ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 4 [November]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

1. Ali M. ELTAMALY, 2. Y. SAYED, 2. Amer Nasr A. ELGHAFFAR

A SURVEY: HVDC SYSTEM OPERATION AND FAULT ANALYSIS

1. Electrical Engineering Dept., Mansoura University, Mansoura, EGYPT
2. Electrical Engineering Dept., Minia University, Minia, EGYPT

Abstract: High Voltage Alternating Current (HVAC) is the most easily and famous way for transmission energy in the world. But, it's important to use High Voltage Direct Current (HVDC) system to link between different frequency grids and at transmission energy on high long distance. HVDC operate at one side "converter station", where, the AC is converted to DC, which is then transmitted to a sending end converter station, converted back to AC, and fed into another electrical network. This paper discusses an overview of HVDC technology to use with transmission system and analyze the fault current between HVAC and HVDC.
Keywords: HVDC, Fault Analysis, Thyristor, Rectifier

1. INTRODUCTION

The main parts in power system to compact the electric grid was consisted of generation part, transmission system, distribution and control parts devices for reliability, stability and efficiency for the power system [1]. With the rapid development of a technology, using HVDC transmission systems with extra-long Over Head Transmission Lines (OHTL) [2]. To synchronize two grids which is different frequency, as 50 Hz with 60 Hz, an example the link between Kingdom of Saudi Arabia to Egypt, it's a multi-terminal HVDC project at a DC voltage of ± 500 kV and a power rating of 3000 MW [3]. This project involves 1500 km of DC OHTL and 16 km of DC cable. This system can be operating a transmit or receive by a rectifier or inverter system. HVDC is consider low power loses at comparing with AC system, but it cannot be used for lightning system and supplying motors. AC systems are using transformers which decreasing or increasing voltage to target value, but, in HVDC system the changing on voltage level are used electronic devices as mercury arc valves, semiconductors devices, thyristors, Insulated Gate Bipolar Transistors (IGBTs), Gate Turn Off thyristors (GTOs) and Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) [4] [5] [6], as shown in figure (1) for the thyristor characteristics. For the construction cost, HVDC it's better from HVAC to decrease the construction cost with long-distance, as shown in figure (2). HVDC has been deployed in submarine applications, while, its high losses value in HVAC system. HVDC has the unusual ability to connect asynchronous networks; this capability will

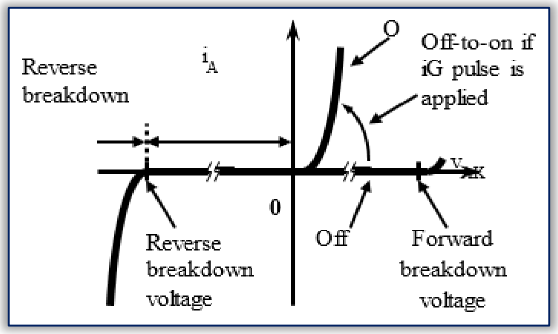

Figure 1. Basic characteristics operation for thyristor

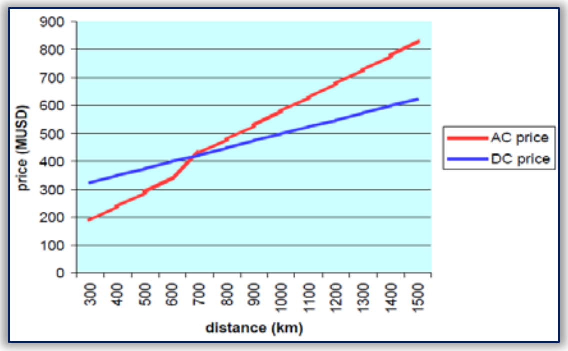

Figure 2. Characteristic curves for the relations between cost with distance for HVDC and HVAC

extend in the future with greater numbers of microgrids. Furthermore, HVDC technologies can provide stability with controlling for power flow, and the ability to segment parts of the power system all of which can enhance the grid's flexibility, reliability, and resilience [7] [8].

