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Protection of Transmission Lines using Discrete Wavelet Transform

Reena Sharma, Aziz Ahmad, Shailendra Kr. Saroj

Abstract— ***The main objectives of transmission line protection scheme are precisely differentiate the faults zone and indicate exact fault type using one end data only so that only faulted line will be removed .Fault generates transient current wave contained distinct frequency bands. In this paper discrete wavelet transform is used to capture two bands of frequencies from the transient current signal using db1 as a mother wavelet. The spectral energies of these two bands are obtained to determine the fault zone. The faulted phase selection is done by the discrete wavelet transform using Haar as the mother wavelet. The coefficient of a frequency band in the range of 1 KHz-3 KHz are obtained for the three phase and ground currents. The average value of the coefficients of each current wave is then computed and used to classify the faulted phase. Fault simulations are performed using MATLAB/Simulink and then the results are interfaced to MATLAB where the algorithm is implemented.***

Index Terms— ***boundary protection, high frequency transient signals, mother wavelet, non-unit protection, power system faults, unit type protection, Wavelet transforms.***

I. INTRODUCTION

The main objective of this proposed protection scheme is to protect the transmission line from any type of fault occurred in the protected zone .The fault occurred in the boundaries of protection zone the relay should give trip signal to the circuit breaker and disconnect the faulted line without any time delay. It should not respond for any fault outside of the protection zone or switching generated transients so that the impact of fault on system stability is reduced. An approach called boundary protection introduces a possibility of precisely differentiating the internal faults from external faults using one end data only [2]. In this case relay at one end can protect the entire line length with no intentional time delay.

The identification of fault zone and classification of faulted phases on a transmission line are essential for relaying decision. In this paper the fault-generated high-frequency Current in a transmission line is used to develop non communication protection schemes [8]. This transient current travels from the fault point along the line. When the current signal meets a point of discontinuity, part of the current signal reflects back and the rest continues to travel along the line [7]. In case of a bus bar, its impedance to earth when dealing with high-frequency signals, the dominant factor of the bus bar impedance is the capacitance and capacitive coupling. This stray capacitance directs a large amount of the fault generated transient high-frequency current components (ranging from 50 kHz–100 kHz) to earth. On the other hand, the lower frequency current components (in the range of 1 kHz–3 kHz) are not affected by the bus bar capacitance. The boundaries of the protection zone of the relay are two remote ends bus bars. The boundary protection as described above was used in [10], [11].Boundary protection has a strong potential, the use of two modal signals in [10] and [11] to cover all kinds of faults. In this proposed scheme discrete wavelet transform is used for Boundary protection due to its better time-frequency localization.

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II. TRANSMISSION LINE MODAL

In order to investigate the applicability of the proposed algorithm, a 400-KV, 50Hz power system is considered for this purpose. The power system model is shown in Fig. 1. It consists of two sources connected via a three-phase 300-km transmission line. The two sources, source 1 and source 2 have short-circuited capacities of 3GVA and 12 GVA respectively. The power angle between the two sources is varied from 10º to 30º. The transmission line consists of two sections of lengths: 200Km and 100 km. The transmission line is ideally transposed and has a flat configuration with 10 m spacing between adjacent conductors. A typical 0.11µF is taken as a stray capacitance of each bus-bar.

The parameters for the systems are:
Line length = 300 km;
Source impedance (both sources):
Positive sequence impedance = (1.31 +j15)Ω;
Zero sequence impedance = (2.33 + j26. 6)Ω;
Transmission line impedance
Positive sequence impedance = (8.25 +j94.5)Ω;
Zero sequence impedance = (82.5+ j308)Ω;
Positive sequence capacitance = 13 nF/Km;
Zero sequence capacitance = 8.5 nF/Km.

Two loads of 500MW with 0.8 power factor lagging are placed at two remote ends A and B to investigate the response of the relay for the load switching operations. Fig.1 is used to illustrate the proposed protection scheme. The proposed relay for the protection of the transmission lines is installed near bus bar A and is responsible for the protection of line section AB.

