DWT Based Fault Detection and Classification of HVDC Transmission Lines

ANUJA P. AMBADE[1], C.M. BOBADE[2]
[1] *Student, G. H. Raisoni college of engineering Amravati*
[2] *Professor, G. H. Raisoni college of engineering Amravati*

Abstract- In this paper, wavelet analysis is used to examine the display and deviation of a typical association of HVDC structure. The wavelet technique is applied in a power system block set with MATLAB/SIMULINK to improve the performance of the HVDC system and provide a precise and reliable fault identification solution. In this study, we use Dabuchies and Symlet wavelets. In order to ensure optimal performance of these frameworks, it is often helpful to be able to quickly identify and address these frustrations. In comparison with fast Fourier transforms and short time interval Fourier transforms, the suggested wavelet-based approach achieves higher productivity.The suggested approach demonstrates how unique characteristics can be produced by monitoring solely the voltage and current of the air conditioner at the side that is being blamed in order to identify common frustrations. The results of our analysis of Symlet and Dabuchies wavelets in this paper indicate that Symlet is superior to Dabuchies wavelet.

I. INTRODUCTION

Due to their advantages over HVAC, the number of HVDC transmission lines and HVDC converting systems is quickly growing worldwide. Large power capacities, extended power transmission distances, quick and flexible power regulation, reduced operation losses, and the most cost-effective benefits make HVDC transmission systems more appealing than HVAC systems in many power system projects [1]. Policies for the large-scale production of electricity have been altered, and more alternative energy sources have been put into place, all in an effort to slow down the dangerously rapid changes in the climate that are being caused by the production of electricity. The finest resources, including wind and tidal energy, are found in offshore locations; therefore, the only viable way to import significant amounts of energy from offshore generation sites is by transmission via lengthy submarine cables. Additionally, the traditional synchronous generator (SG) is being replaced by alternate energy resources and voltage source control (VSC) based HVDC connections, resulting in very low short circuit ratios (SCRs). The two main types of HVDC systems are line communication systems and VSC high voltage direct current systems. HVDC technology can enable asynchronous connections based on VSC voltage source converters between AC load centers and weak and fluctuating energy sources Compared to other power system components, transmission lines have a higher possibility of experiencing faults due to their open environment. These failures can damage equipment and affect the quality and dependability of the power system. Transmission lines that are typically sensitive, durable, and selective in nature are always protected by relays, such as directional Earth fault protection, directional over current protection, line differential protection, and distance protection (non-pilot and pilot). Distance relays are frequently used to safeguard lines. However, a significant disadvantage of distance protection relays during power swings and overloads is that they can trip and overshoot, which has resulted in blackouts in places like the USA in 2003 and Europe in 2006 [3].Different types of DC are present in HVDC transmission systems, with the main focus being on DC link HVDC Transmission faults, pole to pole (positive to negative cable) faults, unbalanced positive and negative pole capacitor banks, and negative and positive cable ground faults. Researchers look into a variety of methods for detecting faults in HVDC transmission lines, including methods based on the k-nearest neighbor (KNN) algorithm, electronics, fuzzy logic, artificial neural networks, traveling wave, support vector machines, and wavelet transform [4]. The author suggested utilizing KNN to detect and categorize defects in HVDC transmission systems. This KNN technique uses rectifier-end ac RMS voltage at both poles along with observed DC-line current and voltage.The signal was created by the author using PSCAD/EMTDC, and MATLAB was used for additional processing and analysis. The most basic machine learning algorithm is KNN.The nearest training sample, denoted as K in the feature space of the suggested algorithm, is integral. K-nearest neighbors are used to determine the classification of data common class among the KNN.There are six distinct KNN classes available in MATLAB. The author uses three common classes—fine, medium, and coarse—to find the distance between the nearest neighbor using the KNN algorithm. The KNN model is trained using six strategies for fault classification. This technology uses just single-end data, with a sampling rate as low as 1 kilo Hertz, to create basic relay algorithms KNN can be used to estimate the location of the fault in another proposed method [5]. The authors describe a five-stage electronic protection scheme for DC faults: (1) fast fault detection; (2) finding the broken DC line; 3) IGBT-CB and VSC blockage;

