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A SYSTEMATIC APRROACH FOR FAULT DETECTION AND LOCATION IN HVDC TRANSMISSION LINE USING WAVELET TRANSFORM

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ABSTRACT
Transmission of electrical power through High Voltage Direct Current (HVDC) system has no doubt first choice for the long transmission of electricity all over the world .The HVDC transmission system having important parameters like controllability of power flow, economy while transmitting bulk power over very long distances, lower transmission losses and absence of stability issues. Thus the HVDC transmission system is preferred in almost all cases where bulk power needs to be transmitted over 500 km and above. The major faults associated with HVDC transmission system are dc line to ground fault, faults on the ac side of the inverter, commutation failure at the inverter. The protection principle based on travelling wave theory provides the fastest protection. Long HVDC lines can be modeled using distributed elements. According to Travelling Wave Theory, when the fault occurs on the transmission line the voltage and current travelling waves appear on the line. The travelling waves generated will carry information related to the condition of the transmission system. In this paper, the behaviors of different faults in HVDC power systems will be analyzed through wavelet transform and the protection criterions based on wavelet technique will be Proposed. The protection can detect the HVDC line fault well and identify the HVDC line fault clearly.

KEYWORDS: ***HVDC Fault, commutation, wavelet transform, Travelling Wave***.

INTRODUCTION
Electrical Energy is the basic necessity for the economic development of a country. It is impossible to estimate the actual magnitude of benefit that electrical energy has contributed in building up of present day civilization. In this modern world, the dependence on electricity is so much that it has become a part of our life. Hence it can be stated that electric power system is back bone for the development of country in all aspects. HVDC enables secure and stable asynchronous interconnection of power networks that operate on different frequencies, or are otherwise incompatible. In addition, HVDC provides instant and precise control of the power flow. Once installed, HVDC transmission systems become an integral part of the electrical power system, improving the overall stability, reliability and transmission capacity.
In HVDC systems, commutation failures in the converter station and single phase short circuit faults at AC side are similar to HVDC line faults. It is not easy to identify them by using pure frequency domain based methods or pure time domain based methods. However, it is an important requirement on HVDC line protections that different fault types should be identified and the correct decision should be made as fast as possible. It is an important requirement on HVDC line protections that different fault types should be identified and the correct decision should be made as fast as possible.
According to travelling wave theory, voltage and current travelling waves appear through the line when fault occurs. The fault generated travelling waves contain sufficient fault information that can be used to construct high-speed fault identification and line protection. In AC power system, the amplitude of fault generated traveling waves changes with the voltage angles. There is always a problem for the travelling wave protection when faults occur during voltage zero crossing. However, for DC power systems there is no such problems so that travelling wave protection is preferably applied to HVDC systems.
Fault generated travelling waves are varied with time and frequency. Pure frequency domain based methods are not suitable for such transient signals. The pure time domain based methods are very easy influenced by noise. Therefore, the travelling wave protection still has the difficulty in practice applications.

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Wavelet transform, a rather new signal analysis method, is particularly suitable for analyzing transient signals. It has the capability of time location as well as frequency location simultaneously during signal analysis. So it is naturally to use it for fault identification and the travelling wave protection. The criterions will be tested through the simulations under different conditions. The influences of similar faults such as commutation failure and AC single phase fault will be discussed. The simulations are carried out through MATLAB. The results will show that the wavelet technique leads to a new way to the fault detection and protection in HVDC system. These studies are carried out with detailed models of HVDC converters and transmission lines simulated in MATLAB and the fault location algorithm is implemented in MATLAB. The appropriate type and scale of continuous wavelet transform coefficients at a given sampling rate is find out through the simulation studies.

LITERATURE REVIEW

HVDC transmission line links are one of the major elements in power system. This lines holds much importance due to the lowest loss of transmission between grids. Fault location is the major issue in HVDC system, due to large distance of transmission from source site to destination. Our Present work focuses on Fault location in HVDC links.

