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Review-The Identification and Location of Fault In VSC-HVDC Transmission

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Abstract

The identification, location and classification of fault are a basic requirement for optimal operation of power system. The precise fault location technique significantly reducing outage time and will improves system reliability and speed for protection control. The classification of faults in HVDC can be identified by monitoring the signals both on AC and DC side of the HVDC system. This paper presents a review in literature of VSC based HVDC system including convertor topologies, fault location and identification techniques based on travelling wave method and wavelet transform is discussed. The identification of faults by using frequency or time domain based method is difficult. Wavelet transform is most suitable method providing excellent discriminative features to classify different disturbances in VSC-HVDC transmission system as it will work based on both time and frequency domain.

Keywords: VSC-HVDC; travelling wave; Wavelet transform; Fault location; Fault identification.

Introduction

The global electrical energy consummation is ascending at an alarming rate with a steady demand to increases the power generation capacity. Electric utilities and end users of electric power are increasingly concerned to meet the growing demand through technologically efficient energy conversion and transmission systems with the incentives to save energy. Transmitting the bulk amount of power over a long distance with minimum of losses is the main criteria for efficient energy power transmission. Compared to HVAC, high voltage direct current transmission (HVDC) is advantageous for bulk power transmission for long distance. It has added advantages such as asynchronous interconnection, offshore transmission, reduced fault current and voltage stabilization and also to mitigate environment concerns. All over the world around 100 HVDC projects are committed and some are under construction. The classical HVDC with some additional devices will be more efficient for applications such as underground, offshore transmission and voltage stabilization. But new converter design technologies like capacitor commutated converter (CCC) and voltage sourced converter (VSC) increased potential ranges for HVDC applications and also resolved significantly problems associated with classical HVDC.

Hence for planning and control operation of power system, reliability is prime stack for HVDC. Specially HVDC lines are mostly suitable for long distances, so proficient protection criteria must be considered. According to travelling wave theory when fault occurs in transmission line, current and voltage wave generated through line. Such waves contain useful information for designing high speed devices for fault identification and line protection. The accuracy of fault location depends upon wave-front, wave speed and their coordination. The amplitude of fault generated wave varies with time and frequency. While the wavelet transform is a new signal analyzing method mostly suitable for analysis transient signal in both time and frequency domain. The objectives of this paper are to provide an overview on VSC based HVDC system including convertor topologies, fault location and identification techniques based on travelling wave method and wavelet transform.

VSC-HVDC System

Converter topologies with line commutated current sources converter with SCRs, usually employing in HVDC scheme for power transmission in early 1990s. Rapid development in power semiconductor devices likes Insulated Gate Bipolar Transistor (IGBTs) and Gate Turn off Thyrister (GTOs) makes VSC technology more popular for high voltage direct current transmission. Fig. (1) VSC-HVDC system and Fig. (2) gives conventional three phase two level VSC topologies. The advantages of VSC-HVDC are,

1) It gives the output with any desired phase angle and magnitude instantly.
2) It can control independently active and reactive power with dynamic enhancement of transient stability.
3) Simply by reversing direction of dc current the control on power flow can be achieved
4) It supplies the power to week or remote isolated loads from main grid by providing power quality enhancement.
5) It will enhance power transfer capability along with improved dynamic performance.

