Identification of faults in series compensated transmission line by using wavelet transform

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***Abstract*— Protecting Transmission lines is important task to safe guard electrical power system. Faults on transmission line should be detected & classified accurately for reliable operation of power system. Firstly such analysis facilitates assessment of fault event and enables protective actions. Secondly restoration measures can be under taken soon after the fault. If we could not be able to detect the faults accurately, it may lead to low power quality and can cause serious problem etc. Existing methods for detection of power disturbances are laborious since they are primarily based on visual inspection of waveforms. More over most of the existing methods are based on deterministic methods. They do not have the ability to adapt dynamically to the system operating conditions and make correct decisions if the signals are uncertain. The solution to the above difficulty is Wavelet Transforms which implements multi resolution analysis, in this paper identification algorithm is proposed and analyzed by using db4 wavelet.**

***Index Terms*— Transmission line Protection, Wavelet, fault identification, compensation, discriminating signal.**

I. INTRODUCTION

Protective relaying is necessary with almost every electrical plant because it senses the abnormal conditions in a part of the power system and gives an alarm or isolates that part from the healthy system. Series capacitors are installed on transmission line because of the various technical and economical advantages like increased transmittable power, improved power system stability, reduced transmission losses; reduced voltage drop, enhanced voltage control and flexible power-flow control. However,these series capacitors and their overvoltage protection devices offer certain problems to protective devices. The nonlinear behavior of a series capacitor arrangement affects the voltage and current signals and, thus, create problems with relay functionality.

The identification of fault zone on a series compensated transmission line is essential for relaying decision and auto-reclosing requirement. In this paper identification of faults on the transmission line is done by using DWT. For fault zone identification two distinct frequency bands are captured from the transient current signal and the spectral energies for these two bands are calculated. The spectral energy of lower frequency band will be lesser than that of the higher frequency band in case of an internal fault but in case of an external fault the higher frequency band energy will get attenuated due to busbar capacitance, hence spectral energy of higher frequency band will be lesser than the spectral energy of lower frequency band. Using this fact and by dividing the spectral energy of higher frequency band by spectral energy of lower frequency band a higher ratio for the internal fault and a lower ratio for the external fault is obtained. The system is simulated in the software PSCAD and for the application of wavelet transform MATLAB is used.

II. SYSTEM MODEL

The proposed algorithm is implemented on a power system model which is shown in fig 1. This system consists of a 400kV-50Hz, three phase transmission line having a length of 400km and two sources S1 and S2 are connected at the two ends of the line. The power angles of the sources are varied from 10^o to 30^o.The transmission line is divided into three sections of lengths 140km, 160km and 100km. The middle section of the line is compensated by a series capacitor having a MOV overvoltage protection device with it.

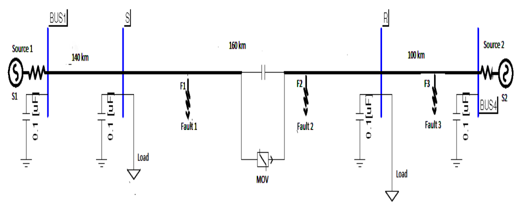

Fig1.Power system model

The three phase capacitor bank is placed at the middle of the transmission line section and it's compensation level is varried in the range 30% to 50%. Stray capacitance of each busbar is taken as 0.1µF. Two loads of 300MW capacities and 0.8 power factor lagging are considered for the investigation of the response of the relay.

III. PROPOSED ALGORITHM FOR PROTECTION

Wavelet analysis is having number of advantages over fourrier analysis which are documented in [12] & [13]. The wavelet transform is a powerful tool in the transient analysis because it can be used for extracting the time and frequency information from the transient signal.

There are various types of mother wavelets such as Daubichies (db), Coiflet (coif), Harr and Symmlet (sym) wavelets. The choice of these mother wavelets plays an important role in the detection and localization of various types of fault transients.The choice of mother wavelet is also dependent upon the particular application. Inthis paper fault zone identification is carried out by using db4 as a mother wavelet.

