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APPLICATION OF WAVELET ENTROPY BASED ALGORITHM ON A FACTS COMPENSATED TRANSMISSION LINE

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ABSTRACT:

Protection of transmission lines is very challenging task including flexible AC transmission system (FACTS). Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controllers (UPFC) are the flexible AC transmission system devices used in this paper. A wavelet is a waveform of effectively limited duration that has an average value of zero. Faults usually occur in a power system due to insulation failure, flashover, physical damage or human error. FACTS controllers are capable of controlling the network condition in a very fast manner and this feature of FACTS can be exploited to improve the voltage stability, and steady state and transient stabilities of a complex power system. The proposed algorithm is accurate and very simple in classification and fault detection.

I. INTRODUCTION

In recent years, it has become more difficult to construct new generation facilities and transmission lines due to energy and environmental problems. Hence, it is required to enhance the power transfer capability of existing transmission lines instead of constructing new ones. Because of all that, it became more important to control the power flow along the transmission lines to meet the need of power transfer. On the other hand, FACTS devices also have the capability of increasing transmission capabilities, decrease the generation cost and improve the security and stability of power system. Fault classification and section identification in a transmission line with FACTS devices is a very challenging task because the presence of compensating devices affect the steady state and transient components of current and voltage signals and create problems with relay functionality. But, their presence is inevitable as they compensate for controlled power flow in the line. Some researchers used current and voltage signals to determine the fault location and fault resistance only without attempting to find the fault type and phase involved. Some others took the advantage of the post fault voltage and current samples taken synchronously from both ends of the line to build a recursive optimization algorithm to find the distance to fault in a transmission line compensated with a series FACTS device. However, it aimed only to location of fault without trying to find its type.

For the purpose of identification and classification of fault, the wavelet entropy theory is applied to produce a simple and accurate algorithm. The algorithm is also applicable to both symmetrical and unsymmetrical short circuit faults. The algorithm is proposed to identify and classify the fault and also determine the phases involved in the fault as well as its location with respect to a FACTS device. For this purpose, a test system is considered with a series compensating FACTS device, the SSSC (Static Synchronous Series Compensator), to which the fore mentioned algorithm is applied.

II. WAVELET ANALYSIS

"A wavelet is a waveform of effectively limited duration that has an average value of zero." It gives a tool for the analysis of transient, non-stationary or time varying phenomena. Wavelet theory is the mathematics associated with building a model for non-stationary signal, with a set of components that are small waves, called wavelets. Informally, a wavelet is a short- term duration wave. These functions have been proposed in connection with the analysis of signals, primarily transients in a wide range of applications. The basic concept in wavelet transform is to select an appropriate wavelet function "mother wavelet" and then perform analysis using shifted and dilated versions of this wavelet. Wavelet can be chosen with very desirable frequency and time characteristics.

According to Fourier theory, any signal can be expressed as a sum of possibly infinite series of sine and cosine. This sum is referred to as Fourier expansion. The big disadvantage of Fourier expansion is it has only frequency resolution and no time resolution. This means it determines all the frequencies present in the signal but it does not tell at what time they are present. To overcome this problem Wavelet transform is proposed. It provides time and frequency information simultaneously, hence giving a time frequency representation of the signal. In the wavelet analysis, the use of a fully scalable modulated window solves the signal-cutting problem. The window is shifted along the signal and for every position the spectrum is calculated. Then this process is repeated many times with a slightly shorter (or longer) window for every new cycle. In the end, the result will be a collection of time representation of the signal, all with different resolutions.

The basic functions used in Fourier analysis, sine waves and cosine waves, are precisely located in frequency information of a signal calculated by the classical Fourier transform is an average over the entire time duration of the signal. There is a local transient over some small interval of time in the total duration of the signal, the transient will contribute to the Fourier transform but its location on the time axis will be lost. Although the short –time Fourier transform overcomes the time location problem to a large extent, it does not provide multiple resolutions in time and frequency, which is an important characteristic for analyzing transient signal containing both high and low frequency components. Wavelet analysis overcomes the limitations of Fourier methods by employing analyzing functions that are local both in time and frequency. Unlike Fourier analysis, which uses one basis function, wavelet analysis uses a number of basis functions of a rather wide functional form. The wavelet functions are generated in the form of translation and dilation of fixed function. The basis wavelet is termed as a mother wavelet. The basic difference is Short time Fourier transform uses a single analysis window whereas wavelet transform uses short windows at high frequencies at high frequencies and long windows at low frequencies.

