RESEARCH ARTICLE OPEN ACCESS

Wavelet Based Fault Detection, Classification in Transmission System with TCSC Controllers

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Abstract
This paper presents simulation results of the application of distance relays for the protection of transmission systems employing flexible alternating current transmission controllers such as Thyristor Controlled Series Capacitor (TCSC). The complete digital simulation of TCSC within a transmission system is performed in the MATLAB/Simulink environment using the Power System Block set (PSB). 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 with FACTS controllers.
Index Terms—Distance relay, Flexible alternating current transmission controllers, TCSC, Voltage Source Converter ,power system protection.

I. INTRODUCTION

The performance of a power system is affected by faults on transmission lines, which results in interruption of power flow. Quick detection of faults and accurate estimation of fault location, help in faster maintenance and restoration of supply resulting in improved economy and reliability of power supply. 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] have used Wavelet Transforms to detect the high impedance arcing faults. Joe-Air Jiang, et al [2] have used Haar Wavelet to detect dc component for identifying the faulty phases. Distance protection schemes using WT based phasor estimation are reported in [3]&[4].

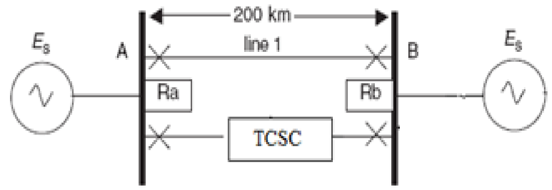


Fig.1.Power system Physical model with TCSC

Due to fast developing communication techniques, it is possible to develop communication-aided high-speed digital protection scheme, which suits the EHV transmission. Better performance can be achieved using two terminal synchronized sampling of signals.

Global Position System (GPS) based algorithms with better performance and accuracy have been proposed in [5]&[6]. There is always a need to develop innovative methods for transmission line protection. In this paper, Wavelet Multi Resolution Analysis is used for detection, classification and location of faults on transmission lines. Detail D1 coefficients of current signals at both the ends are used to detect and classify the type of fault.

II. THYRISTOR CONTROLLED SERIES COMPENSATOR

Figure2 shows the basic circuit for a Thyristor Controlled Series Compensator (TCSC). A TCSC is placed on a 500kV, long transmission line, to improve power transfer. Without the TCSC the power transfer is around 110MW, as seen during the first 0.5s of the simulation when the TCSC is bypassed. The TCSC consists of a fixed capacitor and a parallel Thyristor Controlled Reactor (TCR) in each phase. The nominal compensation is 75%, i.e. using only the capacitors (firing angle of 90deg). The natural oscillatory frequency of the TCSC is 163Hz, which is 2.7 times the fundamental frequency. The test system is described in [7].

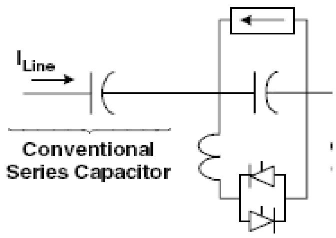


Fig 2.Circuit for a Thyristor Controlled Series Compensator (TCSC).

TCSC Control: When TCSC operates in the constant impedance mode it uses voltage and current feedback for calculating the TCSC impedance. The reference impedance indirectly determines the power level, although an automatic power control mode could also be introduced. A separate PI controller is used in each operating mode. The capacitive mode also employs a phase lead compensator. Each controller further includes an adaptive control loop to improve performance over a wide operating range. The controller gain scheduling compensates for the gain changes in the system, caused by the variations in the impedance. The firing circuit uses three single-phase PLL units for synchronization with the line current. Line current is used for synchronization, rather than line voltage, since the TCSC voltage can vary widely during the operation.

III. WAVELET ANALYSIS

Wavelet Transform (WT) is an efficient means of analyzing transient currents and voltages. Unlike DFT, WT not only analyzes the signal in frequency bands but also provides non-uniform division of frequency domain, i.e. WT uses short window at high frequencies and long window at low frequencies. This helps to analyze the signal in both frequency and time domains effectively. A set of basis 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 $\varphi(t) = \sqrt{2}\sum h(n)\, \varphi(2t-n)$, $\psi(t) = \sqrt{2}\sum g(n)\, \varphi(2t-n)$

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.