Majority of the works were done, using travelling wave techniques. In [2], Morphological application was developed, in [3][4], [5-8] travelling wave technique with wavelet analysis were employed. The majority of the recent works in fault location employs frequency domain techniques like FFT and wavelets. The time frequency localization of wavelets makes it a powerful signal processing tool unlike Fourier analysis. For doing a work in fault location, the type of wavelet (CWT or DWT), mother wavelets etc has to be studied. In [8-12], CWT techniques are employed. Authors of [10] used DWT for fault location. The advantages of different wavelets, development of customized wavelets were discussed in [14-17]. In [18], author's uses fast Fourier transforms for fault location. The core requirement of fault location technique is accuracy. Normal reactance based relay systems are not accurate when long distance transmission lines are considered. The recent state of the art fault location systems couple above signal processing technique with artificial intelligence.

A. USE OF TRAVELLING WAVE BASED PRINCIPLE FOR FAULT LOCATION

- *Travelling wave phenomena*

Travelling wave based fault location methods are more often used in application of long HVDC transmission lines. It is well known that whenever any fault occurs in overhead transmission lines systems, the abrupt changes in voltage and current takes place, at the point of the fault. This generate high frequency electromagnetic impulses called travelling waves which propagate along the transmission line in both directions away from the fault point. These transients travel along the lines and are reflected back at the terminals point.

Thus, this property of the travelling wave is used for extracting the time feature of the surge arrival. The wave-front can be calculated by using continuous wavelet transform. If the wave-front i.e. times of arrival of the travelling waves at the two ends of the transmission line are measured precisely, then the fault location can be determined by comparing the difference between these two arrival times. This difference is between the first consecutive peaks of the travelling wave signal.

- *Line Fault Location Technique:*

In the travelling wave based fault location method, the travelling time of the surges initiated by fault are used for the detection of the HVDC line fault location. Following Fig.1 shows the propagation of the travelling waves along a HVDC line. Assumptions are made as the length of the HVDC line be L, two terminals are say T1 and T2, XF is the distance of the fault form one of terminals and ν is the velocity of the travelling wave. Assuming that these waves are initiated due to a fault occurred at distance XF away from terminal-$T1$ and the waves are travelling at a constant velocity denoted by ν.

There are two main methods used for calculation of the distance of fault depending upon the terminals taken in account i.e.

a) Single ended method b) Double ended method.

In single ended method only one terminal is under consideration, while in double ended method both the terminals are required for calculation.

B.USE OF WAVELET TRANSFORM FOR FAULT LOCATION

A Wavelet is a waveform of effectively limited duration that has an average value zero. Wavelet transform transfers a time varying signal into a time-scale domain and thus can represent the original signal with time as well as frequency information.

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The wavelet transform is capable of providing the time and frequency information simultaneously, i.e. time frequency representation of the signal. The wavelet transform handles frequency logarithmically rather than linearly, resulting in a time-frequency analysis with the constant Δf/f, where Δf is the band width and f is the mid band frequency.
In wavelet analysis the time-domain signal is passed through various high pass and low pass filters, which filter out either high frequency or low frequency portions of the signal. This procedure is repeated every time a small portion of the signal corresponding to some frequency is removed from the signal.

Fourier analysis consists of breaking up a signal into sine waves of various frequencies. Similarly wavelet analysis is breaking up of a signal into shifted and scaled versions of the original wavelet.
A wavelet transform can be divided into two types such as:
a) Discrete Wavelet Transform:
In discrete wavelet transform, wavelet co-efficients are calculated by choosing the scales and positions based on the power of two i.e. dyadic scales and positions.
b) Continuous Wavelet Transform (CWT):
In continuous wavelet transform the co-efficients can be obtained by varying the scale and position continuously as per the requirement. The analyzing wavelet can be shifted smoothly along the time axis of the input signal. The continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function.
Where, a is position, b is scale and the *t* is time duration. Thus, the continuous wavelet transform provides more detailed and continuous analysis of the fault transient. CWT coefficients have better time resolution which is very important to have high accuracy in travelling wave based dc line fault location.

