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Fault Detection for Multi-terminal Transmission Line with Nuclear Power Plant Based on Wavelet Transform

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This paper proposes an improved scheme of fault detection and classification for multi-terminal transmission lines using discrete wavelet transform (DWT). The proposed scheme can correctly detect and classify the faults. The proposed scheme is dependent on line current data only. This scheme is derived in the spectral domain and is based on the application of the DWT. The scheme uses an adaptive threshold level to detect and classify the faults. The ATP/EMTP program is used to evaluate the presented approach. Additionally, the nuclear power plants are planned to be integrated with the Egypt electric network in 2026, hence, the presented approach takes into consideration the installation of El Dabaa power station. The presented approach achieves accurate results under numerous and enhanced the fault detection and classification methodologies.

Introduction

Electrical power systems have rapidly developed during the recent years, which in turn are followed by a considerable increment in the number and the length of the lines under operation. These lines experience various types of faults. In most cases, electrical faults emerge as mechanical damages and require repairs before restoring to the service. Detection and isolation faults are urgent challenges for effective protection of transmission line in power system. Mal-operation of protective relays that are detects, locates and eliminates the faults, will have effects on the power system grid [1].

Despite the economic benefits of using three-terminal transmission lines, they are of more complexity when it comes to protection or fault detection. The fault detection problem in three or multi terminal transmission lines is different from that of two-terminal lines. Hence, the conventional one-terminal and two-terminal fault detection methods are not useful anymore. In recent years, many fault detection and classification methods are presented [2-16]. Most of these methods use the voltage and current phasors at terminals, calculated using the sampled data over one power cycle. Therefore, they can converge to the final result after passing at least one full cycle from the fault occurrence where their convergence is influenced by the decaying DC component, appearing after the fault occurrence due to the inductive-resistive nature of the power system. Most of these methods use fixed values for the parameters of transmission lines or source impedances in their calculation. Whereas, these values can vary in practice by the change in the environmental, operational conditions or the network topology.

Previous studies [2–8] presented schemes based on DWT and used Db4 as a mother wavelet, whereas Bior 2.2 is used in the study of Gafoor et al. [7] as a mother wavelet and Haar used by El Safty et al. [9]. Other researchers[10] presented four multi-wavelet

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packet entropies (Energy entropy, Time entropy, Shannon singular entropy, and Tsallis singular entropy) to extract the features of different transmission line faults, and uses a radial basis function neural network to recognize and classify 10 fault types of power transmission lines. The presented algorithm uses three phase current signals at the head end of transmission line, and the sampling frequency is 10 kHz. Usama et al. [11] presented a scheme based on WT. The presented algorithm depended on the analysis of high frequency transients produced during faults. In another study [12], the DWT in conjunction with modular neural network was presented for fault detection for EHV line. Fault detection is effectively employed using Daubechies-5 with sampling frequency 19.2 kHz. In a previous study [13], the DWT was applied for teed circuits. The scheme use Db5 as mother wavelet with 2 KHz as sampling frequency. The mean fault detection time is 0.25 s. An earlier publication [14] presented scheme based on WT with GPS. The scheme use Db4 as mother wavelet with 12.5 KHz as sampling frequency. A previous study [15] presented an algorithm based on WT. The scheme use Db4 and Db6 as mother wavelet. In another publication [16], the DWT was presented for long transmission lines. The scheme use Db1 as mother wavelet. In other studies [17] and [18], the authors presented schemes based on artificial intelligent for detection classification and location fault in six phase transmission line.

In this work, a method is proposed to detect and classify the faults based on DWT. The Db1 is used as a mother wavelet to analyze the current signals. The maximum absolute value for details and approximation coefficients are used to detect and classify the faults. The presented approach is a test for all fault types. The presented approach achieves accurate results under numerous and enhanced the fault detection and classification methodologies. The present paper is organized as follows: section 2 introduces the wavelet transform tools. The proposed phasor extraction algorithm, for three-terminal transmission lines, is explained in section 3. Section 4 presents the model used to evaluate the presented approach. In section 5, MATLAB and ATP simulation results for the case study are presented and section 6 concludes the work.

