LONG DISTANCE HIGH VOLTAGE DC TRANSMISSION WITH MULTILEVEL VOLTAGE SOURCE CONVERTER STATIONS

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ABSTRACT

This project can be employing multilevel converter (MLC) concept in the rectifier and inverter stations of new HVDC transmission system we can increase the quality of power conversion in these stations thereby eliminating the need of high filters in these stations, reduced switching stresses the proposed topology has been finished by utilizing MATLAB/SIMULINK.

Keywords: HVDC transmission system, Inverter/rectifier station (Multilevel).

1. INTRODUCTION

To increase the use of renewable energy sources for supply of electrical energy, more and more offshore wind farms with multi-connection points to the power system of the mainland are built. However, the large penetration of wind energy as well as other renewable energy sources may challenge stability and security of a conventional power system. At the same time, suitable solutions are needed for integration of offshore wind farms to the onshore grid. To solve this, the rich potential of HVDC technology to control power flows, optimally using offshore energy HVDC systems are initially based on thyristor-based line-commutated converters (LCC-HVDC) and recently on multilevel converter converters (MLC-HVDC). Due to the higher power capacity and lower losses, LCC-HVDC is very attractive for long distance bulk power transmission on land.

However, it needs a strong alternating voltage source to commutate and is sensitive to the grid disturbances. Therefore, LCC-HVDC is not so suitable for offshore applications. On the other hand, MLC-HVDC is attracting more and more attention especially in the collection of offshore wind energy owing to its superior flexibility and independent control of active power and reactive power.

The paper is orchestrated as takes after: the setup of the entire HVDC framework is talked about initially, and afterward the control techniques of assembled framework are portrayed. After that, the contemplations for choice of the principle circuit parameters are clarified. At last, reenactment and trial results are if and contrasted with confirm the legitimacy of the outline.

![Proposed system Block diagram](image)

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2. ARRANGEMENT OF HVDC LAB PROTOTYPE

2.1 Structure of HVDC Lab Prototype

This HVDC framework can exchange 1000 VA evident force with 600V DC join voltage. The HVDC lab framework is at first composed in such a route, to the point that both stations are taking into account three-stage two-level voltage source converters and offer the same converter structure, as demonstrated in Fig. 1. Two force speakers are used to reenact the force framework under distinctive conditions, for example, recurrence variance, uneven voltage, and so forth. Two transformers with Yd-11 design are presented for the seclusion between the force framework and the converters. The HVDC framework can be keep running under either monopole or bipolar operation, depending on the design of the midpoint of DC connection. DC link models with portion lumped parameters are acquainted with imitate the impact of transmission links. To channel the high request PWM recurrence sounds, single-tuned AC-channels are utilized as a part of every side between the transformers and the converter stations. The subtle elements of every segment will be presented in the accompanying areas.

![Diagram](image-url)

**Converter Station**

Since the ordinary two-level topology is chosen, a business IGBT module with 1200V ostensible authority emitter voltage and 10A ostensible gatherer current is used to assemble the rinciple circuit. To give both the bipolar and monopole operation capacity, two gatherings of capacitors are joined in arrangement to get the midpoint. Furthermore, adjust resistors are added to keep the proportionality of capacitor voltage.

Delicate begin circuit is likewise acquainted with manufacture the DC join voltage easily. So the delicate begin resistors will be embedded into the primary circuit to breaking point the inrush current amid startup, and afterward avoided after the delicate begin.

Every converter station is controlled by an ezdspF28335 board which can actualize the elements of control calculations, PWM era, securities and correspondences, et cetera. The required signs for control and securities are detected by transducers, and afterward sent to the DSP after handling on an interface board. Since the data signs of ADC diverts in TMS320F28335 ought to be somewhere around 0V and 3V, all the signs are preprocessed inside of the interface board to adjust this extent.
Additionally, some equipment assurance capacities, for example, DC joint overvoltage insurance and over-burden assurance, were added to piece the PWM motions under serious deficiency conditions. The driver board will enhance the PWM signals from the DSP board and control the IGBTs. There are six detached driver channels inside of the driver board. Each channel is manufactured with a driver IC 1ED020112-F.

3. CONTROL STRATEGY OF HVDC SYSTEM

To build the enduring and element execution of MLC-HVDC framework, a wide range of control techniques have been proposed, for example, vector current control, direct power control also, stage point control [5-6]. Among them, vector current control is exceptionally alluring because of its free control of dynamic force and receptive power and very much created outline approach. Consequently, vector current control is utilized as a part of this MLC-HVDC model. A solitary line schematic of a VSC-HVDC station is given in Fig. 3, where VS is the transport voltage at PCC point, and VC is the basic segment of the yield voltage of the converter station. PS, PC are the dynamic power that encourage into the framework and the converter station, individually.