Given a discrete signal x(n), being fast transformed at instant k and scale j, it has a high frequency component coefficient Aj(k). The frequency band of the information contained in signal components $D_{j(}k)$ and $A_j(k)$, obtained by reconstruction are as follows.

$D_j(k)$: $[2^{-(j+1)}fs, 2^{-j}fs]$
$A_j(k)$: $[0, 2^{-(j+1})fs]$ (j=1,2,…,m) (1)

Where fs is the sampling frequency.

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The original signal sequence x(n) can be represented by the sum of all components as follows.

$$x(n)= D1(n)+ A1(n)= D1(n)+ D2(n))+ A2(n)= \sum_{j=1} Dj(n)+ Aj(n) \qquad (2)$$

III. PROPOSED ALGORITHM TO FAULT DETECTION AND IDENTIFICATION IN TRANSMISSION LINE

The proposed algorithm detects if there is a fault or the compensated system is under normal conditions. It also determines the position of the fault if it is after or before the compensating device. In addition, the algorithm determines the type of fault if it is a single line to ground (SLG) fault, line to line (2L) fault, double line to ground (2LG) fault or a three line to ground (3LG) fault. Finally, the algorithm selects the phases involved in the fault.

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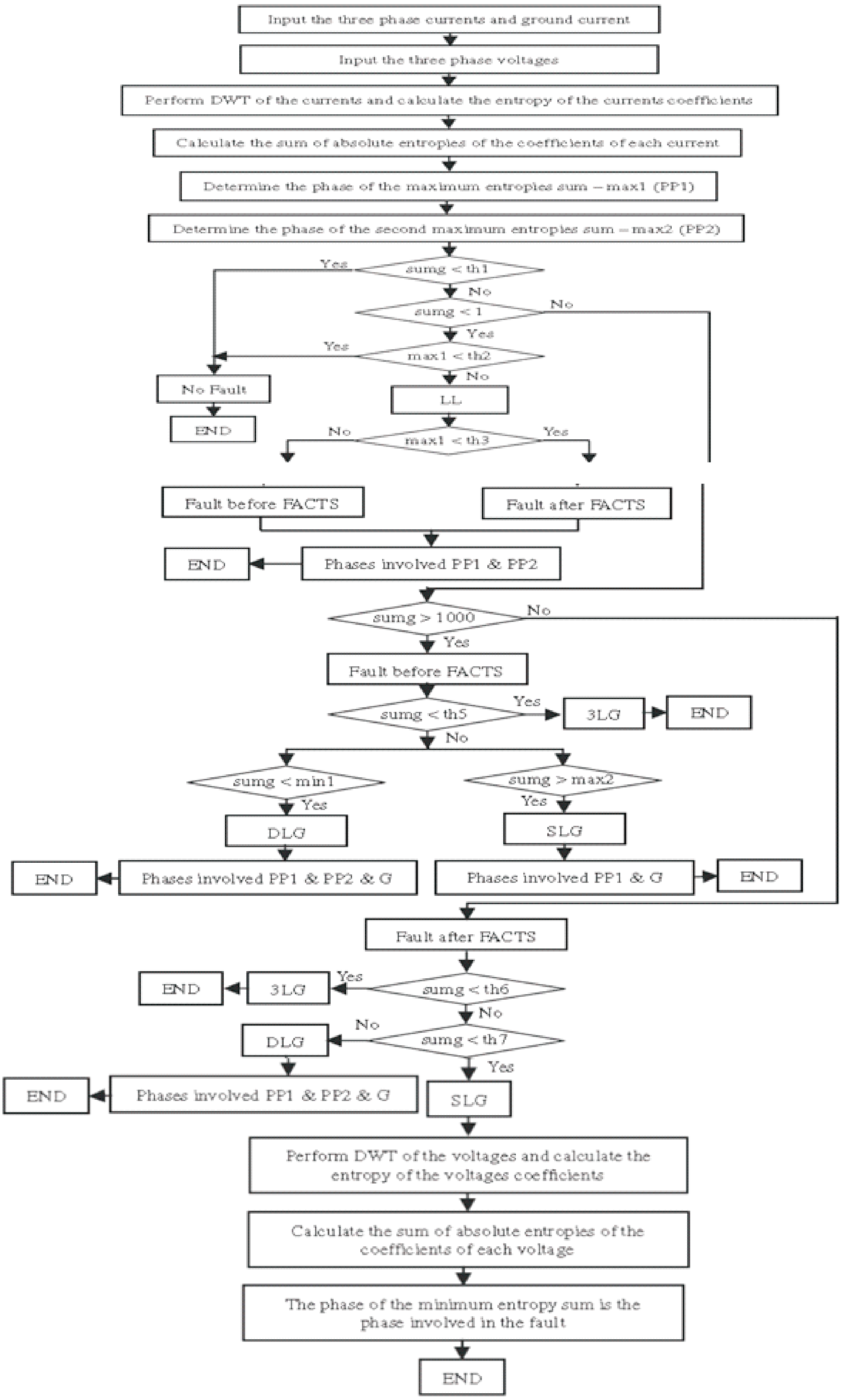


