Classification of Faults in Series Compensated Transmission Line using Wavelet

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Abstract—Fault detection is very tedious task in transmission lines with a fixed series capacitor because of the nonlinear behavior of protection devices and series-parallel resonance. This paper proposes a new method based on DWT for fault classification in this series capacitor is fixed at the middle of the line. The DWT is used here for extracting the unseen factors from the fault current signal and here harr is used as a mother wavelet. The average values of the wavelet coefficients of the lower frequency band for the currents of three phases and ground are computed and as there are higher frequency components in the faulted phases than that of the unfaulted phases, the fault classification can be done easily. The performance of the proposed scheme is checked for the all possible faults at various locations, different compensation levels and different power angles. This transient fault study is carried out using the PSCAD software and the wavelet transform and protection algorithm is implemented in a MATLAB environment.

Key words: Fault Classification, Protection, Wavelet Transform, Series Compensation

I. INTRODUCTION

Protective relaying is very necessary for almost all the electrical plants because it senses the abnormal conditions in the power system and gives an alarm or isolates that faulty part from the healthy system. Series capacitors [3], [4] are installed on transmission line because of the various technical and economical advantages like increased transmittable power, improved power system stability, reduction in 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 [15].

The identification of fault zone on a series compensated transmission line is essential for relaying decision and auto-reclosing requirement. In this paper classification of faults on the transmission line is done by using DWT, considering the fault identification is done.

II. POWER SYSTEM MODEL

For applying this algorithm a 400kV-50Hz power system is considered as shown in figure1.

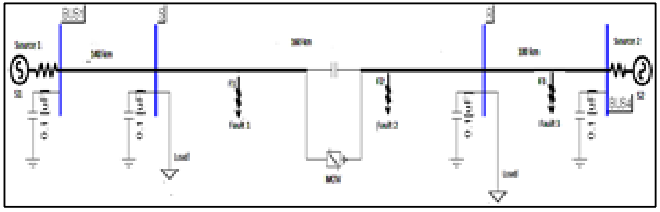

Fig. 1: Power System Model

This power system model is consisting of two sources at the two remote ends of a three phase transmission line and that line is having a length of 400km. The power angle between the two sources is varied from 10 to 30. The transmission line is divided into three sections having the lengths of 140km, 160km, & 100km. The power angle is varied between the two sources from 100 to 300 and compensation by using a three phase capacitor bank with MOV overvoltage protection device is provided at the middle section of the transmission line.

III. PROPOSED PROTECTION ALGORITHM

The transient signal can be analyzed quickly in a well manner by wavelet transform because it is a powerful tool in analyzing the transient phenomena and it extracts time and frequency information from the transient signal. There are number of mother wavelets, For e.g. Harr, Daubichies (db), Coiflet (coif), and Symmlet (sym) wavelets. The detection and localization of fault transient depends upon the choice of mother wavelet. In addition, For short and fast transient disturbances, such as for this study, db4 and db6 are choosen, while for slow transient disturbances, db8 and db10 are selected. In this study db4 is used as a mother wavelet for fault zone identification and Harr is used for fault classification.

A. *Fault Zone Identification*

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

$$Im=Ia-2Ib+2Ic \qquad (3.1)$$

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 1.57 kHz to 3.13 kHz, respectively. For external fault, high frequency current signals are generated and these signals flow from the line. When these signals travel towards relaying point 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 fault F1 and F2 in fig. 1) 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:

$$E_h(r) = \sum_{k=n}^{r} I_{m1}{}^2(k\Delta T)\Delta T \qquad (3.2)$$

$$E_l(r) = \sum_{k=n}^{r} I_{m6}{}^2(k\Delta T)\Delta T \qquad (3.3)$$

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 (3.2) and (3.3) are calculated after the occurrence 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:

$$\text{Ratio}=C*Eh(r)/El(r) \qquad (3.4)$$

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.

The algorithm for the fault identification 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, 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.