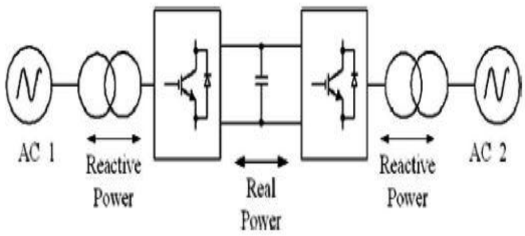

Figure 1: VSC-HVDC system with IGBT

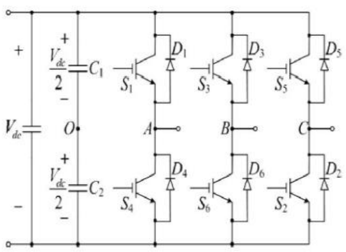

Figure 2: Two level VSC topologies

Lie Xu et. al. [01] presented analysis of VSC-HVDC transmission system under unbalanced AC conditions caused by single line to ground fault. This control strategy improves dynamic performance with the help of main and auxiliary controllers under unbalanced condition. The result obtained by proposed controller is more flexible. The same approach was reported by Cuiqing Du et. al. [02] with three different controllers for SLG fault. The different controllers are analyzed with respect to fault current and protection operation. Individual load is very sensitive for variation of voltage and frequency. With the approach Cuiqing du et. al. [03] proposed a dual control strategy, frequency controller and AC voltage controller to improve power quality in industrial plant. The simulation result show that VSC-HVDC mitigates voltage dips during fault and significantly improves the power quality issue. The similar approach was reported by Cuiqing Du et. al. [04] investigates the performance of inverter supplied industrial plant with use of frequency and AC voltage controller at the inverter station of VSC–HVDC system. This control strategy significantly improves dynamic performance of the system. In three phase power system voltage unbalance may occur frequently due to unbalanced loads, faults in ac system and even unbalanced power supply. Sometime unbalanced grid conditions and system disturbances are mainly responsible for positive and negative sequence of voltage and current. It is great challenge to restrict the positive and negative components during unbalanced conditions because VSC is very sensitive to negative sequence component. Amirnasar Yazdani et. al. [05] introduced a novel unified model based on VSC sequence subsystem and SPWM, represented dynamic behavior of VSC with respect to positive and negative sequence components. This proposed system can control positive and negative sequence subsystem independently. Positive sequence subsystem can be controlled DC bus voltage regulation while negative sequence subsystem can be controlled either balancing AC side line current which reflect second harmonic component on DC bus voltage or eliminating ripple in DC voltage produced unbalanced AC side line current. This proposed model considerably reduced current/voltage stress on converter components and undesirable current and voltage harmonic mitigated.

The appearance of second harmonic voltage on DC bus will increases the stresses on VSC valves and the losses, may be result in system instability. This drawback has been addressed by Jing Zhang et. al. [06] presented single end effective controllers with two synchronous reference frame (SRFs) with separation of positive and negative components to improve the dynamic performances of VSC-HVDC. This proposed scheme performs well under both balanced and unbalanced faults, enhanced dynamic performance marginally. Xinchun Shi et. al. [07] presented delayed signal cancellation method to improve the performance of phase locked loop under unbalanced input voltage. The similar approach was reported by Ya Wanget. al. [08] presented electromagnetic transient model with dual current loop controllers based on synchronous reference frame for VSC-HVDC under line to ground fault AC conditions. The proposed control strategy easily eliminated DC voltage ripple and mitigate additional stresses of the VSC valves by controlling positive and negative sequence current simultaneously. Recently novel control method proposed by Babak Parkhideh et. al. [09] to improve the performance of high power vector controlled back to back VSC system by suppressing possible DC links voltage fluctuations under power line faults and unbalanced conditions. This proposed controllers based on dq-synchronous reference frame relatively at low switching frequency. This proposed control scheme improves transient performance of VSC system in current and emerging applications. It gives less than 1%DC link voltage deviation under most common faults and disturbances. Haifeng Liang et. al. [10] proposed negative sequence voltage compensation control strategy based on mathematical model and power balanced relation. Power balanced relation eliminated negative sequence current and greatly reduced second harmonic ripple. While deadbeat current applied to positive sequence current inner loop control to provides fast and accurate control of generated active and reactive current. It can be found that the proposed control strategy has high dynamic response, less parameters dependence and good performance. The similar approach was recorded by Sanjay K. Chaudhary et. al. [11] presented a control method to mitigate power oscillations and reduced DC voltage overshoot during unsymmetrical faults by controlling negative sequence current injection. Recently Ahmed Moawwad et. al. [12] proposed transient management scheme providing positive and negative sequence controllers to minimized power oscillation caused by asymmetrical faults and hence reduced DC link voltage overshoots. Thus proposed control strategy for VSC-HVDC to provides smooth power transfer during fault conditions, providing increase in system reliability, support the grid during faults and reduce possibility of voltage and frequency instability. In DC system a short circuit causes high frequency transient. Thus in DC system following are main short circuit current sources 1) Converter 2) Transmission line 3) DC capacitor. The characteristic behavior of short circuit current mainly dependent upon the fault location and type of faults. Andreas Wasserrab et. al. [13]

presented analysis of short circuit current in radial HVDC network with frequency dependent line model. J. Rafferty et. al. [14] presented dynamic analysis of behavior of VSC-HVDC under different DC fault conditions. It is observed that ear thing configuration is the main factor in analyzing system operation.

