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A Transient Current Based Transmission Line Protection in the Presence of Interline Power Flow Controller using Neuro-Wavelet Approach

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ABSTRACT

Distance Relays are the unique devices which are used to protect the transmission line from various shunt faults. The reach of the distance relay is independent of the types of fault when compared to the over current protection. When a FACTS device, say, IPFC is incorporated in order to enhance the power flow control, voltage control, etc., on existing transmission line, it will result in significant change in impedance. This in turn will lead to mal operation of distance relay, as the Distance Relays are sensitive to apparent impedance seen by the relay and zones. This paper presents simulation results of the application of distance relays for the protection of double line transmission systems with Interline power flow controller .This paper presents an efficient method based on wavelet transforms, fault detection, classification which is almost independent of fault impedance, fault distance and fault inception angle
Keywords: IPFC, Distance Relay, Wavelets, multi resolution analysis, Power system protection;1. Introduction

1. INTRODUCTION

Power transmission line protection is one of the most important concerns for the power utilities. Different types of fault occur on transmission line. From the transient phenomena, fault on transmission lines need to be detected, classified, location accurately, and cleared as fast as possible. In transmission line protection, fault phase identification and location of fault are the two most important items which need to be addressed in a reliable and accurate manner. Identification and classification of faults on transmission line are essential for relaying decision and auto-reclosing requirements.

Wavelet Transform (WT) is an effective tool in analyzing transient voltage and current signals associated with faults both in frequency and time domain. Chul-Hwan Kim, et al [1] has used Wavelet Transforms to detect the high impedance arcing faults. Joe-Air Jiang, et al [2]&[5] has used Haar Wavelet to detect dc component for identifying the faulty phases. The distance protection schemes using WT based phasor estimation are reported in [3]&[4].

As the consequence of fast growing demands on active and reactive power control and the rapid development of power electronic technology, power electronic based equipments, under the generic name of the Flexible Ac Transmission Systems (FACTS) devices, are being developed in the field of modern power systems. Most FACTS devices have demonstrated their ability to significantly increase the transmission capabilities of the network and considerably enhance the security of the system, because they can control most parameters related to the operation of transmission systems with a quick response. Now FACTS technology is regarded as one of emerging technologies for power system security improvement. Since power system stability is an important problem for secure system operation and transient instability has been the dominant stability problem with the majority systems, transient stability enhancement, which is one of the main applications of FACTS devices, has been attracting much interest of researchers, utilities and manufacturers. Among all the FACTS devices, the combined compensators such as the Unified Power Flow Controller (UPFC) and the Interline Power Flow Controller (IPFC) are regarded as the most powerful and versatile ones [6].The optimal setting for the relay operation to coordinate with the FACTS devices is discussed [7] to overcome the undesired effects of their operation together. More specifically the effect of UPFC [8], STATCOM [9] SSSC [10] are discussed.

The IPFC scheme provides, together with independently controllable reactive series compensation of each individual line, a capability to directly transfer real power between the compensated lines. This capability makes it possible to equalize both real and reactive power flow between the lines; transfer power demand from overloaded to under loaded lines; compensate against resistive line voltage drops and the corresponding reactive power demand; increase the effectiveness of the overall compensating system for dynamic disturbances. In other words, the IPFC can potentially provide a highly effective scheme for power transmission management at a multiline substation.

When a FACTS device, say, IPFC is incorporated in order to enhance the power flow control, voltage control, etc., on existing transmission line, it will result in significant change in impedance. This in turn will lead to mal operation of distance relay, as the Distance Relays are sensitive to apparent impedance seen by the relay and zones. The relay has to compute the impedance as seen from its location and compare it with set value to take the trip decision. Because of the simple series model of the faulted line, the line impedance is directly proportional to the distance of fault .Hence the name *distance relay.* Such a relay is called *under impedance relay.* In practice, however, the word *under is* dropped and the relay is simply called *impedance* relay .It is possible to synthesize several more complicated distinct relay. To distinguish this relay from the other distance relays, it is called as simple *Impedance relay* he positive sequence component is the only component which is present during all faults. Thus, it would be prudent to measure positive sequence impedance between the relay location and the fault so as to cater for every fault.

