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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 with the combination of advanced FACTS devices is very complicated task. In this paper distance protection is applying on FACTS compensated transmission line. Along with this, to detect the faults on transmission lines, type of those faults, and location of the fault an algorithm is proposed. For analysis of fault current and voltage signals of the line, Discrete Wavelet Transform and wavelet entropy calculations are used. The proposed wavelet entropy algorithm also be used to find out which phases are involving in the fault to make the salvation easier. The proposed test system and the results can be obtained using MATLAB/SIMULINK.

Keywords : Transmission lines, FACTS devices, Wavelet entropy algorithm.

1. INTRODUCTION

Transmission lines are essential components of the electrical power system and its protection is important for ensuring system stability and minimizing damage to equipments due to faults that might happen on transmission lines. In past, there were so many difficulties in construction new generation facilities and transmission lines due to energy and environmental problems. Constructing new transmission lines makes the system less security and inadequate control [1]. Therefore, it is required to increase the power transfer capability of existing transmission lines.

FACTS devices have become very popular and giving very effective solution for many power system transmission problems. FACTS devices are employed for various applications such as increasing power transmission capacity of the existing lines ,improving the steady state and dynamic stability limit, improving damping of different types of power oscillations, improving voltage stability, reducing the problem of sub-synchronous resonance and improving HVDC link performance [2].

In this paper, two of the FACTS devices are using *i.e.* SSSC and UPFC. The static synchronous series compensator are used to provide series configuration and SSSC in a power electronic based voltage source converter (VSC) that which in quadrature with the line current. The SSSC can provide either capacitive or inductive series compensation independent of line current. The UPFC is capable of providing simultaneous active and reactive power flow control, as well as, voltage magnitude control. UPFC is combination of SSSC and STATCOM which are interconnected via DC link. Transmission line protection on contains of three main tasks *i.e.* Detection, classification and location of the faults.

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Earlier manual power system monitoring and relaying proved their inefficiency in making the system healthier. Fault identification and phase selection became complicated after the introduction of power electronic devices. A TCSC with fixed capacitor using EMTDC package, Daubechies wavelets are employed for all types if faults and in different operating conditions for fault section identification and phase selection [3]. Several fault location algorithm have been proposed and applied for determining the fault location on transmission lines. Wavelet transform has good time frequency localization ability and it particularly adapted to analyze the singular signals caused by faults [4].

Multi resolution analysis is also known as Multi scale approximation. It is the method of design of discrete wavelet transform. And it is the justification for the algorithm of the Fast wavelet transform. MRA was introduced by Stephane Mallat and Yves Meyer. In the fields of applied mathematics and signal analysis, wavelet theory is rapidly developing. MRA provides natural framework for better understanding of wavelets[5].

Hence it is proposed, wavelet transform provides theory basis for fault detection. Wavelet combined entropy can make full use of localized feature at time-frequency domains. Unsteady signals were dealed through wavelet analysis while information entropy expresses information of the signal. Because of that, wavelet entropy can analyze fault signals efficiently. The algorithm determines the type of the fault and finally the algorithm selects the phases involved in the fault.

2. WAVELET TRANSFORMATION WITH MRA

The frequency spectrum of a signal is basically the spectral (frequency) components of that signal. And the signal frequency spectrum shows what frequencies are existing in the signal. Fourier transform of a signal gives frequency-amplitude representation of the signal. Fourier transform gives only the spectral content of the signal, but it does not give information about at what time those spectral components appear. Therefore, Fourier transform is not a suitable technique for non-stationary signal. The Wavelet transform developed as an alternative to the STFT. If we pass the time-domain signals from various high-pass and low-pass filters, which filters out either high or low frequency portions of the signal. This procedure is repeating and every time some portion of the signal corresponding to some frequencies being removed. This operation is known as decomposition. Wavelet transform gives a variable resolution, whereas Short time Fourier transforms (STFT) gives a fixed resolution at all times.

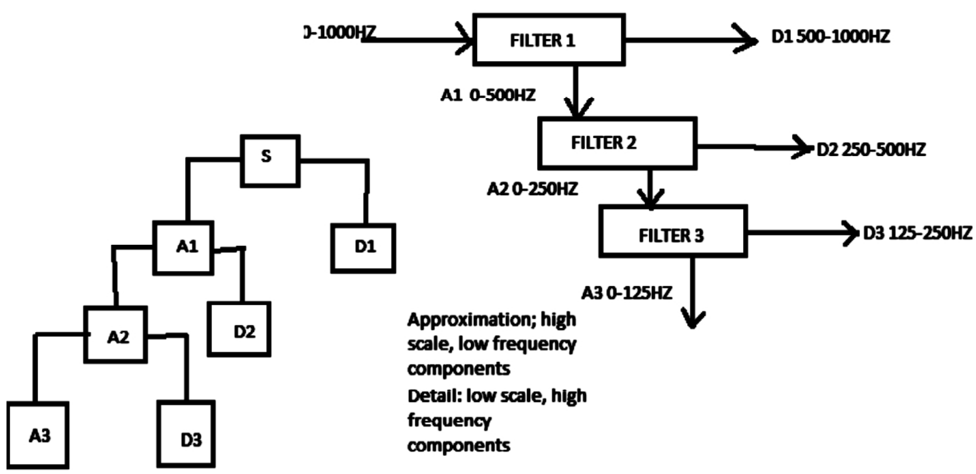

Fig. 1. Frequency resolution.

