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Development of DSP-Based Transmission Line Fault Detection

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Abstract: This paper proposes a new algorithm to detect and classify faults in the electric power transmission line. Transmission line protection is an important issue in power system engineering because 85-87% of power system faults are occurring in transmission lines. This paper presents a technique to detect and classify the different shunt faults on transmission lines for quick and reliable operation of protection schemes. Discrimination among different types of faults on the transmission lines is achieved by the application of evolutionary programming tools. Further, fault signal data are imported into MATLAB for post-processing, and time-frequency analysis using Signal Processing Toolbox in MATLAB.
Keywords: Fault detection, fault classification, power transmission line, advanced digital signal processing, time-frequency distribution

I. INTRODUCTION

Transmission line fault detection and classification are two important features of a protective relay. Detection and classification of the fault must be performed accurately and as fast as possible for the protective relay to de-energize the faulted line to protect the power system from harmful effects such as a cascading outage, thermal overload, and voltage, angular instability, etc. The conventional algorithm for fault detection and classification is based on steady-state components only. That suffers from low protection speed, and also ignores many factors such as fault types, fault resistance, and fault transients which are important from a signal processing point of view for feature extraction of the faulty signal. The commonly used approach for feature extraction is to convert the time-domain signal into the frequency domain. Fast Fourier transform (FFT) is a very well-known signal processing technique to convert the time-domain signal into the frequency domain and is utilized to develop several algorithms for fault detection and classification in electric power systems. However, FFT provides accurate assessment in the case of stationary signals only as it requires the signal to be periodic. Real-world PQ disturbances such as faults, sags, swell, oscillatory transients, etc. are non-stationary signals, and FFT results in an inaccurate assessment of the PQ disturbances due to spectral leakage. Also, FFT is unable to provide any time information on the faulty signal and transient frequency components as computation is performed in the frequency domain only. Regarding the limitations of the conventional FFT method, the application of wavelet transform (WT) is motivated by fault detection and classification. Also, localization as it shows suitable time-frequency localization ability for non-stationary signals. Reference employs discrete wavelet transform (DWT) to design fault classification tool for determining the boundary of operating region for series compensated transmission line, discusses DWT-based technique in detail, and demonstrates that DWT is an excellent online tool for relaying applications.

II. PROPOSED MODEL

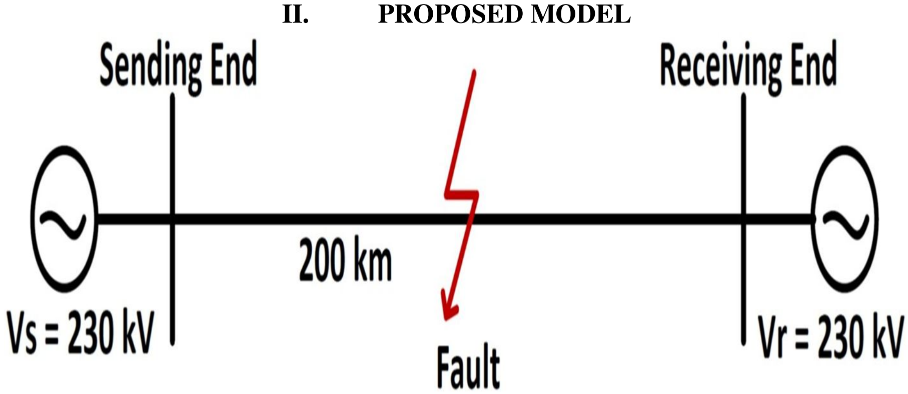

Fig. 1: Simplified model of 230 kV high voltage transmission line.

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TFD-BASED FAULT DETECTION METHOD

In this work, a typical model of a 60 Hz, 200 km, 230 kV high voltage (HV) transmission line with two power sources, sending end and receiving end. The complete power system model is simulated in PSCAD/EMTDC to generate different types of faults. Fault resistance of 0.01 ohm is used in the simulation, and the fault is applied 50 km from sending end at t = 0.2 s and cleared at t = 0.25 s. The positive, negative, and zero sequence components of the transmission line impedance. After PSCAD/EMTDC simulation, faulty signals are imported into MATLAB for post-processing, and the TFD-based time-frequency localization technique is used for feature

TABLE I: Sequence Components of 60 Hz, 200 km, 230 kV Transmission Line Impedance

Sequence Components	R (ohm/km)	X (ohm/km)
Positive Sequence	0.035744	0.507862
Negative Sequence	0.035744	0.507862
Zero Sequence	0.363152	1.326474

traction and single out faults from other PQ disturbances. L. Cohen first generalized all (TFD) as

