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Design and Analysis of Multilevel Inverter Based HVDC System

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***Abstract* – Circuits called voltage source converters (VSCs) transform electricity from one form to another by converting the voltage between the two forms. In high-voltage direct current systems, the use of voltage source converters is essential. The technology of voltage source converters is used to ensure the smooth functioning of any high-voltage direct current system. Because of this, VSC-based HVDC systems are rising in significance when compared to other types of HVDC systems. Due to the high current connected with the starting up process of an HVDC system, a correct beginning procedure is essential in order for the HVDC system to be operated safely. In this research, a new and original solution for the smooth beginning of a VSC-based high-voltage direct current system is suggested, which will effectively restrict the current while operating at high speeds.**

***Index Terms* – THD, optimum angles, Iterative methods, Nine level MLI, Control of inverter, Modular Inverter.**

I INTRODUCTION

All of the world's emerging and developed nations are shifting away from traditional energy sources and toward power provided by nonconventional sources. Photovoltaic energy, wind energy, natural gas energy, and tidal energy are all examples of renewable energy sources. As of right now, India ranks third in the world in terms of electrical energy consumption. EHVAC and high-voltage direct current (HVDC) systems may be utilized to collect the energy generated in the plants. Because of the lower losses associated with high-voltage direct current transmission, it is preferred in electric power transmission. In addition, as compared to EHVAC, the expenditure needed for HVDC is cheaper.

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The break-even distance in HVDC is greater than that in EHVAC, which is one of the most attractive characteristics of the HVDC transmission system. HVDC systems may be built with two or more connections, depending on the application. When comparing the installation of a multiple link HVDC system to the implementation of a two-link system, there are various problems.

The first high-voltage direct current (HVDC) systems are introduced in the year 1897 with the invention of a low-voltage direct current supply over extremely short distances. The invention of mercury arc rectifier technology in power electronics made it possible to convert electricity from alternating current to direct current with relative ease. Advanced technologies make it easier to make breakthroughs in power conversion since they are more straightforward. The high-voltage direct current (HVDC) is comprised of two ends: the transmitting end and the receiving end. In order for the sending end converter to function properly, AC to DC conversion is required, and DC to AC conversion is required at the receiving end. The installation of a converter is required at each end of the power conversion process. The transmission will begin when the electricity has been converted from alternating current to direct current.

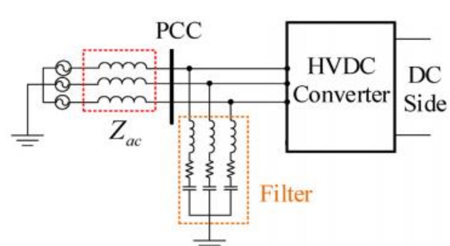

Figure 1: HVDC System.

Continual monitoring of the different voltages and power flows is very important in the performance analysis of high-voltage direct current (HVDC) systems. The changes in power flows and voltages that occur as a result of the addition of a voltage source converter must be carefully investigated, especially in the case of a voltage source converter. In order to examine the system, it is necessary to model the system and the converters that are connected to it. The modeling procedure included the development of mathematical equations pertaining to the system under investigation, as well as the specification of different restrictions to be applied during the management of the power system.

Any system is subject to a variety of operating and control problems. We are experiencing a number of challenges with the VSC HVDC system. The features of the system under investigation are concerned with its operation, control, power flow, stability, converter architecture, converter control strategy, and the power and voltages at different points along the system's path. The following are some examples of potential projects with high-voltage direct current (HVDC) systems.

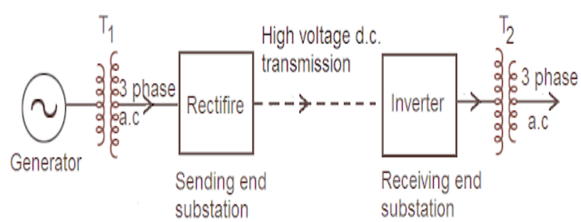

Figure 2: HVDC Block diagram.

- The modelling of two terminals system.
- Analysis of HVDC system in SIMULINK.
- Starting current issues.
- Study of voltages at various ends.
- Study of real and reactive power flows.