Two fundamental equations which determines the wavelet calculations are

$$j(t) = \sqrt{2}\sum_k h_k \varphi(2t-k)$$

$$y(t) = \sqrt{2}\sum_k h_k \varphi(2t-k)$$

The wavelet and scaling functions are prototype of orthonormal basis functions of the form

$$\varphi_{j,k}(t) = 2^{j/2}\,\varphi(2^j t - k)\ ;\ j, k \in z$$
$$\psi_{j,k}(t) = 2^{j/2}\,(2^j t - k)\ ;\ j, k \in z$$

Where

J controls compression and dilation of function in amplitude and time scale. And *k* controls transation of function in time and *z* is the set of integers.

3. FAULT DETECTION AND PHASOR ESTIMATION

(A) FAULT DETECTION

Wavelet transformation allows variable window technique and it is very useful in transient signal analyzation. The first decomposition level of the measured current signals using mother wavelet detects the fault. Faulty signals are high frequency signals. The length of the window is equal to one cycle of the fundamental frequency which is used for fault detection. In this state the normal value of any phase exceeds a certain threshold value which indicates a disturbance.

Norm of D1 measures the amount of energy content in D1

$$\|D1\| = \left[\sum_{k=1}^{n_d} \mathrm{DI}(k)\right]^{1/2}$$

Number of the detailed coefficients at that level.

(B) PHASOR ESTIMATION

The measure voltage and current signal phasor at fundamental frequency can be estimated using 60 hertz sinusoidal reference signal (R1). Using “db4” mother wavelet, for the each data window reference signal and measured signals are decomposed into two levels of decomposition. From the approximate coefficients A2 vector of the second decomposition level, the phasor are estimated. Here R1 is a reference signal. The angle θ between the two vectors is defined as follows

$$\theta = \cos^{-1}\left(\frac{(A_{2R1} \cdot A_{2S})}{|A_{2R1}|A_{2S}||}\right)$$

4. THE PROPOSED FACTS COMPENSATED TRANSMISSION LINE

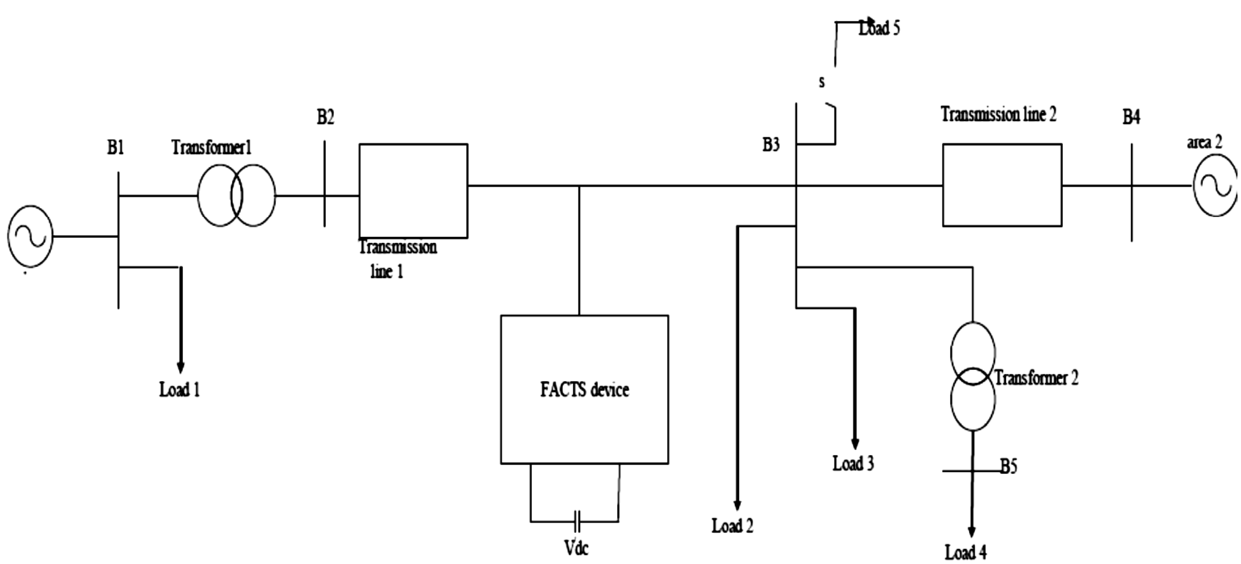

Fig. 2. Proposed model.

In order to find out the fault type and fault location of transmission line, and before applying wavelet transformation on the transmission system, first of all a facts compensated transmission line has to be designed. In this paper, three FACTS devices are used i.e. STATCOM, SSSC, and UPFC.