Discrete Wavelet Transform

Wavelet is a short duration wave that can be defined as any fast decaying oscillatory function that has a zero-average value. WT is relatively a new signal processing tool for transient signals analysis. It breaks down a time dependent signal into shifted and scaled (dilated or compressed) versions of the mother wavelet (basis function). WT has some unique features that make it more suitable for transient signals analysis in a power system [19], such as:

- It has the property of time-frequency localization, even of a small disturbance in a signal.
- WT has a capability of extracting the signal components under different frequency bands while retaining the time domain information.

DWT is used in this paper. It is equal to recursively filtering the signal with a high-pass and low-pass filter pair. The details are the low-scale, high frequency components of the signal produced by filtering the signal by a high-pass filter as shown in Fig. (1). The band width of these two filters is equal. To obtain another level of decomposition, cascading of procedures is applied. The output signal of a low frequency band will be the initial input of the next layer. Wavelet coefficients can be determined mathematically as follows [20]:

$$CA1[K] = \sum_{n=-\infty}^{n=\infty} X[n] * L[2K-n] \tag{1}$$

$$CD1[K] = \sum_{n=-\infty}^{n=\infty} X[n] * h[2K-n] \tag{2}$$

where, CA1[K] and CD1[K] are the coefficients of wavelet decomposition.

In this work, Db4 wavelet transform is applied to decompose the current signals into approximation and detailed wavelet components. The spectral energies of the wavelet components are calculated and then, employed to detect and classify the faults. Fault Indices are calculated based on the max absolute of local end first level detail coefficients (D1) of current signals.

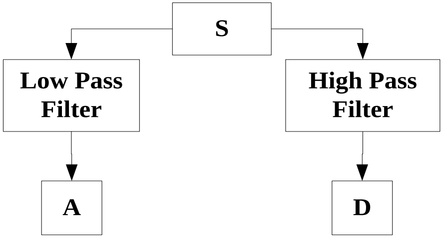


Fig. (1): The wavelet filtering process

Description Of The Proposed Scheme

In this work, a new detection and classification scheme is proposed. The presented approach is used to extract distinctive fault features over one cycle data windows with sampling frequency of 6.4 kHz (128 sample per cycles). Figure (2) shows the presented approach for the fault detection and classification. The proposed fault identification scheme is executed as follow:

- Three phases currents are computed and sampled also the ground current ig from bus 1.
- Obtaining the maximum absolute values for current approximate coefficients (Sa, Sb, Sc) in node [1, 0] and maximum absolute values for current detail coefficients (Da, Db, Dc) in node [1, 1] using DWT with mother wavelet Db4.
- Computing the ground fault index (Sg), where Ig=Ia+Ib+Ic, be obtain the maximum absolute values for ground current approximation coefficient in node [1, 0]
- Classifying the fault types as in Table (1).
- Changing the threshold value adaptively by test the load current.
- Finally, if there is no fault and still there is a considerable difference between the RMS current and the stored load current value, the presented approach will change the threshold adaptively.

The whole process is based on a moving window approach where the one-cycle window is moved continuously by one sample as shown in Fig. (5).

MODEL SYSTEM

The simulation of the tested power system is carried out using the alternative transient program ATP/EMTP. The fault types are chosen based on transmission system as shown in Fig. (4). The main parameters of the tested network are demonstrated in Table (2). In this work, the current signals from bus 1 is used to detect and classify the faults.

Testing Proposed Scheme

The network shown in Figure 4 is simulated for various fault situations. For each type of fault at a particular location, the fault inception angle is widely varied to evaluate the performance of the suggested approach. Influence of fault resistance is also evaluated.