When beginning the VSC HVDC systems, special attention is paid to minimizing the size of the starting current. This is discussed in detail in the following paper: The suggested new beginning control circuit, which is intended to restrict the starting current, as well as the simulation associated with it, are both shown.

II OVER CURRENT IN HVDC SYSTEM

In isolated places, electrical power is produced by hydroelectric power. Typically, they are positioned a long distance away from the load centers. Because of the greater distance between the producing centers and the load centers, the transmission of electrical power becomes more complicated, necessitating the construction of a massive and expensive power transmission infrastructure. Consequently, the transfer of large amounts of electricity across vast distances is a difficult job for electrical transmission experts to do successfully. EHVAC and high-voltage direct current (HVDC) transmission systems are the two most significant technologies that are employed for this purpose.

Construction of the power transmission system should be straightforward and cost-effective, and it should, more critically, allow greater control over the flow of electricity. The high-voltage direct current (HVDC) power transmission technology meets all of the criteria for a reliable transmission system. The fundamental benefit of HVDC is that the direction of power flow is determined by the magnitude of the voltage, but in the case of EHVAC, the phase angle is also necessary. The usage of high-voltage direct current (HVDC) in conjunction with a power electronic converter allows for more control flexibility. Typically, voltage source converters are the most common and best suited for high-voltage direct current applications.

One of the most serious problems associated with the functioning of the system is the regulation of overcurrents that are generated during the system's initialization.

2.1 Overcurrent in HVDC

This study takes into account a two-level inverter-based high-voltage direct current system. Everything from converter stations to power factor arrangement systems and filters and other related equipment is included in this category.

Figure 3 depicts the construction of a two-level high-voltage direct current system. If x is the reactance between two ends and f is the frequency of the system, then we can derive the following equation from the HVDC link:

$$\begin{cases} P = -\dfrac{U_s U_c}{X}\sin\delta \\ Q = -\dfrac{U_s(U_s - U_c\cos\delta)}{X} \end{cases} \quad (1)$$

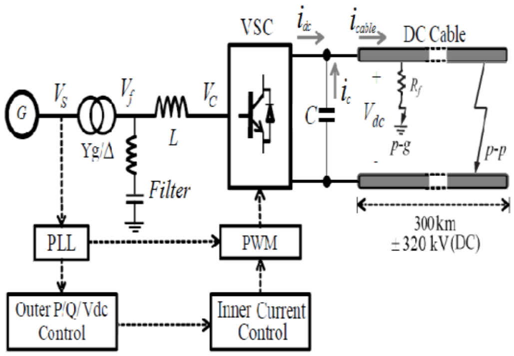

Figure 3: HVDC With two level Inverter.

The above system variables can be expressed in Matrix form as

$$L\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} u_{sd} \\ u_{sq} \end{bmatrix} - R\begin{bmatrix} i_d \\ i_q \end{bmatrix} - \omega L\begin{bmatrix} +i_q \\ -i_d \end{bmatrix} - \begin{bmatrix} u_{cd} \\ u_{cq} \end{bmatrix} \qquad (2)$$

The figure below shows the equivalent circuit of the HVDC system for the system under study.

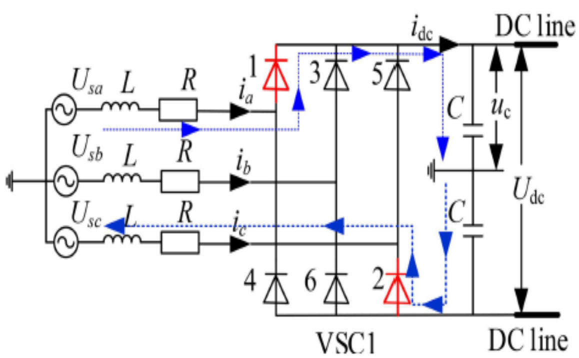

Figure 4: Equivalent circuit.