B. *Fault Classification*

Flow chart for proposed algorithm is as shown in figure2. After detecting the fault and identifying its zone as an internal fault, it is essential to classify its type. If the fault is single phase to ground, which represents more than 70% of transmission-line faults, single-pole tripping would be preferred to enhance the reliability of the system and allow for autoreclosure in case of a transient fault. However, if the fault is not a L-G fault, it is a must to trip the three phases for the safety of the power system. It is must to know about the fault type for reliability analysis of the system and maintenance operation for the faulted phases.

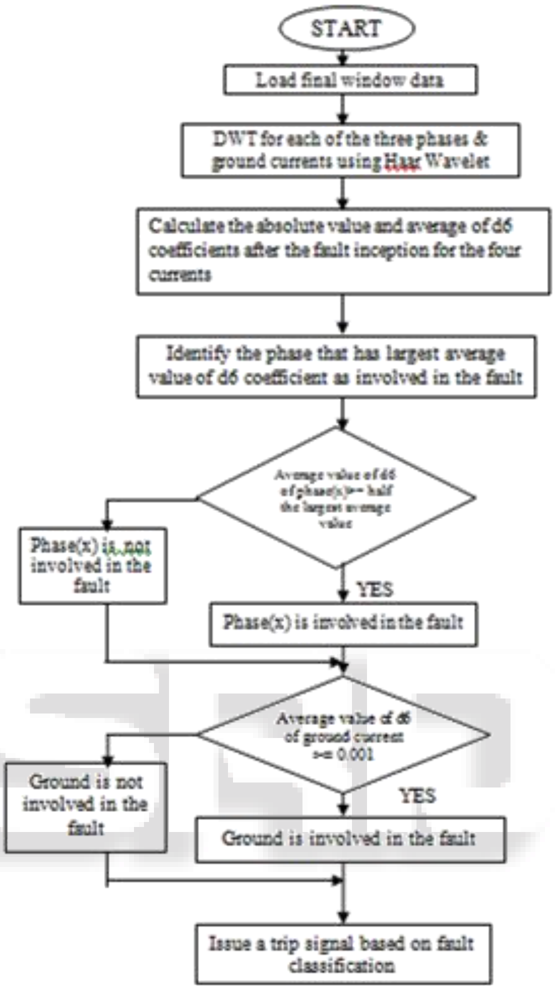

Fig. 2: Classification algorithm

It is known that the faulted phase current, as well as ground current if involved in the fault will contain higher frequency components than the phases which are unfaulted and this fact is the key for the classification algorithm suggested in the paper. The proposed algorithm for classification of faulted phases is shown in Fig.2. After the detection of a fault, the fault classification algorithm starts to operate. The final window at this instant contains 200 samples from the postfault current and 1848 samples from the prefault current. This final window is loaded and discrete wavelet transform (DWT) using Haar wavelet as the mother wavelet is carried out for the three-phase currents and the ground current. Hence, the average of the absolute value of the 200 postfault coefficients of d6, are calculated for the three phases and ground current. These cover the frequency range from 1.5625 to 3.125 kHz. The phase which has the largest average value is identified and considered that it is being involved in the fault. The other two phases are checked for involvement in the fault. The remaining phase, which has an average value more than or equal to half the largest average value, is involved in the fault, else, this phase is not involved in the fault. With respect to ground, the average value of the ground current d6 coefficients is compared with 0.001. If the ground is involved in the fault, its average value will exceed 0.001. After fault classification, a trip signal based on fault type is issued.

IV. RESULTS

The proposed algorithm for classification of faults is shown in fig.2.After the detection of an internal / external fault, the fault classification algorithm starts to operate. The final window at this instant contains 200 samples of postfault current and 1848 samples of prefault current fig(3) This final window is loaded and discrete wavelet transform (DWT) using Haar wavelet as the mother wavelet is carried out for the three-phase currents and the ground current. Hence, the average of the absolute value of the 200 postfault coefficients of d6(fig 3), which cover the frequency range from 1.57 to 3.13 kHz, are calculated for the three phases and ground current. The phase which has the largest average value is involved in the fault. The other two phases are checked for involvement in the fault. The remaining phase, which has an average value more than or equal to half the largest average value, is the faulty phase, else, this phase is not involved in the fault. With respect to ground, the average value of the ground current d6 coefficients is compared with 0.001. If the ground is involved in the fault, its average value will exceed 0.001.