The static compensator is used to eliminate harmonics in the transmission line. The static synchronous series compensator is used to maintain the voltage level in the lines. Unified power flow controller is combination of static synchronous series compensator and static compensator. The control strategies of shunt and series compensators are shown below

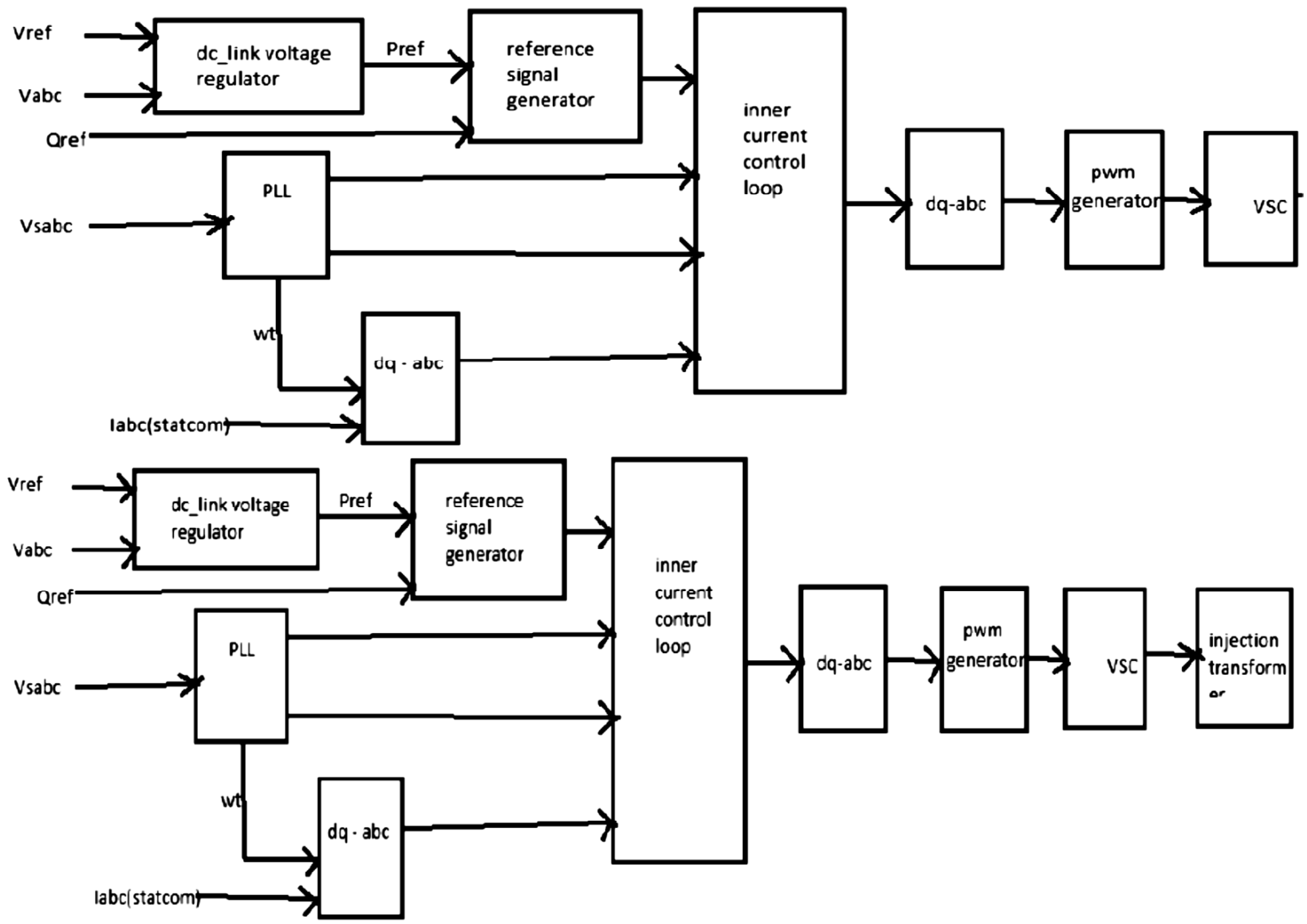

Fig. 3. Shunt and series control strategies.

The main advantage of FACTS device on a power transmission line is to control real and reactive power whatever the uncertainties happened in the transmission line effects on the real and reactive power. Reactive power compensation is the main objective of FACTS device. And also FACTS device has to control real and reactive power output from voltage source converter. In d-q frame ,real and reactive power are expressed as

$$p = \frac{3}{2}\left(V_{sd}I_{dp} + V_{sq}I_{qp}\right)$$

$$Q = \frac{3}{2}\left(V_{sq}I_{dp} - V_{sd}I_{qp}\right)$$

Since PLL calculates $V_{sq} = 0$, real and reactive powers can be rewritten as

$$p = \frac{3}{2}\left(V_{sd}I_{dp}\right)$$

$$Q = \frac{3}{2}\left(-V_{sd}I_{qp}\right)$$

In current control loop of VSI, the modulation indices are

$$m_d = \frac{2}{V_{dc}}\left(u_d - L_s w I_{qp} + V_{sd}\right)$$

$$m_q = \frac{2}{V_{dc}}\left(u_q + L_s w I_{dp} + V_{sq}\right)$$

$L_S wl_{qp}$ And $L_S wI_{dp}$ are decoupling feed forward inputs. u_d And u_q are control inputs. In the model, capacitor employed in DC link instead of a DC voltage source. And a PI controller is to get a reference of active power.

