed to an input for Transient monitor index algorithm given in [13]. The method is already proposed for application of power swing and symmetrical fault discrimination. This method is considered for fault detection application on transmission system. A brief explanation about the proposed methodology is as follows.

3.1. Transient monitors Index estimation

Generally transient monitor function method is clearly explained in [13]. Pristine sinusoidal input results in zero value for TM because the estimated phasor is precisely equal to the input. Existences of TMI values can enhance reliability of the fault detection method by showing clear discrimination between the non-fault and fault events. To obtain this, phasor should be estimated more accurately. A dynamic phasor concept is introduced to evaluate the amplitude and phase of the voltage/current signal during a power swing, A sinusoidal quantity with variable amplitude and phase is defined as

$$S(n) = a(n).\cos\left(n.\theta_1 + \emptyset(n)\right) \qquad (6)$$

Where $a(n)$ and $\emptyset(n)$ are the variable amplitude and phase of the signal respectively and $p(n)$ is the dynamic phasor expressed as

$$p(n) = a(n)..exp\left(j\,.\emptyset(n)\right) \qquad (7)$$

Using second order Taylor series the signal $p(n)$ is used to approximate dynamic around t=0 is given by

$$p(n) = p_{0+}p_1\,.n + p_2\,.n^2$$
$$p_0 = p^{(0)}, p_1 = p'(0), p_2 = p''(0)/2 \qquad (8)$$

According to the equations and for N samples of the signal in (15), the discrete time signal $\{S(n); n = 0,1, \ldots\ldots, N-1\}$ in terms of its Taylor-Fourier coefficients ($P = [P_2, P_1, P_0, P_0^*, P_1^*, P_2^*]^T$) is extracted as

$$S = B.P \qquad (9)$$

Here matrix B is in the basic form with the difference that it contains first and second derivative of dynamic phasor. These coefficients are calculated by least square method as

$$\hat{P} = (B^H.B)^{-1}.B^H.S \qquad (10)$$

The difference between input and recomputed sample data, calculated from the dynamic phasor estimates, is considered as the error of estimation process

$$t = S - \hat{S} = (1 - B.(B^H.B)^{-1}.B^H).S \qquad (11)$$

$$BB = \begin{bmatrix} 1-c_{11} & \cdots & c_{1N}\cos(N-1)\theta \\ c_{21}\cos\theta & \cdots & c_{2N}\cos(N-2)\theta \\ \vdots & \vdots & \vdots \\ c_{N1}\cos(N-1)\theta & \cdots & 1-c_{NN} \end{bmatrix} \qquad (12)$$

Therefore the first array of t is obtained as

$$t_n = (1 - c_{11}\,.\cos(0.\theta_1)).S(0) + (-C_{12}\,.\cos(1.\theta_1)).S(1) + \cdots$$
$$+(-c_{1N}\,.\cos((N-1)\,.\theta_1))\,.S(N-1) \qquad (13)$$
$$\approx 0$$

Where $c_{ij}\{i,j \in 1,2,\ldots N\}$ are constant parameters. The accuracy of phasor estimation obtained by dynamic phasor is higher than static one due to consideration of first and second derivatives of the phasor. Therefore TM is calculated by

$$TMIa = \sum_{n=r-N}^{n=r} |t_{na}| \qquad (14)$$

Where TMI_a is the transient monitor index at phase-a current signal, 't' is the error between the actual samples and reconstructed samples of phase-a respectively. The result of equation.14 shows approximately zero during non fault cases compared to fault period.

3.2. Fault detection criteria

Initially, measure the current signals from the relay location of one cycle of data. These samples are subjected to find the dynamic phasors using Taylor series expansion. From the obtained absolute dynamic phasor values are summed together to estimate transient monitor index value as given in equation.14.