Now a day VSC-HVDC transmission networks have more increasing application for integration of offshore renewable energy onto transmission networks. The short circuit and ground fault due to high discharge current from DC links capacitance is the major faults in DC grid integration system. Location of such faults in VSC based DC network cable is more difficult and Challengeous. Jin Yang et. al. [15] demonstrated the method for locating short circuit and ground fault in DC cable based on voltage reference comparison and initial fault transient respectively. The accuracy of result lies up to 97%. Lidong Zhang et. al. [16] proposed novel power synchronization control method for grid connected voltage source converters to avoid instability caused by standard phase locked loop. This proposed controller is more efficient to limit valve current immediately after ac system fault occurs. A similar approach was reported by Lidong Zhang et. al. [17] proposed power synchronization control for demonstrate fault ride through capability of VSC-HVDC for different network conditions. VSC–HVDC is more suitable for transmission the bulk amount of power. The increases power transmission capability can be archived without additional compensation devices by VSC based series hybrid converter topology as presented by B. Qahraman et al [18]. The incremental power provided more control flexibility and voltage support for conventional converter. VSC-HVDC demonstrated some excellent advantage by providing independent and rapid control of active and reactive power in all four quadrants. Chengyong Zhao et. al. [19] proposed power control strategy by coordinate conversion and variable substitution method based on steady state model of VSC which can able for independent control of active and reactive power. This proposed control strategy gives rapid speed, desirable stability and high accuracy. The similar approach was reported by Wenyuan Wag et. al. [20] presented detail analysis on stability and performance issue associated with active power control.

Increase of asynchronous network ties, recovery from faults disturbances on either network side is required to very much faster in order to maintain constant power with the help of damping and synchronizing power combination gives shorter recovery times to steady state after transient. Fawzi A. et.al.[21] presented a paper to obtained “virtual S.S.S.C.” performance by controlling both synchronizing and damping power. Another feature for asynchronous network ties with the help of VSC –HVDC the installing at the midpoint of transmission line can be increase power transmission by a factor of 1.68 proposed by Huang Z. et. al. [22].Moreover improving the sub synchronous tensional damping closed to generating unit with VSC-HVDC as reported by Nagesh Prabhu et. al.[23] based on linear and non linear transient simulation. It is found that DC voltage control mode of VSC operation close to generating unit provided a small positive damping. Recently R. Thirumalaivasan et. al. [24] presented detail analysis based on Eigen value, transient simulation and damping torque analysis. This proposed novel technique suppresses sub synchronous current in transmission line by injecting a proportional sub synchronous voltage in series with transmission line that effectively mitigate SSR. Du. C. et. al. [25] proposed control strategy for VSC– HVDC during island operation and dynamic performance of the system with three phase fault was investigated. It is found that dynamic response of the system significantly affected by current limit control of converter of VSC-HVDC and also improves the power quality issue of the system during the faults. Voltage stability problem is challenging issue usually large disturbances occurring in heavily stressed power system and increasing reactive power demand. The lack of reactive power availability will lead to voltage instability. H. F. Latorre et. al. [26] analyzes voltage stability by comparing new AC line and DC link based on VSC –HVDC. It is found that the VSC-HVDC significantly enhanced voltage stability of the system, reduced the stress in exciter and increases the margin of operation by keeping the system away from collapsing due to lack of reactive power availability. The voltage collapse can be avoided by decreasing frequency during and after disturbances. Cuiqing Du et. al. [27] proposed different frequency controllers and increases ride through capability during the system disturbances with increase in DC capacitance or converter current limit capability. The frequency controller also improves power quality in industrial system. The similar approach was recorded by I. Erlich et. al. [28] presented a new control strategy for improving fault ride through capability of wind farms. The occurrence of faults in high voltage grid produced voltage drop. This proposed control strategy injected DC voltage of defined magnitude and duration by sending end converter to suppress DC components of short circuit current due to reduction of voltage and result in reducing level of stresses on wind turbine and improving fault ride capability of system. The similar approach recorded by Christian Feltes et. al. [29] introduced controlled voltage drop to achieve fast power reduction completely avoiding overvoltage with the use of demagnetization.