We may get the following formulae from the analysis of the aforementioned system and its equivalent circuit, which will tell us the magnitude of the currents that are created during the beginning process.

$$LC\frac{\mathrm{d}^2 u_c}{\mathrm{d}t^2} + RC\frac{\mathrm{d}u_c}{\mathrm{d}t} + u_c = U_{sa} \qquad (3)$$

$$LC\frac{\mathrm{d}^2 u_c}{\mathrm{d}t^2} + RC\frac{\mathrm{d}u_c}{\mathrm{d}t} + u_c = U_{sm} \qquad (4)$$

$$\begin{cases} i_{dc} = \sqrt{\dfrac{4C}{4L - R^2C}}U_{sm}e^{-t/\tau}\sin\omega t \\ u_c = U_{sm}\left[1 - \sqrt{\dfrac{4C}{4L - R^2C}}e^{-t/\tau}cos(\omega t + \varphi)\right] \end{cases} \qquad (5)$$

$$\begin{cases} \lambda_{1,2} = -\alpha \pm \mathrm{j}\omega = -\dfrac{R}{2L} \pm \mathrm{j}\sqrt{\dfrac{1}{LC} - \left(\dfrac{R}{2L}\right)^2} \\ \varphi = \arctan\dfrac{\alpha}{\omega} \quad \tau = \dfrac{2L}{R} \end{cases} \qquad (6)$$

The current magnitudes that occur during the startup of the high-voltage direct current system (HVDC system) depicted in figure 3 may be calculated using the equations above. It is difficult to maintain control over such currents in the absence of an auxiliary circuit.

A realistic system is considered for the analysis in order to test these currents. The specifications of this system are presented in the table below.

Table 1: Operating parameters.

Parameters	Rated value
phase reactance	$L = 10$ mH
current limiting inductor	$L_1 = 10$ mH
phase resistance	$R = 0.314\ \Omega$
DC capacitor	$C = 500\ \mu$F
transformer ratio	110/10 kV
DC voltage	$U_{dcref} = 20$ kV
rated active power	$P_{ref} = 5$ MW
rated reactive power	$Q_{ref} = 2$ MVar
t_1, t_2	0.1, 1
t_3, t_4	1.5, 2

In a monopolar connection, just one conductor is used, while ground will function as a second conductor in this case. It is feasible to have unidirectional power flow using a mono polar link system. Power may be sent in both directions in the case of a bipolar connection, which is not feasible in the case of a single-direction link. More connections are available for usage with multi terminal links, which allows for the connectivity of different subsystems to be accomplished via the use of several links. In the case of a homopolar connection, the complexity of the control grows as the number of links increases as well.

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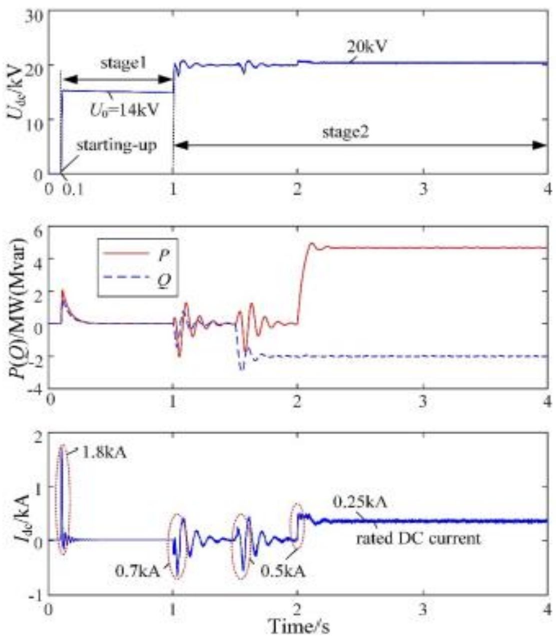

Figure 5: wave forms during starting.

As a result, it is obvious from the above waveforms that the current limiting circuit is required for the effective functioning of the high-voltage direct current system.

III STARTING CIRCUIT DESIGN

The design of the newly suggested beginning circuit for the two-level inverter-based high-voltage direct current system, which was provided in the previous part, is discussed in this section. The current expression is derived, and charts of the results are also shown.