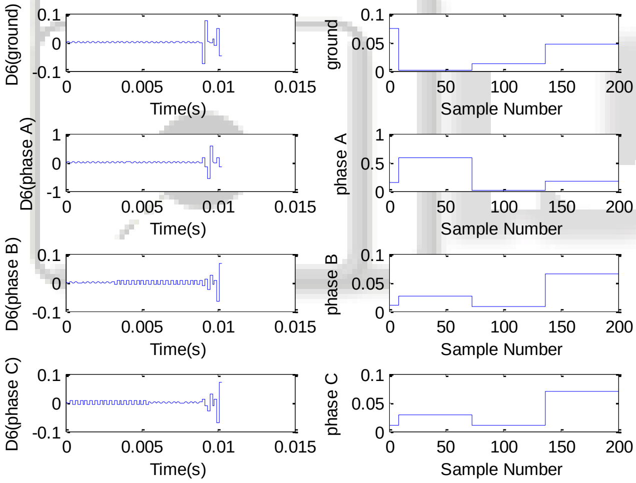

Fig. 3: DWT for the three phases and ground current for an LG internal fault at 48 km from end S using Haar wavelet, (a) d6 of ground current, (b) d6 of phase a current, (c) d6 of phase b current, (d) d6 of phase c current, (e) coefficients of d6 of ground current after fault inception (f) coefficients of d6 of phase a after fault inception, (g) Coefficients of d6 of phase b after fault inception, and (h) coefficients of d6 of phase c after fault inception from the above figure it is observed that the classification criterion from the proposed algorithm is satisfied. i.e. If Average value of d6 of phase (x) >= half of the largest average value.

That phase is involved in the fault else not involved and for checking if the ground is involved in the fault or not the criteria is as follow.

- if the average of ground current >= 0.001
- then the ground is involved in the fault
- else not involved in the fault

average values of d6 of three phases of current and ground current are as shown in table below from above table it is observed that phase A and Ground is involved in the fault hence fault is classified as LG fault.

LG	Phase A	Phase B	Phase C	Ground
48 km Internal	0.2511	0.0319	0.0346	0.022

Table 1: Average Values of Phases

Average value of three phases and ground current at different locations are given in table 2. For getting all these values faults are made at different location on the proposed system model and simulated in PSCAD environment & Matlab.

LG 48 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.2511	0.0319	0.0346	0.022
LG 96 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.1325	0.0327	0.0328	0.0705
LG 50 km External from end R	Phase A	Phase B	Phase C	Ground
	0.0530	0.0187	0.0256	0.0037
LL 48 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.0287	0.0349	0.0065	1.834E-13
LL 96 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.0221	0.0250	0.003	1.6048E-13
LL 50 km External from end R	Phase A	Phase B	Phase C	Ground
	0.0206	0.0108	0.0098	2.2148E-13
LLG 48 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.3475	0.203	0.0251	0.155
LLG 96 km Internal from end S	Phase A	Phase B	Phase C	Ground
	0.1706	0.0045	0.1499	0.0188
LLG 50 km External from end R	Phase A	Phase B	Phase C	Ground
	0.0502	0.0285	0.0232	0.0044

Table 2: Average Value of D6 of Three Phases & Ground Current at Different Location

V. CONCLUSIONS

The application of the wavelet transform in the protection of series-compensated transmission lines has been presented. The algorithm for classification of the fault has been proposed. A single modal signal that covers all types of faults is obtained by combining the three-phase currents of the fault. The purpose of fault classification wavelet analysis, with Harr as the mother wavelet, is for the three-phase and ground currents identification. Averages of the absolute value of d6 coefficients, after fault inception, for the three phases and ground currents, are determined and used to classify the fault type. 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 classification

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