Travelling Wave Methods

In general the long HVDC transmission lines modulated in distributed parameters. When fault occurs due to change in impedance, the voltage and current traveling wave will be generated. The fault generated traveling wave will travel through the transmission line. The voltage change rate du/dt and voltage change amplitude ΔU_{dc} is detected by traveling wave protection. The voltage change is very sensitive of fault resistance. The line protection of HVDC transmission line can be categorized into two types.

(1) Unit protection.
(2) Non unit protection.

The travelling wave due to the fault generated sufficient information that can use for fault detection and protection of line. The accuracy of fault location in HVDC transmission line by traveling wave is mainly depends on wave front, wave speed and their coordination. With this approach Li-Yongli et al [30] proposed a fault location method based on one terminal voltage travelling wave techniques. Fault distance can be obtained by measuring period of voltage traveling waves induced by breaker tripping. Due to the complexity of fault reflected surges discrimination, reliability of single ended scheme is not very satisfactory.

The time domain method is used initial wave head to identify fault location. But accurate fault location depends on calculation of traveling wave speed and natural frequency extraction. So calculation of traveling wave speed is extremely difficult with time domain method as wave speed is fully frequency dependent. With this approach Song Guo Bing et. al. [31] parameter single ended protection and fault location method based on natural frequency on a distributed parameters transmission line. The proposed method easily extracts natural frequency from post fault data from any section and accurately locate fault. So compare to traditional time domain method it is more simple and reliable and accurate for locating fault with an error being less than 1% and does not need to detect accurate wave head. Similar approach was recorded by Zheng-You-He et. al. [32] proposed a novel algorithm based on traveling wave natural frequency using current data from single end only by using 10 msec data window. By extracting dominant natural frequency through spectrum analysis of traveling wave, fault point is estimated by calculating velocity of traveling wave reflect coefficient. Simulation result show that proposed method performs well for different faults and fault resistances. Lin Yong Wu et. al. [33] proposed a single ended fault location technique by extracting dominant component of travelling wave of natural frequency. By using Laplace domain analysis relation of natural frequency to wave velocity, line length and fault point at particular frequency are determined. Obtained result gives more reliable solution as compare to traditional time domain traveling wave method.

Due to the complexity of fault reflected surges discrimination, reliability of single ended scheme is not very satisfactory. With the use of fault generated initial surges, double ended method is more reliable than single ended method. Pine Chen et al [34] proposed fault location method based on modern travelling wave with types D and A principle. The obtained result provided very high reliability and more accuracy and maximum location error not more than 0.3% of total line length. Wu Zhihua et. al. [35] proposed a novel double terminal fault location method by utilizing time information of reflected wave. This proposed method gives very high accuracy and error less than 200m obtained for fault location. Jiale Suonan et. al. [36] proposed novel algorithm based on two terminal data at a sampling rate of 100 KHz. This proposed algorithm developed based on distributed parameters line model in which fault location can be identified from calculated voltage distribution, result from any section of post fault data. O. M. K. Kasun Nanayakkara et. al. [37] proposed a method for novel fault location in star connected multi terminal HVDC system by using two terminal traveling wave based fault locator. This proposed can accurately detect faulty pole segment as well as exact fault location by obtaining accurate single arrival times from time synchronized measurements. The difficulties associated with proposed implementation are the need for high sampling frequency and dependency of wave front detection.

The accuracy of fault location in HVDC transmission line by traveling wave is mainly depends on wave front detection, wave speed and their coordination. The accuracy of wave front detection has significantly improved with the use of wavelet theory and mathematical morphology. As distance increases frequency components which also increases deformation and attenuation. Result inaccurate detection of traveling wave head. Hongchun Shu et. al. [38] proposed a phase model transform method based on complex frequency domain, which derive the transfer function between traveling wave signal source and observation point. The fault point location accuracy at any point is calculated without the historical waveform data. Zhang Yi Ning et. al. [39] presented fault location algorithm for HVDC line fault location based on variant traveling wave speed. If fault is close to line terminals, error in fault distance are large. The proposed algorithm significantly improves accuracy and reliability of fault location with error is within 0.1%. Similar approach was recorded by Xu min et. al. [40] presented a novel method to improve accuracy of fault location by coordination scheme of wave front and wave speed.