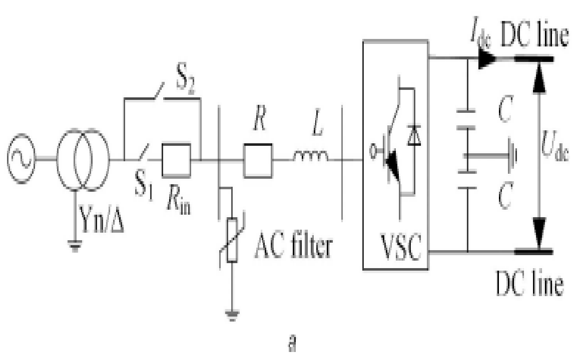

Figure 6: Starting circuit of HVDC

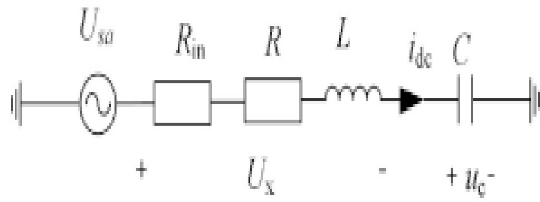

Figure 6: Equivalent Circuit of Starting Circuit.

Following is the method to derive the current expression after adding the control circuit in the existing system.

$$LC\frac{d^2u_c}{dt^2}+R_1C\frac{du_c}{dt}+u_c=U_{sm} \tag{7}$$

$$\begin{cases} i_{dc}=\sqrt{\dfrac{4C}{4L-R_1^2C}}U_{sm}e^{-t/\tau}\sin\omega t \\ u_c=U_{sm}\left[1-\sqrt{\dfrac{4C}{4L-R_1^2C}}e^{-t/\tau}cos(\omega t+\varphi)\right] \end{cases} \tag{8}$$

Where,

$$\varphi=\arctan\frac{\alpha}{\omega}\quad \lambda_{1,2}=-\alpha\pm j\omega= -\frac{R_1}{2L}\pm j\sqrt{\frac{1}{LC}-\left(\frac{R_1}{2L}\right)^2} \tag{9}$$

$$\begin{cases} i_{dc}=\dfrac{U_{sm}}{L}te^{-t/\tau} \\ u_c=U_{sm}\left[1-\left(1+\dfrac{t}{\tau}\right)e^{-t/\tau}\right] \end{cases} \tag{10}$$

Where,

$$\lambda_{1,2}=-\alpha=-\frac{R_1}{2L} \tag{11}$$

$$\begin{cases} i_{dc} = \sqrt{\dfrac{4C}{R_1^2C - 4L}} U_{sm} e^{-t/\tau} \mathrm{sh}\beta t \\ u_c = U_{sm}\left[1 - \sqrt{\dfrac{4C}{R_1^2C - 4L}} e^{-t/\tau} \mathrm{sh}(\beta t + \varphi)\right] \end{cases} \quad (12)$$

Where,

$$\varphi = \arctan\frac{\alpha}{\beta} \quad \lambda_{1,2} = -\alpha \pm \beta = -\frac{R_1}{2L} \pm \sqrt{\left(\frac{R_1}{2L}\right)^2 - \frac{1}{LC}} \quad (13)$$

The maximum value of the current is obtained using following equations.

$$t_{max} = \frac{\ln\lambda_2 - \ln\lambda_1}{\lambda_1 - \lambda_2} \quad (14)$$

$$i_{dcmax} = \sqrt{\frac{4C}{R_1^2C - 4L}} U_{sm} e^{-t_{max}/\tau} \mathrm{sh}\beta t_{max} \quad (15)$$

And the condition to achieve the minimum current is

$$i_{max}\sqrt{R_1^2 + (\omega L)^2} \geq U_{max}$$

The power expressions are given by

$$k_1 = \frac{\Delta P_{max}}{\Delta U_{dcmax}}$$

$$\Delta U_{dc} = U_{dcref} - U_{dc}$$

$$\Delta U_{dcmax} = U_{dcmax} - U_{dcref} = U_{dcref} - U_{dcmin}$$

It is clear from equations (10), (12), and (13) that the current is kept to a bare minimum when the control circuit is used in an HVDC system. By including the suggested control circuit at the beginning of the circuit, the initial current magnitude was reduced significantly in magnitude.

Here is a list of the control circuits that are necessary to keep those variables under control:.