This paper presents fault detection and classification can be accomplished within a half a cycle using detail coefficients of currents at both the ends. For this purpose the three phase of the local terminal are decomposed with Bior1.5 mother wavelet, over a half cycle window are obtained. This paper presents an efficient methods based on wavelet transforms for both fault detection and classification which is almost independent of fault impedance, fault location and fault inception angle. The proposed protection scheme is found to be fast, reliable and accurate for various types of faults on transmission lines.

2. WAVELET ANALYSIS

Wavelet analysis represents a windowing technique with variable size. Wavelet analysis allows the use of long time intervals where more precise low-frequency information is required, and shorter intervals where high-frequency information is required.

Power transmission line protection is one of the most important concerns for the power utilities set of basic functions called Wavelets, are used to decompose the signal in various frequency bands, which are obtained from a mother wavelet by dilation and translation. Hence the amplitude and incidence of each frequency can be found precisely. Wavelet Transform is defined as a sequence of a function {h(n)}(low pass filter) and {g(n)}(high pass filter). The scaling function φ(t) and wavelet ψ(t) are defined by the following equations

$$\varphi(t) = \sqrt{2}\sum h(n)\,\varphi(2t-n),\ \psi(t) = \sqrt{2}\sum g(n)\,\varphi(2t-n) \qquad \text{Where } g(n) = (-1)^n h(1-n)$$

A sequence of {h(n)} defines a Wavelet Transform. There are many types of wavelets such as Haar, Daubachies, and Symlet etc. The selection of mother wavelet is based on the type of application. In the following section a novel method of detection and classification of faults using Multi Resolution Analysis of the transient currents associated with the fault is discussed. The Continuous Wavelet Transform (CWT) $W_f(u, s)$ of a function f(t) is given generated by translations and in multiresolution analysis [5], Digital filters of different cutoff frequencies are used to analyze the signal at different scales. The signal is passed through a series of high pass filters to analyze the high frequencies, and it is passed through a series of low pass filters to analyze the low frequencies.

3. SYSTEM ANALYSIS AND SYSTEM DESCRIPTION

The single line diagram of horizontal configuration transmission line with IPFC is considered along with the various blocks of the proposed scheme as shown in Figure-1.

The system consists of two transmission lines and resembles the multiline system with IPFC configuration. In this figure, the IPFC is connected between two parallel transmission lines. The IPFC structure is realized by connecting two Static Synchronous Series Compensators in both the lines and adjoining them at the common dc link. The performance of relays for different fault types, fault locations, and fault resistances is analyzed to show the impact of VSC-based IPFC on distance protection of the multiline system.

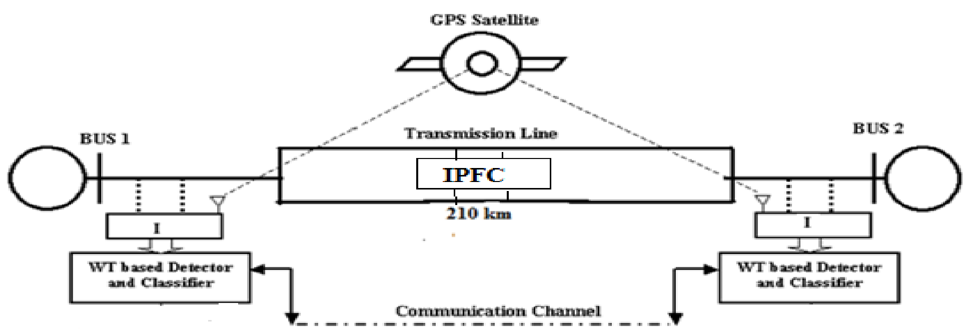


Fig.1. System considered along with the proposed scheme for Double line Transmission System with IPFC

The transmission line to be protected in the system connects two AC systems represented by equivalent voltage source behind constant impedance. Modeling of Two 210-km parallel 500-kV transmission lines terminated in two 9000-MVA short-circuit levels (SCLs) sources and the angle difference is 20^0.The Distributed transmission line is represented by ten sections. Two static synchronous series compensators (SSSC) are connected into the system through a 15 kV/22 kV Y/Y series transformer to inject an almost sinusoidal voltage of variable magnitude and angle, in series with the transmission lines to regulate the power flow through the transmission line. Fig 2 shows Simulation diagram for Double line Transmission System with IPFC.