IV. DETECTION AND CLASSIFICATION OF FAULTS

Figure-1 shows the single line diagram of the system considered along with the various blocks of the proposed scheme. Two 200-km parallel 500kV transmission lines terminated in two 9000-MVA short-circuit levels (SCLs) sources and the angle difference 40^0 with 60HZ.The 100MVA and FACTS controller is installed in the middle of the second transmission line. Synchronized sampling of three phase currents and voltages at both the ends is carried out with the help of a GPS satellite. The detail D1 coefficients used for detection and classification of the type of fault are transmitted through the fiber-optic communication channel to the remote end.

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 added 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 $I_{f1} = \Sigma \left| D1_E \right|$.

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 180^0.

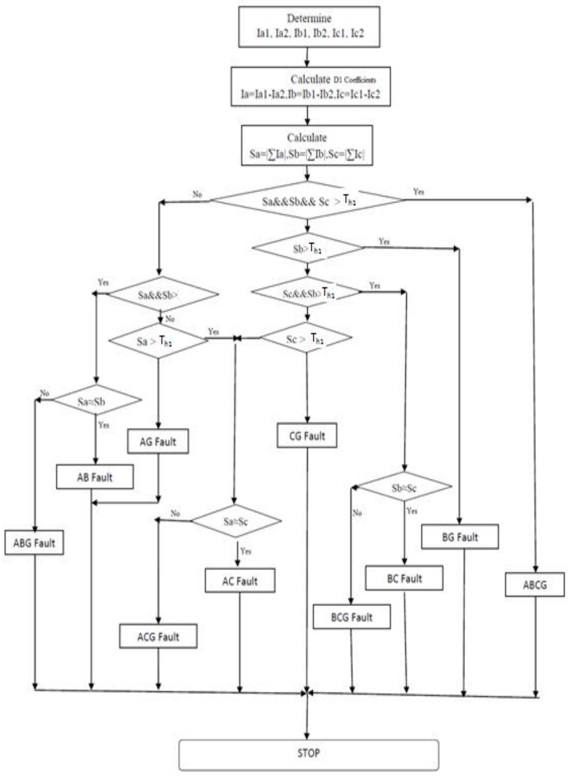
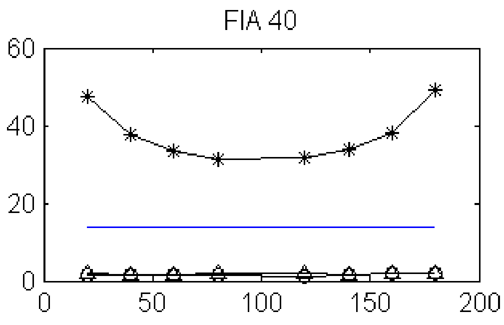
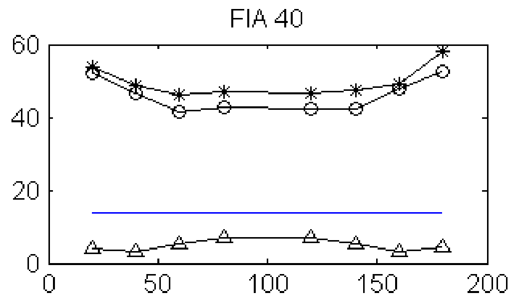


Fig 3. Flow chart for the fault classification

The complete flow chart for the fault classification is as shown in Figure 3



(a)



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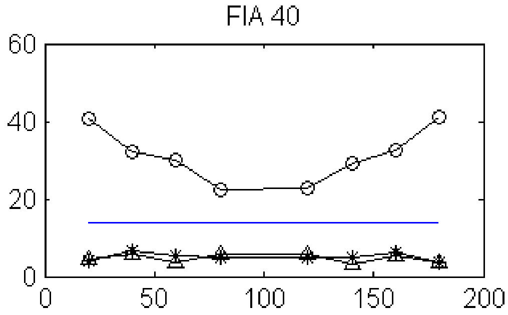