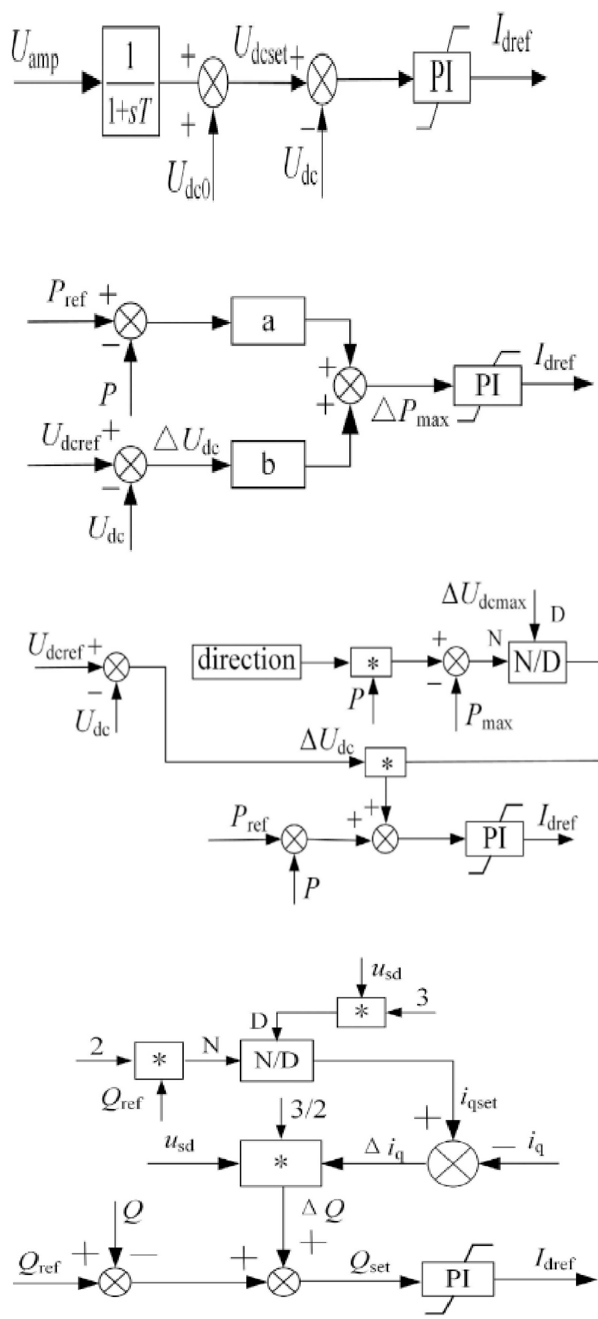

Figure 7: various control circuits.

By using the control circuits described above, it is feasible to produce a low beginning current, which is beneficial in achieving smooth control of the whole system throughout operation.

$$i_{qset} = \frac{2Q_{ref}}{3u_{sd}}$$

$$\Delta i_q = i_{qset} - i_q$$

$$\Delta Q = \frac{3}{2}u_{sd}\Delta i_q$$

$$Q_{set} = Q_{ref} - Q + \frac{3}{2}u_{sd}\Delta i_q$$

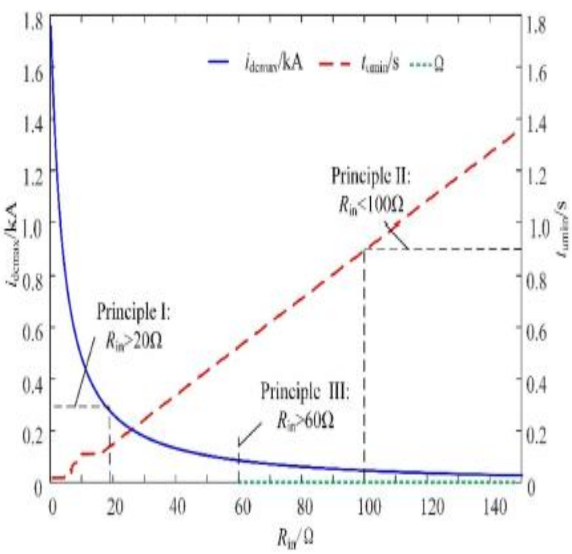

Figure 8: various parameters of the circuits.

The preceding equations represent the change or fluctuation in the current and power, as well as the values of other parameters. Through the use of equations, it is possible to compute the variation.

IV SIMULATION RESULTS

When testing the rapid beginning with restricted current, simulations are carried out for the test system, and the results are shown in this area. The values and graphs for different parameters are produced and displayed in this section. All of the simulations of the test system are carried out using the PSCAD program, which is designed specifically for the research and analysis of areas relevant to the power system.

