HVDC System Control between Different Frequencies Networks and Fault Analysis with HVAC System

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Abstract

High Voltage Alternating Current (HVAC) is the most easily and famous way for transmission energy in the world. But, it’s better to use High Voltage Direct Current (HVDC) system to link between different frequency grids and at transmission energy on high long distance. HVDC system consists of three essential parts: converter station to convert AC to DC, transmission line and second converter station to convert back to AC. Back-to-back interconnection is the famous way that’s uses with connection as intern’s tie between two various frequency HVAC systems. HVDC transmission systems can be arranged in many ways on the basis of cost, flexibility, and operational requirements. This paper discusses HVDC control, operation and comparing fault analysis with HVAC system.

Index Terms-HVDC, Rectifier, Fault Analysis, Power System.

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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 [4]. 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), as shown in figure (1) for the thyristor characteristics [5]. For the construction cost, HVDC it’s better from HVAC to decrease the construction cost with long-distance, as shown in figure (2) [6]. 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 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].
There are various methods for controlling the HVDC in the multi-terminal grid but the protection system is the main supporting. HVDC system still lagging HVAC systems, without rated protection devices and logic. But, by using double thyristors switches, the diode freewheeling effect can be eliminated and the fault in dc line can be calculated. This clears the fault without commanding trip to open the Circuit Breaker (CB), and can operate fast with automatic power transmission recovery, which considerably improve the dependability of the HVDC system. Fault action in the multi-terminal HVDC can be detect by supervising to any changes in some system parameters, the accurate methods to detecting the fault by using three parameters, as suggested in, initial current change, rise time of the first wave front of the branch current and the oscillation pattern. Because the time to clearing fault is the critical command, so use of local information at each VSC in their protection scheme instead of telecommunication as much as clear the DC fault.

HVDC system CB design can use the AC CBs, it's used with the fast DC switches. This design is cheaper than using the DC CBs, which only start to emerge. Two types of faults are of concern, Line to Line (LL) fault, and single Line to Ground (LG) fault [8]. The HVDC fault is the main interest in an HVDC system, its effect is more common than the AC fault. To meet the target from using the protection system functions and applications, the frequency-dependent model is separated into the distributed parameter model plus a compensation matrix related to the frequency dependent nature, and FIR filters are adopted to fit the compensation matrix [9].

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]. Statistics of HVDC transmission systems include converter transformers, converter valves, AC filters, capacitor, and DC filers, smoothing reactor, transmission lines and control protection devices. While failure types in HVDC systems are various and complex, they can be classified into six types: AC and its device, Converter Valve, DC control and protection, primary equipment's, transmission lines and others. Failures in HVDC systems have a great influence on operating reliability so that reliability indices are influenced directly or indirectly [12].

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 [13]. 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) [14]. 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 [15]. 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: The monopolar link connects two converter stations by a single conductor line and earth or sea. The bipolar, where two converter stations are connected by bipolar (±) conductors and each conductor has its own ground. Homopolar two connectors of the same polarity [16]. The multi-terminal HVDC transmission systems have more than two converter stations, which could be connected in series or parallel. These links can be abbreviating as below.

3.1 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) [17]. But, Monopolar link has several disadvantages because it uses earth for close current loop. So, is not much in use nowadays.

![Figure 6 Design type of monopolar ground return HVDC](image)

3.2 Bipolar link

It 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) [18]. 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. Bipolar links are most commonly used in all high power HVDC systems.

![Figure 7 Design type of bipolar ground return HVDC](image)

3.3 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 [19].