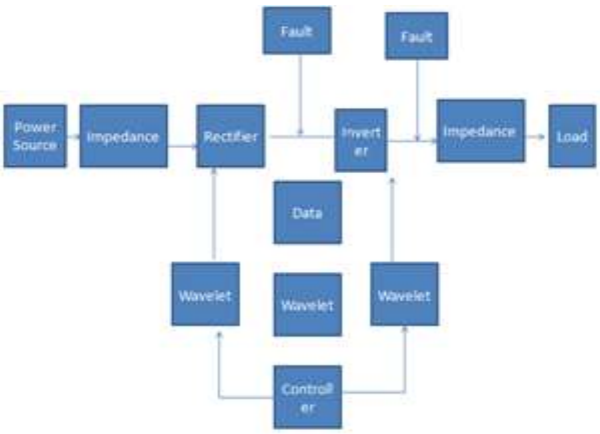

Fig.1 Block Diagram of approach

PROPOSED METHODOLOGY

The methodology for this is to identify the fault on HVDC transmission line , through Wavelet Transform a MATLAB tool. A detailed analysis of different faults, its location is found using MATLAB program. Protection scheme for the fault is proposed. MATLAB simulink model and program cordially operates to detect &protect the fault.The MATLAB programs are also deigned to locate and identify the Fault . MATLAB/SIMULINK is a high-performance multifunctional software that uses functions for numerical computation, system simulation, and application development. Power System Blockset (PSB) is one of its design tools for modeling and simulating electric power systems within the SIMULINK environment It contains a block library with common components and devices found in electrical power networks that are based on electromagnetic and electromechanical equations. PSB/SIMULINK can be used for modeling and simulation of both power and control systems.

OBJECTIVES

The high voltage direct current (HVDC) is most essential for bulk power transfer and large scale demands. Due to heavy power demand, maintenance of power quality has become very difficult. Most common disturbances are faults on the system . These disturbances lead to heavy damage to HVDC transmission system and converter

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stations due bulk power. The other disturbance like internal faults in converter and equipments also produce same effect. Some are very severe while some have less impact. Hence the identification and controlling of these faults is essential and control system plays a prominent role in the overall performance of the transmission system. Fault identification is very important for the secure and optimal exploitation of electric power systems . The Wavelet Analysis can be used as a tool for providing discriminative features with small dimensions to classify different disturbances in HVDC transmission system. This project explores the application of wavelet based multi-resolution analysis (MRA) for signal decomposition to monitor some of the faults in the HVDC system. The faults in HVDC System can be classified by monitoring the signals of the HVDC System like Inverter side AC phase currents, DC Voltage, DC current.

In HVDC systems, commutation failures in the converter station and single phase short circuit faults at AC side are similar to HVDC line faults. It is not easy to identify them by using pure frequency domain based methods or pure time domain based methods. However, it is an important requirement on HVDC line protections that different fault types should be identified and the correct decision should be made as fast as possible.

Therefore this project has the following objectives:-

1) To observe & identify the different DC faults in HVDC power systems.
2) To analyzed the behaviors of different faults in HVDC through wavelet transform.
3) The proposed criterions will be tested through the simulations under different conditions.
4) To locate the distance of the fault.

ALGORITHM FOR FAULT LOCATION IN HVDC LINE

The proposed simplified fault location algorithm which is an offline calculation is illustrated in Fig. 2. This calculation can be initiated once the primary protection scheme identifies the dc line fault. The fault location scheme maintains a runtime input data buffer, which will be saved when a fault is detected. The size of this buffer depends on factors such as the primary protection time delay, sampling time and the transmission line length of the specific HVDC scheme. The largest time delay in the system is used to estimate the buffer size.