(4) locating the fault on a DC line and (5) restoring normal service by de-blocking the IGBT-CB and VSC IGBT. The proposed protection's EMTDC/PSCAD digital simulator is used to verify the results. Positive line to ground, negative line to ground and line to line DC shortcoming recognized and safeguard the VSC by IGBT-CBs and IGBT of VSC blocker. Current and voltage feature extraction quickly identifies a defective line. Fast DC switches opened the identified faulted DC line if the fault was confirmed to be permanent. The converter framework and IGBT-CB sunblock and administration resume of M-VSC-HVDC. Fault detection by the substantial voltage difference between the voltage at the fault location and that of the capacitor. The DC fault is confirmed by a high value of |did|/dt. For the same outcome as for the same fault in the AC line, it is not necessary to detect the DC fault. Later on, this plan can likewise be executed at AC side of the HVDC framework by the little change in the arrangement of the model [6-7]. For fault location, the author utilized a 200-kilometer, two-terminal VSC-HVDC Transmission system with ANN and WT. Two-terminal VSC-HVDC transmission system model in PSCAD and MATLAB, with ANN and wavelet analyses applied to the outcomes. The principal worry of shortcoming by creator is shaft to post shortcoming. To verify the efficacy of the proposed fault location method, various simulation results are obtained by altering the fault resistance and location along 200 km. Fault current data are processed using wavelet analyses in this method to generate the XD coefficient that is used as an input for ANN. In order for an ANN to learn about the future, it needs to be fed the line current's XD coefficient (IDC12 and IDC21). 640 training epochs and training (Bayesian regularization) were used to develop the algorithm. The initial data for ANN are 80% the test data, and the remaining 20% are used to test ANN. The predicted values and the actual values are computed as error vectors, and their comparison to the simulation output differs significantly. ANN can find DC issue by low mistake and high connection coefficient [8-15]. This study can be expanded to include multi-terminal network compilation and other fault-locating methods in the future. Creator proposed a philosophy of single finished and twofold finished making a trip wave to foster the issue area method and carry out on G-Nan 500 KV HVDC Transmission framework in China which contain three unique stages where first voyaging wave handling framework and information securing second Pc base expert station and third organization of correspondence are utilized. The purpose of the traveling wave coupler is to reduce transients brought on by an overvoltage HVDC suppression capacitor. These transients acquire a sampling period of one second, which they store locally and exchange before sending it to a PC base master station for the power system, which is installed at a remote dispatch center, via special data communication or public telephone network. The PC master station is in charge of permanently storing fault generator transient data on a hard drive for later processing and automatic fault distance calculation. This framework has a limit with area blunder of around 0.3% 3km of the complete line length [16-17]. The creator examines the insightful calculation in light of SVM for VSC-HVDC framework for issue area with single-finished estimation makes the shortcoming as usable variable of energy, time, and recurrence to catch issue highlights from Hilbert-Huang Change HHT for preparing model. Utilizing HHT, obtain immediate frequency and boundary spectrum analysis. The qualities recurrence, time delay, high recurrence energy, and energy lessening are utilized as the contribution of (s-SVR) support vector relapse to get issue distance. The bat algorithm (BA) is used to optimize the model's algorithm and select the s-SVR parameter for cross-validation with another optimization method. Additionally, the high frequency variance contribution rate (HVCR) is used to identify the

fault area. The VSC-HVDC reenactment is developed to confirm with the ±500m precision and dependability of the proposed strategy. The method can be used to locate the hybrid DC transmission line's fault in the future. The author suggested using a single-ended and double-ended traveling wave method to develop a technique for finding faults and implement it on the G-Nan 500 KV HVDC Transmission system in China. This system has three distinct stages, the first of which uses a traveling wave processing system and data acquisition, the second of which uses a PC base master station, and the third uses a communication network. The purpose of the traveling wave coupler is to reduce transients brought on by an overvoltage HVDC suppression capacitor. These homeless people obtain examining time of 1μs which is locally putting away, and trade then, at that point, toss exceptional information correspondence or public phone network with one another and send it to PC base expert station for power framework and which is introduced at remote dispatch community. PC ace station is answerable for store for all time shortcoming generator transient information into hard plate for additional handling and issue distance ascertaining naturally. The system is limited by a location error of approximately 0.3 percent over three kilometers of the entire line [18, 19]. Faults in a voltage source-based HVDC transmission line system are identified and classified using DWT-based methods in this study. The threshold value of the system and the norm of detail coefficient are compared for fault detection and classification.