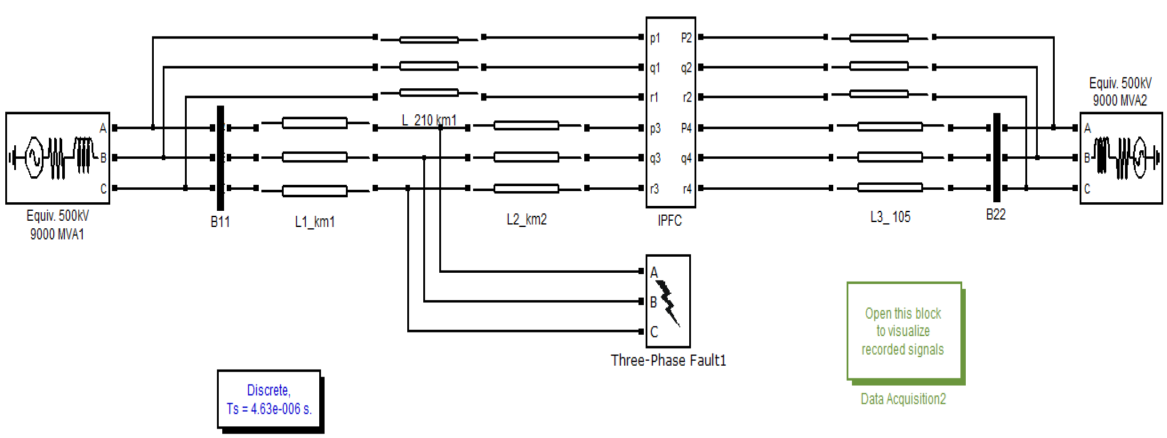


Fig.2: Simulation diagram for Double line Transmission System with IPFC

Details of Wavelet and associated parameters are given in table.1

Table.1

Mother Wavelet	Bior 1.5
Sampling frequency	216Khz
Information Analyzed	Detail at 1,D1
Frequency band	108Khz-54Khz
Number of Samples per cycle	3600
Occurrence of Fault	Second cycle
Data window length	One cycle/17.7ms

4.DETECTION AND CLASSIFICATION OF FAULTS

The three phase currents of the local terminal are analyzed with Bior.1.5 mother wavelet to obtain the detail coefficients ($D1_L$) over a moving window of half cycle length. These $D1_L$ coefficients are then transmitted to the remote end. The detail coefficients received from the remote bus ($D1_R$) are subtracted to the local detail coefficients ($D1_L$) to obtain effective D1 coefficients ($D1_E$). The Fault Index (I_{f1}) of each phase is then calculated as $I_{f1} = \Sigma |D1_E|$.

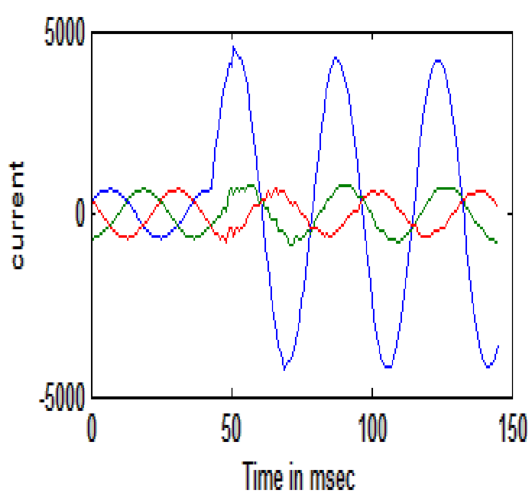


Figure 3 Three Phase currents at Terminal-1 of AG fault at 40% of the Transmission line with IPFC from Terminal-1