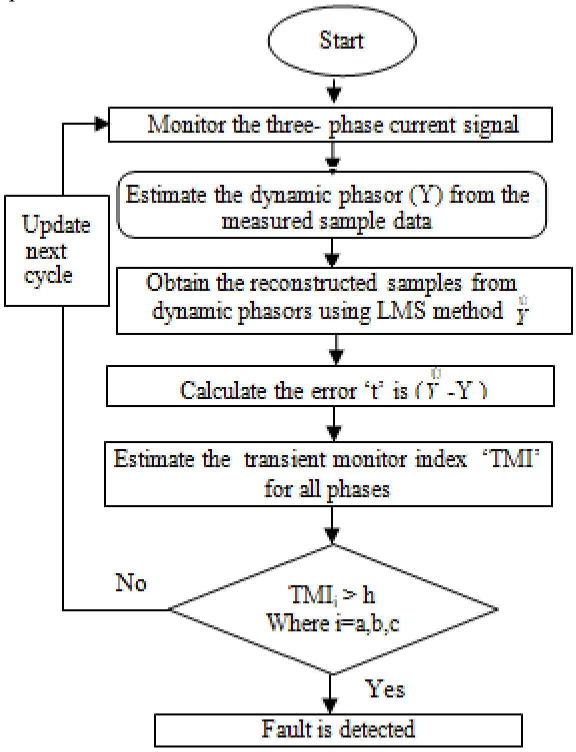

Figure 3: Flow chart of the Proposed Algorithm.

TMI index values are helps in differentiating non fault and fault events respectively. Based on this, fault detection criteria are implemented by assigning a proper selection of threshold 'h' in order to discriminate them is given in equation.15.

$$\text{if } abs(TMI_i) > h \text{ where } i = a,b,c \text{ Trip signal s generated} \qquad (15)$$
$$\text{Otherwise no fault}$$

Trip signal is generated only when the TMI values are exceeds set threshold value, otherwise no-fault case. The entire algorithm is clearly given in flow chart as show in figure3. To validate the performance of the proposed method an extensive simulation results are carried out and presented in the next section.

4. Simulation Results

A 500 kV, 50 Hz single line diagram transmission network is considered as shown in fig.4 to verify the proposed fault detection method.

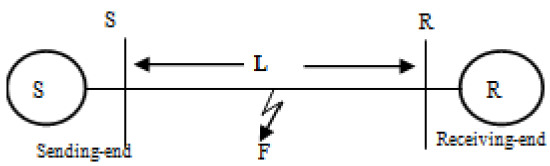

Figure 4: A 500 kV, 50Hz 400km long transmission circuit

Simulation is carried out in MATLAB/SIMULINK software and the system data is provided in Appendix. Sampling frequency of 2 KHz is considered to measure the voltage and current signals from relay location. The proposed method is verified by engendering several critical fault situations and the dynamic conditions like, change in load angle, change in frequency.

3.1. Comparative Results for fault & non fault events

To investigate the performance of the proposed method is considered at different fault situation as shown in simulated cases. Each case is presented along with other existing approaches of method-1 sample to sample (SS) [10] , method-2 cycle to cycle (CC) [11] and method-3 moving sum approach (MS) [12] as a comparative study with proposed method (TMI).

Case-1: Let us consider a single line to ground fault in transmission line at 100 kms from relay end with fault resistance of 100 ohms and incepted at 0.0252 sec. The corresponding result is shown below in figure.5. In this study, it reveals that the methods [10] & [11] were unable to detect the fault during this event but method [12] and proposed one will detect within 3.3 msec after the fault inception.

Case-2: Let us consider a line to line fault involved with ground in transmission line at 200 kms from relay end with fault resistance of 50 ohms and incepted at 0.0285 sec. The corresponding result is shown below in figure.6.