Fig.1. flow hart of a proposed algorithm

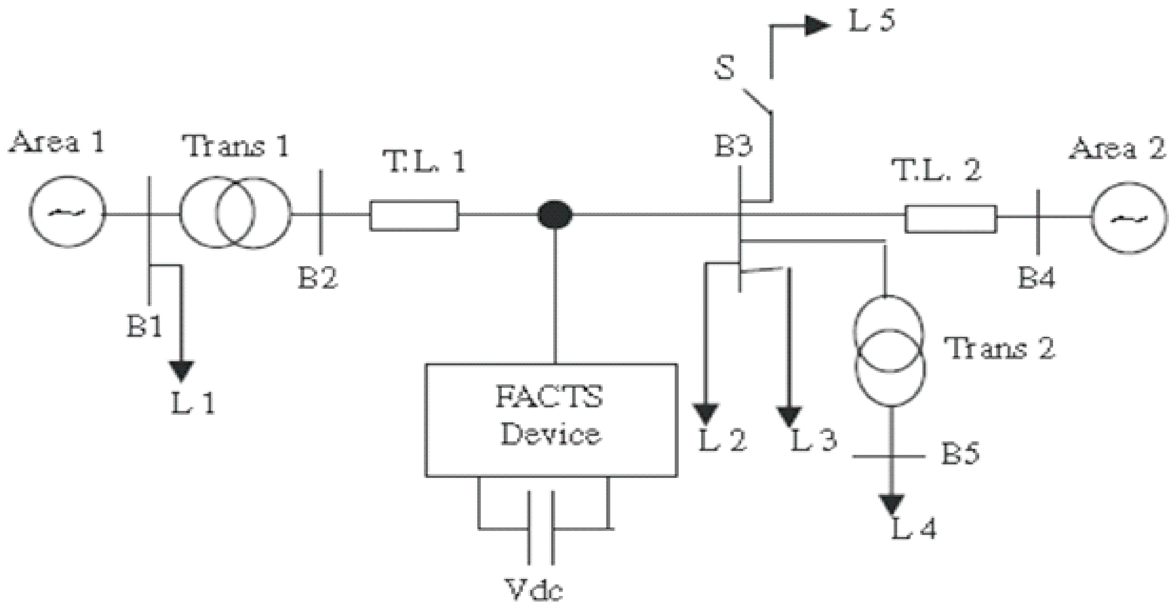
The transient signals of the three phase currents and voltages are produced using the simulation model built with the power block set of the SIMULINK. A discrete wavelet transformation is performed using two level Symmetric wavelet for the three phase current signals (Ia, Ib and Ic) and the ground current Ig,

where $I_g = I_a + I_b + I_c$ (3)

The entropy of each coefficient of the four currents is then calculated. The sum of absolute entropies of such coefficients for each current is then calculated (suma, sumb, sumc and sumg). The sums related to the three phase currents are then arranged to determine the maximum sum (max1) corresponding to phase PP1, the minimum sum (min1) and the intermediate sum (max 2) corresponding to phase PP2.