2. HVDC OPERATING SYSTEM

At large amounts of power required to transmit for over long distances, it's the benefit to using HVDC system, also for interconnections between different frequency systems. Where, at long distance, it can be more economical that's discussed in figure (2), [10]. In additional, decreasing in the value of the power losses, and reduced cost of a DC line construction, can offset the additional cost of converter stations at each end of the link. Also, at HVAC significant amounts of energy are lost due to corona discharge, the capacitance between phases or, in the case of buried cables, between phases and the soil or water in which the cable is buried [11].

Power in DC system can be calculating, as show in equation (1).

$$P = IV \qquad (1)$$

and, power losses can be calculating from equation (2).

$$P = IR^2 \qquad (2)$$

Basic rules in In HVDC system at transmitting end is to convert HVAC to HVDC and at receiving end convert this HVDC back to HVAC. These changes can be applying by rectifiers and inverters, as shown in figure (3) and figure (4) respectively. Moreover, the important devices assist with this system are filters, thyristors, (IGBT) and Voltage Source Converter (VSC) [12]. The differential firing of the thyristors in two series-connected gates is used to produce a decrease in both the harmonic generation and the reactive volt-ampere absorption for the rectifier mode of operation [13]. Maximum benefit is obtained when one bridge has a large rating compared with that of the second bridge in series with it, as shown in figure (5).

