HVDC Line Design and Protection: A Survey

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Abstract – ***In this paper HVDC (High Voltage DC) transmission line design and protection is presented. Growing concern about the generation of the power and distribution it to the far ended consumer became very important issue. To prevent the system from power loss, and power theft HVDC is employed over a range of long distance. HVDC units are comprised with rectification, inverters and protection unit.***

Key Words: HVDC, 12 Pulse transformers, Protection, Modeling.

I. INTRODUCTION

The HVDC systems are becoming more and more popular in the present power network. One can estimate the future for long distance transmission of power from one end of generation to another end of consumer. In this paper fundamental concept of HVDC line is discussed along with the power capability and design of components. HVDC system consists of rectification unit, cable or transmission line and the inverter unit. Such a system is more popular when the transmission is done for the long distance as the transmission loss is very great area of concern. For the shorter or medium line distance this becomes costlier than the conventional ac transmission. Since the HVDC unit requires at sending end a well developed and controlled rectification, and an inverter at receiving end. Number of rectification unit may be one or greater than one, but the inversion unit count depends on the supply point, *i.e.* how many number of supply point is connected to the system. Although, the shorter range of transmission, this may increase the cost of installation, operation and maintenance of the system. Comparatively with the conventional AC network, HVDC has advantages such as high transmission capability, transmission of power over long distance and low line loss.

HVDC system came to existence as fully developed and controlled system in late 1970s. due to great research on the thyristors as high frequency and power switching element. Basic converter used Graetz bridge is shown in figure 5 which is popular till date since it has characteristic for the high switching frequency.

From past few decades protection of HVDC line using travelling wave and other method was great area of research. Up till now, many researchers have reported their contribution in the field of HVDC line protection and classification of faults. But, the accuracy of protection depends on the how accurate the system is modeled. However, accuracy of modeling of converter and HVDC line is also a great area of concern to be followed.

In [1]–[6], author had discussed about the various protection scheme for the high voltage DC system and the protection of rectification and inverter unit also. Since the rectification and the inverter unit comes with the controlled scheme and their controller behaves as the protection unit for the system integration.

In literature [7]-[9] author had discussed the advantages of the HVDC over the conventional AC transmission system. The modeling and the converter analysis is not has been discussed.

As travelling wave protection and the line regulated protection has several disadvantages. In the [10-12] author described the method of differential backup protection and that is much slower and requires the synchronization of data.

However, in this paper the line protection scheme is not discussed. But the modeling aspect of the HVDC for the protection is discussed which will help to improve the protection strategy for the sake of continuity of the supply.

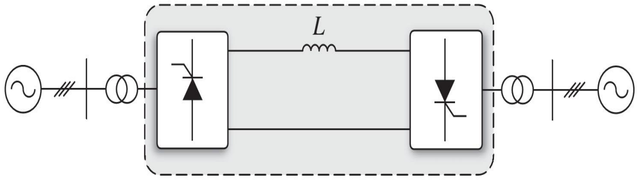

Fig. 1 Back to Back Connection of the HVDC link

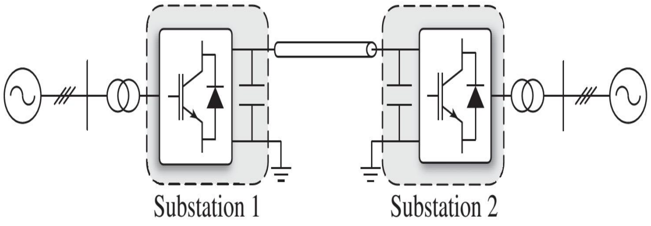

Fig. 2 Monopolar Link arrangement of the system

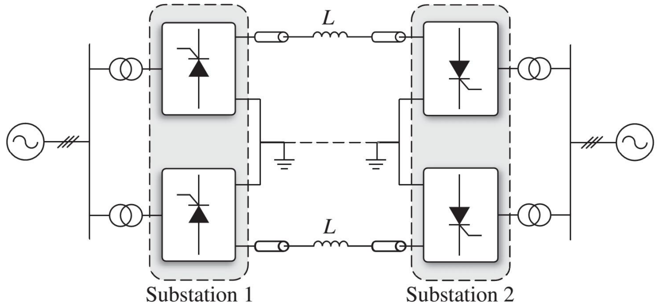

Fig. 3 Bipolar Arrangement of the system.