- Case 1: Different fault types in Section1 (bus-bar1) with 60Ω fault resistance.
- Case 2: Different fault types in Section 2 at 132 km away from bus-bar 1 with 5Ω fault resistance.

All results as shown in Tables (3 and 4). It is noticed that in all cases the approximated and details coefficients for healthy phases are smaller than faulted phases. Thus, it is clear that presented approach is valid for detecting and identifying faults at any section.

Conclusion

The current study presents a new adaptive fault detection and classification in ring configuration power system. The three-phase currents at bus 1 have been utilized for detection and classification of faults using DWT. The presented approach is dependent on line current data only. The presented approach is derived in the spectral domain and is based on the application of the DWT. The presented approach uses an adaptive threshold level to detect and classify the faults. Based on simulation results, the presented approach has been a successful tool in the detection and classification of various types of faults in all the sections of multi-terminal transmission systems. The case studies establish that the suggested approach is not affected by fault location, load changing, fault incidence angle and fault type and fault resistance.

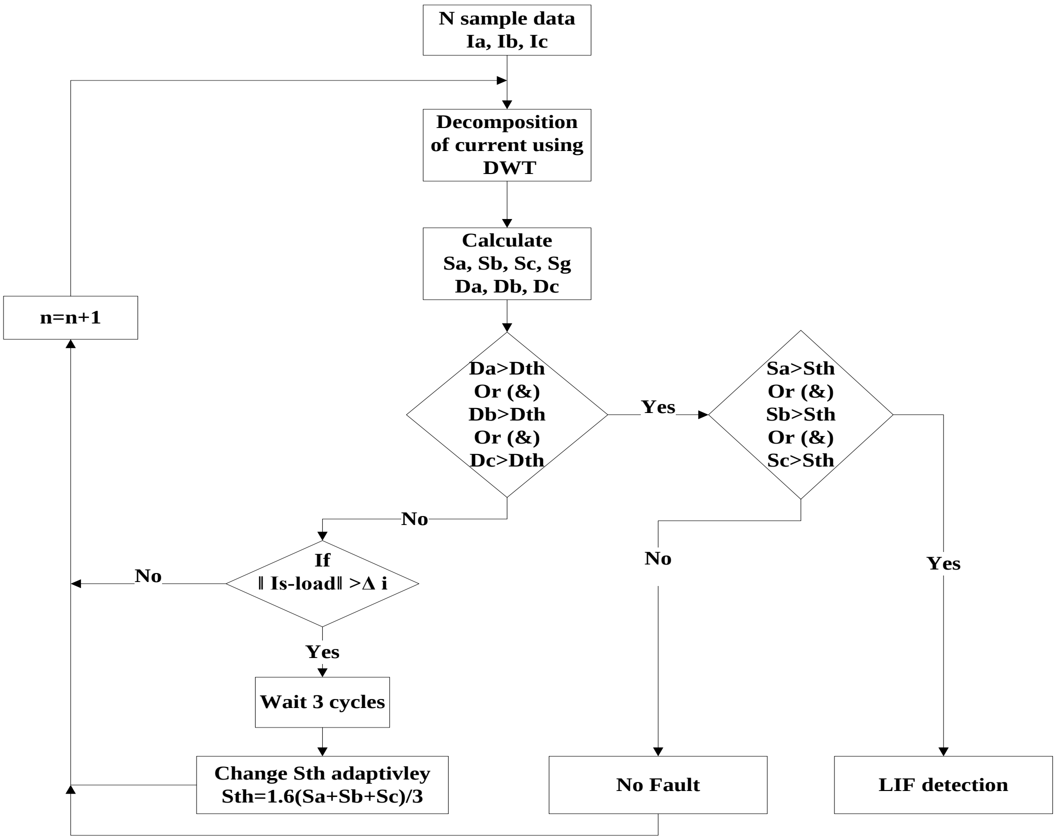


