International Journal of Advanced and Innovative Research (2278-7844) /
Volume 7 Issue 3

Protection of HVDC Transmission Line: A Survey

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***Abstract:*-This review paper describes and addresses the various protection schemes and methods of High Voltage Direct Current (HVDC) transmission line. Before the discussion of protection of HVDC transmission line, the major components and various types of faults occurred on HVDC transmission line are described. The process of protection and control of HVDC line starts from fault type, cause and location detection will be analyzed. Various papers which are reviewed below used different methods to protect the system. The protection scheme covers manually, automatically or through simulation before implementation.**

Keywords:HVDC;HVAC;LCC;VSC;GPS;SVM;PSCAD/EMTDC;MATLAB;RMS;RTDS;OHL;FC;SFAC;externalfault; internal fault; travelling wave; transient

Introduction

HVDC technology has developed rapidly over the last 20 years and so has the confidence in it, resulting in a shift from AC to DC for bulk power transmission. These advancements in HVDC technology has also increased the boundaries of HVDC application, making it possible to transport bulk power to more remote and distant locations than ever before. This has, however, led to the requirement of much longer dc transmission lines. The high-voltage DC (HVDC) transmission systems are extensively being put into use owing to the several advantages they offer in comparison with their high-voltage AC (HVAC) counterpart such as fast and flexible control, enhanced power handling capability, lesser losses, better stability, more economical and so on. With the latest advancements in the field of power electronics, the break-even distance above which HVDC is economical compared with HVAC has brought down to almost 500 km. They play an increasingly important role in fields as large capacity power transmission, power transmission to islands, power supplement for weak receiving girds, and serve as vital interconnections between HVAC grids. Stability and reliability of HVDC transmission systems have direct impact on the security of connected AC grids. HVDC transmission lines are longer and have high failure possibility. Therefore, it is very important to improve HVDC transmission line protection in order to guarantee the safety and reliability of HV power grids. According to operation experience and feedbacks of existing HVDC systems, the operating HVDC line protection scheme has problems, such as invalid and inadaptable setting criterion, the dependency of simulation. The existing protection schemes are imperfect.

The transmission lines act as very important elements in any power system as it is these components that carry electric power from the point of generation to the end user. The more efficient the protection scheme in any system, the more reliable, economic and efficient the whole system would be. The series inductance offered to the fault current is very less in a DC line. Hence, the faulty section of the line needs to be detected and isolated as soon as possible to reduce the damage it would cause. This demands a fast and accurate fault detector and locator algorithm.

Basic HVDC system

An HVDC system comprises of many components inside. The main components are divided into three main parts. The main parts are: the rectifier, the DC link and the inverter side.

Components of HVDC transmission line

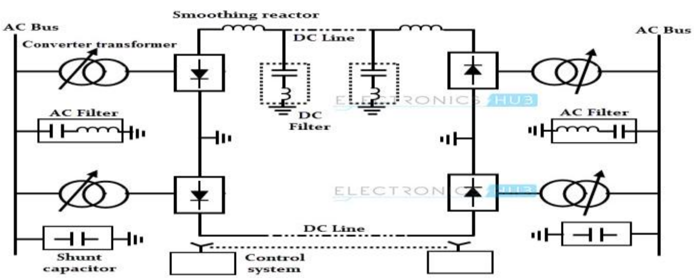

Fig 1 components of HVDC transmission line

Some main components of HVDC transmission line are discussed below.

Converters- The converters has great role in HVDC transmission system. It performs two operations on two different sides. At sending end and at receiving end such as conversion from AC to DC like rectifier and DC to AC like inverter respectively.

Transformers- the transformer used in HVDC transmission line is also called converting transformer.

Filters- filters can installed on both sides of the HVDC line as AC filter and DC filter. These filters play a great role in rectifying harmonic parameter. One of the harmonic parameters is harmonic current which occurs both on AC and DC side if the HVDC line. These harmonic currents are limited by AC filters on AC side.

HVDC Overhead Transmission Lines- HVDC cables can be used in the water, underground or overhead. So, the cable going to be used must fit to the amount of voltage to transmit.