Mathematical Analysis-

Cv(t, ν; f) = 1 4π 2 Z Z Z v(u + τ 2)v ∗ (u − τ 2) × f(ξ, τ)e −jξt−jτ ν+jξudξdτ du (1)

: where Cv(t, ν; f)

is the time-frequency distribution (TFD) of the analytic (complex) representation of a signal v(t), and v ∗ (t) is the complex conjugate of v(t)? f(ξ, τ) is a two-dimensional parameterization function known as the kernel. The variables ξ and τ represent a frequency domain shift and a time-domain shift, respectively. TFD is considered an advanced DSP technique as it overcomes the limitations of conventional DSP methods such as FFT, and has some advanced features. For example, it provides simultaneous time and variable frequency information and has some advanced applications, for example, radar, sonar, seismic, and medical imaging systems in real-time. Note that in signal processing energy of a signal v(t) is defined as |v(t)| 2 . As seen in (1), a product of v(u + τ 2) and its complex conjugate v ∗ (u− τ 2) provides instantaneous energy information of the signal v(t) which is obtained via a time-marginal property of TFD. This energy information of the signal in the time-frequency domain is utilized to single out faults from other PQ disturbances. However, TFD is a bi-linear transform, and interference or cross terms (unwanted frequency components) are introduced as a result of the by-product. It may cause inaccurate detection of a fault. Among all TFD, reduced interference distribution (RIDB) has shown the most suitable properties to minimize the interference terms.

Principle Average of IFDR Over Half a Cycle.

Type of Faults	Principal Average, P_A	Principal Average, P_B	Principal Average, P_C
ABC_G	0.5759	0.6780	0.5652
A_G	0.4669	0.0468	0.0557
B_G	0.0538	0.5375	0.0530
C_G	0.0435	0.0417	0.4537
AB_G	0.5794	0.6132	0.0354
BC_G	0.0362	0.6373	0.5388
AC_G	0.5974	0.0351	0.5200
AB	0.5686	0.5649	0.0120
BC	0.0090	0.5577	0.5631
AC	0.4450	0.0079	0.4418

However, it is noticed that the value of the principal averageis not enough for fault classification as the principal average of faulty phase under different types of faults has a similar value. For example, principal average P_A and P_B for AB_G and AB faults are approximately equal which may result in inaccurate classification of faults. In order to obtain a reliable fault classification method under various conditions, fault indicators FI_A, FI_B, and FI_C for phases a, b, and c are introduced here to indicate the principal average value for different types of faults as

$\varepsilon = FI_A + FI_B + FI_C$.

Fault Classification Based on Fault Indicators.

Fault Indicator, FI_A	Fault Indicator, FI_B	Fault Indicator, FI_C	$\varepsilon = FI_A + FI_B + FI_C$	Fault Classification
1.8683	2.3768	1.8150	6.0661	ABC_G (LLLG)
19.3589	1.9404	2.3094	23.6087	A_G (LG)
1.1152	20.1322	1.0837	22.3311	B_G (LG)
1.1390	1.0505	21.3099	23.4954	C_G (LG)
17.3121	18.3804	0.1188	35.8113	AB_G (LLG)
0.0554	18.7878	15.7290	34.5722	BC_G (LLG)
18.1688	0.1263	15.6853	33.9805	AC_G (LLG)
48.3899	48.0685	0.0423	96.5067	AB (LL)
0.0321	62.9571	63.5763	126.5655	BC (LL)
57.3363	0.0356	56.9168	114.2867	AC (LL)

III. LITERATURE SURVEY

The method is developed based on advanced digital signal processing (DSP) and the time-frequency distribution (TFD) technique. Since it shows suitable properties to extract the time-varying signature of non-stationary signals and high-frequency transients introduced by typical power quality (PQ) disturbances in electric power systems. The proposed method first separates the fault disturbance component from the steady-state signal and represents it in the time-frequency domain. Thereby for feature extraction to single out faults from other common electric PQ disturbances such as voltage sags and oscillatory transients. Once a fault is detected, TFD-based new index Instantaneous Fault Disturbance Ratio (IFDR), which provides energy information of fault disturbance compared to steady-state signal, is utilized to classify different types of faults. The analysis results show that the proposed method can classify faults successfully by setting up thresholds obtained with an IFDR index for different types of faults. In this work, different types of fault signals are generated using PSCAD/EMTDC simulation software. Further, fault signal data are imported into MATLAB for post-processing, and time-frequency analysis using Signal Processing Toolbox in MATLAB.