3.1 Standard of MLC-HVDC System

As per Fig. 3, the reactor current can be communicated as

$$I_s = \frac{V_s - V_i}{R + jX} = \frac{V_s - V_c \angle \delta}{|Z| \angle \theta}$$

(1)

In this manner, the clear power infused into the force framework is

$$\hat{s}_s = P_s + jQ_s = \hat{V}_s \hat{i}_s^* = \hat{V}_s \left[ -\frac{V_s - V_c \angle \delta}{|Z| \angle \theta} \right]$$

(2)

Decaying (2) into genuine and nonexistent parts, the dynamic force and receptive force that nourish into the matrix can be composed as
Given that the resistance of the transmission line is moderately little, Eq. (13) can be improved as

\[
\begin{align*}
P_d &= \frac{V_J V_c}{|Z|} \cos(\delta - \delta) - \frac{V_c^2}{|Z|} \cos \delta \\
Q_d &= \frac{V_J V_c}{|Z|} \sin(\delta - \delta) - \frac{V_c^2}{|Z|} \sin \delta
\end{align*}
\]

where \( |Z| = \sqrt{R^2 + X^2} \), \( \delta = \text{atan}(X / R) \), \( X \gg R \).

Fig. 5 demonstrates the reliance of dynamic force and responsive power on point \( \delta \) and converter terminal voltage VC. Since the point \( \delta \) is little amid typical operation, it can be inferred that dynamic force is basically chosen by the point \( \delta \), while responsive force is profoundly in reliance on the converter terminal voltage VC. Along these lines, the force exchanged can be controlled by altering the adjustment list \( m \) and the stage Framework HVDC line Air conditioning channel edge of reference waveforms. Nonetheless, the dynamic force and receptive force are still combined with one another for this situation.

3.2 Internal Current Control

To acknowledge autonomous control of dynamic force and responsive power, vector current control can be utilized. As per Kirchhoff’s Law, the dynamic comparisons for the VSC-HVDC station indicated in Fig. 3 are:

\[
v_{S_{abc}} - v_{C_{abc}} = L \frac{dL_{S_{abc}}}{dt} + R L_{S_{abc}} \quad (15)
\]

Under Sinusoidal PWM balance, the converter terminal voltage is controlled by the balance file as

\[
v_{C_{abc}} = m_{abc} \frac{V_{DC}}{2} \quad (16)
\]

By utilizing the supposed Park Transformation, (15) in abc directions can be changed into a synchronous pivoting d-q reference outline. The recreation center change grid utilized as a part of this paper is characterized as

\[
T_{abc\rightarrow dq} = \frac{2}{3}
\begin{bmatrix}
\sin \phi & \sin(\phi - 120^\circ) & \sin(\phi + 120^\circ) \\
\cos \phi & \cos(\phi - 120^\circ) & \cos(\phi + 120^\circ) \\
1/2 & 1/2 & 1/2
\end{bmatrix}
\]

In the wake of applying Park Transformation, (15) can be modified as

\[
L \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R & \omega L \\ -\omega L & -R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} v_{ad} \\ v_{aq} \end{bmatrix} - \frac{V_{DC}}{2} \begin{bmatrix} m_d \\ m_q \end{bmatrix} \quad (18)
\]

where the d- and q-hub adjustment files are gotten from (16) as

\[
m_d = 2v_{ad} / V_{DC} \quad m_q = 2v_{aq} / V_{DC}
\]
Subsequently, the physical model of a VSC-HVDC terminal demonstrated in Fig. 4 can be determined. It is seen that the VSC-HVDC framework is a multi-variables, coupled framework. To decouple the framework and dispose of the consistent state lapse, md furthermore, mq can be controlled by the accompanying control mathematical statements

\[
\begin{align*}
    m_d &= \frac{2}{V_{DC}} \left( -u_d + \omega L_i + v_{sd} \right) \\
    m_q &= \frac{2}{V_{DC}} \left( -u_q - \omega L_i + v_{sq} \right)
\end{align*}
\]

where \( u_d \) and \( u_q \) are two new assistant control variables acquired from the PI controllers which direct the dq-tomahawks streams, and they are characterized as

\[
\begin{align*}
    u_d &= k_p (i_d^* - i_d) + k_i \int (i_d^* - i_d) \, dt \\
    u_q &= k_p (i_q^* - i_q) + k_i \int (i_q^* - i_q) \, dt
\end{align*}
\]

Substituting (19) into Eq. (18) then

\[
L \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R & 0 \\ 0 & -R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} u_d \\ u_q \end{bmatrix}
\]

Eq. (23) demonstrates two decoupled, first-arrange frameworks. As a result, the d-pivot and q-hub streams can be controlled autonomously.