Mohammed Shukr et. al. [41] proposed fault location technique in VSC HVDC system transmission line based on active line impedance estimation. The impedance between observe point and fault location is estimate by obtaining voltage and current transient by Fourier transform. This proposed algorithm uses both real and imaginary part of measured transmission line impedance. The estimated fault resistance can help idea regarding severity of fault. Ernesto Vazquez et. al. [42] proposed high speed traveling wave distance protection for transmission line based on principal component analysis. A PCA algorithm discriminates between external and internal faults by varying sign of first principal component. The similar approach was recorded Peyman Jafarian et. al. [43] proposed a new technique of two terminal transmission line based using principal component analysis. This proposed algorithm rapidly discriminated most of faults in less than 2 msec on polarity, magnitude and time interval between the detected travelling waves at relay location. It improves capability of traveling wave detection for the faint and close in fault but increases noise immunity of protection technique. The fault detection based on the traveling wave direction principle presented by Carlos Aguilera et. al. [44] . The algorithm applies wavelet transform to voltage signal and calculate spectral energy is used for detecting fault while the fault direction can be determine by comparing slope change polarities of voltage and current signals for specific time interval. Xinzhou Dong et. al. [45] presented fault classification and faulted phase selection algorithm based on initial current traveling wave with the help of wavelet transform technology

Xiaodong Zheng et. al. [46] proposed a unit protection scheme using transient energy principle based on distributed parameters line model. The internal and external fault can easily identify by increments of transient energy in DC line. Due to distributed nature of long transmission line, the distributed shunt branches generated large amount of unbalanced current. Current differential protection cannot play the role of back up protection function for high impedance line fault. Aimin Li et. al. [47] completely analyzes dynamic performance characteristic of HVDC line protection system and its influence on control system and also presented improved scheme by providing delayed at least 500 msec to avoid mal-operation of the protection. The similar approach was recorded by Cai Yixuan et. al. [48] analytical method to evaluate the performance of HVDC traveling wave protection. With similar approach Heng Xu Ha et. al. [49] presented a complete protection scheme with TWDP for bipolar transmission line. TWDP can function as main protection for bipolar HVDC transmission line, discrimination criteria is established by using polar mode traveling wave while ground mode traveling waves are utilized for faulty line detector for bipolar operation modes. Han Kunlun et. al. [50] explained traveling wave protection as main protection, under voltage protection and differential protection as back up protection for HVDC transmission line. The author also analyzes influence of fault location, fault resistance and external disturbance to HVDC line protection. Ying Zhang et. al. [51] investigates the fault characteristics for various internal fault conditions of bipolar HVDC line on the basis of symmetrical component analysis. The identification of faulty pole and classification of faults based on zero and positive sequence backward traveling wave. The result obtained by RTDS simulation show that proposed scheme detect faulty pole rapidly and correctly.

As non unit protection scheme is concerned, it utilized local information presented by Fei Kong et. al. [52] for bipolar HVDC lines. The proposed scheme performance is evaluated by using RTDS and real time HVDC devices. The protection scheme not only can detect the fault rapidly but also have better performance in detecting high impedance fault.

Wavelet Transform Methods

In case of AC transmission line the magnitude of voltage and current travelling wave changes with respect to voltage angels. If the fault occurs zero cross over point, it is big challenge for travelling wave based protection for AC transmission line. But in case of DC transmission line there is no such problem, hence travelling wave theory is most suitable for HVDC transmission line. It is always challenges to identify and locate the fault with fast and more reliable method for stable power system operation. The amplitude of fault generated travelling wave varies with time and frequency. So it is very difficult to identify HVDC faults with respective pure frequency or pure time domain method. The pure time domain method more influence by noise while pure frequency domain most affected by time varying transient signals. Hence travelling wave protection provided certain limitation in practical applications. The wavelet transform is more suitable method for analyzing the transient signals in both frequency as well as time domain method.