5. PROPOSED ALGORITHM FOR TRANSMISSION LINE

When faults are happening in the system, the amplitude and frequency of the signal will change as the system change from normal to faulty state. The entropy will change accordingly. It may become incapable to deal some abnormal signals while wavelet can. Therefore wavelet transform along with entropy gives better utilization of localized feature at time frequency domains. The unsteady signals were analyzed by wavelet transformation, while entropy speaks about information of the signal.

The proposed algorithm for transmission line detects if there is any faults on the line. And also determines the position of the fault i.e. it is before or after the FACTS device. Along with this the algorithm determines the fault type *i.e.* SLG or L-L or DLG or 3LG. And also the algorithm determines the faulty phase. A DWT performs two-level symmetric wavelet for current signals I_a, I_b, I_c and the ground current I_g are

$$I_g = I_a + I_b + I_c$$

Entropy coefficients of these four currents are then calculated. And then the sum of absolute entropies of those coefficients for the phase and ground currents *i.e.* suma, sumb, sumc and sumg is calculated. These are arranged to determine max1 corresponding to phase PP1, min1 and max2 corresponding to phase PP2. These calculations also done for voltages in case the algorithm detected SLG after the compensating device. The proposed flow chart proceeds as follows:

- If sumg < th1 –No fault
- If sumg > th1 and sumg < 1 –check
  - o if max1 < th2 –No fault
  - o if max1 > th2 – LL fault, then check max1 to find the position with respect to FACTS device.
- If sumg < th1 –No fault
- If sumg > th1 and sumg < 1 –check
  - o if max1 < th2 –No fault
  - o if max1 > th2 – LL fault, then check max1 to find the position with respect to FACTS device.
  - o If max1 < th3 – fault after FACTS device else before
- If sumg > th1 and sumg >1 – check sumg again
- If sumg > 1000 –fault before FACTS device else after
- For a fault before FACTS device