IV. CONCLUSION

This simulation project proposes a new method for fault detection and classification in high voltage transmission lines based on advanced digital signal processing techniques and time-frequency analysis. The efficacy of the proposed method is justified by applying it to simulated 230 kV transmission line faults in PSCAD/EMTD simulation software allowed by post-processing the faulty signals in MATLAB Signal Processing Toolbox employing time-frequency distribution (TFD). It is shown that TFD can be used effectively for feature extraction of non-stationary signals in the time-frequency domain, and to single out the fault from other types of PQ disturbances. MATLAB/Simulink-based method and C language method for the implementation of the proposed Relay Model are also discussed along with the DSP techniques which can be applied in IDMT characteristic implementation to improve the performance of the system during false tripping.

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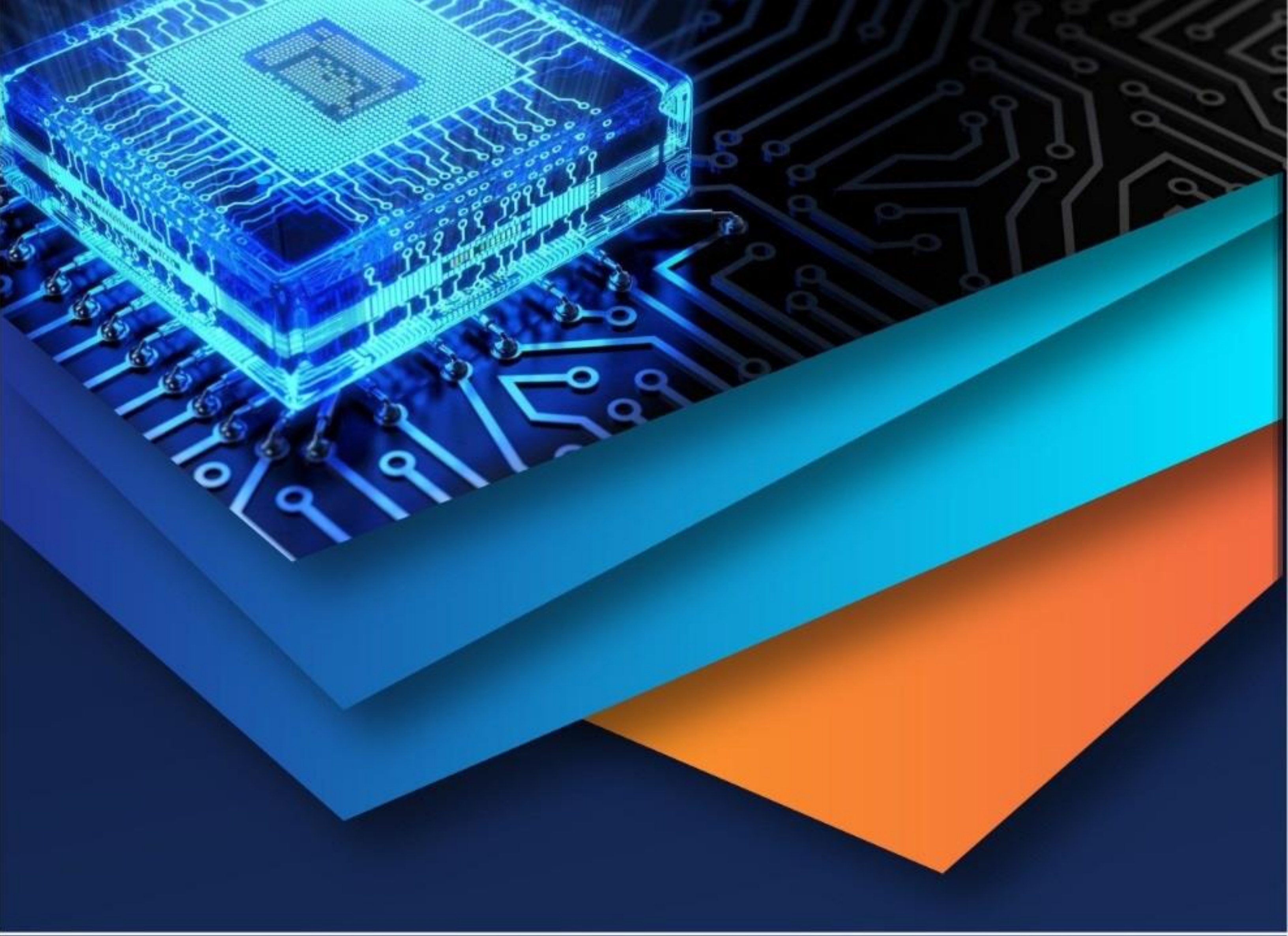

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