IV. FAULT-ZONE IDENTIFICATION

For fault zone identification a modal signal is taken by combining the currents of three phases as follows

Im=Ia-2Ib+2Ic (1)

All types of faults will get covered by this signal when algorithm is implemented. Modal signal can eliminate the existence of any common mode signal. The fault generated current noise is having various frequency ranges and to capture most of this current noise generated by fault, a sampling frequency of 200kHz (i.e., 4000 samples per cycle) is taken for the analysis. This algorithm uses the detail 1 (d1) and detail 6 (d6) coefficients therefore decomposition of wavelet is carried out from scale1 to scale6. This decomposition can cover the frequency range of 50 kHz to 100 kHz and 1.5625 kHz to 3.125 kHz, respectively. For external fault (e.g.,F3 in fig1) high frequency current signals are generated and these signals flow from the line. When these signals travel towards relaying point the the high-frequency components included in detail 1 are attenuated by the stray capacitance of busbar R. On the other hand, for internal fault (e.g., F1 and F2 in fig1) the fault generated high-frequency current signals travel and reach the relaying point but there is no attenuation of the signal by the busbar R. The stray capacitance of busbar R does not affect the high frequency current signal for the frequency band of detail6 because it acts as an open circuit to it. A threshold value of 0.1 for the coefficient of d1 is selected which will trigger the protection scheme mentioned. This threshold is decided by making a comparison of d1 coefficients for internal and external faults before and after the inception of fault. After the faulty condition has been detected as described above the relay starts calculating the discriminating signals for detail 1 and detail 6 from the modal signal for every sample as mentioned bellow:

$$E_h(r) = \sum_{k=n}^{r} I^2{}_{m1}(k\Delta T)\Delta T$$

$$E_l(r) = \sum_{k=n}^{r} I^2{}_{m6}(k\Delta T)\Delta T$$

Where ,

$E_l(r)$ - discriminating Signal of high frequency band (d1)

$E_h(r)$ - discriminating Signal of high frequency band (d6)

I_{m1} - detail 1 (d1) coefficients of modal signal

I_{m6} - detail 6 (d6) coefficients of modal signal

ΔT - Sampling time step

n - fault inception sample number

r -current sample where r > n

These discriminating signals (1.1) and (1.2) are calculated after the occurence of faulty condition only and at sample number n. The summation in the above two equations increases by one sample with each new sample following. After the calculation of discriminating signals El(r) and Eh(r), discrimination ratio is calculated for every sample as follows:

$$\text{Ratio}=C*Eh(r)/El(r) \quad (4)$$

Where C is a normalization factor C and it's value is taken as 700 in this analysis depending upon the simulation results.

If the discrimination ratio is greater than or equal to 1 for 200 samples (1 ms), then relay decides that the fault is an internal fault and a trip signal is issued. But, if that ratio is less than 1, the relay waits for 1/4 cycle after the detection of an abnormal condition to decide if the condition is an external fault .

A flowchart for fault zone identification is shown in Fig. 2 The algorithm starts with a moving window of width equal to 1/2 cycle (2048 samples exactly), where it calculates the wavelet coefficients of the modal signal inside the window. This window slides sample by sample until the detection of any abnormality. The detection criterion is $d1 > 0.1$. If a fault is detected, the microprocessor-based relay then starts to calculate Eh(r) and El(r) using the coefficients of d1 and d6, as shown in (2) and (3), and initiates a counter called "fault counter." Following this, the relay calculates the discrimination ratio. If this ratio is more than or equal to unity, this means that the fault is an internal fault and the relay starts to increase a trip counter by one. The relay then takes the next sample and determines the wavelet transform of the new window from which it calculates Eh(r), El(r) and the ratio and rechecks it, and so on. When the trip counter reaches the threshold value, which is here 200 counts or 1 ms, The relay issues a trip signal to the circuit breaker to open the faulted section, section SR in Fig.1. If the ratio is less than unity, the abnormal condition will be an external fault.

V.PERFORMANCE EVALUATION

The power system model shown in Fig. 1 is used to simulate various types of faults at different locations in order to evaluate the performance of the protection scheme. The power angle between the two sources is varied from 10^0 to 30^0; the capacitor compensation level is varied from 30% to 50%. The relay is tested for internal faults, external faults and it proved its ability to identify the abnormality in case of an internal and external fault.

VI. RESULTS FOR IDENTIFICATION OF FAULT

The Figure 1 shows model used for the simulation in PSCAD for fault at 3 different distances, i.e. two faults F1 & F2 between bus S and R, are inside the protected zone (internal) and one fault F3 is outside the protected zone(external fault). Fault F1 is applied at a distance 48 km from bus S. Fault F2 is at distance 96km from bus S & fault F3 is applied at a distance 50km from Bus R, at these three fault locations the different types of faults i.e. LG, LL, LLG, LLL, & LLLG are applied.

A. Results by visual inspection

For this purpose three phase LLG fault currents for the above mentioned two cases (F1 and F3) are captured. A modal signal of this captured fault current wave is calculated by using the equation1. A DWT by using db4 as a mother wavelet is applied over the modal signal for the calculation of detail1(d1) and detail6(d6) coefficients by using MATLAB software. Fig. 2 and 3 show the waveforms of original fault current signal, modal signal with it's prefault and postfault samples, d1 and d6 coefficients respectively.