II. METHODOLOGY BASED ON DISCRETE WAVELET TRANSFORM

Mallat introduced the concepts of wavelet architecture, DWT, and multitenacity theory (but still non-compact) in 1987. DWT is the application of WT with a discrete wavelet scale and translation that adheres to predetermined guidelines. The signal is broken down into mutually specified orthogonal sets of wavelets using DWT. With a large computing time reduction, DWT offers enough information for both original signal analysis and synthesis. A scaling function that describes the scaling properties of a wavelet can be used to construct one. Compared to alternative wavelet family forms, DWT is simpler to implement. An excellent tool for examining power system transients related to transmission line faults is the DWT with MRA. Using low pass and high pass filters, DWT breaks down the signals into detail coefficients and approximation coefficients at various resolution scales [20]

2.1 Fundamentals of wavelet transform

The wavelet transform is a technique or transform that is used to handle signals that are not amenable to processing using FFT or other accessible transforms. Unlike other sinusoids, which range from minus to plus infinity, its average value is zero. There is a finite range. Wavelets are highly helpful for the analysis of constant frequency signals because of their uneven and non-symmetrical nature. Wavelets can also be used to operate signals that contain undesirable harmonics and oscillations. The wavelet transform of a cosine wave at level 20 is displayed in figure 4.5 below.

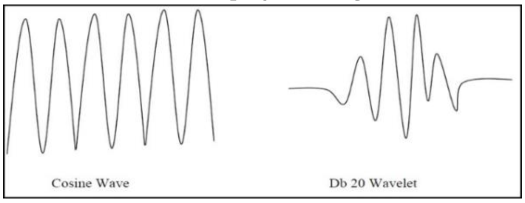

Figure 4.5: Wavelet Transform of Cosine wave

Other transformations, such FFT and DFT, are helpful tools for analyzing the frequency components of signals, but they do not allow us to comment on specific temporal instants. Wavelet transform, on the other hand, concentrates on low frequency components for long time intervals and high frequency components for short ones. As a result, the analysis of signals exhibiting localized oscillations and impulses grows exponentially.

2.2 Need of wavelet transform

We have found that both the fault current signals and the inrush currents are non-periodic in character based on our examination of the inrush and fault currents. Additionally, it is noted that the nature of these signals is oscillatory and that localized impulses are superimposed on the power frequency and its harmonics.

2.3 Discrete wavelet transform

Discrete Wavelet Transform is used to separate the data in various frequency components, as does the FFT. As FFT is used to separate unwanted signal such as noise from the original signal in the same sense DWT is also used for analysis of the signals and avoiding unwanted outages.

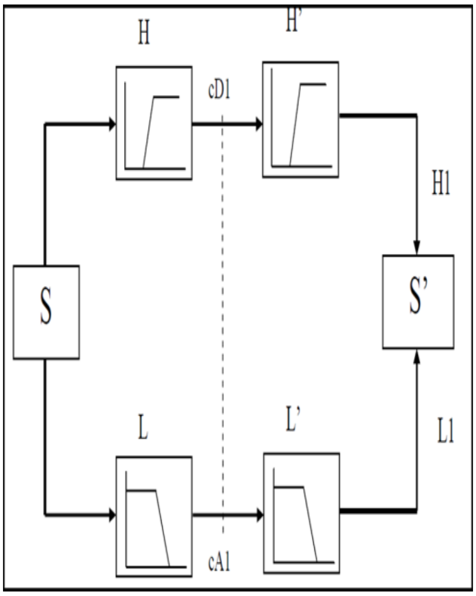

Figure 4.6: Single level Discrete Wavelet Transform

While we are unable to comment on a specific time interval with FFT, we are able to remove the noise or frequency that was computed at a specific instant with DWT. We can use this to operate the signal in a different way by keeping some useful data and removing some unwanted signals at different points in the interval. After removing the unwanted signals, we can easily reconstruct the signal with IDWT. DWT's operation will now be demonstrated through a block diagram: The discrete wavelet change can be separated into two sections the left half which is known as disintegration and comprises of the forward change and the right half which comprises of forward change and is known as the remaking segment. In the center is a line which is utilized to isolate the two parts and is likewise used to add the intricacy in the framework. The input signal is processed by the high pass filter "H" in figure 4.6, and the coefficient "cD1" is produced. This sign is additionally gone through a high pass recreation channel 'H' to create the detail coefficient H1. The sign S is likewise gone through a low pass deterioration channel L to deliver the coefficient cA1, which is additionally gone through a low pass reproduction channel L‟ to create the estimate L1. The high pass filters, H and H, are found in the upper filters, while the low pass filters, L and L, are found in the lower ones.