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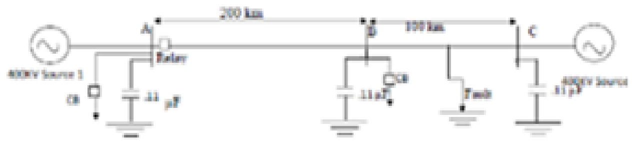

Fig.1. Transmission Line Modal

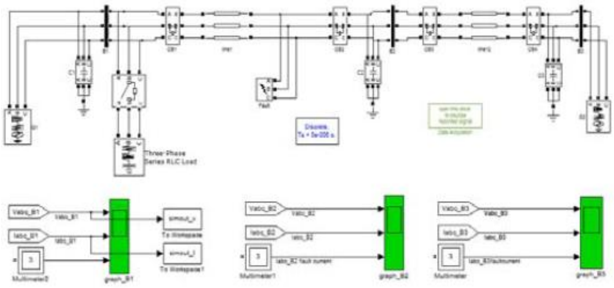

Fig.2. Simulation Modal

III. PROPOSED PROTECTION ALGORITHM

A. Fault Detection

Fault detection can be obtained from the details of the first decomposition level of the modal current signals using db6 wavelet. This level contains the high frequencies that are associated with faults. The length of the sliding data window used for fault detection and it is equal to the half cycle of the fundamental frequency. By calculating the norm of the detail coefficients (d1) for the modal current, the disturbance on the transmission lines can be identified. If the calculated norm value of modal current signal exceeds a certain threshold value, a fault is ascertained. The calculated norm of d1 measures the amount of energy in d1. This norm can be calculated as:

$$d_1 = [\ \sum_{k=1}^{nd} d_1(k)]^{1/2}$$

Where nd is the number of detail coefficients at that level .

B. Fault Zone Identification

The three phase currents from bus A are extracted, sampled and then combined to from the model current signal given by equation (2).

I m = Ia - 2Ib+2Ic . . . . (2)

Simulation result shows that the modal current signal shown in (2) is sufficient for all fault types.

Identification of the fault zone can be performed by extracting two distinct frequency bands (details) from the modal current signal using DWT, from which two discrimination signals are calculated based on spectral energy analysis for these two bands .The spectral energy of the higher frequency band will be larger than that of the lower frequency band in case of an internal fault. In case of an external fault, the higher frequency band energy will be severely attenuated due to the bus bar capacitance and, hence, will be smaller than the lower energy band. This fact is used in the proposed protection scheme to discriminate internal fault from external fault. In case of a switching operation, high-frequency transient are also produced, but these high-frequency signals have lower spectral energy then those generated from faults as will be shown latter in the simulation results. Hence, by setting a threshold value for the spectral energy of the high-frequency component, switching operation can be easily distinguished from faults.

The fault generates a current noise of different frequency ranges. In order to capture most of the fault-generated noise, the sampling frequency is taken as 200 kHz (i.e., 4000 samples per cycle). Wavelet decomposition from scale 1 to scale 5 is obtained ,the coefficients of detail 1 (d1) and detail-5 (d5), covers frequency ranges from 50 kHz to 100 kHz and from 3 KHz to 6 kHz respectively.

Figure 3(a) and (b) show the simulation result of an internal fault three phase pre and post fault currents for a single phase to ground fault a-g at 150 km from end A. Rf =200Ω ,FIA =45° with power angel of 20° between the two sources. Also, its model signal and wavelet decomposition d l & d5 using db1 as a mother wavelet is shown in Fig. 4(a) and (b).

The coefficients of d1 for either fault, before and after fault inception, it is noticed that d1 coefficients are zero prior to fault occurrence and at the fault instant, their value rises sharply. Hence, the decision was made to use a threshold value for the coefficient of d1.

This value will trigger the proposed protection scheme, which will decide on the type of fault (i.e., internal, external, or switching operation) the detection of an abnormal condition, using the detection criteria mentioned above, the relay start to calculate the discrimination signals, based on spectral energy analysis, for detail 1 and detail 5of the model current signal every sample as follows:

E_h (r) = $\sum_{k=n}^{r} I^2 m\ (K\Delta T)\Delta T$ .... (1)

E_l (r) = $\sum_{k=n}^{r} I^2 m\ (K\Delta T)\Delta T$ .... (2)