II. HVDC LINE TWO POLE SYSTEM

A typical arrangement of HVDC system with the all unit named is shown in figure 4. While figure1, 2 and 3 shows the different arrangement of the HVDC system. It depicts the double pole arrangement of the power network with the possible fault location named in figure itself. Small unit of capacitor and the inductor elaborates the function of filter. In the arrangement, filters are designed to remove the harmonics and higher frequency components. For a 12 pulse rectification system generally h=12n, harmonic are removed. Where n = 1,2,3,4,. . . while the filters are designed to operate at the 12/24 or 12/24/36 level of frequency for dc filter. .

In a two pole arrangement the first pole represents the positive DC line while the second pole represents the negative DC line. The scheme is also known as bipolar HVDC line. However, the single pole arrangement is known as the uni-polar HVDC link.

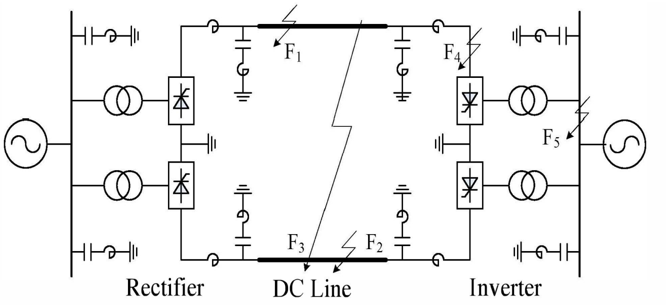

Fig. 4 A Typical arrangement of HVDC system, all units including the possible fault locations.

Rectifier Operation of HVDC Line

In this section rectification operation of HVDC unit is discussed. In rectification process, 12 pulse, 24 pulse and 48 pulse system becoming so modern using Graetz Bridge is shown in fig.2. For 24 and 48 pulse operation the rectification transformer are installed.

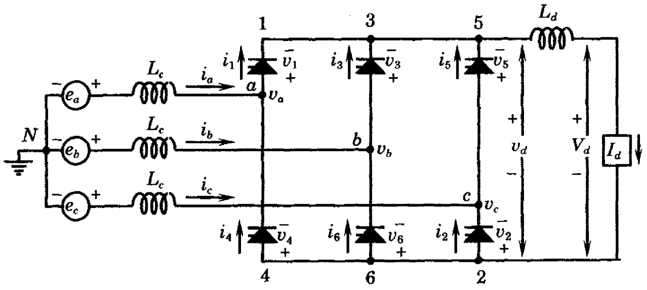

Fig. 5 A three phase fully controlled rectification system.

Figure 2 represents the converter circuit with the source leakage inductance of transformer L_c.

$$\begin{aligned} e_a &= E_m \sin(\omega t) \\ e_b &= E_m \sin(\omega t - 120°) \\ e_c &= E_m \sin(\omega t - 240°) \end{aligned} \tag{1}$$

Equation (1) represents the source with peak magnitude of E_m and phase voltages are placed in space with $120°$ to each other. In order to rectify the three phase AC two types of rectification comes with the process viz. controlled and un-controlled system. In this paper controlled rectification is used. There are two types of converter for the application as VSC and CSC, generally CSC is used as it has constant current through the line which reduces the line loss, eddy current loss and other components.

For a Valve,

$$V_{do} = \frac{3\sqrt{3}}{\pi} E_m \cos\alpha \tag{2}$$

Where, equation (2) shows the output voltage at the dc terminal. In equation (2) α is firing angle for the valve operation for a three phase system it varies from 0 to 120 degrees.