III. PROPOSED ALGORITHM OF FAULT DETECTION

At various locations of HVDC Transmission Lines, faults of various categories, such as positive to ground, negative to ground, and positive to negative, are analyzed. Fig. 2 displaying an IGBT-based VSC-HVDC transmission system with self-commutation. In this proposed technique for shortcoming discovery of HVDC Transmission Lines, the proposed model of HVDC Transmission Lines are first reproduced in MATLAB/Simulink, Then the Waveform of Issue signals are kept in work area through Current Change and degree block. At these current signals, DWT is used to select the three-level mother wavelet db1. These signals are broken down by DWT into approximation and detail coefficients. The norm of the detail coefficient at each of the three levels is then calculated and compared to the threshold value. The proposed method's flow chart can be seen in Figure 3. In good working order, the norm value of the detail coefficient is lower than the threshold value, whereas in bad working order, the norm value is higher than the threshold value. The equation [21] can be used to calculate the norm of detail coefficients.

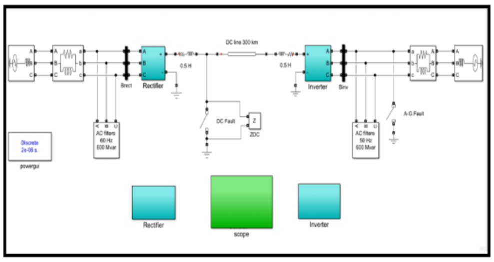

Figure 3.1 Simulink Diagram of 12 Pulse HVDC System

IV. DISCUSSION ON PROPOSED HVDC SIMULINK MODEL

HVDC Transmission Line with a Bipolar SVC Converting Station, as shown in FIG. 6, uses an IGBT forced-commutated voltage-sourced converter to convert an AC system with a 220 KV, 200 MVA power source into HVDC (+/- 100 kV DC). Transmission lines with a length of 300 kilometers are used to transport HVDC power. An inverter station with a rating of 200 megawatt hours and a voltage of 220 kilovolts converts this power into HVAC, and a 220-kilovolt substation connects three phase loads to the HVDC Transmission Lines. MATLAB/Simulink is used to simulate faults on HVDC Transmission Lines that are positive to ground, negative to ground, and positive to negative at various locations. DWT is applied at these shortcoming current signs for issue identification and order. The proposed Simulink model's parameters are depicted in Table 1.

Table 1. System and Transmission line parameters

HVAC Source Rating	200 MVA
HVAC Source Voltage	220 KV
HVDC Source Rating	200 MVA
HVDC Transmission Line voltage	100 KV
Line length	400 KM
Frequency	50 HZ
Line Resistance Per Kilometer	0.10
Line Inductance Per Kilometer	0.5e-3
Line Capacitance Per Kilometer	0.5e-9

V. DISCUSSION AND ANALYSIS OF RESULTS

MATLAB / Simulink was initially used to design the suggested approach. By applying DWT to the current signals of HVDC Transmission lines at three levels, different types of faults in the line were identified and categorized. Additionally, the third level detail coefficient norm is computed and compared to the system's threshold value for defect identification and categorization. The maximum normalized value at maximum load under typical operating conditions for the chosen system is the threshold value. In order to discover and classify the several types of defects in an HVDC system, including AC and DC faults, wavelet transform is employed. The voltage and current signals on the dc rectifier side and the ac inverter side are monitored by the system.

The following fault cases were simulated

1. Normal operating case
2. Dc line fault
3. Ac fault(LG) at inverter end

DC Side Monitoring

On the DC side, various cases are seen and are as follows: DC Line Fault, AC Line Fault, and Normal Case

Normal Case

Figure 4.1 displays the typical DC voltage and current waveforms. Both a transient and steady state period are present in the voltage and current signals in this.In this case, the steady state signal period is 0.03 to 0.3 seconds, while the transient signal duration is 0 to 0.03 seconds.