### 3.3. External Control Loop

Contingent upon the attributes of associated systems what's more, the part of HVDC station in the framework, distinctive external circles can be utilized. Generally, the HVDC station associated with a solid system will be utilized to control the DC Link voltage, while the other station will control the dynamic force or the AC voltage. Both stations can control their receptive force independently.

Since in the utilized synchronous pivoting reference outline, the q-hub voltage equivalents to zero under the unaltering operation of stage lock-circle. The momentary forces infused into the converter station can be streamlined as
Thusly, the dynamic force and responsive force are in extent to the d-hub current and q-hub current, separately. Accordingly, they can be controlled by id and iq, either with a straightforward open circle control or with an input control circle for progressed dynamic reaction and precision.

Correspondingly, the DC joint voltage and the AC voltage can be likewise controlled by id and iq, individually. Fig. 6 shows quickly the control methodologies of the VSC-HVDC lab model.

4. OUTLINE OF MAIN CIRCUIT PARAMETERS

The primary circuit parameters of HVDC, for example, the estimation of reactors and DC joint capacitors, have noteworthy impact on the relentless and dynamic execution of the entire framework and must be precisely picked.

4.1 Air conditioning Reactors

The AC reactors focus the force exchange capacity of the HVDC framework and can successfully restrict the consonant substance in the current and voltage. Along these lines, amid the reactor outline, the present following speed, the THD and the force exchange ability have been taken into contemplations. Since customary three-stage two-level converter topology is utilized as a part of the model, (15) can be revised in the type of taking after exchanging capacities.

\[
\frac{dL_i}{dt} = -v_a + \frac{S_a + S_b + S_c}{3} V_{DC} - S_{v_{DC}}
\]  

where \( v_a \) is the matrix voltage, \( S_a, S_b, S_c \) are exchanging capacities of every stage, and they are characterized as

\[
S_i = \begin{cases} 
1 & \text{(up switch on)} \\ 
0 & \text{(low switch on)} 
\end{cases} \quad (i = a, b, c)
\]

Amid one exchanging period indicated in Fig. 7, the current changes in time span T1 and T2 can be gotten from (26) as

\[
\Delta I_i = \frac{T}{L} \left( v_a + \frac{S_a + S_c}{3} V_{DC} \right)
\]  

To accomplish high power quality, the line current should be fit for following the sinusoidal reference waveform amid the entire line cycle. Given the most genuine condition amid zero-intersection point, the accompanying relationship ought to be fulfilled.
\[
\frac{\Delta i_1 - \Delta i_2}{T_s} \geq \frac{I_m \sin(\omega T_s)}{T_s} \approx I_m \omega
\]

where \(I_m\) is the top estimation of appraised current.

In this way, the scope of reactance ought to be \([11, 12]\)

\[
L \leq \frac{2V_m}{3I_m \omega}
\]

(31)

Moreover, the reactors ought to be sufficiently huge to breaking point the current swells. As per (26), the present change inside \(\Delta t\) can be communicated as

\[
\Delta n = \Delta t \frac{\Delta i}{L} \left[ V_n + \left( \frac{S_a + S_b + S_c}{3} - S_a \right) V_{dc} \right]
\]

(32)

Considering the present swell around the top of current waveform, the present extent fulfilling the necessity of current swell is \([11]\)

\[
\frac{V_m T_s (2V_{dc} - 3V_m)}{2V_{dc} \Delta n_{\text{max}}} \leq L
\]

(33)

where \(V_m\) is the crest estimation of stage voltage, \(\Delta n_{\text{max}}\) is the permitted current swell that is generally 20% of evaluated current.

The reactors likewise influence the force exchange ability of the VSC-HVDC framework. As indicated by (14), (16) and the confinement of force exchange capacity, it is found

\[
P_s^2 + Q_s^2 \leq S_{\text{max}}^2
\]

\[
P_s^2 + Q_s^2 \leq \left( \frac{V_{dc} m V_{dc} \sqrt{2}}{2 \sqrt{2}} \right)^2
\]

(34)

Therefore, the responsive force exchange ability is constrained by the reactance when the working states of the framework have been chosen. To satisfy the prerequisite of certain responsive force exchange capacity, the reactance ought to fulfill the relationship controlled by (34). In this way, the scope of reactance ought to be

\[
X \leq \frac{0.6123 V_{dc} V_s - V_s^2}{Q_{\text{max}}}
\]

(35)

where \(Q_{\text{max}}\) is the greatest receptive force that can be exchanged.

Table 2 gives a synopsis of configuration results. As can be seen, there is still a major extent for conceivable estimations of reactors, and 37.5 mH reactors are utilized as a part of the last outline, which relate to 0.15 for every unit esteem (p.u.) in the model.