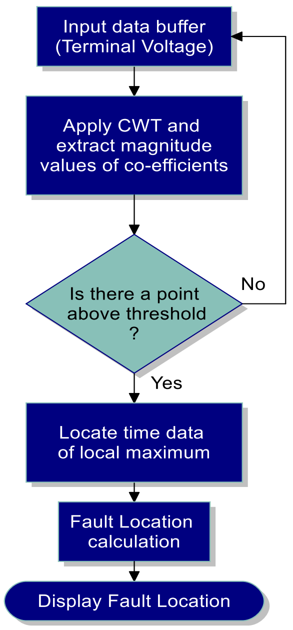

Fig 2. Algorithm for Fault Location in HVDC Line

SIMULATION MODEL

Simulations are done using a HVDC transmission network, assuming overhead transmission line of 300 km line. This test network has line voltage of 500kV as the nominal dc voltage and it is designed to deliver 5000MVA of active power. A mono-polar HVDC configuration is used, instead of the bipolar arrangement. The only reason behind this is reduce the complexity, and the system can also work well on bipolar configuration, since most of

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the present day HVDC systems are built in bipolar configuration. The schematic diagram of the test network is shown in Fig.3

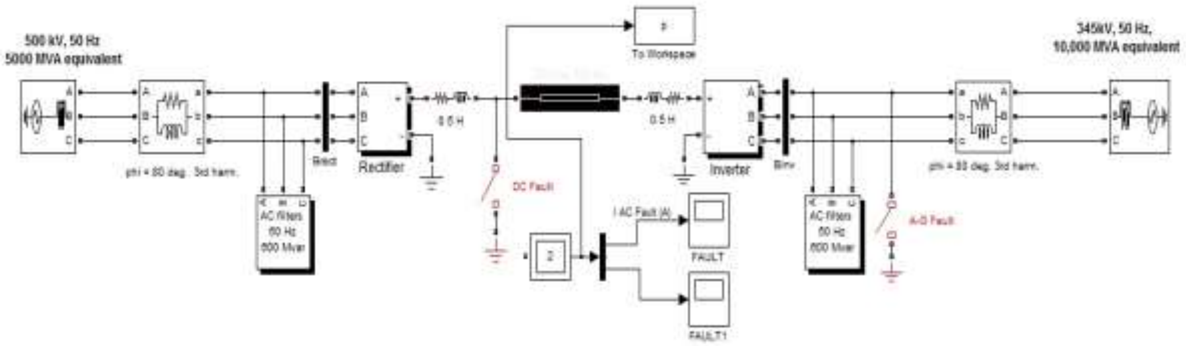

Fig.3. Schematic diagram of HVDC Test network

The total line resistance is 7ohms, as the line is dc line, the impedance reactance does not come into the picture. The line current is 1500A at full load i.e. when both the poles are carrying max load. The dc fault is manually applied at the distance of 15kms in the transmission line. It has to be examined if the proposed technique applied works correctly or not. Also series dc reactor is an important aspect in line commutated type HVDC system. Typical value of the smoothing reactor is in the range of 0.5-1H. Therefore, 0.5H smoothing reactor is placed in series with the transmission line at both ends. The test networks are modeled in MATLAB. The terminal voltage and surge capacitor current measurements are monitored for large number of simulation cases with different dc line fault locations.

RESULTS AND DISCUSSION

The simulation results of the dc line fault location method are represented for the test network of HVDC system with 300 km long overhead dc transmission line. The dc fault on 15kms has been manually carried and hence the accuracy is checked by the CWT technique. The SIMULINK and MATLAB programming has to be done for the same. The tests performed gave the results by the usage of terminal voltage measurements as the input signals to the algorithm.

The fig. 4 shows the occurrence of the fault created in model manually at the distance of 15Kms from the sending end.

Fig. 5 shows the changes in the DC line surge current and terminal voltage observed during DC fault at the rectifiers. It can be directly observed that there are rapid changes in the frequency of current and voltage at the instant of fault.