By comparing Figs. 3 and 4, it can be seen that the coefficients of d6 are almost the same for both faults, while d1 coefficients are significantly different in the two cases. The coefficients of detail 1 are attenuated extensively in case of an external fault such as F3 in fig 1but in case of an internal fault, such as F1 and F2 in fig 1, the high-frequency current signals reach the relaying point without attenuation, hence from this a point can be noticed that d1 coefficients of the external fault current signal are having less magnitude than d1 coefficients of internal fault current signal.

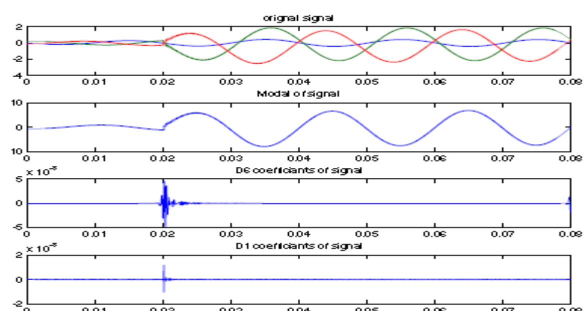

Fig3. (BCG internal fault at 96km)

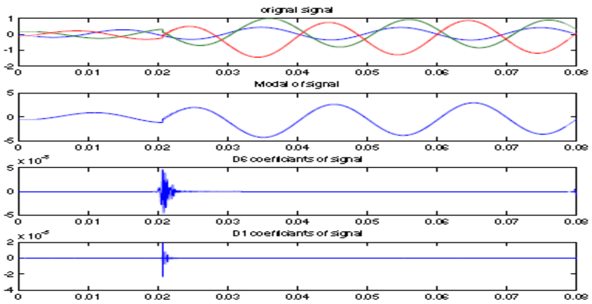

Fig4.(BCG external fault at 50 km from bus R)

B. Results by calculating ratio of discriminating signals

After the detection of an abnormal condition, the relay starts to calculate the discriminating signals based on spectral energy analysis, for detail 1 and detail 6 of the modal signal every sample then the discrimination ratio i.e. the ratio of the spectral energies is calculated(eq.3) and if the ratio of spectral energies of d1 and d6 is greater than or equal to 1 for 200 samples, the relay decides it is an internal fault and the relay issues a trip signal. However, if the ratio is less than 1, the relay decides that the abnormal condition is an external fault.

Fig 4 shows a LG fault current waveform simulated in PSCAD, while fig 5 shows waveform for it’s 2048 samples(1848 prefault samples and 200 postfault samples of the final window), modal signal of 2048 samples, d1 and d6 coefficients, energies of d1 and d6 coefficients . fig.5.4 shows the (E1)Energy of d1, (E2) Energy of d6 & Ratio of Energies.

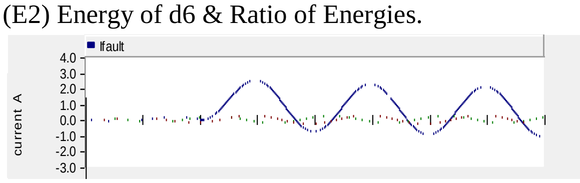

Figure 5. fault current waveform for LG fault at 48 km from bus S

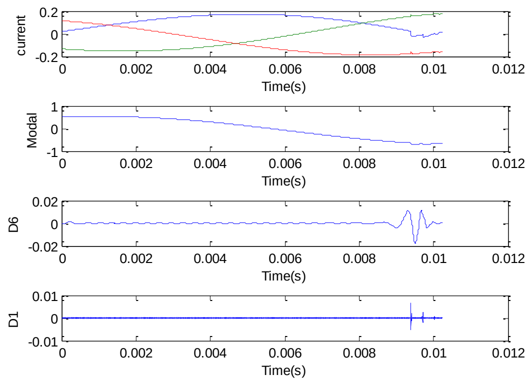

Fig 6 LG internal fault at 48 km from end S (a) three phase currents at the final window (b) modal signal (c) detail6 (d) detail1

From the figures(6 and 7) the ratio for 200 samples (1ms) is calculated and is found to be greator than one as 6.4401.Hence the relay decides that the fault is an internal fault and it issues a trip signal. Thus the algorithm is able to identify the fault and it’s zone.This procedure is applied to F1, F2 & F3 for Fault type LG, LL, LLG, LLL & LLLG and the ratio of discriminating signals is calculated to identify the fault type.