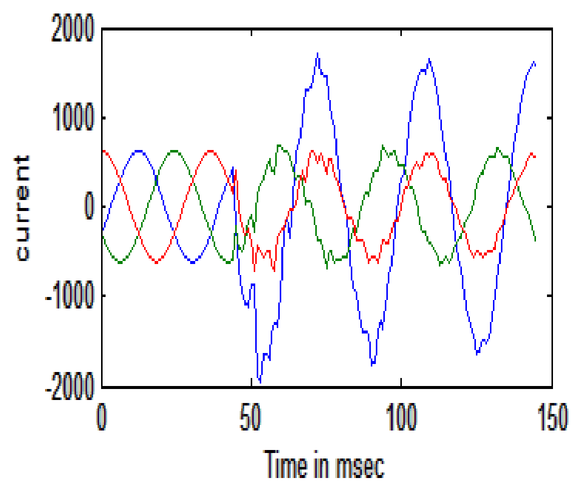


Figure 4 Three Phase currents at Terminal-2 of AG fault at 40% of the Transmission line with IPFC from Terminal-1

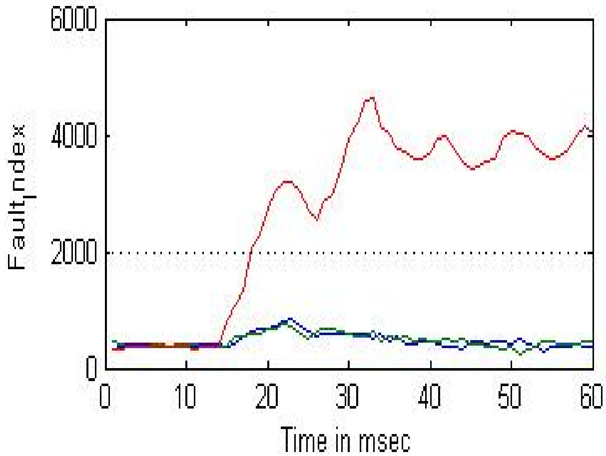


Figure 5: Variation of Fault Index for AG fault at 40% of the Transmission line with IPFC from Terminal-1

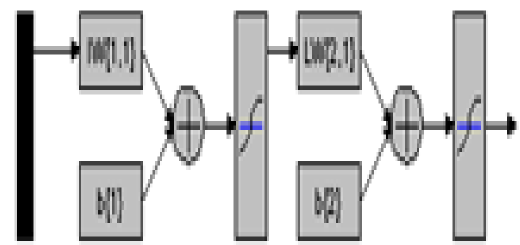


Fig 7.Neural Network Structure

Figures 3&4 show the variation of three phase currents for AG fault and Figures 5 illustrate the variation of Fault Index for phase-A for the same fault. The types of faults considered in the analysis are L-G, L-L-G, L-L, L-L-L, faults. The simulations show that fault inception angle has a considerable effect on the phase current samples and therefore also on Wavelet transform output of post-fault signals. As the waves are periodic, it is sufficient to study the effect of inception angle in the range of 0^0 to 160^0 in step of 20^0. The complete flow chart for fault classification is as shown in Figure 6.

5. ESTIMATION OF FAULT LOCATION

Subsequent to detection and classification of fault, estimation of fault location is carried out using ANNs [6-7]. For this purpose the three phase currents of the local terminal are decomposed with Bior1.5 mother wavelet over a half cycle window are obtained. This is done concurrently with the decomposition D1 used for fault detection and classification to speed up estimation of fault location. For an LG, LL, LLG and LLLG fault, D1 decomposition of any one faulty phase can be used to estimate fault location.fig 7 represents NN structure.

The details of the ANN architecture described as follows:
Input layer: Detail D1 coefficients of current signals using Bior1.5 wavelets at both the ends are used location of fault.
Number Layers: 2
Number of neurons: 10
Transfer function: pure line