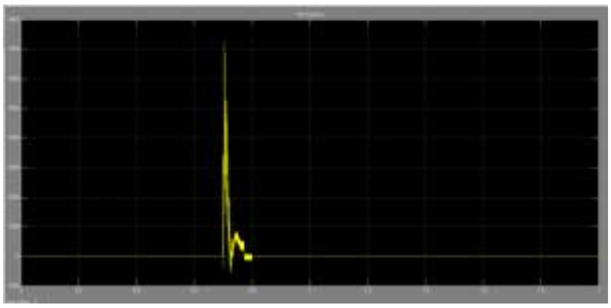

Fig. 4 DC fault

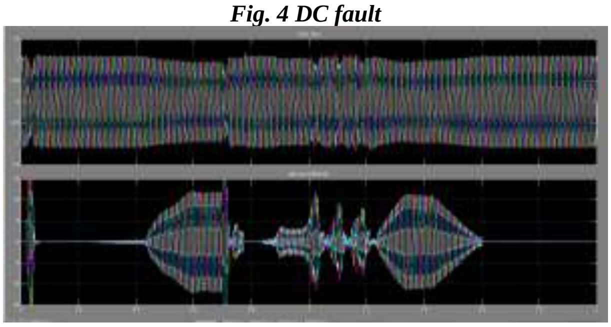

Fig. 5 DC line current & voltage at the rectifier during DC line fault

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Fig. 6 shows the plot of CWT coefficients. The wavelet used is 'DB4' and the decomposition level is set to 5. It can be directly observed that before and after the occurrence of fault, the co-efficient values are nearly zero, but at the instant of fault occurrence, there is sudden increase in the values of coefficients which reaches to the local maximum.

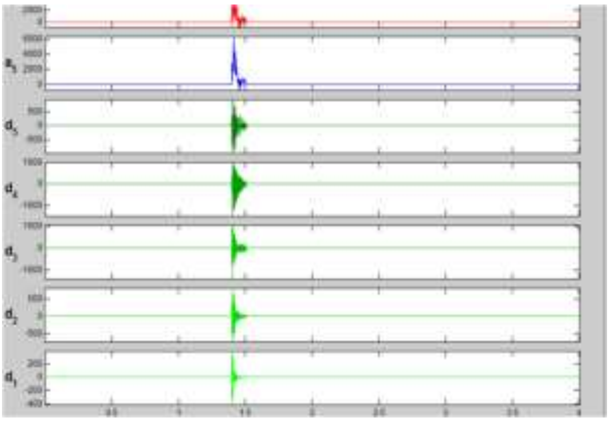

Fig. 6 CWT coefficients for DC fault

At detail level 5 (d5), the time location of the local maximum is extracted (t) and then it is translated to the actual distance in Kms by using the formula

$$L = \frac{t \text{ x } v}{2}$$

Where v is the velocity of travelling wave in km/s and L is the fault distance in km from the measuring point. For the above experiment, the fault is created at 120 kms from the sending end, and the value of t is found to be 0.403 ms. after converting it to distance in kms, L is found to 120.90 Kms.

CONCLUSION

Based on the concept of traveling wave a fault location technique is proposed in this paper. For the purpose of location of the fault the behavior of travelling wave when fault occurs is used and presented. If the fault on the long HVDC transmission line, is not detected, then it may destroy the power system equipment permanently which is definitely not cost efficient. Because of accuracy and prompt measurement of the location of the fault from the receiver or sending terminal, the traveling wave based fault detection methods are developing the interests of the power engineer. Wavelet Transform is utilized to accurately detect the arrival time of travelling waves at the converter terminals. Accurate and precise measurement of the faulty segment and the exact location of the fault is making the wavelet transform technique more reliable for the power engineers. The time as well as the further damage which happens due to the fault is prevented by this method.. The WT technique works offline which again saves the time irrespective of the internet. Thus, the Fault detection in long transmission line using Wavelet Transform method is becoming the field of attraction for many of the electrical power system engineers.

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