Faults in HVDC transmission line

The transmission distance of HVDC system is particularly long, and this makes the probability of HVDC line fault increased greatly. The actual data coming from electric power enterprises show that 50% faults happened in HVDC system belong to HVDC line faults [7]. And this becomes a serious threat to the power system operation safely and steadily. The operation of HVDC system is often affected by the AC system and the HVDC control system, and this makes its operation environment more complex. At the same time, the process of HVDC line fault isn't analysed clearly and the principles of it are also analysed deficiently. All of these mentioned above make it difficult to the research of HVDC line protection. The actual operational data also show that the effect of the current HVDC line protection system is limited. So, it is necessary to study in depth the factors which are affecting the operation of HVDC line protection system. Faults in HVDC transmission line are various types. The study of these faults is very essential for reasonable protection design because fault will induce a significant influence on operation of HVDC transmission system. Especially for overhead DC transmission line, the problem in recovery process should be taken into account to ensure that the system can restore rapidly under temporary fault condition. The short-circuit fault is symmetrical and the ground fault is unsymmetrical. Faults on DC transmission line are generally caused by external mechanical stress [5]. The DC Line to Line fault and DC Line to Line fault are common types of fault which are permanent and required lengthy repairing process. For overhead DC transmission system faults are temporary and caused by lightning strikes and pollution. Some common types of AC fault occur on AC side in overhead HVDC transmission system such as Line to Line fault, Line to Ground fault and LL-L fault. In HVDC system, faults on rectifier side or inverter side have major effects on system stability. The various types of faults are considered in the HVDC system which causes due to malfunctions of valves and controllers, misfire and short circuit across the inverter station, flashover and three phase short circuit.

Protection view of HVDC transmission line

Lots of research has been made about HVDC line protection systems. In some references made a detailed introduction to the configuration and structure of the HVDC line protection system. In other papers, the responses of HVDC line protection system during a line fault are analysed by the simulation of the typical accident cases. And in, some defects of HVDC line protection system are pointed out on the basic of introducing its realization principles, and a new wavelet transformation protection method is discussed. Although there have been a lot of research work and publications on the protection systems applicable for HVAC transmission systems, work has not comparatively progressed in the field of HVDC transmission systems. It needs to be found out as to whether the methods implemented in HVAC are equally applicable to HVDC systems [9].

The traditional protection system for the HVDC transmission line often uses the voltage and its change rate to detect a ground fault in the dc line. The present-day primary protection schemes for HVDC transmission lines employ travelling wave based methods, whereas the back-up protection is based on DC minimum voltage and DC line differential protection methods. In [21] the travelling wave algorithms estimate the fault location based on the time taken by the fault generated travelling wave to propagate along the transmission line. In methods requiring two-terminal data, the global positioning system (GPS) is usually employed to keep the measurements synchronized. In this review paper the traveling wave algorithm is slightly discussed.

Literature review on HVDC system protection

Protection of HVDC transmission line safeguards the security of overall power system. The[1] paper presents a complete protection scheme for detecting, classifying and locating the fault in HVDC transmission lines using support vector machines (SVM). SVM has been used for protective relaying application in HVAC transmission line, however very limited works have been reported for HVDC transmission line. In this work, a ±500 kV HVDC transmission system is developed in PSCAD/EMTDC and the measurement signals obtained are analyzed in MATLAB. The rectifier side AC RMS voltage, DC voltage and current on both the poles are continuously monitored, and given as input to the SVM binary classifier in order to detect the presence of fault in the line. Once a fault is detected, the SVM multi-class classification module predicts the type of fault and the SVM regression algorithm predicts the location of fault. The feature vector used in the classification and location modules is the standard deviation of the signals over half cycle before and after the occurrence of fault. The method proposed is simple as it requires single-end data and a direct standard deviation of one cycle data gives very accurate results. The detection and classification modules are 100% accurate whereas the fault location module has a mean error of 0.03%.