Inverter Operation of HVDC Line

To supply back the dc power to the grid it is important to have a inversion operation. Since the valves are unidirection and does not allow to reverse the power directly. Therefore, DC voltage is reversed using the control angle to operate more than the $90°$ and less than $180°$ this angle is known as extinction angle.

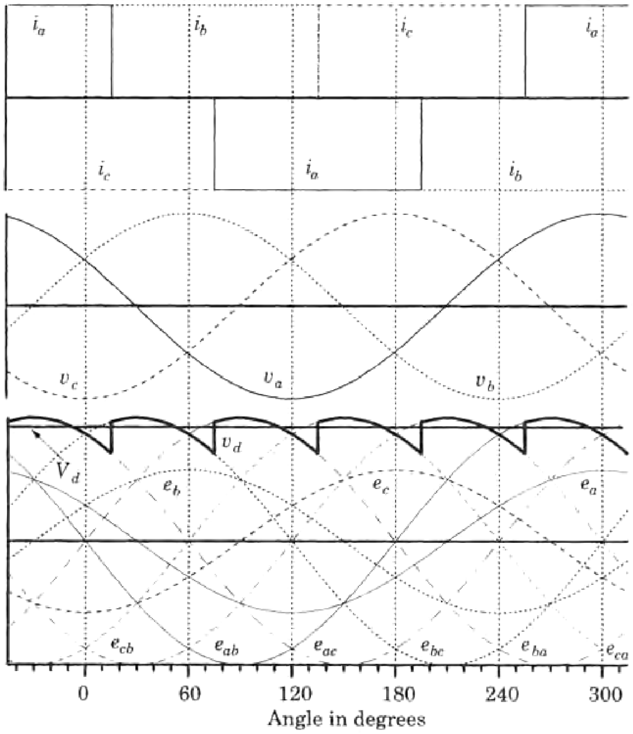

Fig. 6 Typical controlled waveform for the HVDC Rectification unit

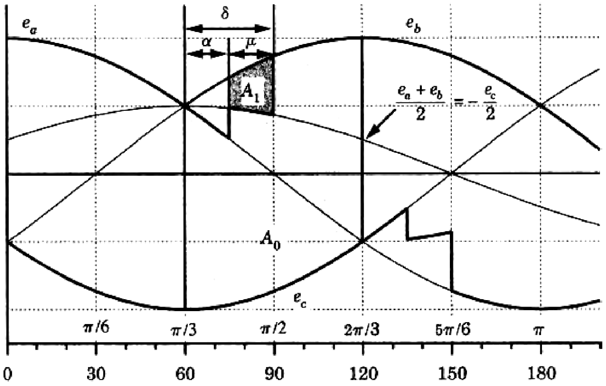

Fig. 7 Rectification with overlap angle

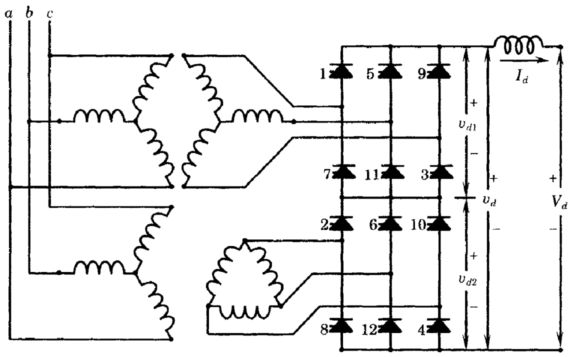

Fig. 8 A 12-pulse converter arrangement.

In figure-8 converter arrangement with the phase shift transformer is shown. In this a 12-pulse system is maintained so that the system will provide the proper isolation and the pulse shifting for a low dc ripple voltage profile.