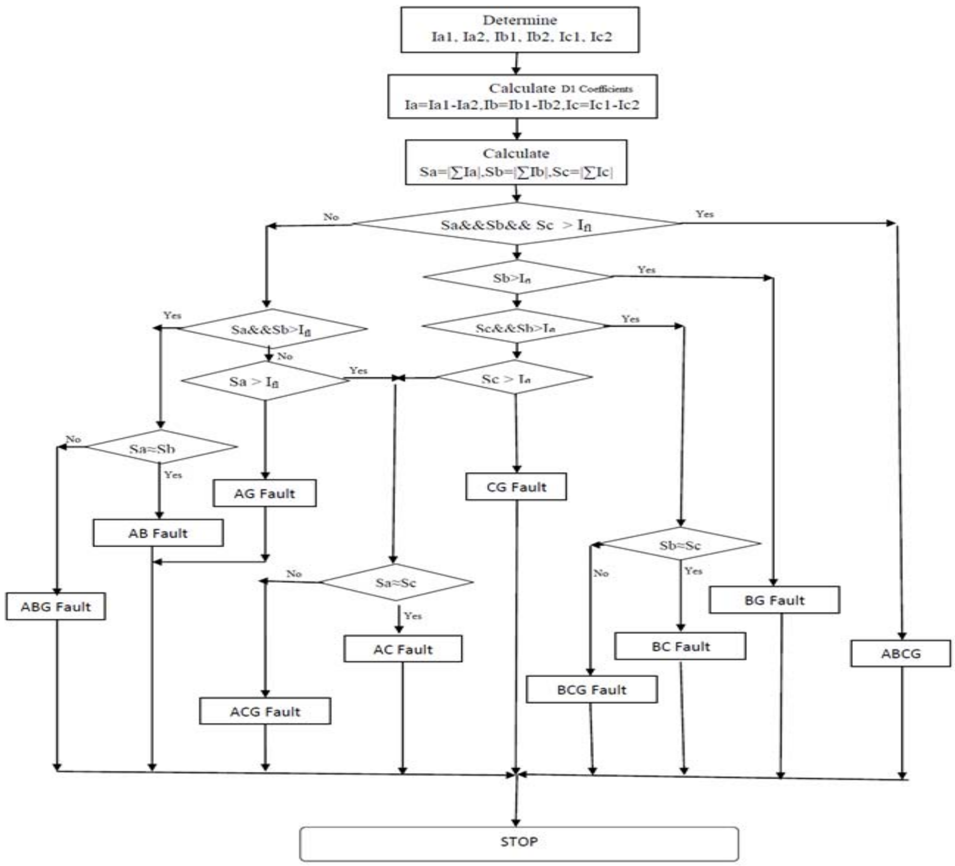
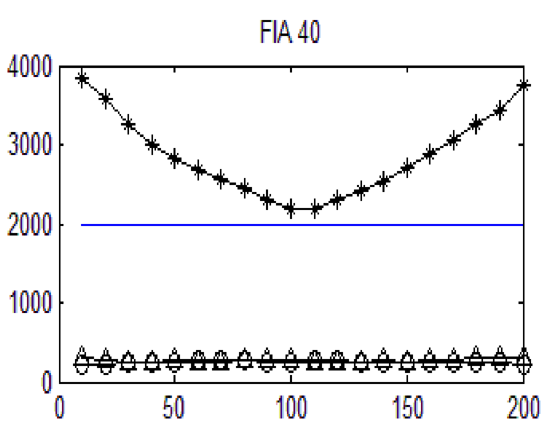


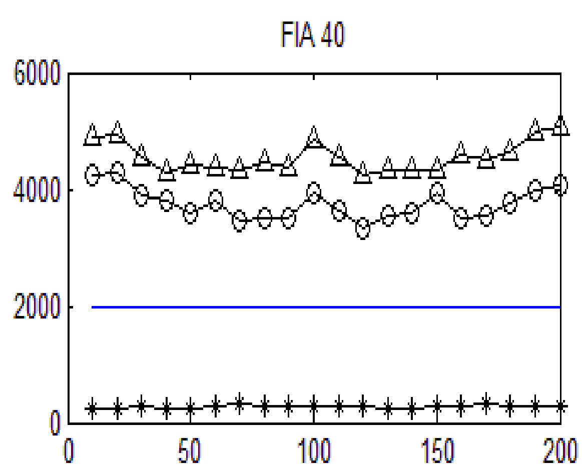
Fig.6 Flow chart for the fault classification using wavelet Detailed coefficients.