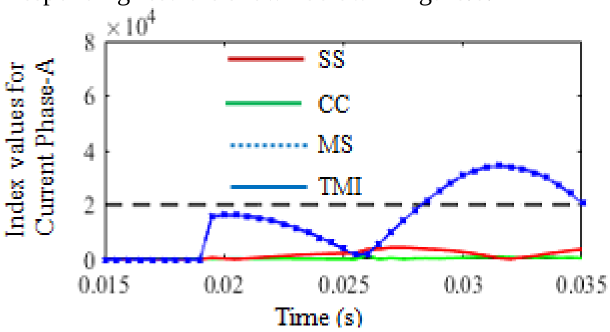

Figure 5: Result for proposed method

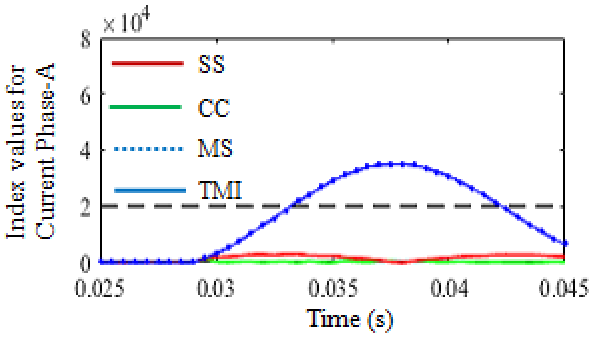

Figure 6: Result for proposed method

In this study, it exhibits that the methods [10] & [11] were unable to detect the fault during this event but method [12] and proposed one will detect within 5 msec after the fault inception.

Case-3: Let us consider a line to line fault in transmission line at 380 kms from relay end with fault resistance of 25 ohms and incepted at 0.0217 sec. The corresponding result is shown below in figure.7.

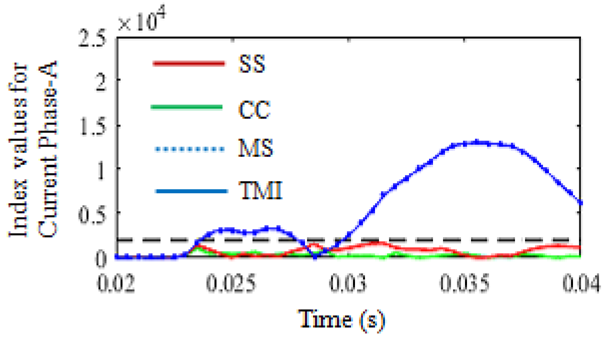

Figure 7: Result for proposed method

In this study, it exhibits that the methods [10] & [11] were unable to detect the fault during this event but method [12] and proposed one will detect within 2.3 msec after the fault inception.

Case-4: Let us consider a three-phase fault in transmission line at 20 kms from relay end with fault resistance of 150 ohms and incepted at 0.0205 sec. The corresponding result is shown below in figure.8.

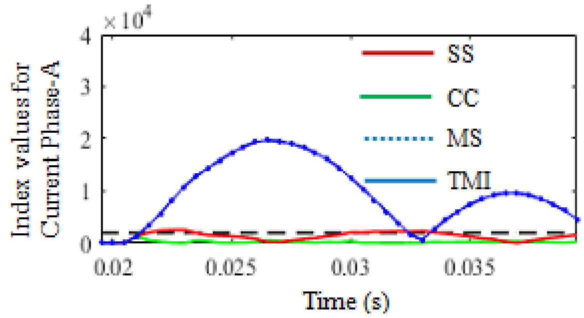

Figure 8: Result for proposed method

In this study, it exhibits that the methods [10] & [11] were unable to detect the fault during this event but method [12] and proposed one will detect within 1 msec after the fault inception.

Case-5: To study the influence of sampling frequency variation on transmission system with 1 kHz is considered for simulation. Let us consider a three-phase fault in transmission line at 20 kms from relay end with fault resistance of 150 ohms and incepted at 0.0205 sec. The corresponding result is shown below in figure.9.

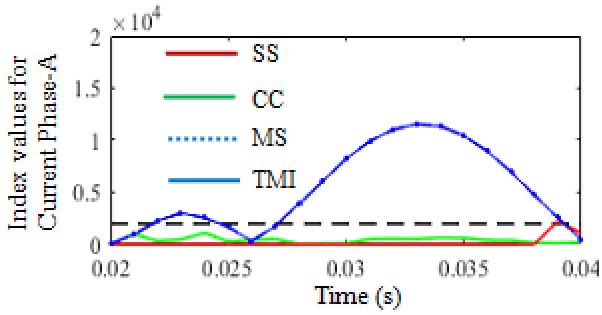

Figure 9: Result for proposed method

In this study, it exhibits that the methods [10] & [11] were unable to detect the fault during this event but method [12] and proposed one will detect within 2.3 msec after the fault inception.