The simulated results for some of the above mentioned cases are shown in this paper.

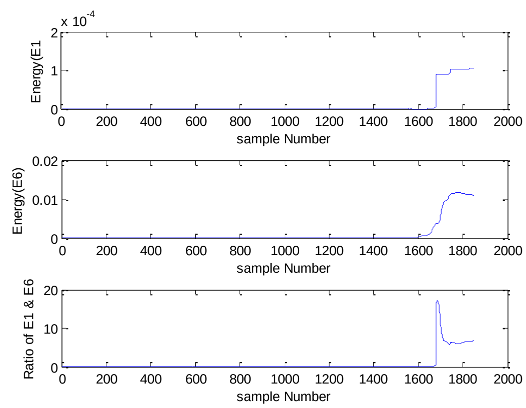

Fig 7: internal fault at 48 km from end S (a) discriminating signal (E1) (b) discriminating signal (E2) (c) Ratio of discriminating signals.

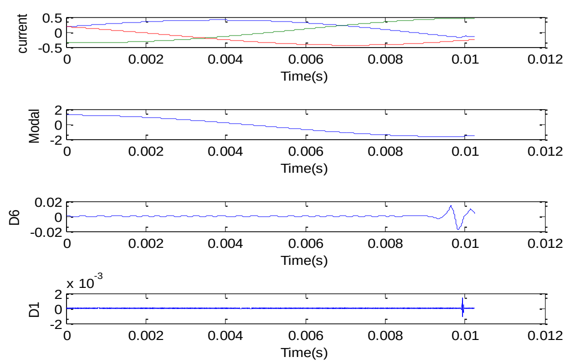

Fig.8: LG Fault at 50km external from end R (a) three phase currents at the final window (b) modal signal (c) detail6 (d) detail1

From the figures 8 and 9 the ratio for 200 samples (1ms) is calculated and is found to be less than one as 0.1417. Hence the relay decides that the fault is an external fault and it issues a trip signal. Thus the algorithm is able to identify the fault and it's zone. The system performance is tested for various types of faults at different locations and the wavelet analysis is carried out. The results obtained are represented in tabular form (Fig 10).

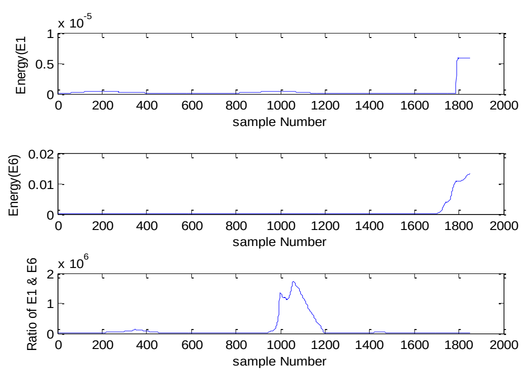

Fig9: LG Fault at 50km external from end R a) discriminating signal (E1) (b) discriminating signal (E2) (c) Ratio of discriminating signals.

Table1. Result of identification of zone of various faults at different locations

Type of fault	Location of fault	Discrimination ratio for 200 samples	Zone of fault
LL	48km from bus S	55.7544	Internal
	96km from bus S	19.3737	Internal
	50km from bus R	0.1639	External
LG	48km from bus S	6.4401	Internal
	96km from bus S	21.0081	Internal
	50km from bus R	0.1417	External
LLL	48km from bus S	15.0085	Internal
	96km from bus S	73.138	Internal
	50km from bus R	0.0753	External
LLLG	48km from bus S	56.9177	Internal
	96km from bus S	22.3207	Internal
	50km from bus R	1.1778E-06	External
LLG	48km from bus S	35.9481	Internal
	96km from bus S	18.8223	Internal
	50km from bus R	0.1777	External

VII. CONCLUSION

Protection of series compensated transmission line by using wavelet transform has been presented in this paper.Detection of fault and identification of fault zone has been proposed with suitable algorithm. A single modal signal that covers all types of faults is obtained by combiningThe three-phase currents of the fault are combined to form a modal signal which covers . Wavelet analysis, with db4 as a mother wavelet, is performed for the modal signal where detail 1 and detail 6 are obtained. The spectral energy of each detail is obtained and the ratio of the two energies determines whether the fault is internal or external. Moreover, a threshold level for the high-frequency energy differentiates between external faults and switching operations. Faults with various types, conditions, and locations have been tested. The simulation results indicated that the proposed technique has a very high accuracy in fault detection, zone identification.

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