**Table 2: Determination of Reactors**

<table>
<thead>
<tr>
<th>Limitations</th>
<th>Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current ripple and THD</td>
<td>0.054 p.u. &lt; X</td>
</tr>
<tr>
<td>Current tracking speed</td>
<td>X &lt; 1.374 p.u.</td>
</tr>
<tr>
<td>Power transfer capability</td>
<td>X 0.389 p.u.</td>
</tr>
</tbody>
</table>

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4.2 DC link capacitors

The DC link capacitors are the vitality support on DC side; they can confine the DC voltage swell and decrease DC voltage varieties amid aggravation. In the meantime, they can impact the reaction of voltage circle. Take the delicate begin technique when the converter station is keep running as rectifier as an illustration, the DC join controller will be soaked before the DC join voltage achieves the evaluated DC join voltage. In this way, the rectifier will charge the DC join capacitor with most extreme DC current. To react to this thought, the DC join capacitors ought to be [11].

\[
C \leq \frac{I_r}{0.74 R_{Le}} \tag{36}
\]

where RLe is the evaluated DC load resistance, and tr is the expected rising time of DC connection voltage. In a VSC-HVDC framework, the DC join capacitors should likewise be able to give certain time term of vitality stockpiling. In the event that the proportion between the vitality of DC connection capacitors and the evaluated force limit of the HVDC station is characterized as \( \square \), then the DC join capacitance can be chosen by [12-13].

\[
C \geq \frac{2\tau S_N}{V_{DC}^2} \tag{37}
\]

where SN is the appraised force limit of HVDC station. It is proposed in [12] that the time consistent \( \square \) ought to be littler than 5ms to keep consistent operation and 2ms is regularly utilized in reasonable designing.

4.3 Three-stage Parallel Filter

As far as possible for infused consonant and non harmonic twisting of force units into the framework is managed what's more, settled in national network codes. These prerequisites must be fulfilled by the force plant administrator. Because of missing or fragmented administrative system numerous Transmission System Administrators (TSO) treat HVDC stations the same path as force plants associated with the high voltage framework.

The filter dimensioning process focuses mainly on the lower harmonics injections. For high distortion switching frequency injections corresponding damping devices must be added. Usually the necessary capacitive power, that has to be provided in order to compensate the injection of lower harmonics, is taken as a reference for filter designing. The value according to [1] is between 10% and 30% of nominal apparent power.

5. SIMULATION RESULTS

Simulation is performed using MATLAB/SIMULINK software. Simulink library files include inbuilt models of many electrical and electronics components and devices such as diodes, MOSFETs, capacitors, inductors, motors, power supplies and so on. The circuit components are connected as per design without error, parameters of all components are configured as per requirement and simulation is performed.

**Simulation parameters**

Gen Station=25KV, 50Hz 10MVA  
Transformer-1 :-50KVA; 50Hz ;25KV/11KV  
Tr. Line:- 0.1Ohm, 2mH  
Rectifier /Inverter Station:-  
IGBT switches; Ron= 1Ohm; Vf_drop=0V  
Snubber parameters:- Rs=0.1Mohm; Cs=100MF  
DC link capacitance Cdc=1800uF  
Grid model:- 11KV, 50Hz
Calculations at Rectifier Station

Output Voltage equation of 3-Ph Bridge rectifier

Maximum DC Voltage, \( V_{dc} = 3\sqrt{3} \cdot V_m / \pi \)

\( V_m \) = peak AC terminal voltage

Here, \( V_m = 11KV \cdot \sqrt{2} \)

\[ = 11000 \times 1.414 \]

\[ = 15554 \]

Therefore,

\[ V_{dc} = 3\sqrt{3} \cdot \frac{1554}{3.14} \]

\[ = 2.5KV \]
Waveforms

a) Input voltages and currents at rectifier station

b) DC link voltage

Calculations at Inverter Station

By using five level inverter at AC output voltage will be more compared to convectional VSI.

Peak value per half cycle = 4KV + 4KV
= 8KV peak

c) Inverter Output and Grid side voltage

Total Harmonic Distortion

THD - total harmonic distortion is the measure of harmonic content in the voltages injected by this inverter station into grid. Here in this extension system it is

THD = 1.42

Percent improvement in THD value by employing 5-level inverter station

% THD = (THD2 - THD1) / 19.2 * 100
= (19.2 - 1.4) / 19.2
= 0.92 * 100
6. CONCLUSION

By employing multilevel converter concept in the rectifier and inverter stations of new HVDC transmission system we can increase the quality of power conversion in these stations thereby eliminating the need of high filters in these stations, reduced switching stresses. Simulation study is carried out using MATLAB/SIMULINK software.

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