6. RESULT ANALYSIS

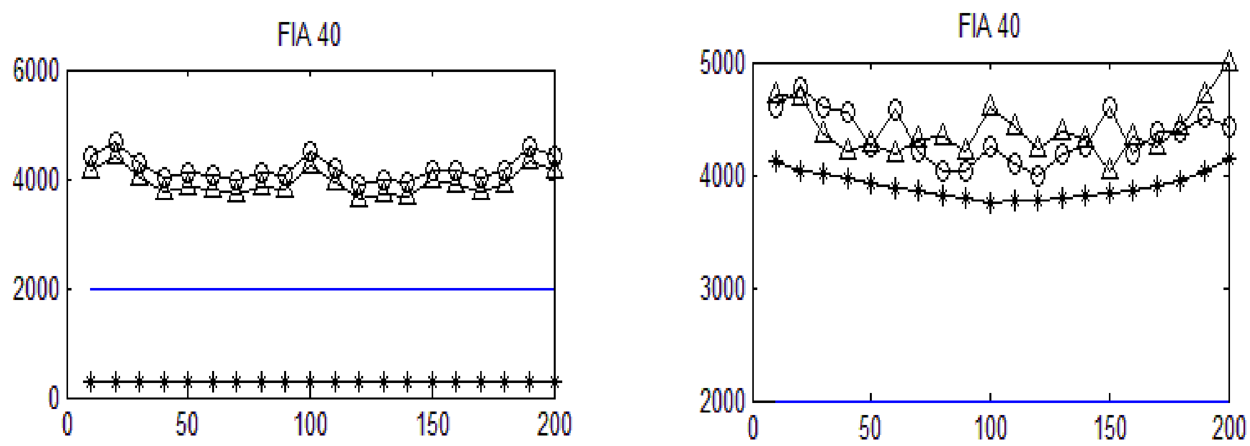
The obtained result by using the algorithm for different faults are given below



(a)

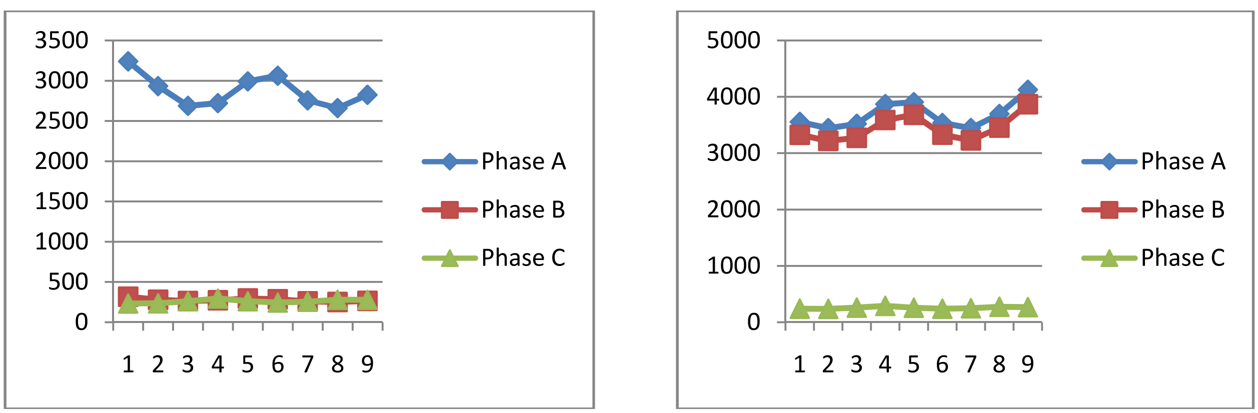


(b)