Case.6: To study the load variation on the transmission system a test case is simulated by varying power flow variation by changing the load angle at 80 degrees on the receiving end of the transmission system. During this conditions the existing methods of sample to sample and cycle to cycle approaches may operate the relay by detecting it as fault where as moving sum and proposed methods is able to discriminate the fault and non fault event clearly and is observed from the figure.10.

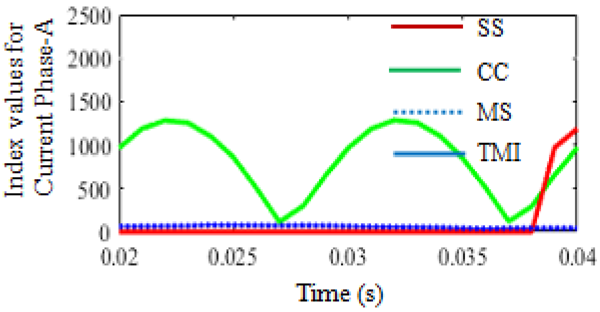

Figure 10: Result for proposed method

Similarly different fault events are simulated to validate the proposed method from existing method and results were tabulated in table-I.

Table I: Comparative Assessment report

S. No	*Fault distance in (kms)*	*Fault resistance*	*Fault inception time (sec)*	*Detection times (ms) of methods*			
				[10]	*[11]*	*[12]*	*Proposed*
1	100	10	0.0217	2	2	2	2
2	350	350	0.0250	F	F	6	6
3	280	580	0.0284	F	F	1.6	1.6
4	50	490	0.0200	F	1.5	1	1
5	450	340	0.0317	F	F	1.8	1.8
6	260	350	0.0326	F	F	1.9	1.9
7	300	500	0.0350	F	F	2	2
8	150	5	0.0367	1.3	1.3	1.3	1.3
9	250	100	0.0365	1	1	1	1
10	300	600	0.0300	F	F	2	2

5. Conclusion

A novel fault detection algorithm is developed in order to discriminate fault and non fault events using TMI values. This approach is developed in [13] for an application fault detection during power swing to supervise the distance relay operation under symmetrical fault condition. This method is studied under different critical conditions like variation of fault distance, fault resistance and fault inception on 500 kV, 50 Hz transmission network. A comparative study is also performed with existing approaches of sample to sample method [10], cycle to cycle approach [11] amd ,moving sum approach [12]. The results show that the proposed method is more robustness under any fault situations and faster response. It has a drawback only of computational burden in order to estimate the reconstructed samples for estimation of error. But, the method will overcome the drawbacks available in the conventional techniques. The entire study is considered on MATLAB/SIMULINK environment.

Appendix-A

The parameters of the 500-kV system:
Source parameters:
Sending end impedance Z1=1.1+j*16.336 ohms,
α(load angle)=0.
Receiving end impedance : Z1= 0.44+j*7.853 ohms,
α(load angle)=4degrees.
Transmission lines:
Line length = 400 km; R1=0.0198, Ro=0.01828, L1=0.8192e-3, Lo=2.7400e-3, C1=0.0135e-6, Co=0.0092e-6;
Sampling frequency = 2 KHz.

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Author Profile

Pavan kumar Chintha is pursuing M.tech in S.R.K.R Engineeering college Bhimavaram from India. He completed under graduate from the same college. His area of interest is power system protection, signal processing techniques application to power system relaying

Kumarraja Andanapalli is pursuing his PhD in NIT Raipur, received his M.E & B.E Degree from SRKR Engineering College, Bhimavaram and ANITS, visakhapatnam from India in 2013 & 2008. Currently he is working as an Assistant Professor in the Department of EEE at SRKR Engineering College.. His research area of interest is power system protection, wide area protection, signal processing applcation to power system relaying

Nazeer Shaik is pursuing his PhD in Annamalay University, tamil nadu. He received his M.E & B.E Degree from SRKR Engineering College, Bhimavaram and Prakasam engineering college, Kandukur from India in 2013 & 2010. Currently he is working as an Assistant Professor in the Department of EEE at SRKR Engineering College..His research area of interest is power system protection, wide area protection,