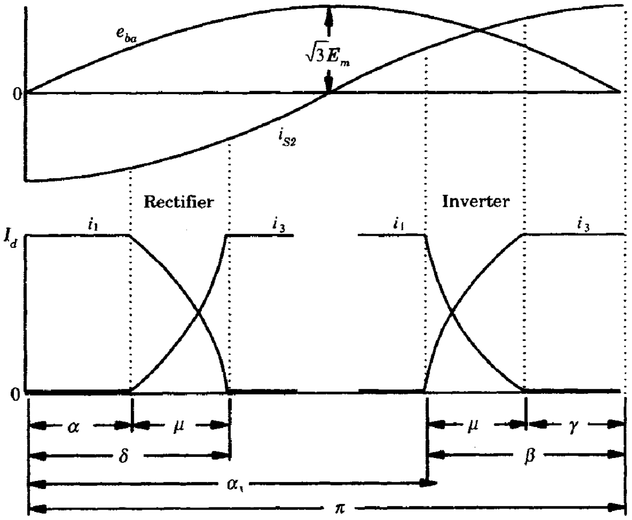

Fig. 9 Rectification and Inversion operation

It is clear from the figure 9 that the change of firing angle produces negative voltage and the converter can be used as inverter. A similar unit can be installed at both end and the firing angle will be the deciding factor for the power flow.

$$
\begin{array}{ll}
0 \le \alpha < 90^\circ & \textit{rectification} \\
90^\circ \le \alpha < 180^\circ & \textit{inversion}
\end{array}
$$

III. PROTECTION REQUIREMENT

In order to meet the design requirement and feasibility of the system it is mandatory to fulfill the basic protection requirement of the HVDC system. In this reliability, fault redundancy, dependability, durability and the accuracy of protection system is involved.

In this protective system different issues are covered with the fundamental requirement of the power safety of various connected equipment.

Generally, protection systems are divided into the groups of side of protection. As AC-side protection, transformer protection, filter and auxiliaries protection, line side protection, DC link protection against under-voltage.

Protection strategy involves:

- AC side protection
- DC Side Protection
    - Valve protection
    - Filter protection
    - Auxiliaries Protection
    - Unit-Protection
    - DC link Protection
- Protection against line fault
- Protection against pole-ground fault.
- Insulation breaking
- Delay-angle communication fault
- Other associated faults.

In addition, as from reliability perceptiveness of the system as component count increases the reliability of system decreases and failure rate increases.

It requires a detailed study of behavior and the characteristic of the every component count in order to analyze fault behavior.

Nevertheless, including all the aspect of fault behavior and the component faults, it is also mandatory to locate the fault at any end and location. It is also clear from figure 10 that the installation of HVDC takes place only when the breakeven point of distance is achieved for a specific zone and environmental condition. This includes the transportation of equipments and installation cost.

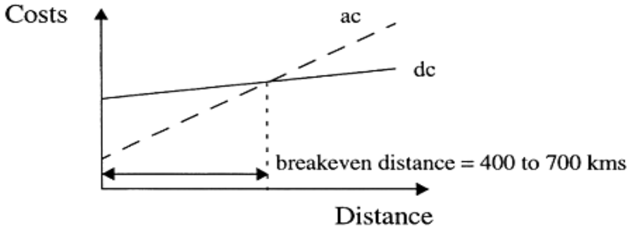

Fig. 10 Comparison of ac-dc transmission Method

IV. CONCLUSIONS

In this paper brief introduction of HVDC system with their advantage over large and complex network of HVAC has been discussed. Also, the two basic component of HVDC system has also been discussed here. Fundamental understanding of HVDC system provides the future development for the protection and the synthesis of faults in HVDC system. In future paper the fault and the location of fault will be dealt in detail.

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REFERENCES

[1] J. Liu, C. Fan, and N. Tai, “A Novel Pilot Directional Protection Scheme for HVDC Transmission Line Based on Specific Frequency Current,” no. Powercon, pp. 20–22, 2014.

[2] L. Xing, Q. Chen, Z. Gao, and Z. Fu, “A New Protection Principle for HVDC Transmission Lines Based on Fault component of Voltage and Current,” pp. 1–6, 2011.

[3] J. Suonan, S. Gao, G. Song, Z. Jiao, and X. Kang, “A Novel Fault-Location Method for HVDC Transmission Lines,” vol. 25, no. 2, pp. 1203–1209, 2010.