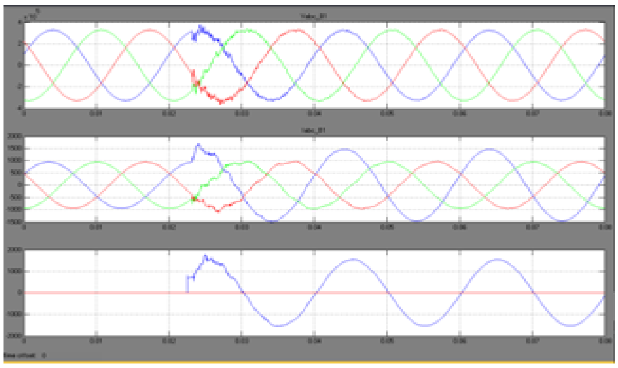

Fig. 3 AG internal fault (a) three phase pre and post fault voltage(b) three phase pre and post fault current(c)modal signal.

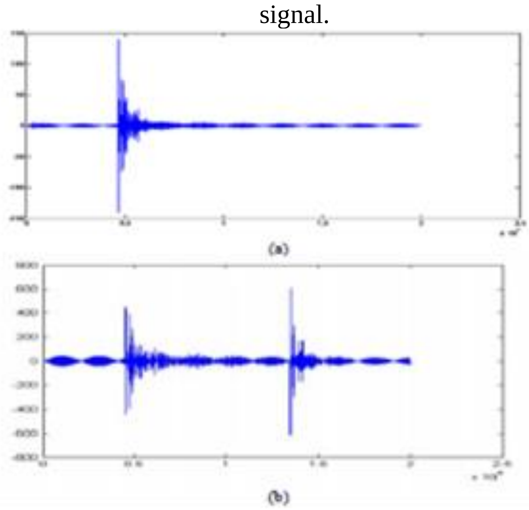

Fig.4 (a) detail 1 of modal signal,(b)detail 5 of modal signal

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Where
Eh (r) - Discriminating signal of high- frequency band (d1)
EI (r) - discriminating signal of low-frequency band (d5)
Im1 – Detail 1(d1) coefficients of modal signal

Im5 – Detail 5 (d5) coefficients of modal Signal
ΔT - Sampling time step
N -- Fault inception sample number
r – Current sample where r>n

It can be seen that (1) and (2) are calculated only after the detection of an abnormality at sample number n. With each new sample following n, the summation in (1) and (2) is increased by one sample. After the calculation of Eh(r) and El (r), the discrimination ratio is calculated every sample also, as follow:

Ratio = C x Eh(r)/El(r)

Where, C is a normalization factor and is taken as 400 in this study based on simulation results. If this ratio is ≥ 1 for 200 samples [1ms], 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 waits for 1/4 cycle after the detection of an abnormal condition is an external fault or a switching operation. A flowchart for fault zone identification is shown in fig.5. The algorithm starts with a moving window of width equal to half cycle [2000 samples]; it calculates the wavelet coefficients of the modal signal inside the window.

This window slides samples by sample until the detection of any abnormality. The detection criterion is d1>4.45 Amp. If a fault is detection, the microprocessor- based relay then starts to calculate Eh(r) and El(r) using the coefficients of d1 and d7, as shown in (1) and (2) 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.

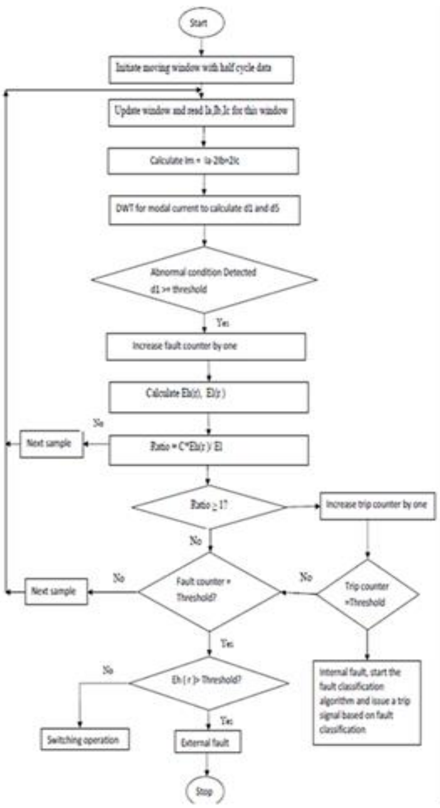

Fig.5 Flow chart for fault zone identification

The relay then takes the next sample and determines the wavelet transform of the new window from which it calculates, Eh(r) and ,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 initiates the classification algorithm (to be explained later in this section) and then issues a trip signal to the circuit breaker to open the faulted section, section AB in Fig.1 If the ratio is less than unity, the abnormal condition may be an external fault or a switching operation. The relay increases the fault counter by one and condition to take new samples until the fault counter reaches 1000 (i.e.5 ms). Before making a decision for an external fault or a switching operation the value of Eh (r) is checked .if Eh(r) is more than the threshold, and then the condition is an external fault, else the condition is a switching operation.