Fig. (2): Flow chart

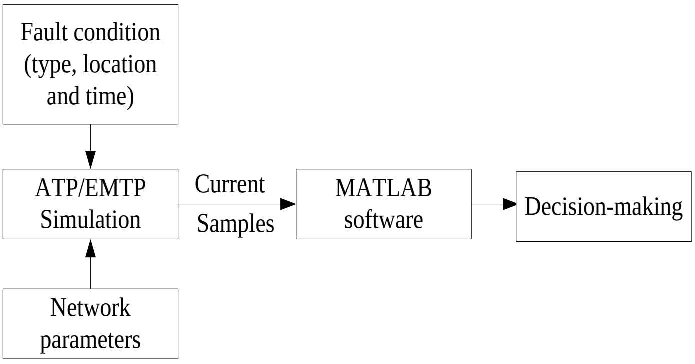


Fig. (3): The fault patterns process

Table (1): Fault classification rules

Fault type	S_a D_a	S_b D_b	S_c D_c	S_a
AG	$S_a > S_{th}$ $D_a > D_{th}$	$S_b < S_{th}$ $D_b < D_{th}$	$S_c < S_{th}$ $D_c < D_{th}$	$S_g > S_{gth}$
BG	$S_a < S_{th}$ $D_a < D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c < S_{th}$ $D_c < D_{th}$	$S_g > S_{gth}$
CG	$S_a < S_{th}$ $D_a < D_{th}$	$S_b < S_{th}$ $D_b < D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g > S_{gth}$
ABG	$S_a > S_{th}$ $D_a > D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c < S_{th}$ $D_c < D_{th}$	$S_g > S_{gth}$
BCG	$S_a < S_{th}$ $D_a < D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g > S_{gth}$
ACG	$S_a > S_{th}$ $D_a > D_{th}$	$S_b < S_{th}$ $D_b < D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g > S_{gth}$
AB	$S_a > S_{th}$ $D_a > D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c < S_{th}$ $D_c < D_{th}$	$S_g < S_{gth}$
BC	$S_a < S_{th}$ $D_a < D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g < S_{gth}$
AC	$S_a > S_{th}$ $D_a > D_{th}$	$S_b < S_{th}$ $D_b < D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g < S_{gth}$
ABCG	$S_a > S_{th}$ $D_a > D_{th}$	$S_b > S_{th}$ $D_b > D_{th}$	$S_c > S_{th}$ $D_c > D_{th}$	$S_g < S_{gth}$