Xia Yibin et. al. [53] proposed new technique to identify fault location by using wavelet analysis. Dyadic wavelet analysis is used to abstract fundamental frequency voltage and current signals from faulted transmission line signals. Simulation results show that wavelet transform is more accurate and reliable method than Fourier transform. Fernando H. Magnago et. al. [54] presented method to analyze the power system fault transients to determine fault location by wavelet transform. Faulted signals are transformed from time domain into time-frequency domain with the help of wavelet transform and wavelet transform coefficients at two lowest scales are used. Fault location problem can be solved by using both single and synchronizing two ended method recording fault transients. In case of two ended synchronized, recording arrival time of first transient peak depend on the velocity of line and fault distance and independent on type of faults. Hence method provided accurate result compared to single ended method .Distance between the fault point and bus is calculate by using synchronizing two ended method ,

$$x = (1 - \mathrm{Vm.td})/2 \quad (1)$$

Where,l : Length of the line, X : Distance to fault from bus, V_m : Speed of travelling wave.

L. Shang et. al. [55] proposed a new high speed HVDC line fault detection and identification based on wavelet modulus maxima (WMM). Wavelet modulus maxima (WMM) is able to distinguish transient response based on edge detection. WMM is effective for the edge detection up to signal with 15% noise. The similar approach was reported by L.Shang et.al.[56] analyzes different fault behavior in HVDC through wavelet transform. There are various faults occur in HVDC system such as (a) Arc back (b) Commutation failure (c) Misfire (d) DC line to ground fault (e) AC fault etc. K. Rajesh et. al. [57] presented criteria to detect instant of fault location and kind of fault`s based on wavelet modulus maxima. The WMM can easily detect sudden changes in voltage and current signal. The fault location can easily calculated by using following relationship,

$L = (V \times \Delta T)/2$ - - - - -- - - - - For HVDC

$L = (V \times \Delta T)$ - - - - -- - - - - For AC

Where, L: Distance in Km.

ΔT: Time delay between first two oppositely polared WMM.

V: Velocity of wave $=3\text{x}10^8$ m/Sec.

The pure time domain method provides an incorrect result in HVDC transmission line with high fault resistance and lightning stroke on HVDC lines. Sometime lightning stroke on HVDC line are rich in high frequency transient component larger than those caused by fault, result in mal -operation of protection circuitry. A.M.Gaouda et. al. [58] presented a new technique for classification of typical disturbances based on wavelet multi resolution signal decomposition. The classification of large typical disturbances makes complexity of discrimination process. The parameters of discrimination model became highly variable due to parameters dependence with time and frequency. It is necessary to decrease the number of variable or data to manageable size to overcome the above problems. This proposed method can extract important information from distorted signals from both DC and AC side of HVDC system. The classification can be based on distribution of distorted signal energy at different resolution level to detect and localize the fault for optimal operation of power system. This proposed technique gives high efficiency as compared to FFT. The similar approach was reported by Haifeng Li et.al.[59] presented to distinguish lightning strokes from line fault using multi resolution signal decomposition based on energy distribution features to avoid mal-operation of protective relay. Wang gang et. al. [60] proposed new high method to analyze transient voltage generated by fault for HVDC line based on multi-resolution technique. The proposed criteria based on high frequency transient component to discriminate between internal and external fault in HVDC transmission line. Simulation result show that for internal fault high frequency component are prominent and for outside fault high frequency component of transient voltage are poor. This proposed criteria easily identify and improving the performance under the influence of lightning stroke and providing more effective and reliable result.