C. Fault Type Identification

After detecting the fault and identifying its zone as an internal fault, it is essential to classify its type. If the fault is signal phase ground, which than represent more than 70% of transmission-line faults, single-pole tripping would be preferred to enhance the reliability of the system and allow for auto closure in case of a transient fault. However, if the fault is not a signal phase to ground fault, it is must to trip the three phases for the power system.

Knowledge of the fault type is also essential for reliability analysis of the system and maintenance operation for the faulted phases. 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 unfaulted phases and this fact is the key for the classification algorithm suggested in this scheme. The flowchart for fault zone identification is shown in fig 5. After the detection of an internal fault the fault classification algorithm starts to operate. The final window at this instant contains 200 sample of post fault current and 1800 samples of pre fault current. This final window is loaded and discrete wavelet transform (DWT) using db1 wavelet as the mother wavelet is carried out for the three-phase currents and the ground current. Hence, the average of the absolute value to the 200 post fault coefficients of d5, which cover the frequency range from 1 to 3 kHz, are calculated for the three phases and ground current. The phase and the ground which has the largest average value are identified as being involved in the fault. The other phases are checked for involvement in the fault. The remaining phase, which has an average value more than t, or equal 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 coefficient is compared with the largest average value. If the ground is involved in the fault, its average value will exceed the largest average value. After fault classification, a trip signal based on fault type is issued.

II. SIMULATION RESULT

A series of simulation is done using Simulink and sim power system toolboxes of MATLAB software for various types of fault at different fault location on the power system modal

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Fig. 1. in order to generate time domain input signal. The power angle between the two sources is taken 20°, fault inception angle 45°, and with different fault resistance Rf. The simulation starts in steady state and at t = 20 ms, a fault is applied.

Simulation result in the tables given below show, that the proposed protection scheme is first take decision about the fault zone on the basis of ratio of Eh and El, if it is greater than 1then it decides the fault is internal and then starts the process to determine the involvement of phase and ground in the fault as described above.

Simulation is done at different fault locations in the protected zone and with different fault resistance Rf .Result shown in the tables I and II.

While when simulation is done at different location beyond the protected zone with different fault (LG, LLG, LL, LLL) and with different fault resistance results shown in the table number III.