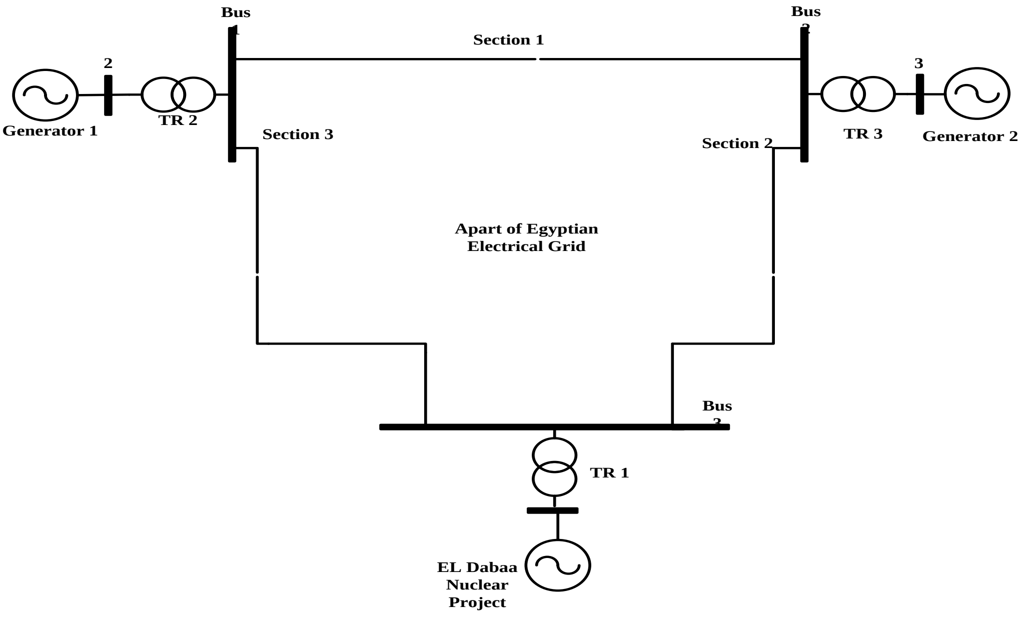


Fig. (4): Single line diagram

Table (2): Transmission lines information

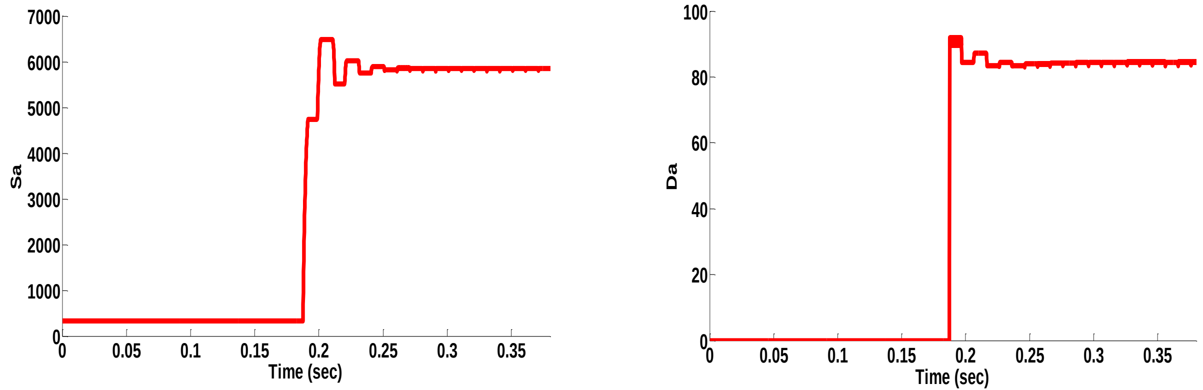
System type	O.H.T.L		W1= 12.6 m
No. of phases	3	Width between phases	W2= 13.4 m
Resistivity	100 Ω m		W3= 14.2 m
Inner radius of conductor	0.373 cm	Outer radius of conductor	1.3055 cm
DC- resistance	0.08285 Ω /km		H0 = 52 m
Spare	50 cm	Height of tower / phases	H1= 43 m
Alpha	0^0		H2= 35.4 m
Number of bundles conductor	2		H3= 27.6 m

Table (3): Results of fault classification for case 1

types of faults	occurrence time fault(sec)	Approximation and detail coefficient Max absolute values				Result
		$S_a \times 10^3$ D_a	$S_b \times 10^3$ D_b	$S_c \times 10^3$ D_c	S_g	
AG	0.07	5.883 84.25	0.784 0	0.764 0	7.3025e+003	AG
BG	0.073	0.795 0	5.986 85.36	0.792 0	7.9033e+003	BG
CG	0.065	0.732 0	0.795 0	6.359 95.35	8.5090e+003	CG
ABG	0.067	6.231 110.25	6.562 112.3	0.795 0	8.9429e+003	ABG
BCG	0.069	0.748 0	5.991 99.35	6.015 101.3	8.5417e+003	BCG
ACG	0.072	7.231 111.3	0.786 0	6.991 108.3	7.364e+003	ACG
AB	0.066	7.326 98.35	7.025 99.85	0.776 0	5.354e-004	AB
BC	0.064	0.792 0	6.856 98.36	6.598 92.65	6.637e-004	BC
AC	0.06	7.0135 92.35	0.765 0	6.846 89.36	4.453e-004	AC
ABCG	0.071	6.985 102.3	6.968 102.5	6.953 102.9	7.179e-004	ABCG
ABC	0.068	5.861	5.891	5.875	5.72e-005	ABC

99.35	98.99	99.12

Also for case 1, Fig. 5 (a and b) shows the approximate and detail coefficients respectively in the presence of L-G fault when the fault occurs at 0.18 sec.