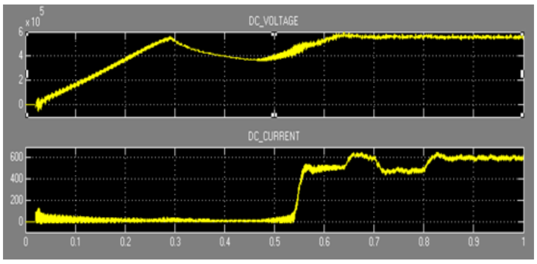

Figure 4.1 DC voltage and DC Current for Normal Condition

DC Line Fault Case

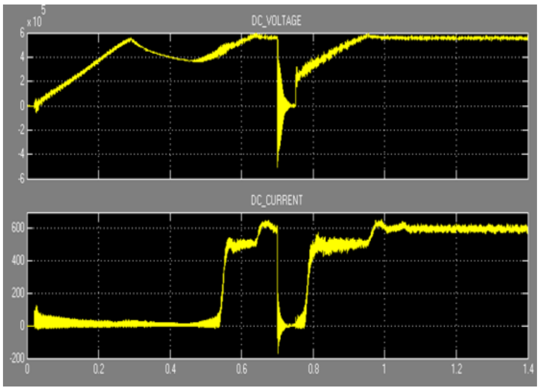

Figure 4.2: DC Fault Case DC Voltage and DC Current 7.Figure 4.2 illustrates how the fault occurs at t=0.7 sec, increasing DC current and decreasing DC voltage. When the DC line voltage drops, the energy it contained is released back into the AC network. After the issue is fixed, the DC voltage and DC current will return to normal.

AC Line Fault Case

Phase A of the inverter bus experiences a single phase to ground fault that lasted for five cycles. The rectifier current controller tends to lower the current by increasing its firing angle alpha and operating in the inverter area when this fault is applied at t=0.7sec. This fault causes the voltage to collapse as seen in Figure 4.3 and the DC current to rise to 2pu.

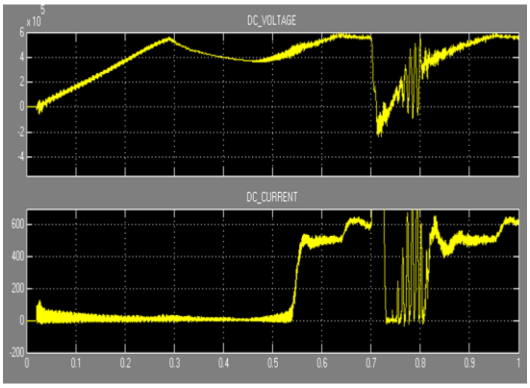

Figure 4.3 DC Voltage and DC Current for AC Fault Case

Inverter Side Monitoring

Different cases are observed on INVERTER side which are described as follows: Normal Case, DC Line Fault and AC Line Fault

Normal Case

Figure 4.4 displays the three phase voltages and currents under typical operating conditions. Every phase has the same voltage magnitude, and the phase current signals have the same magnitude as well.

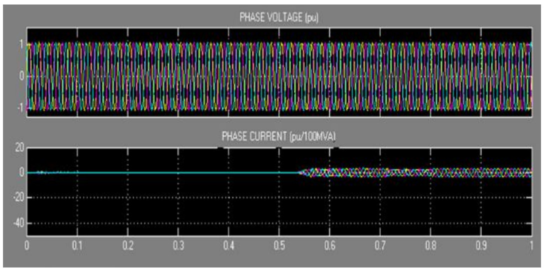

Figure 4.4 Phase Current and Phase Voltage for Normal Condition

DC Line Fault Case

The three phase voltage signals were shown in Figure 4.5 in which phase faultoccurred at phase A at time t=0.7sec. The voltage magnitude becomes zero and remainingphases B and C magnitudes are same as normal operating condition. The current magnitude also decreases to negative value.