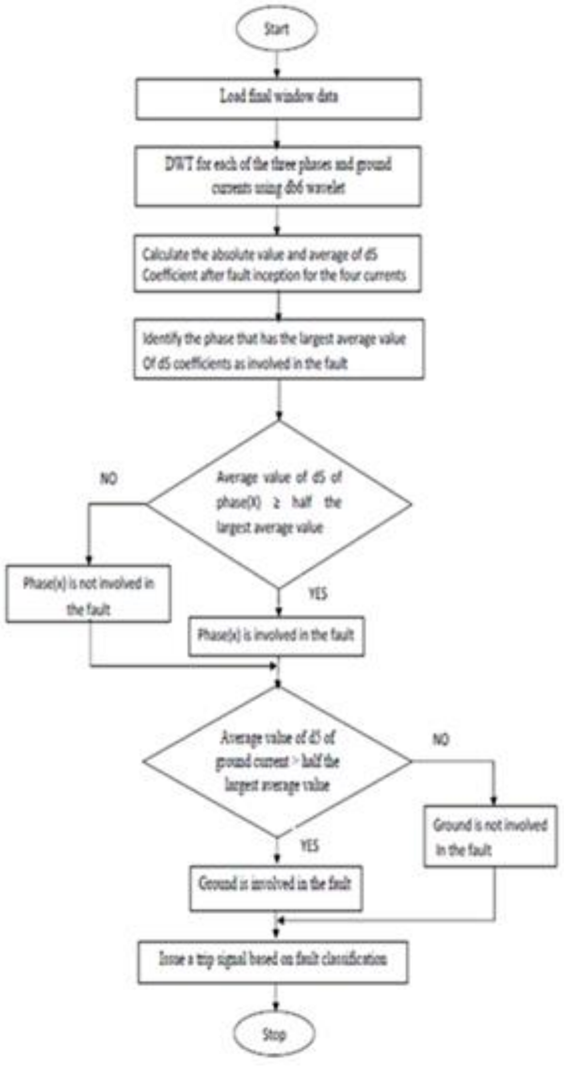

Fig. 6 flow chart for fault type selection

Table I Maximum value of spectral energy of d1 & d5 coefficients; and ratio for internal fault at different location and Rf = 200Ω.

Internal faults		Eh	El	ratio
LG	AG	8.1135e+3	4.2957e+4	75.5496
	BG	3.5044e+5	7.6868e+7	1.8236
	CG	3.2258e+5	7.1476e+7	1.8053
LLG	ABG	2.0981e+4	1.2887e+5	65.1227
	BCG	1.0252e+5	1.4856e+7	2.7604
	ACG	2.5722e+5	5.7995e+7	1.7741
LL	AB	3.2118e+4	3.0070e+5	42.7241
	BC	3.3651e+5	7.4172e+7	1.8148
	AC	5.2047e+5	1.2326e+8	1.6890
LLL	ABC	4.0648e+4	9.4505e+5	17.7021

Table II Average of absolute value of d5 coefficient, after fault inception, for the three phase & ground currents for fault, at Rf =200Ω.

Internal fault		A	B	C	G
LG	AG	29.5618	11.828	6.5236	33.9952
	BG	19.0999	28.6617	23.6106	57.4858
	CG	7.787	8.3626	17.2434	14.6247
LLG	ABG	33.5765	29.7562	22.4106	45.7195
	BCG	13.1282	27.1605	21.3304	32.7801
	ACG	28.1052	11.407	19.0717	31.2528
LL	AB	35.2234	25.5412	13.3855	16.6654
	BC	6.6226	22.9249	21.0801	10.47
	AC	16.2919	7.6191	24.4765	2.1491
LLL	ABC	46.0181	55.5537	28.0698	18.0225

Table III Maximum value of spectral energy of d1 & d5 coefficients; and ratio for External fault at different location and different faults with Rf = 200Ω.

External faults		Eh	El	ratio
LG	AG	3.2490e+3	5.6944e+7	0.0228
	BG	4..1990e+4	1.7083e+9	0.0098
	CG	1.519e+6	5.6944e+9	0.0809
LLG	ABG	2.2218e+6	8.0163e+9	0.1109
	BCG	3.2508e+6	1.5291e+10	0.0850
	ACG	5.2664e+6	2.6203e+10	0.0803
LL	AB	6.1012e+6	2.9840e+10	0.0827
	BC	6.5432e+6	3.1658e+10	0.0836
	AC	7.008e+6	3.3477e+10	0.0837
LLL	ABC	1.815e+6	6.833e+9	0.01062

III. CONCLUSION

Application of the discrete wavelet transform for the boundary protection of the single circuit transmission lines as well as fault classification has been proposed in this scheme. The multi resolution ability of wavelets in decomposition the signal into different Frequency bands in both time and frequency allow accurate fault detection, classification and identification of the fault zone. Spectral energy reflection the transient characteristic and identification of the fault, modal a current is used as the criterion of identifying internal or external fault. Wavelet analysis, with db6 wavelet, is performed for the modal signal and the ratio of the two energies determined whether the fault is internal or external. Moreover a threshold level for the high-frequency energy differentiates between external faults and switching in operation. Using Haar as the mother wavelet, the three phase and ground currents. The averages of the absolute value of d5 coefficient after fault inception of each current wave is then computed and used to classify the faulted phase and ground involvement.

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The simulation result demonstrates that the proposed protection scheme for line protection is independent of the effect of fault inception angle, fault impedance, fault types and fault location. This protection scheme can detect, even a single-line to ground fault with high fault resistance correctly .The operation time of the protection is less than half cycle. The proposed protection scheme has excellent selectivity, reliability and sensitivity and is feasible to be implemented in real time. The proposed protection scheme has a significant improvement to the traditional protection schemes such as distance protection regarding speed of operation and performance.

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