(a) Approximation coefficient for AG fault

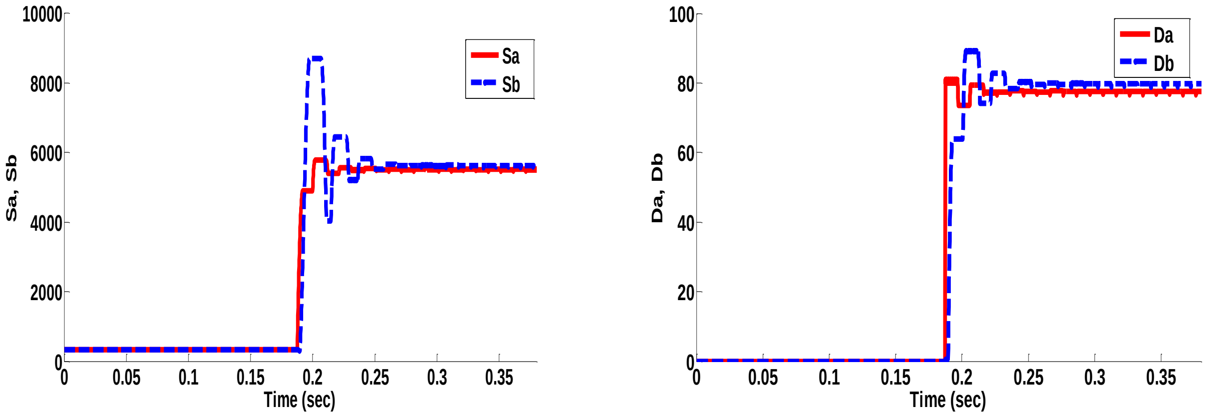
(b) Detail coefficient for AG fault

Fig. (5): Approximate and detail coefficients in the presence of L-G fault case 1

Table (4): Results of fault classification for case 2

types of faults	occurrence time fault(sec)	Approximation and detail coefficient Max absolute values				Result
		$S_a\times 10^3$	$S_b\times 10^3$	$S_c\times 10^3$	S_g	
		D_a	D_b	D_c		
AG	0.069	6.369	0.753	0.721	6.3156e+003	AG
		95.25	0	0		
BG	0.071	0.786	7.369	0.795	8.6352e+003	BG
		0	95.36	0		
CG	0.059	0.789	0.756	6.359	7.9653e+003	CG
		0	0	94.35		
ABG	0.068	5.935	5.993	0.784	7.5692e+003	ABG
		80.23	81.69	0		
BCG	0.071	0.748	6.821	6.235	6.9865e+003	BCG
		0	98.35	96.3		
ACG	0.068	7.861	0.756	6.989	6.364e+003	ACG
		101.1	0	105.2		
AB	0.064	7.563	6.956	0.699	7.364e-004	AB
		97.69	95.63	0		
BC	0.069	0.765	6.896	6.986	5.635e-004	BC
		0	96.32	90.69		
AC	0.071	7.656	0.862	7.956	7.235e-004	AC
		90.36	0	85.32		
ABCG	0.069	7.236	7.296	7.253	4.235e-004	ABCG
		101.3	101.7	101.3		
ABC	0.073	6.213	6.836	6.365	5.986e-005	ABC
		98.21	99.63	98.69		

Also, for case 2, Fig. 6(a and b) shows the approximate and detail coefficients respectively in the presence of LL-G fault when the fault occurs at 0.18 sec.



(a) Approximation coefficient for AG fault (b) Detail coefficient for AG fault

Fig. (6): Approximate and detail coefficients in the presence of LL-G fault case 2

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