![Figure 8 Design type of monopolar metallic return ground return HVDC](image)

4. Fault Analysis between HVAC and HVDC system

Electric Faults can be defined as the flow of a massive current through an alternative path which leads to cause serious equipment’s damage, interruption of power, personal injury or death. In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault" [20]. In transmission line faults, roughly 5% are symmetric. If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases being no longer applicable. There are three common types of ‘asymmetric faults’. A ‘line to line’ fault is a short circuit between lines, caused by the lines come into physical contact. Again, a ‘line to ground’ fault is a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or another storm damage. In a ‘double line to ground’ fault, two lines come into contact with the ground (and each other), also commonly due to storm damage [21]. Faults on cables are permanent as damage happen in the cable insulation and not the self-healing air like on OHLs. Faults in the cables require large cavity to identify the location of the fault to maintain and return the system to service [5] [21]. 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. 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 [22].
5.1 Single line to ground fault analysis between HVAC and HVDC

The simulation for both faults between HVAC and HVDC system at SLG fault [23]. 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.

5.2 Line to Line fault analysis between HVAC and HVDC

Line to line fault consider 10% from faults occurs in the system. Figure (13) and figure (14) show the fault current wave value for HVAC and HVDC systems, respectively. Table (1) shows the results of line to line fault results. It is clear from this results that, the fault current in HVAC system is very high compared to HVDC system.

5.3 Three phases to ground fault analysis between HVAC and HVDC

The fault current from simulation results of symmetrical fault in HVAC and HVDC are shown in Figure (15) and figure (16), respectively. Table (1) shows the same results as values. These results show that, the fault current in HVAC is very high compared to HVDC system.
Figure 11 SLG fault current for HVAC system

Figure 12 SLG fault current for HVDC system

Figure 13 Line to line fault current for HVAC system

Figure 14 Line to line fault current for HVDC system

Figure 15 Three phase to ground fault for HVAC system

Figure 16 Three phase to ground fault for HVDC system
Table 1 HVAC system comparing with HVDC system at the same system conditions

<table>
<thead>
<tr>
<th>Fault</th>
<th>Point analyze</th>
<th>HVAC current (P.U)</th>
<th>HVDC current (P.U)</th>
<th>Deferent HVAC Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL-G</td>
<td>Peak up</td>
<td>2.1</td>
<td>1.6</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>Peak down</td>
<td>4.2</td>
<td>1.6</td>
<td>2.62</td>
</tr>
<tr>
<td>LL</td>
<td>Peak up</td>
<td>6.04</td>
<td>1.75</td>
<td>3.45</td>
</tr>
<tr>
<td></td>
<td>Peak down</td>
<td>6.03</td>
<td>1.75</td>
<td>3.45</td>
</tr>
<tr>
<td>3Ph-G</td>
<td>Peak up</td>
<td>7.04</td>
<td>2.1</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>Peak down</td>
<td>7.02</td>
<td>2.2</td>
<td>3.19</td>
</tr>
</tbody>
</table>

5. HVDC system advantage and disadvantage

HVDC was first introduced in the 1950s. It produced many advantages including the interconnection of asynchronous networks, economic benefits, long-distance power delivery and environmental benefits [24].

5.1 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.

5.2 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 is 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

This paper presents of solving the problem for transmission energy between different frequency network’s depending on HVDC system. HVDC has certain advantages over HVAC transmission system as it has very low corona loss, required less insulation, lower voltage drop. The cost of light Towers& Poles, Insulators, cables and conductors are low so the system is economical. Most importantly, the concept of skin effect, dielectric losses, Inductance and Surges, Communication signal interference, synchronizing and stability problems are not found in HVDC transmission system. This paper shows an overview of control, operation, Also, shows the fault current' analysis and comparison between HVAC and HVDC power transmission system. This is done by using MATLAB/SIMULINK software to simulate and compare the result between HVAC system with HVAC system under SLG fault, LL fault and 3ph -G fault in transmission line for both HVAC and HVDC topologies. For better analysis and comparison, both simulation environments are kept same and the length varying from 400 km 500 KV. The results show that for each and every given fault condition; 'Fault current' in HVAC transmission system is much higher than HVDC transmission system. Also, the effects of 'fault current' in HVAC transmission system are highly destructive while effects are gentle, negligible and less harmful in HVDC transmission system.

References