  If sumg < th5 -3LG fault

  else

  If sumg > max2 – SLG fault

  else

  if sumg < min1 – DLG fault
- For a fault after the FACTS device

  If sumg < th6 – 3LG fault

  Else

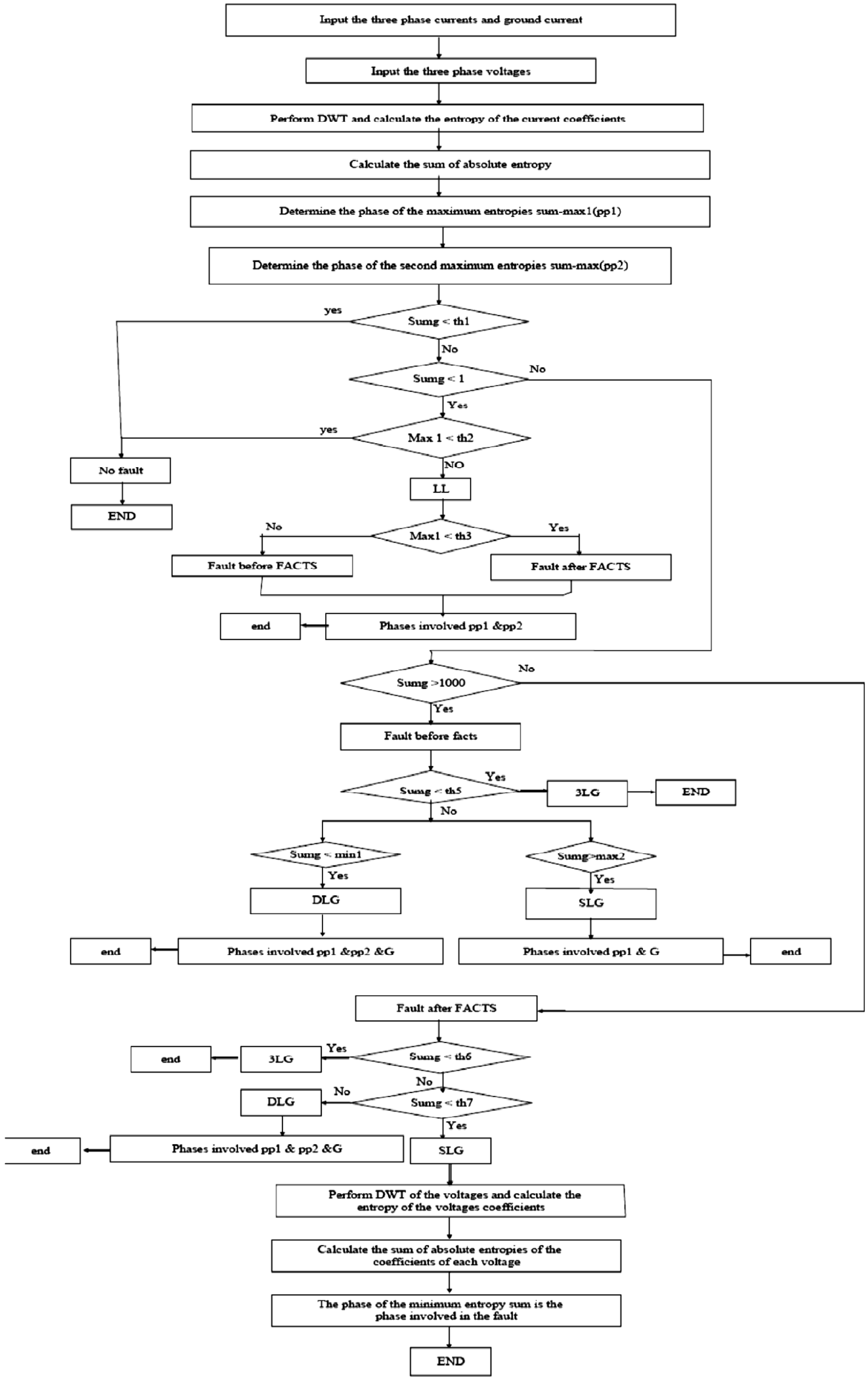

Fig. 4. Proposed algorithm.

If sumg > th6 then
If max1 > th7 - DLG
Else
It is SLG fault

- Determination of phase involved in the fault

  LL fault – PP1 and PP2

  DLG fault - PP1, PP2 and ground

  SLG fault – PP1 (if fault before FACTS device)

For SLG fault, if it is happening after the FACTS device, sum of current entropies are incapable to find out the phase involved in it. It is possible with voltage entropy calculations. Minimum sum is considered as the faulted phase

6. SIMULATION RESULTS

The test system fault resuls before SSSC are shown below :

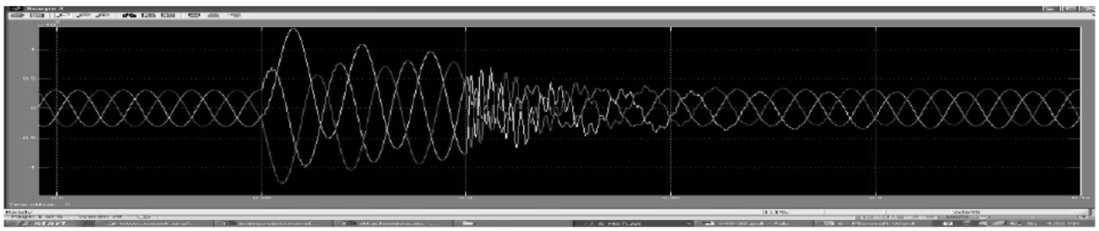

Fig. 5. Three phase current waveforms during 3LG fault before the SSSC.