On the other side, [2] uses the method of natural frequency to protect HVDC line. Natural frequency is formed because that fault traveling wave reflects between fault point and the line end. And it has definite mathematical relationship with fault distance. Characteristics difference of natural frequency values under different fault types is analysed in this paper, including dc transmission line faults, VSC converter faults, and ac system faults. And protection criterion is formed based on the characteristics difference of natural frequency. Moreover, the exiting line protection schemes for VSC-HVDC system are researched in [2]. A model of VSC-

HVDC system is established in PSCAD/EMTDC software. Adaptability of the proposed protection scheme is verified by simulation test under different fault conditions. Simulations results show the proposed protection scheme can operate reliably and quickly under different fault conditions and has good adaptability and practicability.

In [3] an analytical method of fault characteristic for the HVDC system based on frequency response characteristics of boundary elements is presented here. The computational formulas of transfer function and input impedance are deduced using the distributed parameter model of HVDC transmission line, and the amplitude-to-frequency characteristics of the transfer function and input impedance are analysed.

Based on the amplitude-to-frequency difference between internal and external faults, a non-unit protection method for VSC-HVDC transmission line is presented. Using the current ratio of high-to-low-frequency, this protection method can distinguish internal from external fault. The presented algorithm only uses local-end current, has high operation speed, and is easy to implement. Simulations on a ±200 kV VSC-HVDC system are conducted to demonstrate the validity and feasibility of the developed protection method.

A protection system based on HVDC line scheme in [4] a novel non unit transient-based protection scheme for bipolar high-voltage direct current (HVDC) lines is proposed. The protection scheme is composed of a starting unit, a boundary unit, a directional unit, a faulty pole identification unit, and a lightning disturbance identification unit. The prototype based on the proposed scheme is developed and its performance is evaluated through a hardware-in-the-loop test using real-time digital simulator (RTDS) and real HVDC control devices. Better than the presently used line protection, the proposed protection not only can detect faults on HVDC lines more rapidly and accurately in different HVDC operation modes, but is also more effective in detecting high-impedance grounding faults. In addition, the novel protection is designed to identify lightning disturbances from short-circuit faults correctly, which avoids the unnecessary restart of HVDC systems due to protection misjudgement.

The protection scheme of HVDC line can also be attained through novel protection method. The protection scheme of HVDC line can also be attained during transient condition. The relation between the parameters of dc transmission line and the variation of transient energy and transient power has been analysed under various fault conditions in [7]. According to that, a new transient energy and transient power protective scheme is proposed. It is developed based on the distributed parameter line model in which the transient energy distribution over the line can be obtained from the voltage and current measurements at both terminals and the fault can be recognized from the calculated value simply. The test system is modelled based on the CIGRE benchmark, simulated using MATLAB/Simulink considered the distributed parameters of the dc transmission line. Comprehensive test studies show that the performance of transient energy and transient power protection scheme is encouraging. It can not only identify internal fault and external faults correctly and quickly, but can also respond to the high ground resistance fault. Finally, two main factors, including fault resistance and transmission distance, that affect the performance of the protection are also discussed.

The wisest way of detecting faults and protecting the HVDC line is focusing on the type of fault. In [9] HVDC line protection system is composed of traveling wave protection as the main protection, under voltage protection and differential protection as the backup protection. The responses of the HVDC line protection criterion are not same at different fault situations, and it also makes the operation characteristics of the line protection quite different. In this paper, based on the EMTDC simulation platform and an actual HVDC power transmission system and its protection system, the changes of voltage and current of the HVDC line are measured, and the influences of fault location, fault resistance and the external disturbance to the HVDC line protection are also analysed in detail. At the same time, the relation between the rejecting act of the protection and the factors mentioned above are also discussed in [9], and some improvement schemes are also proposed.

As discussed above, the traveling wave method of protection of HVDC line is most common type. At present, traveling wave protection's reliability of HVDC transmission line in projects is not satisfying. This review paper makes simulations for various faults using electromagnetism emulator PSCAD/EMTDC and MATLAB/Simulink. Great deals of simulations indicate that this traveling wave protection has a good anti-jamming capability and ascendant action performance to detect the transient energy and power.