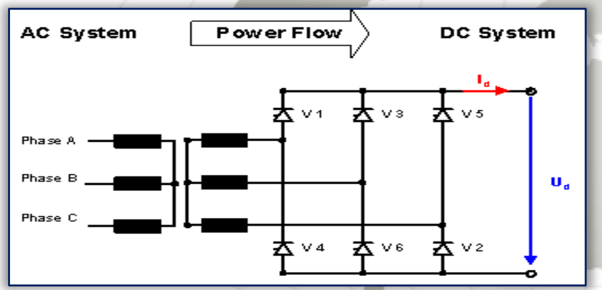

Figure 3. Operating the rectifier with HVDC system

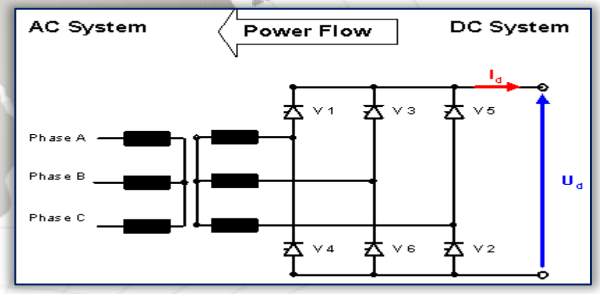

Figure 4. Operating the rectifier with HVAC system

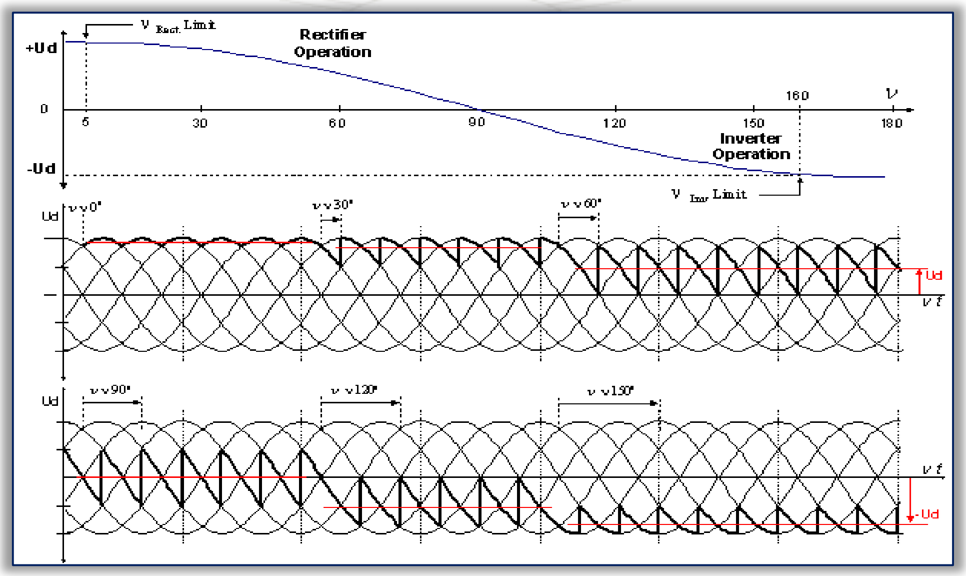

Figure 5. Relationship of DC voltage Vd and firing angle α

3. HVDC SYSTEM TYPES LINK

HVDC links are classified into three types, these links can be abbreviating as below.

- **Monopolar link**

It contains a single connector from the negative polarity and uses the earth or the sea to close the current loop. Monopolar link uses two of converters placed at the end of each pole. The grounding of the poles is fixed about 15-55 km from the substation this type design is show in figure (6) [14]. But, Monopolar link has several disadvantages because it uses earth for close current loop. So, is not much in use nowadays.

Bipolar link

Its uses two conductors, one negative and other is positive with respect to ground or sea. The midpoints of converters at each terminal station are earthed via electrode lines, as shown in figure (7) [15]. Voltage between conductors is equal to twice the voltages between any two conductors and earth. Since one connector in a positive polarity with respect to ground and the other is in the negative polarity with respect to the ground. In this link, at one pole goes out of operation, the system may be changed to the monopolar mode with close the current loop by the ground. Thus, the system continues to supply the half-rated power. Bipolar links are most commonly used in all high power HVDC systems.

Homopolar link

It has two connectors of the same polarity of the electrodes is usually negative, this link always operating with the earth or metallic return. In homopolar link, the poles are operated in parallel, thereby reducing the cost of insulation, as shown in figure (8), the homopolar system is not used presently [16].

4. FAULT DETECTION IN HVDC SYSTEM

HVDC systems are the same AC system for the expecting for the reason for faults in the system, but, with additional failure modes created in the converter stations. OHTL generally more expecting faults, such as lightning strikes, than buried transmission systems. The reason as fault in the system by lightning generally requires no repair as the air that breaks down for a flashover to occur self-heals thus the fault is temporary [11] [12] [13]. It is a few equipment's are failed or needs replacing, but even if damage occurs, the maintenance is almost easy on an OHL. Faults on cables are permanent as damage happen in the cable insulation and not the self-healing air like on OHLs [9]. Faults in the cables require large cavity to identify the location of the fault to maintain and return the system to service.[17]. This is dangerous for submarine HVDC cable systems, where replacement or maintain means raising the cable from the seabed, removing the failed part and replacing it with a new section. A fault on a submarine cable is therefore very serious and can result in the HVDC system being out of service for up to six months. Figure (9) and figure (10) are used to compare the fault current between HVAC and HVDC. Where, figure (9) shows a simple simulation for HVAC transmission system, figure (10) shows a simple simulation for HVDC transmission system.