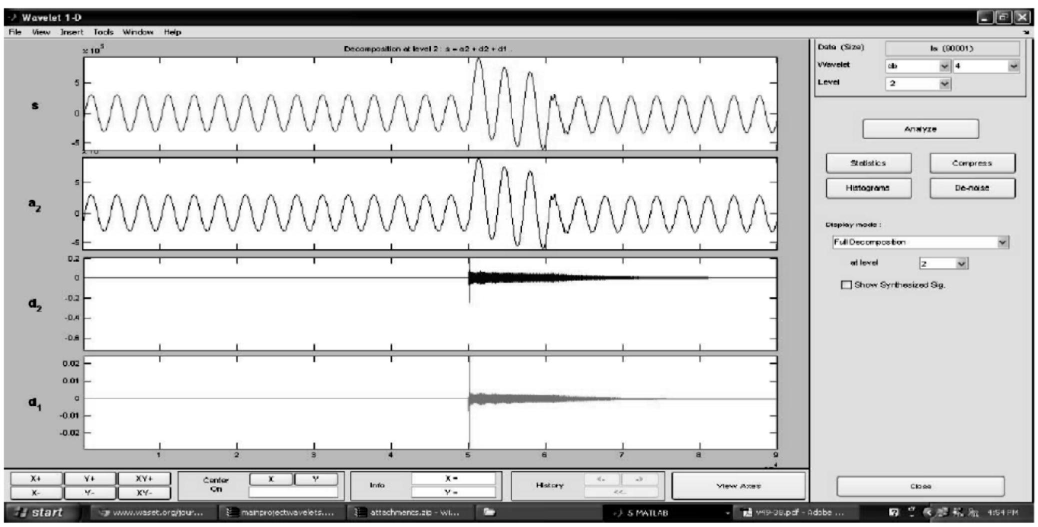

Fig. 6. Approx. and details of phase A current during 3LG fault before SSSC

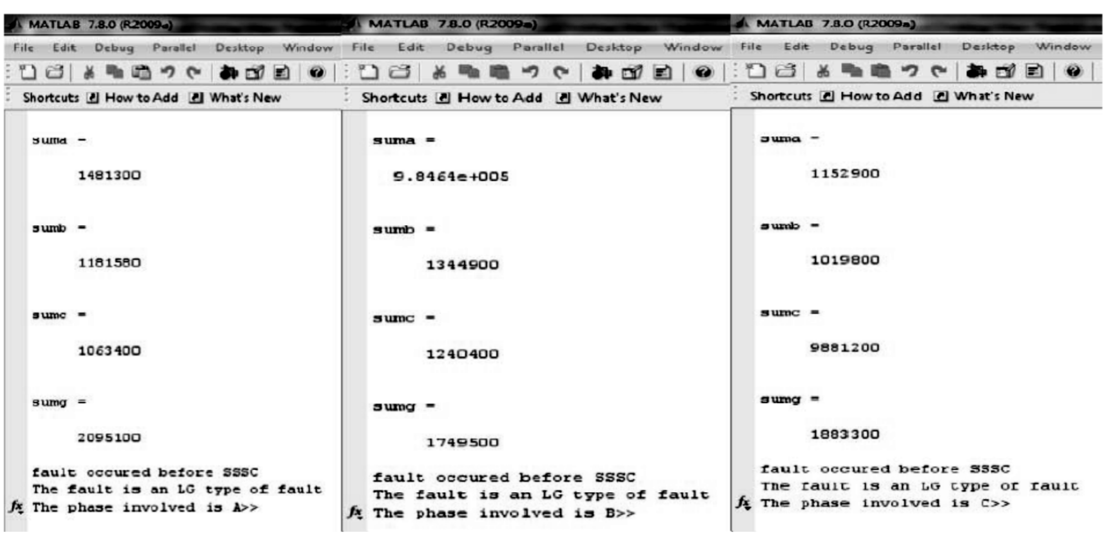

Fig. 7. Single line-to-ground fault.

Test system results of faults after SSSC are :

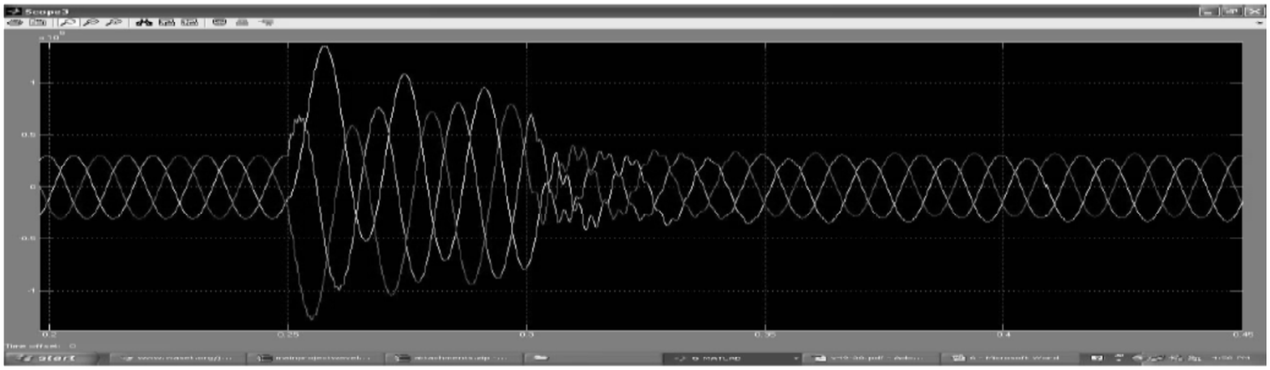

Fig. 8. Three phase current waveforms during 3LG fault after the SSS.