Another component of HVDC system, the neutral component also needs protection [11]. The concept of [11] described the principle of fault detection and its simulator study, principal circuitry, field test results and field performance records on the neutral line protection system for an HVDC transmission system. In the protection system, 125 Hz AC current injected to the neutral line is utilized as a pilot current to detect the neutral line faults. The pilot current injection is made through the neutral line surge capacitor without detracting its capability. Combined with a metallic return protecting breaker, the protection system [11] has demonstrated a satisfactory performance on the grounding fault clearance without interrupting the power transmission.

As the distance of a transmission line increases, the complexity increases and protection will be compulsory. Mainly [12] firstly discusses the shortcomings faced by the existing protection systems and then attempts to develop a protection system that is not plagued by the same shortcomings, to ensure that the proposed protection system will in fact be able to provide the required level of protection for HVDC systems with extremely long transmission lines. For increased reliability, the proposed system is able to make all protection decisions solely on local detection but telecommunications can be used, when available, to try and optimize the overall response of the protection system.

The converter valve can be different type. In [13] both line commutated converter (LCC) and voltage source converter (VSC) and this is called use of hybrid converter. The hybrid high-voltage direct current (HVDC) transmission system comprising a line commutated converter (LCC) at the sending end and a voltage source converter (VSC) at the receiving end has broad prospects in many application fields. At present, the protection of HVDC transmission line usually utilizes the transient signals to discriminate faults, and the line boundary characteristics are the key influence factors to the post fault transients. In [13], the different boundary characteristics at each end of the hybrid HVDC system transmission line are investigated, in both frequency domain and time domain. And suggestions for the transmission line protection are proposed. High Voltage Direct Current (HVDC) technology has certain characteristics which make it especially attractive for transmission system applications. HVDC transmission system is useful for long-distance transmission, bulk power delivery and long submarine cable crossings and asynchronous interconnections.

The study of faults in [14] is essential for reasonable protection design because the faults will induce a significant influence on operation of HVDC transmission system. Most importantly [14] provides the most dominant and frequent faults on the HVDC systems such as DC Line-to-Ground fault and Line-to-Line fault on DC link and some common types of AC faults occurs in overhead transmission system such as Line-to-Ground fault, Line-to-Line fault and L-L-L fault. In HVDC system, faults on rectifier side or inverter side have major effects on system stability. The various types of faults are considered in the HVDC system which causes due to malfunctions of valves and controllers, misfire and short circuit across the inverter station, flashover and three phase short circuit.

Fault type and detection of location of fault is the primary concern of protection of HVDC transmission lines. Transient characteristics of voltage and current on HVDC transmission lines for faults on HVDC transmission lines, lightning strokes and commutation failures are analysed and the corresponding simulation methods are clearly provided.

Types of fault can be classified as inside the HVDC line (internal fault) and outside the HVDC line or on the AC transmission line (external fault). In [16] the theoretical analyses about the traveling wave transmission process for internal and external faults at HVDC transmission lines show that, in a short time, for internal faults, the backward traveling waves can be detected at both line terminals. For external faults, the backward traveling wave can be detected only at one line terminal. The backward traveling wave in the other terminal is zero in theory. Taking the calculation error and noise into account, the amplitude of the backward traveling wave is still very small. Thus, the identification method for internal and external faults for HVDC lines can be proposed by comparing the amplitude of the backward traveling waves at both ends of line. For internal faults, the ratio of the integral results is relatively small. However, for external faults, the ratio of the integral results is relatively large. Plenty of simulation results based on PSCAD/EMTDC and MATLAB/Simulink indicate that the proposed protection method can discriminate internal faults from external faults under various fault conditions including faults with high fault resistances.

It can be possible to protect and control the HVDC transmission line by using the method of differential protection. Traditional high-voltage DC (HVDC) current differential protection has problems on identifying fault current and has long delay. In [17], a novel current differential protection principle for HVDC transmission lines is proposed. By the adoption of distributed parameter model, differential current criterion is formed at a selected point on the transmission line. When fault occurs on DC line, setting point differential current reaches a high value. When no fault occurs or fault occurs outside the DC line, setting point differential current reaches a small value. Comparing with the traditional current differential protection, the proposed principle eliminates the impact of distributed capacitive current and has no requirement of delay. Comparing with travelling wave protection, fault identification can be performed during both transient and steady states, and the proposed method has reasonable sampling frequency requirements and has high reliability. Simulation analysis shows that the proposed principle identifies faults reliably and rapidly. The proposed principle in [17] is theoretically novel and practically applicable.