[4] F. Kong and B. Zhang, “A novel disturbance identification method based on empirical mode decomposition for HVDC transmission line protection,” no. 2.

[5] X. F. Jin, G. B. Song, and Z. B. Ma, “A Novel Pilot Protection for VSC-HVDC Transmission Lines Based on Parameter Identification,” pp. 1–6.

[6] X. Zhang, J. Bai, G. Cao, and C. Chen, “Electrical Power and Energy Systems Optimizing HVDC control parameters in multi-infeed HVDC system based on electromagnetic transient analysis,” *Int. J. Electr. Power Energy Syst.*, vol. 49, pp. 449–454, 2013.

[7] X. Q. Liu, Q. Song, W. H. Liu, H. Rao, S. K. Xu and L. C. Li, "Protection of non permanent faults on DC overhead lines in MMC? based HYDC systems," IEEE Trans. Power Del., vol. 28, no. I, pp. 483-489, Jan., 2013.

[8] P. Bresesti, W. L. Kling, R. L. Hendriks, and R. Yailati, "HYDC connection of offshore wind farms to the transmission system," IEEE Trans. Energy Convers., vol. 22, no. 1. pp. 37-43. Mar., 2007.

[9] B. R. Andersen and X. Lie, "Hybrid HYDC system for power transmission to island networks." IEEE Trans. Power Del., vol. 19. no. 4, pp. 1884-1890, Oct., 2004.

[10] Y. S. Quan, X. P. Li, Y. W. Ma, and J. W. Yang, "Distance protection scheme with traveling wave for HYDC based on wavelet transform," (in Chinese) Automation o.fElectric Power Systems, vol. 29, no. 18, pp. 52- 56, Sept., 2005.

[11] X. S. Zhou. and R. Lin, "Analysis of relay protection action for HYDC line and testing method," (in Chinese) High Voltage Engineering, vol. 32. no. 9, pp. 33-37, Sep .. 2006.

[12] X. D. Zheng, N.L. Tai, G. L. Yang, and H. Y. Ding, "A transient protection scheme for HYDC transmission line," IEEE Trans. Power Del., vol. 27, no. 2, pp.718-724, Apr. 2012.

[12] H. C. Shu, X. C. Tian, J. Dong, G. B. Zhang, K. Z. Liu, S. Y. Sun, and Y. Yang, "Simulation and analyses for Yun-Guang ±800 kY HYDC transmission line protection system," (in Chinese) Proceedings o.f CSEE, vo1.31, no.31, pp.179-188, Nov., 2011.

[13] X. D. Zheng, N. L. Tai, J. S. Thorp, and G. L. Yang, "A Transient Harmonic Current Protection Scheme for HYDC Transmission Line," IEEE Trans. Power Del., vol. 27, no. 4, pp.2278-2285, Oct. 2012.

[14] K. D. Kerf, K. Srivastava, M. Reza, D. Bekaert, S. Cole, D. Y. Hertem, and R. Belmans, "Wavelet-based protection strategy for DC faults in multi-terminal YSC HYDC system," lET Gener. Transm. Distrib., vol. 5. no. 4, pp.496-503. Aug., 2011.

[15] X. I. Liu, A. H. Osman, and O. P. Malik, "Hybrid traveling wave/boundary protection for monopolar HYDC line," IEEE Trans. Power Del., vol. 24, no. 2, pp. 569-578, Apr. 2009.

[16] X. D. Zheng, N.L. Tai, G. L. Yang, and H. Y. Ding, "A transient protection scheme for HYDC transmission line," IEEE Trans. Power Del., vol. 27, no. 2, pp.7 I 8-724, Apr. 2012.

[17] G. Wang, J. B. Luo, H. F. Li, and Z. K. Li, "Transient energy protection for±800 kY UHYDC Transmission Lines," (in Chinese) Automation of Electric Power Systems, vol. 34, no. 1, pp.28-31, Jan., 2010.