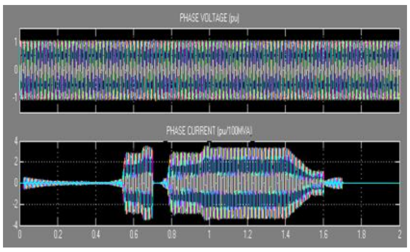

Figure 4.5 Phase Voltage and Phase Current for DC Fault Case

AC Line Fault Case

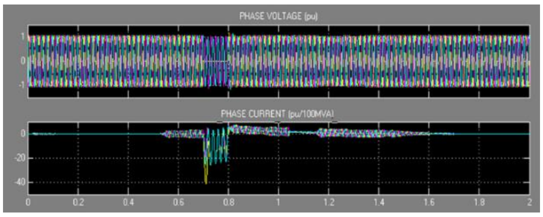

Figure 4.6 Phase Voltage and Phase Current for AC Fault Case

Figure 4.6 displayed the three phase voltage signals, with phase A experiencing a phase fault at time t=0.7sec. The voltage magnitude drops to zero, while the levels of phases B and C remain consistent with standard working conditions. Additionally, the magnitude of the current drops to zero.

Wavelet Extraction Technique

Wavelet means short wave. In others words we can say that it is a time microscope. It helps to decompose the signals at different frequencies. It helps to get the approximate signals. Wavelet satisfies two conditions: it must be oscillatory and its amplitude must be non- zero.

Multi Resolution Analysis

In this analysis the signals are observed at different frequencies at different resolutions. It is best for short duration of higher frequency. It is similar to short time fourier transform. Dabuchies and Symlets. Both the wavelets are taken at level 4 and compare the coefficients of both the wavelets and analyzed which is better for the identification of fault.

Comparison of Wavelets and Their Coefficients

Comparison of Wavelets and their coefficients are describing as follows:

DC Side Monitoring

The signal's breakdown at various levels using the db4 wavelet is displayed in Figures 4.7 and 4.8. In this picture, the original signal is denoted by s, the approximate signal is represented by a4, and the various wavelet levels are represented by d1–d4.

- Normal voltage case

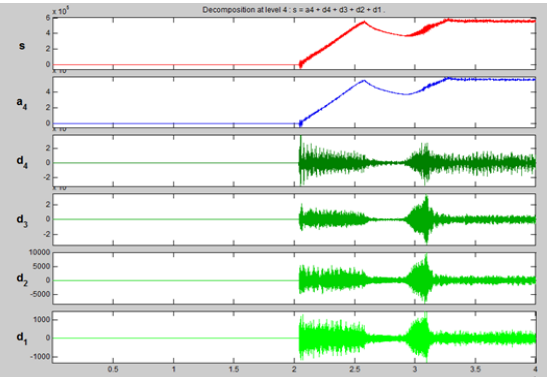

Figure 4.7 db4 for DC Voltage for Normal Condition

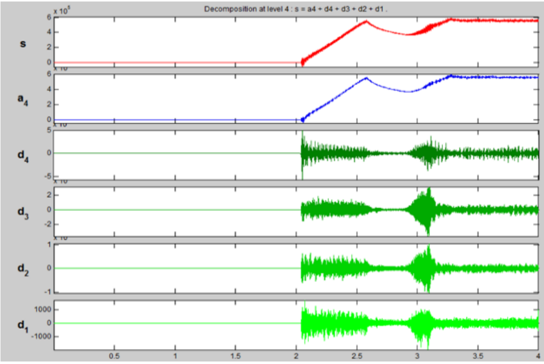

Figure 4.8 sym4 for DC Voltage for Normal Condition

The DC voltage signal at various levels is broken down using the db4 and sym4 wavelets, as shown in Figures 4.7 and 4.8. The mean and standard deviation for a normal condition are computed.

CONCLUSION

In this dissertation, the features of the signals with and without faults are extracted using a novel wavelet-based multiresolution analysis technique. The system fault that arises is also located using this method. so that we can quickly apply protection to the system after a fault has been identified, enhancing its accuracy, dependability, and overall performance. Using two wavelets—Dabuchies and Symlet at level 4—we dissect the signals at various levels in this dissertation technique. We then compute the mean and standard deviation of the system with and without fault, comparing the two wavelets to see which is more accurate. Findings indicate that Symlet wavelet has higher accuracy when compared to Dabuchies.

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