Another method of protection of HVDC line is underground fault detection using underground cable. High Voltage Direct Current (HVDC) transmission right-of-ways will have to be realized preferably as cable systems, especially near densely populated areas. Hence, overhead line (OHL) systems in combination with underground cable sections near urban areas – so-called partial underground cabling systems – become a viable option. This however leads to new challenges regarding system protection, since different converter control actions are required for OHL faults compared to cable faults. Within [18] the behaviour of HVDC systems with partial underground cabling and full bridge Modular Multi-Level Converters (MMC) during line faults is investigated in a PSCAD/EMTDC model to identify possibilities to differentiate OHL and cable faults and subsequently adjust the converter operation. As the results indicate, differentiating the fault type based on local current and voltage measurements does not seem feasible, except for simple cable-OHL topologies and, if enhanced waveform analysis algorithms are applied. However, if instead cable current differential protection is used for the system's cable sections, faults can be characterized correctly within short time and the converter stations are able to alter their operating point accordingly.

A component of High Voltage Direct current (HVDC) transmission line includes AC system. In [19] the system protection is implemented through AC line current fault detection and control. [19] A HVDC test system modelled in PSCAD/EMTDC and MATLAB/Simulink is used to classify, determine and detect the fault type occurred in the system.

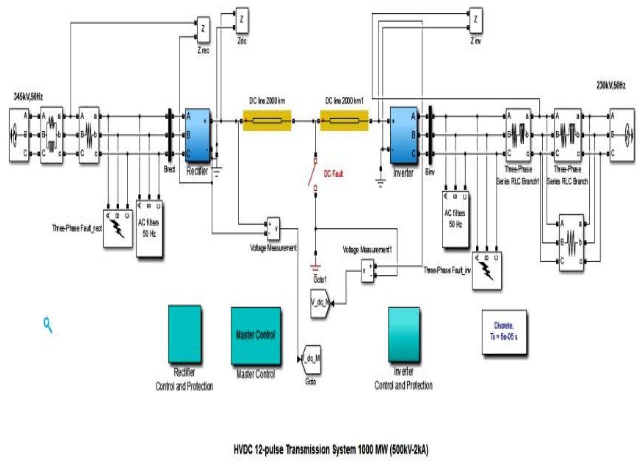

Fig 2 Sample Simulink model of HVDC system

Conclusion

It is verified that, HVDC transmission is more convenient and advantageous system than HVAC transmission line. To protect and control HVDC transmission line, various methods and analysis are discussed above. Even though the analysis method of different authors is diversified, the main target is to protect the system from different types of fault.

Acknowledgement

First of all I would like to give special thanks to the almighty who is the creator of everything. Secondly, I am grateful for the authors of the paper which I have reviewed in this paper. The last but not the least I would like to thank all of u who helped me to review different papers based on HVDC line protection.

References

[1] Complete protection scheme for fault detection, classification and location estimation in HVDC transmission lines using support vector machines by Enifer Mariam Johnson, Anamika Yadav Electrical Engineering, NIT, Raipur, G.E. Road, Raipur, Chhattisgarh 492010, India.

[2] VSC-HVDC Line Protection Based on Current Natural Frequency by Zhao Zhao, Duan Jiandong, Liu Jing Xi'an University of Technology Xi'an, Shaanxi, China

[3] Analytical Method of Fault Characteristic and Non-unit Protection for HVDC Transmission Lines by Xu Chu, Guobing Song, Member, IEEE, and Jun Liang, Senior Member, IEEE

[4] Development of a Novel Protection Device for Bipolar HVDC Lines by Fei Kong, Zhiguo Hao, Member, IEEE, Song Zhang, Student Member, IEEE, and Baohui Zhang, Senior Member, IEEE

[5] A Transient Harmonic Current Protection Scheme for HVDC Transmission Line by Zheng Xiao-Dong, Student Member, IEEE, Tai Neng-Ling, Member, IEEE, James S. Thorp, Life Fellow, IEEE, and Yang Guang-Liang

[6] A Novel Protection Scheme for HVDC Line by ZHENG XLDRDong, TAI NengLing, YANG GuangLiang, DING HaoYin, SUN ShuJie, BO ZhiQian LI NaiHu Electrical Engineering Department, Shanghai Jiao Tong University, Shanghai 200240' China; 2 East China Grid Company, Shanghai 200002' China; 3 ALSTOM T&D Technology Center, Shanghai 200012' China

[7] A Transient Protection Scheme for HVDC Line by Xiaodong Zheng, Tai Nengling, Member, IEEE, Yang Guangliang, and Ding Haoyin

[8] Study on Protective Performance of HVDC Line Protection With Different Types of Line Fault by Han Kunlun, Cai Zexiang, Liu Yang School of Electric Power South China University of Technology Guangzhou, China.

[9] A Novel Scheme of HVDC Line Voltage Traveling Wave algorithm Protection Based on Wavelet Transform by LI Zhen-qiang', LV Yan-ping2 'Wuhan High Voltage Research Institution, Wuhan, 430074, Hubei, China 2School of Electrical Engineering, Wuhan University, Wuhan, 430072, Hubei, China

[10] NEUTRAL LINE PROTECTION SYSTEM FOR HVDC TRANSMISSION by Y. Kato, A. Watanabe, H. Konishi, T. Kawai Member IEEE Hitachi, Ltd. Tokyo, Japan, Y. Inoue, H. Irokawa Electric Power Development Co., Ltd. Tokyo, Japan

[11] A Protection System for Long HVDC Transmission Lines by D. Naidoo1* and N.M. Ijumba2 1Eskom Distribution, P.O. Box 66, New Germany 3620, South Africa 2Faculty of Engineering, University of KwaZulu Natal, Private Bag X54001, Durban 4000, South Africa

[12] Study on the Transmission Line Boundary Characteristics of the Hybrid HVDC System by Yanting Wang, and Baohui Zhang Shaanxi Key Laboratory of Smart Grid Xi'an Jiaotong University Xi'an,

[13] Study of Various Types of Faults in HVDC Transmission System by Ashwini K. Khairnar1, Dr. P. J. Shah2, PG Scholar, Electrical Engineering Department 1, Head, Electrical Engineering Department2, SBT's College of Engineering & Technology,Bambhori, Jalgaon.

[14] Fault transient simulation analysis fo HVDC line by Luhua Xing, Dandan Zhang, Wenbo Li1, Qing chen2, state grid Shandong Electric Power Research Institute1, key laboratory of power system intelligent dispatch and control of ministry of education Shandong University2,Jinan, China

[15] Identification method for internal and external faults based on amplitude feature backward travelling wave for HVDC transmission line by Xiaopeng Li, Sheng Lin, Shuai Jiang, Sichuan Province, China

[16] Current differential protection principle of HVDC transmission system by Shu-ping Gao1 , Qi Liu2,3, Guo-bing Song2 1College of Electrical and Control, Xi'an University of Science and Technology, Xi'an 710054, Shaanxi 2College of Electrical Engineering, Xi'an Jiaotong University, Xi'an 710049, Shaanxi Province, 3Shaanxi Electric Power Design Institute Co., Ltd, China Energy Engineering Group, Xi'an 710054, Shaanxi

[17] Fault analysis of HVDC systems with partial underground cabling by P Tünnerhoff*, M Stumpe*, A Schnettler*, *Institute for High Voltage Technology, RWTH Aachen University, Schinkelstr. 2, 52056 Aachen, Germany.

[18] Protection scheme for high-voltage directcurrent transmission lines based on transient AC current by Jian Liu , Nengling Tai, Chunju Fan, Wentao Huang Department of Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240

[19] Fault Location Estimation in HVDC system Using ANN byJenifer Mariam, JohnsonAnamika Yadav.