The wavelet and entropy calculation are performed also for the three phase voltages in case the algorithm detected a single line to ground fault after the compensating device. The entropy sums of the three phase voltages are used to determine which phase is included in the fault. The proposed algorithm is applied in three main steps. First, the fault is detected then its type and position with respect to the compensating device are determined. Finally, the phases included in the fault are identified. A detailed flow hart of the proposed algorithm is shown.

I. TEST SYSTEM



The Power System Blockset (PSB) and SIMULINK software have been used to instrument the test system for implementing the proposed algorithm. The simulation results were used to obtain coefficients used in the algorithm. The test system is therefore elaborated in this section along with its parameters as given in the appendix section of the reference paper

[1]. The single line diagram of the test system is as follows.

V. SIMULATION RESULTS

5.1 Faults before SSSC

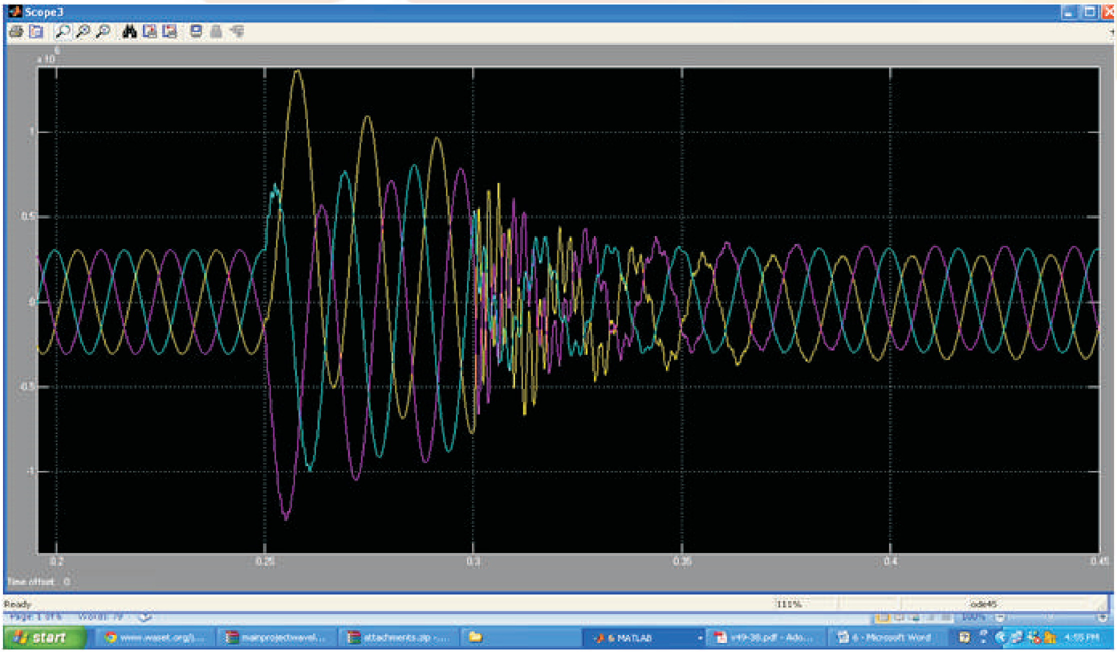