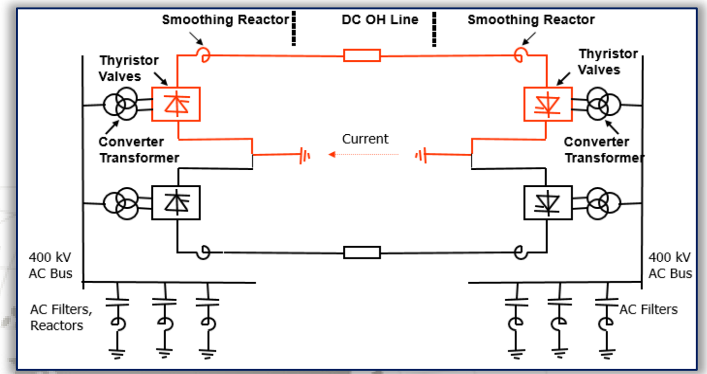

Figure 6. Design type of monopolar ground return HVDC system

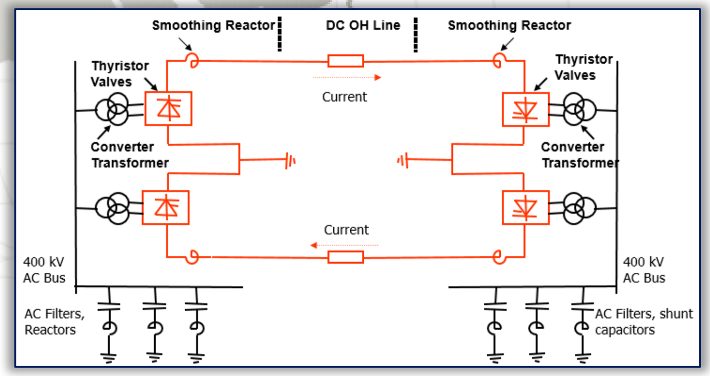

Figure 7. Design type of bipolar ground return HVDC system

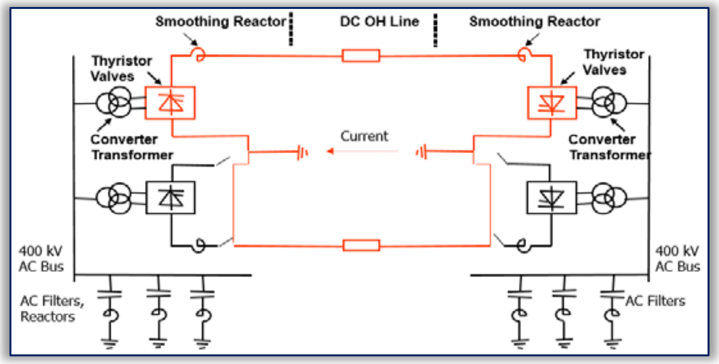

Figure 8. Design type of monopolar metallic return ground return HVDC system

The simulation for both faults between HVAC and HVDC system at SLG fault [18]. Where, this fault considers 85% from the OHTL faults, this comparison uses the same line parameters for HVAC and HVDC and line length. In figure (11) shows SLG fault current for HVAC and figure (12) shows the SLG fault current for HVDC. By comparing between two faults will prove the effect of SLG fault current is less in HVDC system from HVAC system. In table (1) is shown the results for the fault current is high with HVAC system comparing with HVDC system.