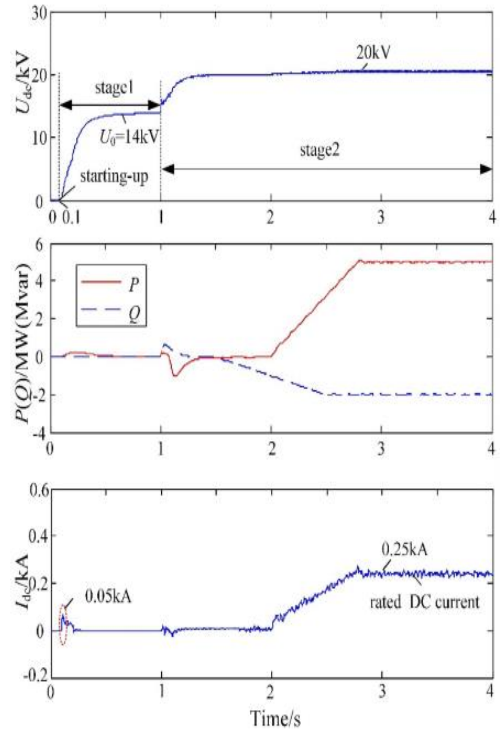

Figure 9 Voltage, power, and Current.

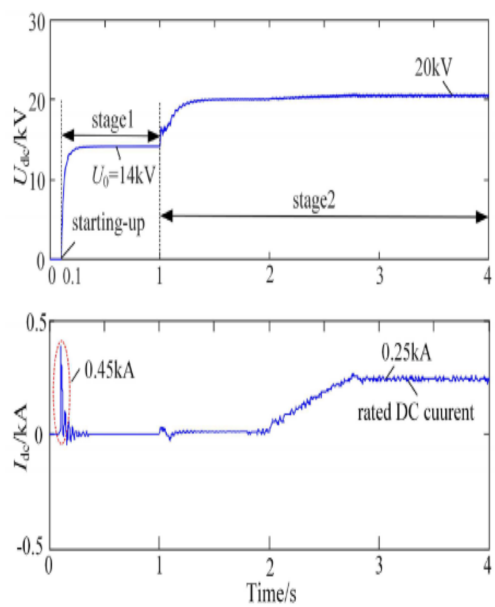

Figure 10: Changes In Current And Voltage.

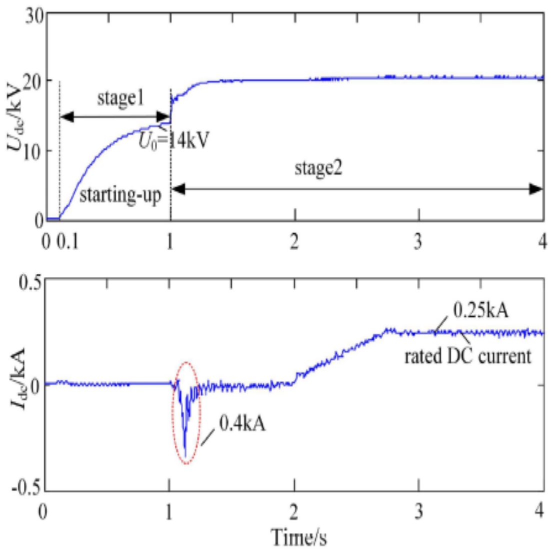

Figure 11: Load Voltage for various Resistance.

When comparing the results of the simulation to the results of the system without a beginning circuit, it is evident that the current during the system's startup is lowered when using the starting circuit.

Table 2: Values of various parameters.

Control types	Parameters	Value
DC voltage slope control	T	0.067 s
	k	30 kV/s
active power adaptive droop controller	ΔU_{dcmax}	1 kV
	P_{max}	6 MW
reactive power deviation controller	i_{qset}	0.133 kA

V CONCLUSIONS

The suggested and studied performance of the auxiliary starting circuit is discussed in detail. The redesigned beginning circuit, which is better suited for the VSC HVDC system, is tested, and the results of the simulation are acquired using the PSCAD computer-aided design program. The findings demonstrate that the use of the new circuit reduces the beginning current to a very low value, which is much lower than the rated value of the circuit. As a result, this study recommends the use of the beginning circuit to ensure proper functioning of the high-voltage direct current system with voltage source converters.

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