The similar approach was reported by Rashmi A. Keswani et. al. [61] presented identification of different disturbances based on multi-resolution signal decomposition with DWT tool. The identification of inverter side fault simply by monitoring inverter AC side phase current while rectifier side fault by monitoring DC voltage and current. The internal fault within the converter can identified by analyzing the combination of valve current with DC current and inverter AC phase current. The accuracy of fault location for long line is basically depending upon the detection of wave front arrival times. The continuous wavelet transform (CWT) provides better accuracy than discrete wavelets transform (DWT) technique for detecting the arrival time of travelling wave. Kasun Nanayakkara et. al. [62] investigated two terminal travelling wave method based on CWT. The magnitude of real spike caused by travelling wave reflecting can be changes due to noise problem. Under above case measured distance can be incorrect result mal operation of protective relay. As compare to wavelet WMM is a compact representation of signal, WMM white noise increases as the scale of wavelet transform decrease. Boundary protection is less affected by noise and on deionization process requirement. Thus for distance protection, boundary of protection zone is the most important issue to distinguish internal fault from external fault. Xiaolet Liu et. al. [63] proposed hybrid protection algorithm based on travelling wave protection and boundary protection principle with SWT for monopolar HVDC transmission line to distinguish internal fault from external fault. Travelling wave protection scheme for HVDC transmission line is evaluated with inductive and capacitive termination. Voltage signal is used for inductive termination while current signal for capacitive termination and easily overcome above mentioned problems. The similar approach was reported by Xiaolet Liu et. al. [64] proposed hybrid protection scheme for bipolar HVDC transmission line to detect fault, faulty pole and fault location under various conditions. For travelling wave protection it is very difficult to identify the arrival instant of wave correctly due to effect of mutual coupling between pole line and opposite polarity of different pole.

The proposed scheme remove above mentioned mutual coupling effect completely. Here current boundary signal is used for bipolar system with capacitive termination. Pannala Krishna murthy et. al. [65] proposed method to detecting HVDC transmission various line faults by using wavelet transform. By recording magnitude of absolute maximum value of wavelet coefficient normal operating condition can be discriminated from DC line fault and AC fault conditions. The wavelet coefficient of DC voltage is used over DC current for providing high degree accuracy for identification of fault. The proposed method providing faster, easier and more reliable solution for identification of HVDC faults with 99.3% efficiency for fault location. Hongchun Shu et al. [66] presented new technique to analyzes transient signal in UHVDC transmission line based on S transform. The S-transform is useful mathematical tool to analysis non stationary signals to discriminate internal and external fault. For external fault high frequency transient voltage will be attenuated and signals remain unchanged for internal fault. The similar approach was reported by Hongchun Shu et al. [67] presented new technique to analyzes transient signal in UHVDC transmission line using wavelet transform based on multi-resolution analysis to distinguish internal fault from external fault. Luhua Xing et. al. [68] presented criteria to identify faulty line based on variation characteristics of fault component of voltages and currents. The internal and external faults can be differentiated by comparing polarities of faulty component of currents at the end of faulty line. The polarity feature can be extracted by using wavelet transform. This proposed method show high selectivity speed, sensitivity and more reliability to identify faulty line. The similar approach was reported by Xiaolei Liu et. al. [69] proposed hybrid boundary protection scheme with FPGA for bipolar HVDC transmission line. FPGA provides high speed signal processing with high performance and more apparent flexibility. Line parameters are mostly depending upon frequency. Jiale Suonan et. al. [70] proposed distance protection algorithm based on frequency dependent parameters model to distinguish internal fault from external fault. The frequency dependent model can be divided into distributed parameter model plus compensation matrix. The proposed model is more accurate than distributed parameter model and effectively overcome problems associated with frequency dependent parameter model. It can enhance the measurement accuracy of fault distance at the remote end faults. The simulation result show that the proposed algorithm gives relative error of fault distance is less than 1.6% as compared to 3% for distributed parameter model. Thus it improves the performance of distance protection applied to HVDC transmission line.

Conclusion

The VSC-HVDC is very promising and highly flexible transmission technology providing unique solution for many applications with additional features. The ability to recognize and precise location of faults can be extremely useful in order to secure an optimal system operation. Various factors are considered that affect performance of protection such as transient caused by lightning strokes, border distortion, high ground fault resistance, external fault and line terminal configurations. In some cases travelling wave protection providing certain limitations with respect to pure frequency or pure time domain method. The wavelet transform can be providing discriminative features with small dimensions to classify various faults in HVDC transmission by monitoring signal of both AC and DC side. The identification of inverter side fault simply by monitoring inverter AC side phase current while rectifier side fault by monitoring DC voltage and current. This technique provided high accuracy and reliability for fault identification and location compared to travelling wave and fast Fourier transform method.

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