Fig.3:Three phase current waveforms during 3LG fault before the SSSC

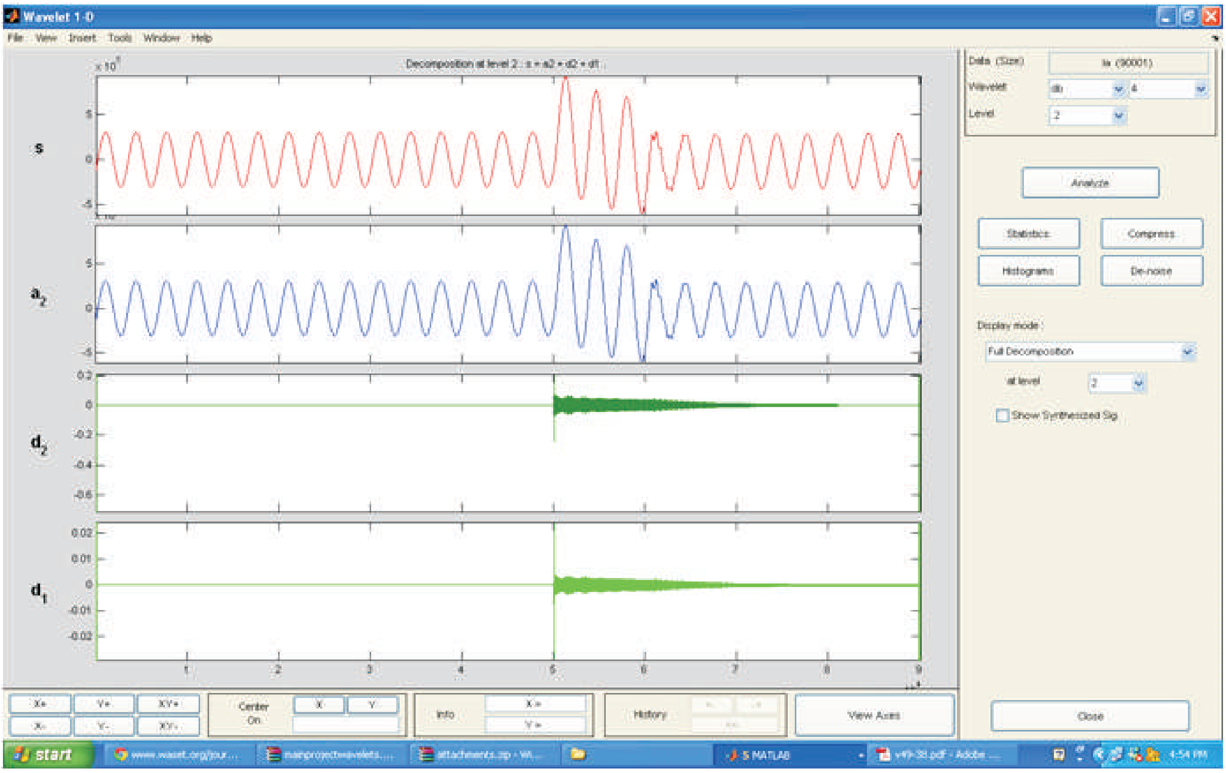


Fig.4: Approx. and details of phase A current during 3LG fault before SSSC

Table.1: The Sum of Absolute Entropies of the Coefficients of Each Current before SSSC

Fault Type	*suma*	*sumb*	*sumc*	*Sumg*
AG	1.48×10^6	1.18×10^6	1.06×10^6	2.09×10^6
BG	0.98×10^6	1.34×10^6	1.24×10^6	1.75×10^6
CG	1.15×10^6	1.02×10^6	1.45×10^6	1.88×10^6
AB	5.5×10^6	4.86×10^6	0.99×10^6	0.045
BC	0.91×10^6	3.6×10^6	2.96×10^6	0.043
CA	5.27×10^6	0.94×10^6	6.04×10^6	0.0517
ABG	5.91×10^6	4.61×10^6	1.06×10^6	0.59×10^6
BCG	0.98×10^6	3.77×10^6	2.99×10^6	0.74×10^6
CAG	5.39×10^6	1.01×10^6	6.03×10^6	0.60×10^6
3LG	8.20×10^6	4.64×10^6	5.3×10^6	0.33×10^6

The sum of entropies of the coefficients of each of the phase voltages were calculated by using the voltage and current values. The waveforms of the three phase currents in case of 3LG fault before the SSSC are shown above. The wavelet coefficients (approximate A2, level 1 detail D1 and level 2 detail D2) of phase A current are also shown above.