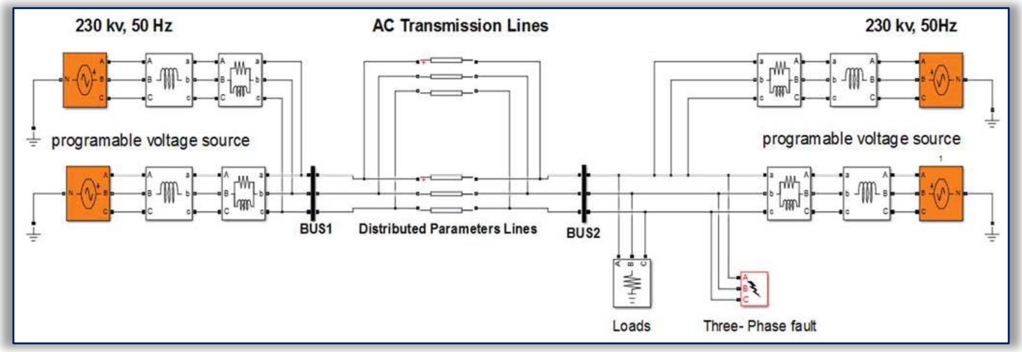

Figure 9. HVAC Power Transmission System

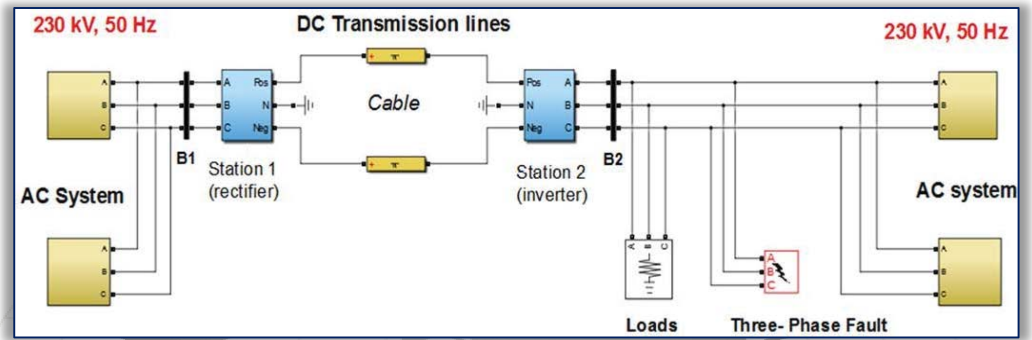

Figure 10. HVDC Power Transmission System

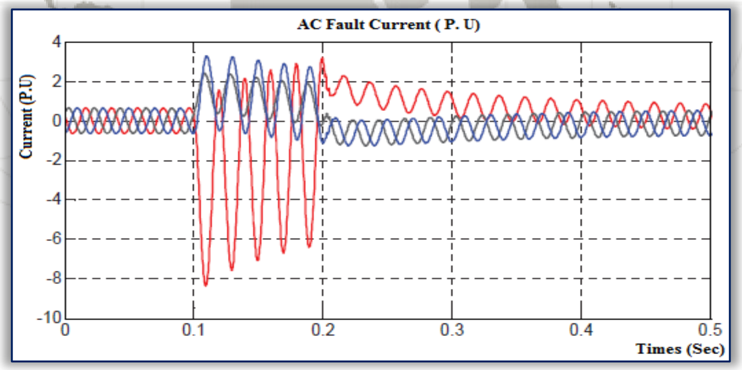

Figure 11. SLG fault current for HVAC system

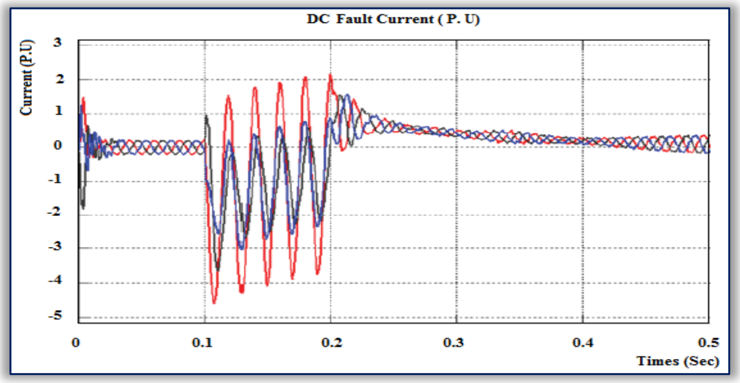

Figure 12. SLG fault current for HVDC system

Table 1. Fault current at HVAC system comparing with HVDC system at the same system conditions

Fault	Point analyze	HVAC current (P.U)	HVDC current (P.U)	Deferent percentage
SL-G	Peak up	3.21	2.18	32.08
	Peak down	8.15	4.35	46.62

5. HVDC system advantage and disadvantage

- Advantage HVDC system
  - HVDC cables undersea Consider high capacity comparing AC losses.
  - Long distance for transmitting power without intermediate taps.
  - Power transmission between unsynchronized two AC different frequency or voltage systems.
  - Connecting a remote generating plant to the distribution grid
  - Minimizing the line cost for, fewer conductors and thinner conductors since HVDC does not suffer from the skin effect.
  - Synchronizing renewable energy sources with the AC grid.
- Disadvantage HVDC system
  - The HVDC conversion is considered the main disadvantage, also the switching and control.
  - Its high cost for using the inverters, that represented a limit capacity
  - HVDC inverters are a high loss power at smaller transmission distances.
  - The inverters costs may not be balanced by reductions in line construction cost and lower line loss.
  - HVDC CBs are more complex because the mechanism must be included in the CBs to trip circuit and open the current loop. So, at operating under high loads, the arcing and contact wear should be high rated value to absorb the switching arc.