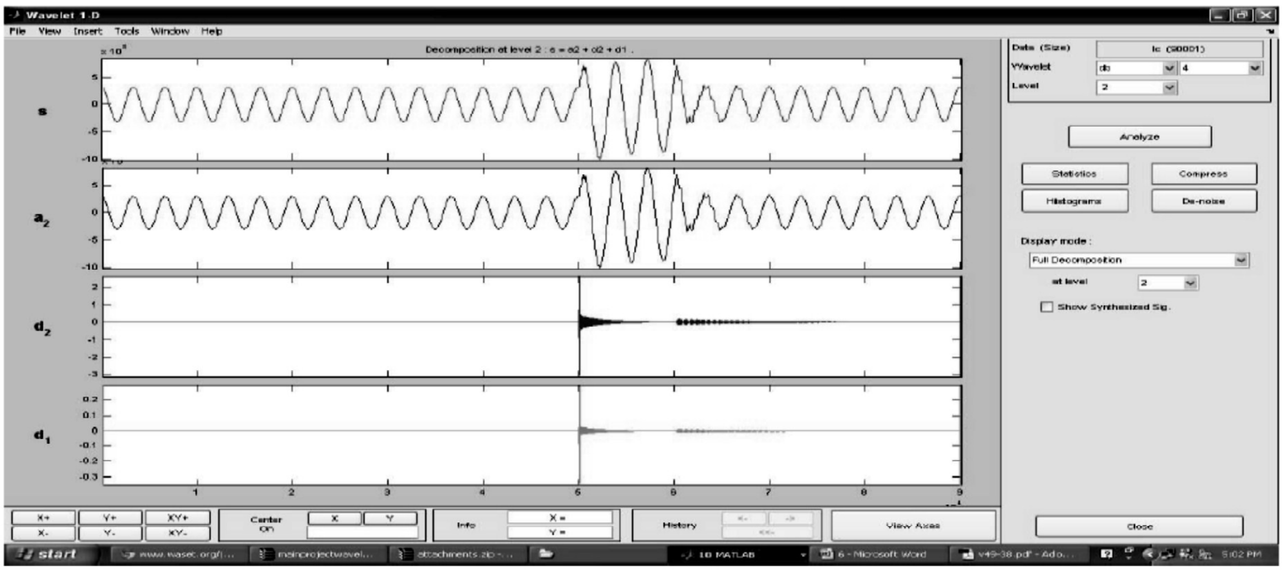

Fig. 9. Approx. and details of phase A current during 3LG fault after SSSC

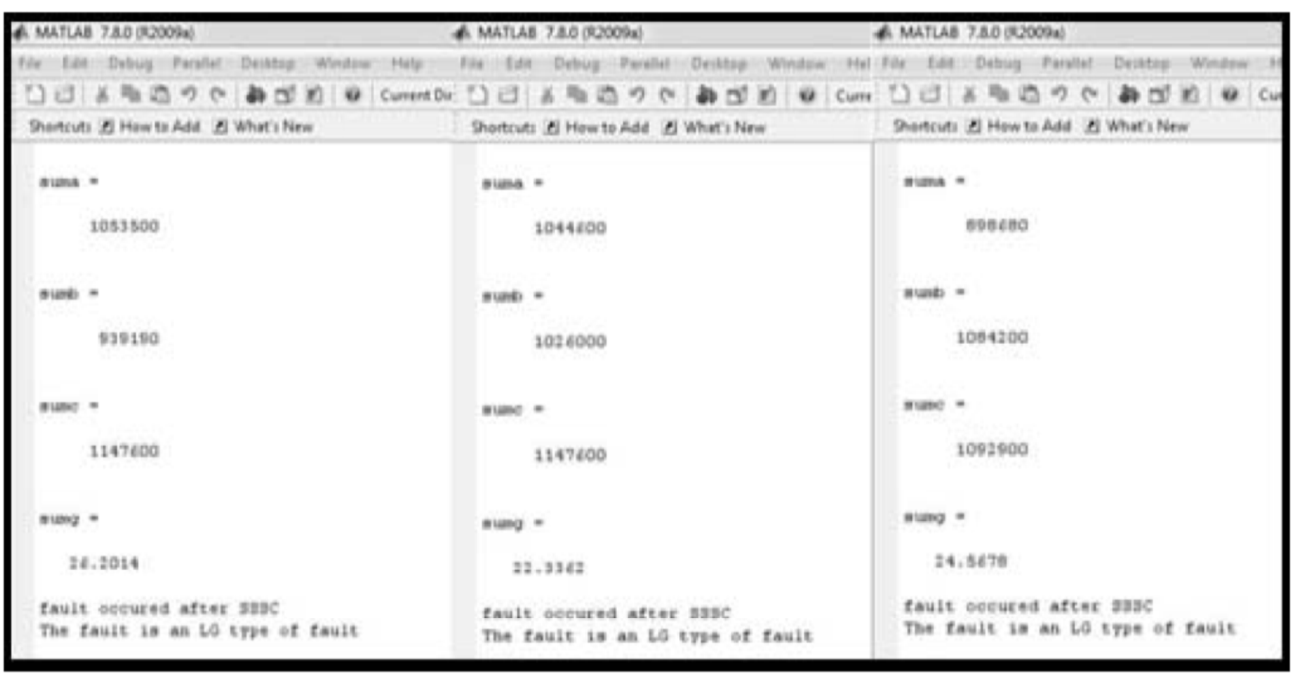

Fig. 10. Single line-to-ground fault.

Faults before UPFC:

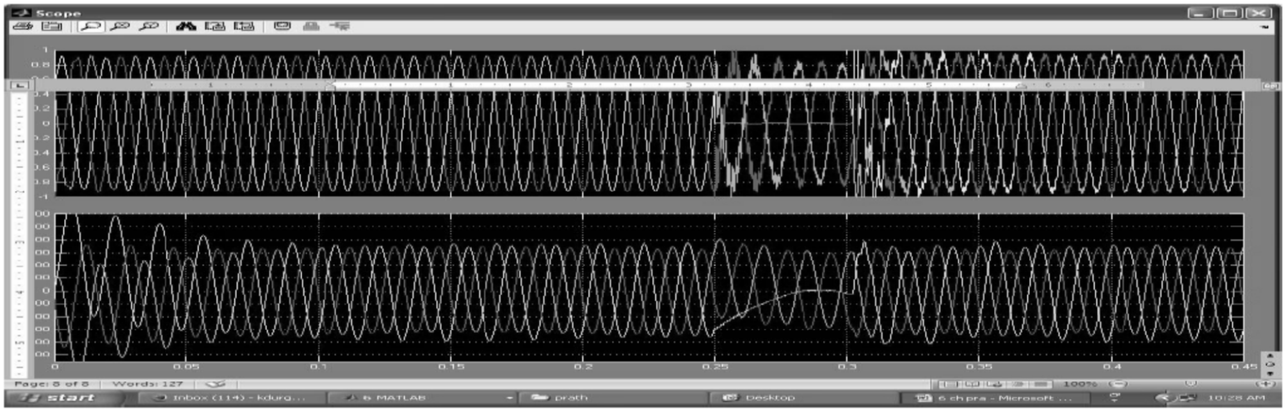

Fig. 11. Three phase current waveforms during 3LG fault after the UPFC

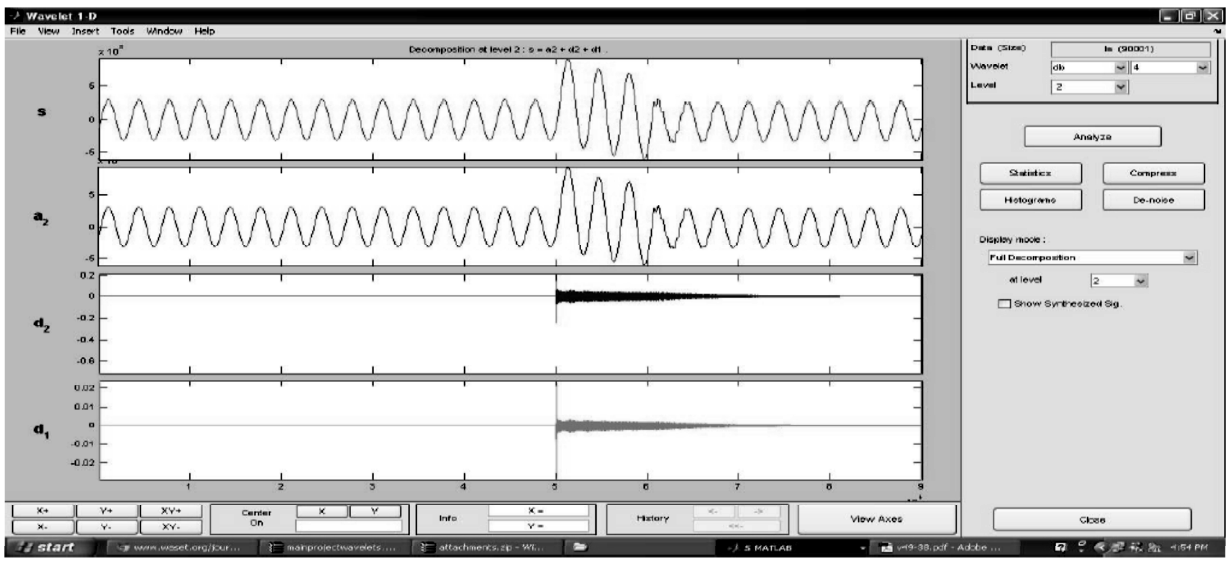

Fig. 12. Approx. and details of phase A current during 3LG fault after UPFC

Fig. 13. Single line-to-ground fau.

Fauls after UPFC

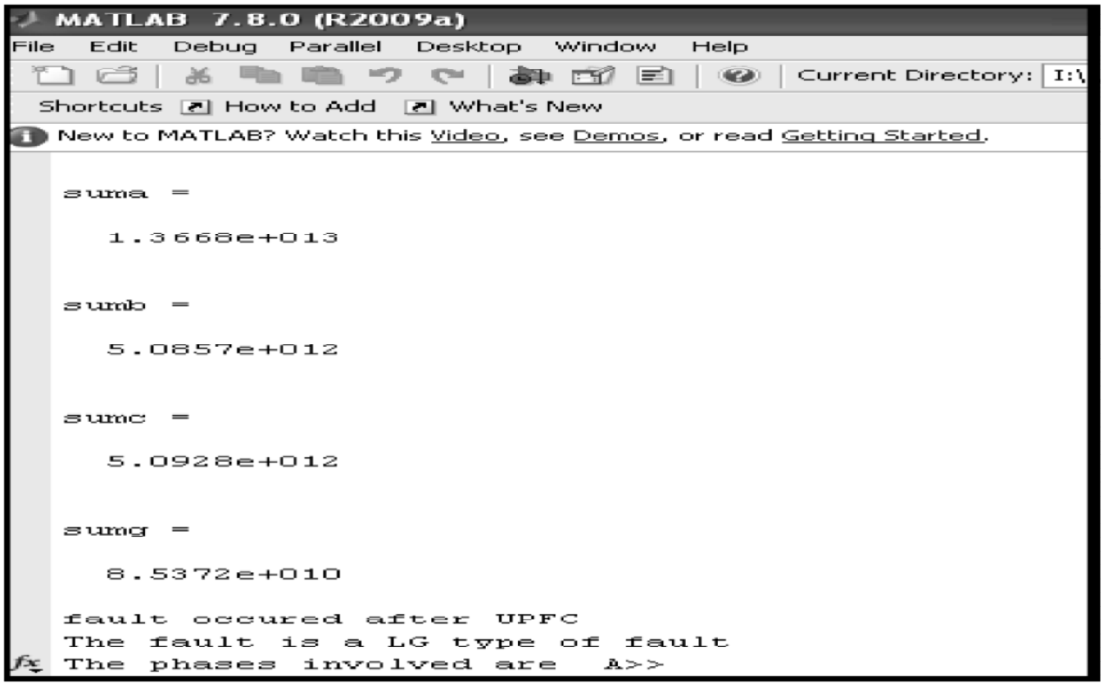

Fig. 14. Single line-to-ground fault.

7. 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.

8. REFERENCES

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