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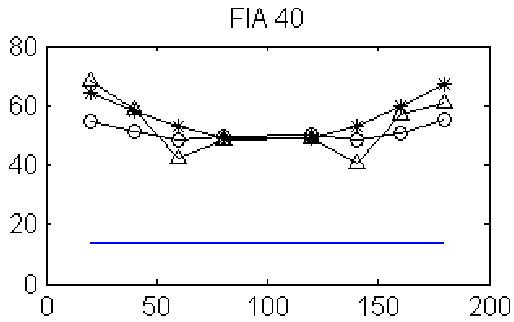
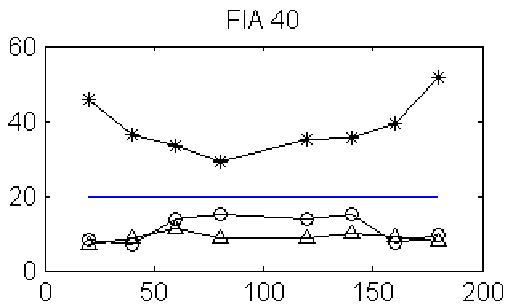
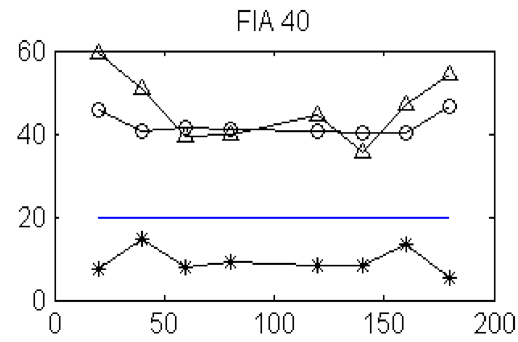


(d)

Fig 4.Variation of fault index for (a) LG Fault on Phase A (b) LLG Fault on ABG (c) LG Fault on Phase C (d) Variation of fault index for LLLG Fault on Phase ABC.



(a)



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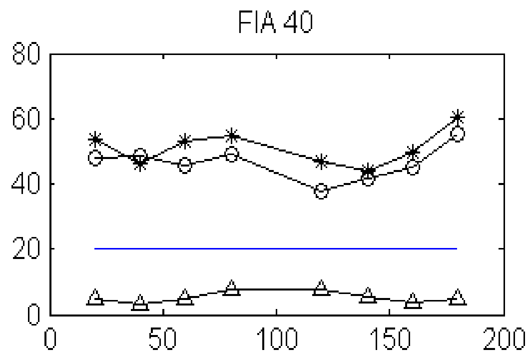
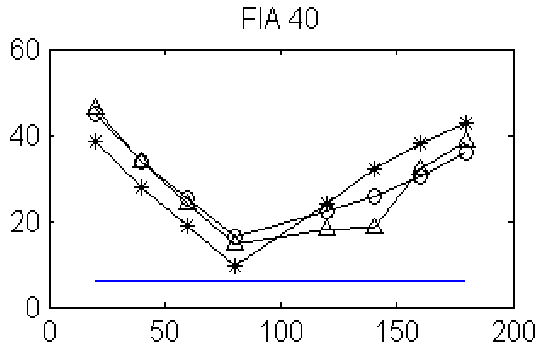


(c)



(d)

Fig5.Variation of fault index (a)for LG fault on Phase B with TCSC Controller(b)for LLG fault on Phase AC with TCSC Controller (c) for LLG fault on Phase AB with TCSC Controller (d) for LL fault on Phase AB with TCSC Controller.

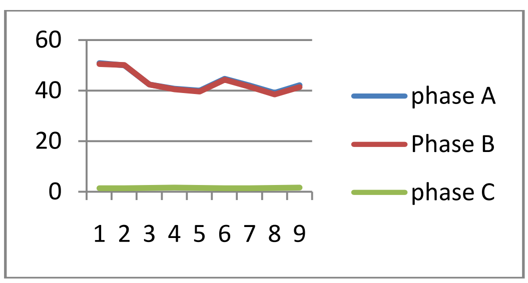


Fig6. LLG Fault without FACTS Controller

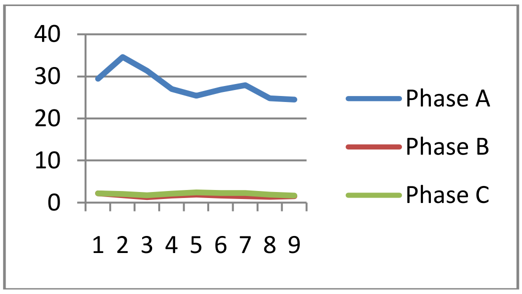


Fig7. LG Fault without FACTS Controller

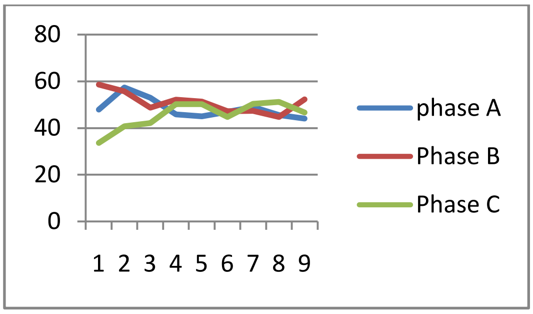


Fig8. LLLG Faults without FACTS Controller

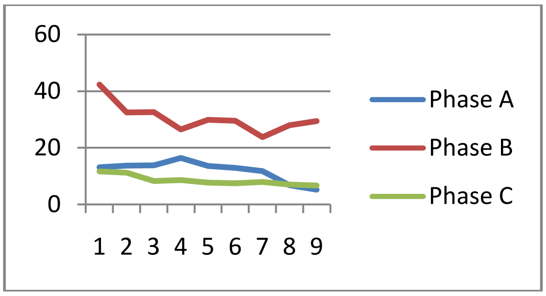


Fig9. LG Fault with TCSC Controller

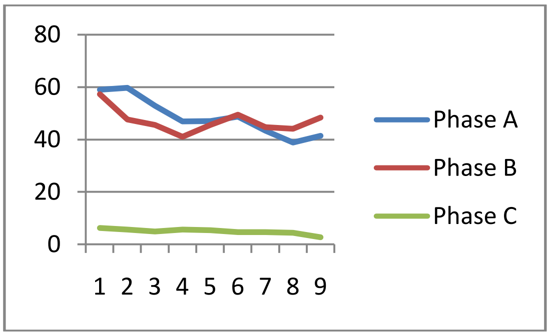


Fig10. LLG Fault with TCSC Controller

The fault index of three phase currents for transmission line is shown Figures 4 show the variation of three phase currents D1 Coefficients of Phase A, Phase B &Phase C for LG, LLG&LLLG fault on transmission line without FACTS Controller. Figure 6,7and 8shows the LLG,LGand LLLG Fault without FACTS Controller, Figure 9&10 shows the LG and LLG Fault with TCSC Controller.

It is observed that the fault index of faulty phase is large compared to those of healthy phases. Figure shows the variation of Fault Index I_{f1} in case of ABG fault. Thus the number of faulty phases is determined by comparing the Fault Index (I_{f1}) with a Fault Threshold (T_{f1}).The proposed algorithm has been tested for all types of faults, considering variations in fault locations and fault incidence angles (θ) in the range 0-180^{o}. This scheme is proved to be effective in detecting and classifying various types of faults.

V. Conclusion

WT based multi resolution analysis approach can be successfully applied for effective detection and classification and location of faults in transmission lines. The complete digital simulation of the TCSC within a transmission system is performed in the MATLAB/Simulink environment using the Power System Block set (PSB). 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 with FACTS controllers 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.

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