5.2 Faults after SSSC

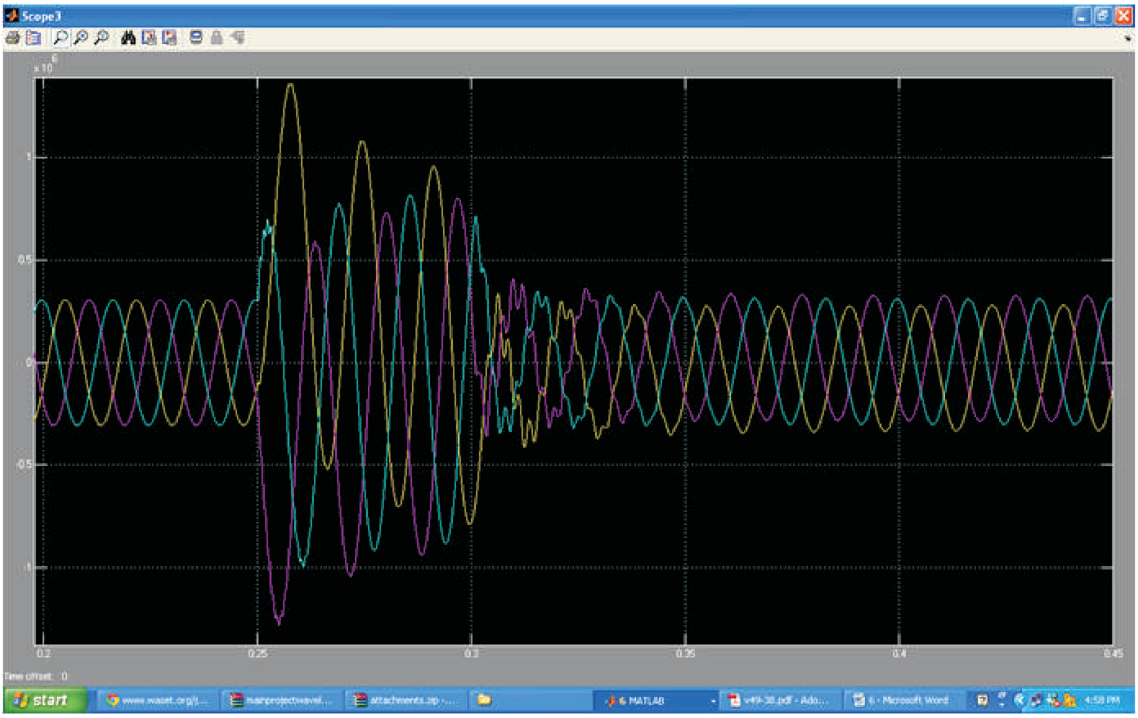


Fig.5: Three phase current waveforms during 3LG fault after the SSSC

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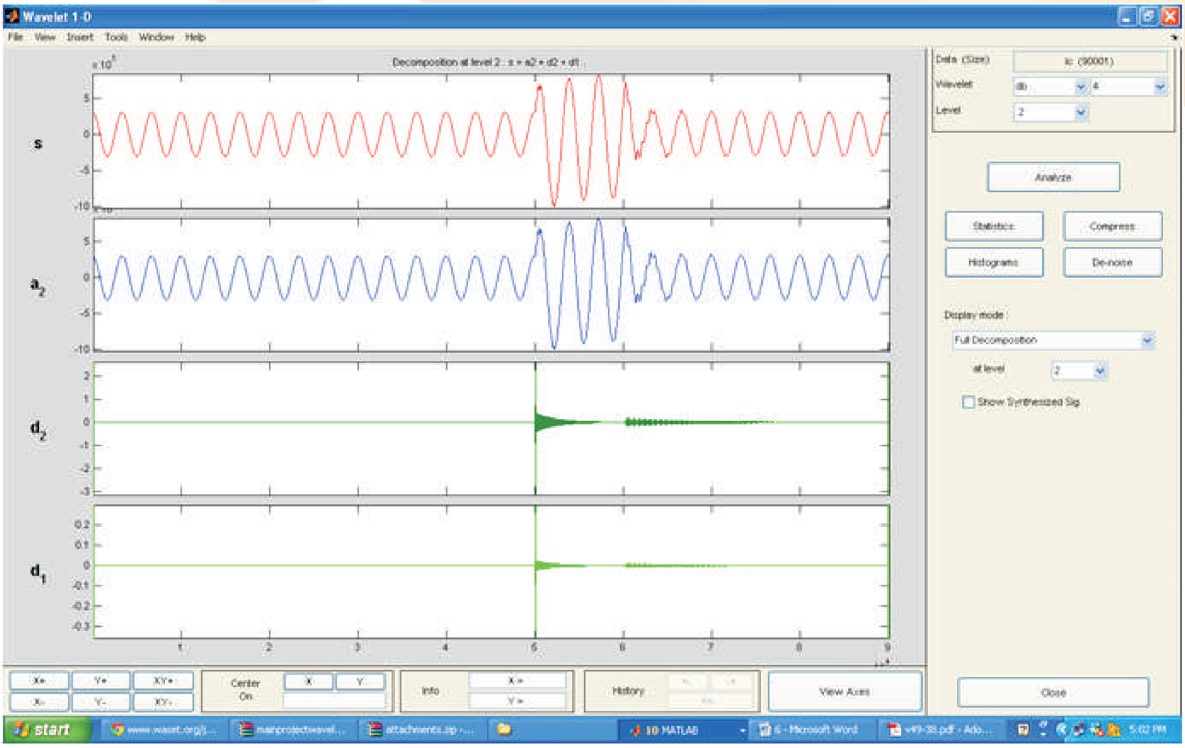

Fig.6: Approx. and details of phase A current during 3LG fault after SSSC

Table.2: The Sum of Absolute Entropies of the Coefficients of Each Current after SS

Fault Type	*suma*	*sumb*	*sumc*	*sumg*
AG	1.05×10^6	0.94×10^6	1.15×10^6	26.2
BG	1.04×10^6	1.03×10^6	0.99×10^6	22.34
CG	0.89×10^6	1.08×10^6	1.09×10^6	24.57
AB	2.29×10^6	1.94×10^6	0.93×10^6	0.17
BC	0.88×10^6	1.88×10^6	1.54×10^6	0.15
CA	2.01×10^6	0.85×10^6	2.48×10^6	0.14
ABG	2.24×10^6	1.84×10^6	0.89×10^6	20.73
BCG	0.86×10^6	1.72×10^6	1.43×10^6	21.77
CAG	1.95×10^6	0.78×10^6	2.33×10^6	21.67
3LG	2.93×10^6	3.17×10^6	2.18×10^6	9.78

VI. CONCLUSION

Fault classification and section identification in a transmission line with FACTS devices is a very challenging task. Some researchers used current and voltage signals to determine the fault location and fault resistance only without attempting to find the fault type and phase involved. Earlier an adaptive Kalman filtering approach has been proposed for protection of uncompensated power distribution networks and compensated transmission system employing an advanced series compensator. However, the Kalman filtering approach finds its limitation, as fault resistance cannot be modelled and further it requires a number of different filters to accomplish the task.

Hence, it is proposed a new algorithm to detect and classify the fault and identify the fault position in a transmission line with respect to a FACTS device placed in the midpoint of the transmission line. Discrete wavelet transformation and wavelet entropy calculations are used to analyze during fault current and voltage signals of the compensated transmission line. The proposed algorithm is very simple and accurate in fault detection and classification. A variety of fault cases and simulation results are introduced to show the effectiveness of such algorithm. In this project a test system is built using SIMULINK. The resulting data under different fault types and position with respect to the compensating device are analyzed using the modified WE algorithm than that in to consider the system compensation. The test results show the effectiveness of the proposed algorithm.

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