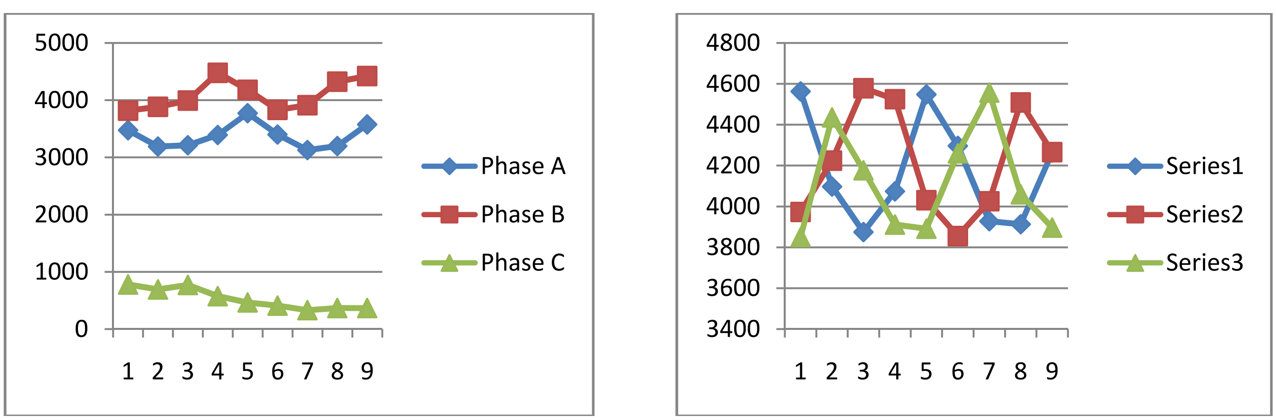


(c) (d)

Fig8. Variation of fault index for transmission line at Fault inception angle 40^0 (a) LG Fault on Phase A (b) LLG Fault on AC (c) LL Fault on AC (d) Variation of fault index for LLLG Fault on Phase ABCG



(a) (b)



(c) (d)

Fig9.Variation of fault index at 60km from Bus1 (a) for LG fault on Phase AG (b) for LL fault on Phase AC (c) for LLG fault on Phase ACG (d) for LLlG fault on Phase AbCG

Table 1: ANN based fault location Analysis with IPFC

Fault type	Actual Distance	Transmission line			Transmission line with IPFC		
		Fuzzy Distance	Error Distance	%Error	Fuzzy Distance	Error Distance	%Error
ag	20	26	6	3	24	4	2
	40	40	0	0	40	0	0
	80	80	0	0	80	0	0
	100	110	5	2.5	104	4	2
	130	132	2	1	130	0	0
	160	160	0	0	158	-2	-1.0
	180	176	4	2	172	8	-4
bg	20	24	4	2	24	4	2
	40	40	0	0	44	4	2
	80	82	2	1	80	0	0
	100	110	10	5	106	6	3
	130	134	4	2	130	0	0
	160	160	0	0	164	4	2
	180	186	4	2	186	4	2
bc	20	26	6	3	26	6	3
	40	40	0	0	38	-2	-1
	80	80	0	0	80	0	0
	100	110	10	5	100	0	0
	130	130	0	0	130	0	0
	160	160	0	0	156	-4	-2
	180	174	6	3	184	4	2
abcg	20	28	8	4	22	2	1
	40	38	-2	-1	40	0	0
	80	80	0	0	80	0	0
	100	106	6	3	102	2	1
	130	130	0	0	130	0	0
	160	160	0	0	156	4	2
	180	176	6	-3	174	6	3

The proposed algorithm has been tested for all types of faults at different locations by simulating AG, BG, CG, AB, BC, AC, ABG, BCG, ACG and ABCG faults at different locations of transmission line with STATCOM. The variation of Fault Index I_{f1} with the location varying from 20km to 200km with step size is 20km for all types of faults of transmission line in presence of STATCOM at 40^0 and 60^0 degrees of Fault inception angles. The fault index I_{f1} of all faulty phases varies with the type of fault. However its value remains greater than Threshold T_{h1}. The fault Index of healthy phases remains less than the threshold value. It can also be observed that the End Zone faults can be easily detected.

6. CONCLUSIONS

This paper presents an efficient method based on wavelet transforms both fault detection and classification which is almost independent of fault impedance, fault location and fault inception angle of transmission line fault currents. Fault detection and classification can be accomplished within a half a cycle using detail coefficients of currents at both the ends. The proposed protection scheme is found to be fast, reliable and accurate for various types of faults on transmission lines, at different locations and with variations in incidence angles with and without Interline power flow controller.

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