6. CONCLUSION

Nowadays HVDC is very important in transmission energy. In the future, this technology apparently will be improving with high spread. It's not economical to design and manufacture high-cost HVAC with high voltage transmission energy for long distance. But, by using the HVDC system will save cost and power losses for high voltage transmission energy. In AC system, the frequency and reactive power will effect on the system stability. But, HVDC is absence the frequency, furthermore, this doesn't create reactive power, so it's more stable from HVAC. This paper shows an overview of control, operation, and SLG fault current analysis and comparison between HVAC and HVDC power transmission system.

References

[1] Sarnon, Mohd Zaki "Two ways power flow with renewable energy integration" Master thesis, Universiti Tun Hussein Onn Malaysia, 2013.

[2] A. Barker and W.M. Ritchie "Brownout' voltage stability-system measurement and simulation" AC and DC Power Transmission, 1991.

[3] [Internet]. Available online in https://transgridsolutions.com/our-work/projects/kingdom-of-saudi-arabia-egypt-hvdc-link/

[4] Tuan A. Le "Operation of HVDC Grids in Parallel with AC Grids" Master of Science Thesis in Electric Power Engineering, Department of Energy and Environment Division of Electric Power Engineering, 2010.

[5] Power Semiconductor Devices, Available online, http://www.allaboutcircuits.com/technical-articles/a-review-on-power-semiconductor-devices/

[6] Yidong Hong and Tao Yu "Reliability Improvement Strategies for HVDC Transmission System" Energy and Power Engineering, 2013, 5, 52-56.

[7] H. Nouri, A. Tabbel, N. Douib, H. Aitsaid and Y. Zebboudj "Numerical Analyze of Corona Discharge on HVDC Transmission Lines" World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:9, No:6, 2015.

[8] Project group WPS4-1050 "Control of VSC-BASED HVDC transmission systems for OFFSHORE Wind power plants "Master Thesis, Department of Energy Tehnology Pontoppidanstr_de 101 Aalborg University, Denmark, 2010.

[9] Mujib J. Pathan and V. A Kulkarni "Fault annalysis of HVDC transmission systems" International Journal of Electrical Engineering & Technology (IJEET) Volume 7, Issue 3, May–June, 2016, pp.106–116.

[10] Md Mizanur Rahman1, Md. Fazle Rabbi, Md. Khurshedul Islam and F. M. Mahafugur Rahman "HVDC over HVAC Power Transmission System: Fault Current Analysis and Effect Comparison" Conference Paper · April 2014.

[11] Tomasz Drobik "High-voltage direct current transmission lines" IEEE Conference Publishing ul. Pulaskiego 32/13, 46-100 Namyslow, Poland.

[12] H.R. Chamorro and G. Ramos "Harmonic and power flow hybrid controller applied to VSC based HVDC stations" ResearchGate, 2015.

[13] Gil Marques and Matteo Iacchetti "Overcurrent estimation in a doubly-fed induction generator-DC system during a voltage dip in the dc grid" IET Renewable Power Generation, 2016: 1024 –1032.

[14] S. Wenig, M. Goertz and J. Prieto "Effects of DC fault clearance methods on transients in a full-bridge monopolar MMC-HVDC link" Innovative Smart Grid Technologies - Asia (ISGT-Asia), 2016 IEEE.

[15] Dirk Van Hertem "HVDC grid layouts" Wiley-IEEE Press, 2016.
[16] Prashant Agnihotri, A. Kulkarni and Aniruddha Gole "A Robust Wide-Area Measurement Based Damping Controller for Networks with Embedded Multi-Terminal and Multi-Infeed HVDC Links" IEEE Transactions on Power Systems, 2017.
[17] Morris Brenna, Federica Foiadelli and Michela Longo "Fault detection HVDC systems applied to renewable sources" Harmonics and Quality of Power (ICHQP), 2016, 17th International Conference on Electronic.
[18] Smko Zangana and Ergun Ercelebi "Enhance Power Quality by HVDC System, Comparison Technique between HVDC and HVAC Transmission Systems "World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:10, No:2, 2016.

ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering