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Overcurrent system suppression measures for HVDC transmission system

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Abstract. LCC-HVDC technology, an essential Commutated Converter based on High Voltage Direct Current, is extensively employed in power system. However, because DC side overcurrent has the potential to seriously affect both system stability and equipment dependability, it has long been the focus of LCC-HVDC systems. This research presents an effective overcurrent suppression technique for the LCC-HVDC side overcurrent. This work first explains the damage caused by DC side overcurrent. A defect or abnormal situation in an LCC-HVDC system can result in DC side overcurrent, which can have a number of negative effects, including equipment damage, power grid instability, and system collapse. Therefore, it is imperative to address the DC side overcurrent issue in order to ensure the system's reliability and safe functioning. The overcurrent suppression method is then presented in this study. This research then presents an overcurrent suppression technique. This approach is predicated on a thorough examination of the properties of DC side pass current in conjunction with power electronic device regulation. First, the primary cause of the DC side pass current is identified by examining its source. Next, a control algorithm is created that has real-time monitoring and suppression capabilities for the DC side overcurrent. The method is able to precisely detect the overcurrent and promptly implement the necessary control measures.This study contrasts simulated trials carried out in the actual LCC-HVDC system with the conventional overcurrent suppression technique. The results show that the proposed overcurrent suppression strategy improves stability and reaction speed while effectively suppressing the DC side overcurrent. Furthermore, the method exhibits strong resilience and flexibility across a range of malfunction scenarios and operational contexts.

Keywords: HVDC power transmission system, MATLAB modeling, controlling means.

1. Introduction

Electricity has emerged as one of the most significant infrastructural components of modern civilization, and a reliable and efficient power transmission system is essential to the continuous operation of social production and individual life. The power system is facing increasingly difficult difficulties in the areas of grid stability and power transmission efficiency due to its continued expansion and the rapid increase in power load. Long-distance and high-power transmission flaws in the conventional AC transmission system are becoming more and more noticeable. On the other hand, HVDC transmission systems are now an essential component of contemporary power systems due to their high efficiency, low loss, and capacity to block interference. HVDC transmission systems have several benefits over AC transmission systems, including extended transmission distances, minimal transmission losses, and robust power grid regulatory capabilities.[3] Using a large capacity, long-distance power transmission system is more feasible and cost-effective than using the traditional AC power transmission technique. Thus, from a theoretical and practical application perspective, a comprehensive grasp of the HVDC transmission system, including its idea, control technology, and simulation technique, is very important. First of all, a thorough examination of the HVDC transmission system's principle and control technology may assist identify the internal workings of the system, provide solutions to issues, and increase power transmission efficiency. Second, by creating a simulation model of an HVDC transmission system, various control techniques may be evaluated and confirmed, serving as a guide for real-world implementation. Finally, the optimization control research may improve the HVDC transmission system's stability, dynamic responsiveness, and operational efficiency. With the continued development and deployment of new energy, the role of HVDC transmission systems in energy complementarity and power grid dispatch is becoming increasingly important. Therefore, in order to promote the use of new energy sources, advance power system development, and boost power grid stability, it is imperative to perform extensive research on the theory, control technology, and simulation technique of HVDC transmission systems.

Since its invention in the 1960s of the previous century, high voltage direct current (HVDC) technology has come a long way. Because of the nation's fast growing power industry and increasing power demands, HVDC utilization is growing in China. Many HVDC projects are now completed in China, including Northwest to North China, Qinghai to Jiangsu, and other projects that have been successfully completed and placed into operation. These accomplishments provide strong support for the integration of HVDC technology into the power grid [1]-[3]. Other nations also make extensive use of HVDC. HVDC research started in Europe in 1960, and the Swedish-German HVDC Interconnection Project, the first large-scale HVDC project in history, was put into action in the early 1980s. HVDC transmission technology is also frequently employed in North America; one example is the Canada-United States HVDC connection project. Furthermore, a few emerging Asian nations have started utilizing HVDC technology. Two examples of these projects include the joint DC power transmission project between China Southern Power Grid and Vietnam State Grid, as well as the DC power transmission from India's Kurakula nuclear power station.[4]

The investigation and use of HVDC transmission technologies have entered a new phase. Currently, researchers mostly concentrate on the following areas: first, learn about the design and operation of the HVDC transmission system, taking into account the technologies used for DC voltage regulation, DC filtering, and converters; Second, investigate the HVDC transmission system's control technology, encompassing both DC and AC side control technologies; Thirdly, the HVDC system is modeled and studied through simulation research, which includes building a simulation model, choosing system parameters, and creating a simulation experiment. Fourth, discuss the evolution and utilization of HVDC transmission technology, including how power systems make use of these systems and the direction that future development is taking. As the power sector expands and power loads increase, HVDC transmission technology is becoming increasingly important in improving power transmission efficiency, cutting energy loss, improving power quality, and improving power system stability. As China's power industry continues to grow and HVDC transmission technology continues to be innovated, it will only progress and become more important as one of the key technological instruments in the power system. Qualities of a transitioning HDI-HVDC system.

Stability, reliability, and economy are the problems with the HVDC transmission system that need to be fixed. To improve system stability, the HVDC transmission system's control and protection measures need to be strengthened, along with system monitoring and problem diagnostics. The design and manufacturing quality of the HVDC transmission system must be improved, and scientific maintenance and management techniques must be put in place to ensure the system's reliability. Raising the stability of the LCC-HVDC transmission system will require more system building, lower operating costs, and higher transmission efficiency. Suppressing the overcurrent and of LCC-HVDC transmission technology is required in order to address these issue [5]-[8].

The main circuit and control mechanism of the LCC-HVDC technology are systematically presented in this paper. The filter, converter, and converter transformer are the three main parts of LCC-HVDC. In the second section, the control strategy of the LCC-HVDC system is presented in detail, its control

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concept is studied, and its advantages and disadvantages are discussed. This study presents an overcurrent suppression technique that effectively reduces DC side overcurrent. It is divided into two modules: an overcurrent suppression module and a fault detection module. The approach is predicated on a thorough examination of the LCC-HVDC system control plan. An LCC-HVDC system model is built using Simulink, and a simulation experiment is carried out to verify the effectiveness of the overcurrent suppression strategy. The simulation results show how well the recommended overcurrent suppression method works to lower the DC side overcurrent in LCC-HVDC.

1.1. System Layout

Because DC voltage offers a lower transmission loss, higher transmission capacity, and a longer transmission distance than AC power transmission, it is employed as the transmission medium in High Voltage Direct Current (HVDC) technology power systems. The most important part of the entire HVDC transmission system is the converter station, which is in charge of HVDC conversion and transmission. The grounding electrode and transmission line are further parts of the system. The converter station is made up of two parts: a rectifier that converts alternating electricity back into direct current and an inverter that converts direct current into alternating current. Filters, control devices, a thyristor, an IGBT, and more converters make up the converter.

HVDC works like this: AC power from AC system I is sent to the AC bus, AC power is converted to DC by rectifier transformer, DC power is sent to inverter station via DC connector, DC power is converted to AC by inverter, and finally, AC power is sent to receiving system II via converter transformer. The basic structure of the system is shown in Fig. 1.

The two main components of the HVDC system are the converter station, which consists of the rectifier and inverter stations, and the HVDC transmission line, which consists of various converters, DC flat wave reactors, AC and DC filters, reactive power compensation devices, DC transmission lines, and electrodes.

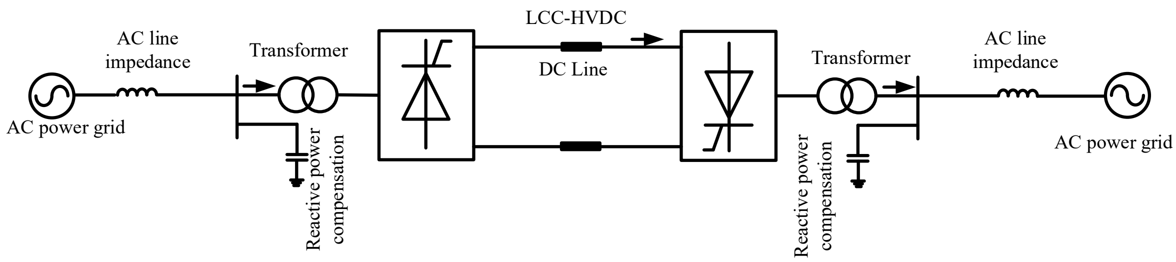

Figure 1. LCC-HVDC system

1.2. Transient Characteristics of LCC-HVDC

Normally operation of the DC transmission system achieves the goal of rectifier side DC current control. The basic concept diagram of constant current regulation is shown in the figure. The current error ε between the current detection value and the current reference value will rise when the DC current size I_ lowers as a result of the comparison operation. As a result, α will drop the current detection value I, D will rise, and the current Idr_ref reference value will be reached. Nonetheless, the present amplitude I_will rise as d increases. This is because the current error ε between the measured and reference current values will reduce as a result of the comparison procedure. This will raise α, which in turn will cause the measured value of the current I to decrease and reach the current reference value I.

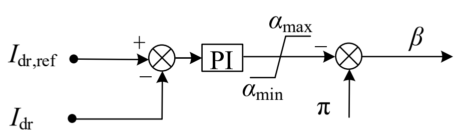

Figure 2. Rectifier side current control block diagram

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By using the minimum value of the inverter side γ Angle's previous cycle, the measurement value of the DC system's turn-off Angle γ is achieved. The gamma angle in this system is 20°, while the maximum deviation limit is set at 31°. The control block diagram in the illustration illustrates how the maximum current deviation control may be changed to 51°.

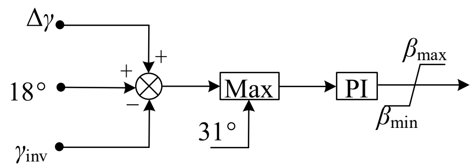


Figure 3. Fixed cut-off Angle control block diagram

The constant current control principle governs both the rectifier side and the inverter side. Typically, ΔI is 0.1 p.u., and the rectifier current set value Idr, ref, has a larger current margin than the inverter current set value Idi, ref. The divergence between the actual value and the DC current set value on the inverter side serves as the input. The control logic is shown in Fig. 4.

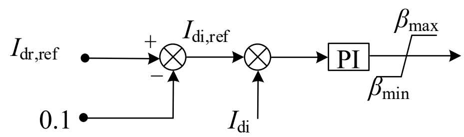


Figure 4. Constant current control block diagram

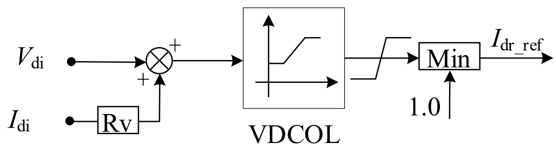
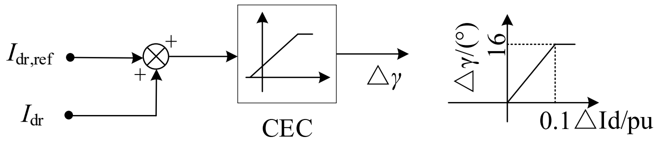


Figure 5. VDCOL unit

The function of VDCOL is to limit DC current when either the AC voltage or the DC voltage drops below a certain threshold. The VDCOL logic is shown in Fig. 5. The purpose of the current deviation control is to accomplish a smooth transition on the inverter side between the fixed turn-off angle and the VDCOL control. The difference between the rated and actual current levels is used to alter the turn-off angle. If the maximum turn-off Angle is reached, the prescribed current is controlled. The control block diagram is shown in Fig. 6. With a value of 0.08, the variance per ampere current is frequently increased by 0.01° to 0.1°.



(a) Logic block diagram (b) oscillogram

Figure 6. Current deviation control

Control and modification of the HVDC transmission system is the primary purpose of the trigger angle changes made by the converter at both ends of the line. It is quickly and easily modifiable, which may guarantee different DC transmission techniques, enhance system functioning, and enhance the performance of the AC system on both ends.

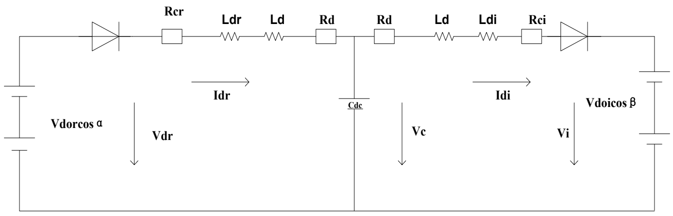


Figure 7. High voltage DC system equivalent circuit diagram

The DC voltage on the rectifier side is represented by Vdr in the image, while the DC voltage on the inverter side is represented by Vi. Ldr is the converter end inductance value; Ldi is the inverter flat wave reactor inductance value; Ld is the 1/2 DC wire inductance value; Rd is split into the 1/2 DC line resistance value; and Cdc is the HVDC line ground capacitor. DC is indicated at the rectifier end by Idr and at the inverter end by Idi. The voltage at the capacitor's two ends is expressed as Vc. The optimal DC voltage for no-load rectification is Vdoi, and the ideal DC voltage for no-load rectification is Vdor. Of them, the two parameters that matter are α and β. Among these, the rectifier and inverter's two parameters are α and β, respectively. Rci is the equivalent commutator resistance, while Rcr is the equivalent commutator resistance at the rectifier end.

$$R_{\mathrm{cr}} = \frac{3}{\pi} X_{\mathrm{cr}}, \quad R_{\mathrm{ci}} = \frac{3}{\pi} X_{\mathrm{ci}} \tag{1}$$

Xcr and Xci are respectively converter reactance of inverters. Among them, the relationship between the ideal no-load DC voltage and AC voltage is:

$$\begin{cases} V_{\mathrm{dor}} = kV_{\mathrm{ar}} \\ V_{\mathrm{doi}} = kV_{\mathrm{ai}} \end{cases} \tag{2}$$

The number of converter bridges connected in series is denoted by B in the formula above. The dynamic equations of a DC transmission line may be obtained from Fig. 7 in accordance with the circuit principle as follows:

$$\begin{cases} (L_{\mathrm{dr}} + L_d)\frac{\mathrm{dI_{dr}}}{\mathrm{dt}} = -R_d I_{\mathrm{dr}} + V_{\mathrm{dr}} - V_c \\ (L_{\mathrm{di}} + L_d)\frac{\mathrm{dI_{di}}}{\mathrm{dt}} = -R_d I_{\mathrm{di}} - V_{\mathrm{dr}} + V_c \\ \mathrm{C_{dr}}\frac{dV_c}{\mathrm{dt}} = I_{\mathrm{dr}} - I_{\mathrm{di}} \end{cases} \tag{3}$$

Similarly, the DC output voltage of the rectifier and inverter is expressed as follows based on the equivalent circuit diagram and circuit theory:

$$\begin{cases} V_{dr} = kV_{ar}cos\alpha\text{-}R_{cr}I_{dr} \\ V_{di} = kV_{ai}cos\beta\text{-}R_{ci}I_{di} \end{cases} \tag{4}$$

The line voltage on the secondary side of the converter transformer on the commutator side is denoted by Vdr, while the line voltage on the inverter side is denoted by Vdi. Equations (2.4) and (2.3), respectively, can be substituted to produce the mathematical model of the HVDC system:

$$\begin{cases} (L_{\mathrm{dr}} + L_d)\frac{\mathrm{dI_{dr}}}{\mathrm{dt}} = -2R_d I_{\mathrm{dr}} + kV_{\mathrm{ar}}\cos\alpha\text{-}V_c \\ (L_{\mathrm{di}} + L_d)\frac{\mathrm{dI_{di}}}{\mathrm{dt}} = -kV_{\mathrm{ai}}\cos\beta + V_c \\ \mathrm{C_{dr}}\frac{dV_c}{\mathrm{dt}} = I_{\mathrm{dr}} - I_{\mathrm{di}} \end{cases} \tag{5}$$

During the steady state functioning of the DC system, the DC current remains constant, meaning that the ground capacitance Cd may be disregarded.

$$I_d = I_{\mathrm{di}} = I_d \tag{6}$$

It can be obtained from equation

$$I_d = \frac{k(V_{\mathrm{ar}}\cos\alpha - V_{\mathrm{dor}}\cos\beta)}{2R_d + R_{\mathrm{cr}} + R_{\mathrm{ci}}} = \frac{V_{\mathrm{dor}}\cos\alpha - V_{\mathrm{doi}}\cos\beta}{2R_d + R_{\mathrm{cr}} + R_{\mathrm{ci}}} \tag{7}$$

Meanwhile, according to the analysis and above, The power of the rectifier is

$$P_{\mathrm{dr}} = V_{\mathrm{dr}} I_d \tag{8}$$

The power on the inverter side is

$$P_{\mathrm{di}} = V_{\mathrm{di}} I_d = P_{\mathrm{dr}} - 2R_d R_d^2 \tag{9}$$

2. Overcurrent Coordinated Control for HDI HVDC System

2.1. Introduction to Overcurrent Coordinated Control Strategy

The DC side-overpass current suppression method is shown in Fig. 8. The two components of the technique are the DC current additional control module and the fault judgment module. As seen in the image, Id is the actual DC current value of the HVDC and Id_ref is the DC current setting value. ΔI is the difference between the DC current's set and actual values; Urms and Urms_ref stand for the effective and setting values of the AC voltage, respectively.

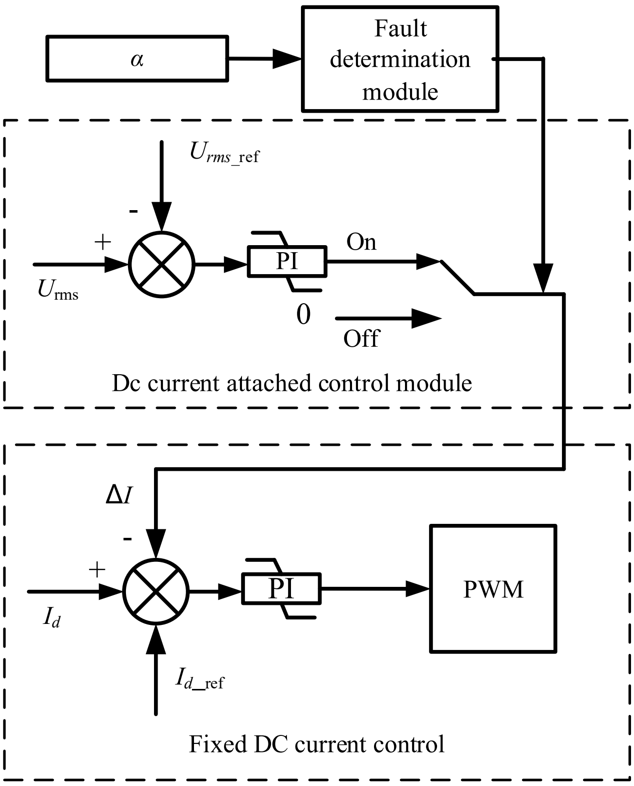


Figure 8. Overcurrent coordinated control block diagram

When the HVDC system faults, the effective value of the AC voltage will change and diverge from its predetermined value. A current deviation setting value is generated by PI when the deviation is managed, and this value impacts the fixed DC current control. The triggering angle, α, for the HVDC fixed AC current regulation may now be expressed as

$$\alpha = X_P + X_I + (U_{\mathrm{LCC}} - U_{\mathrm{LCC\_ref}})(K_{\mathrm{P1}} + K_{\mathrm{I1}}/s) = X_P + X_I + X_{\Delta I} \tag{10}$$

Where, in the rapid current response module, and denote, respectively, the integral time constant and proportional coefficient of the PI controller. The reactive power compensation (ΔI) function, which is

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the compensation component of the PI controller output for constant AC current regulation (XΔI), is first calculated by the PI controller. The DC current will decrease due to an increase in α when the commutation fault occurs because the reactive power generated by HVDC will respond more quickly.Generally speaking, the current flowing through a DC transmission line is calculated by dividing its equivalent resistance by the potential difference between its two ends.

$$I_d = \frac{1.35(E_r \cos \alpha_r)}{(3/\pi)X_r + R_d} \tag{11}$$

Where is the DC current on the HVDC rectification side is the commutation angle on the commutation side; is the effective no-load line voltage on the valve side of the converter transformer's finishing side; and are the equivalent commutation reactances on the inverter side and the commutation side. is the equivalent resistance of the DC transmission line. Only in cases when the system characteristics and the commutator bus voltage on the commutator side remain constant is the size of the commutation failure significant. After the fault occurs, the rectifier side's trigger angle value and reaction speed can be increased to reduce the overcurrent.

2.2. Overcurrent Fast Response Module

The reactive current setting value i_{qref} of VSC-HVDC following a commutation failure is represented as follows:

$$\begin{aligned} i_{\text{qref}} &= X_P + X_I + \left(U_{\text{LCC}} - U_{\text{LCC\_ref}}\right)\left(K_{\text{P1}} + \frac{K_{\text{I1}}}{s}\right) \\ &= X_P + X_I + X_Q \end{aligned} \tag{12}$$

where the integral time constants (KI1) and proportional coefficients (KP1) of the PI controller in the rapid reactive response module, respectively, are expressed. XQ is the compensation component that the PI controller outputs for determining AC voltage control, and ΔQ is the amount of reactive power compensation.

Reactive power consumption on the LCC-HVDC inverter side increases rapidly in the event of commutation failure. At this time, XQ >0 increases the reactive power response speed in VSC-HVDC and causes a notable rate rise in iqref. The reactive power generated by the LCC-HVDC rectification side will be absorbed by VSC-HVDC over the interconnection line, preventing the LCC-HVDC AC voltage from rising sharply. The integral component output of the PI controller affects XQ <0 in the formula once the commutation bus on the rectification side of LCC-HVDC changes from increasing to decreasing in voltage. Reactive power is absorbed by VSC-HVDC; nevertheless, the rate of absorption decreases rapidly.

3. Verification of Simulation Analysis

3.1. HDI-HVDC Model Based on IEEE 39 Nodes is Established

The overall simulation model of the CIGRE HVDC transmission system was developed in Simulink in accordance with the structural diagram, as seen in the picture. The system is powered by a single machine and has a fixed capacitor and damped filter on the AC side, with a short-circuit ratio SCR of 2.5. The rated voltage of the DC system is 500kV, and its rated capacity is 1000MW. The converter is 12 pulses.

Table 1. CIGRE HVDC model parameters

Parameters	Values
Dc voltage Udc	500kV
Reactive power P	1000MW
Smoothing reactor inductance Xdc	5.0Ω
Firing angle α	20°
extinction angle γ	15°

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The AC voltage and frequency on the LCC-HVDC rectifier side are 345 kV and 50 Hz, respectively. Two of the filters have reactive powers of 252.5 Mvar each: a C-damped filter and a second-order high-pass filter. The reactive power compensation device emits 125Mvar of reactive power. The transformer has a leakage reactance of 0.18pu, a capacity of 603.73MVA, and a ratio of 345/213.4557.

The AC voltage of the LCC-HVDC inverter side is 230kV and the frequency is 50Hz. The filters include a second-order high-pass filter and a C-damped filter, both of which emit a reactive power of 252.5Mvar. The reactive power emitted by the reactive power compensation device is 125Mvar. The transformer has a ratio of 230/209.2288, a capacity of 591.79MVA and a leakage reactance of 0.18pu.

The resistance of the series damping circuit is 5000Ω, the capacitor C is 0.05uF, the unit impedance is 0.41Ω/km, and the impedance of the AC line is X/R 6.0. R-L-L system refers to the AC equivalent system on the inverter side, while R-R-L type refers to the AC equivalent system on the rectifier side. These two equivalent circuits exhibit distinct impedance characteristics in the lower harmonic band. While the R-L-L type exhibits more damping for the lower harmonic wave, with the third harmonic impedance angle and the fundamental wave impedance angle being the same, the R-R-L type has the same impedance angle for both.

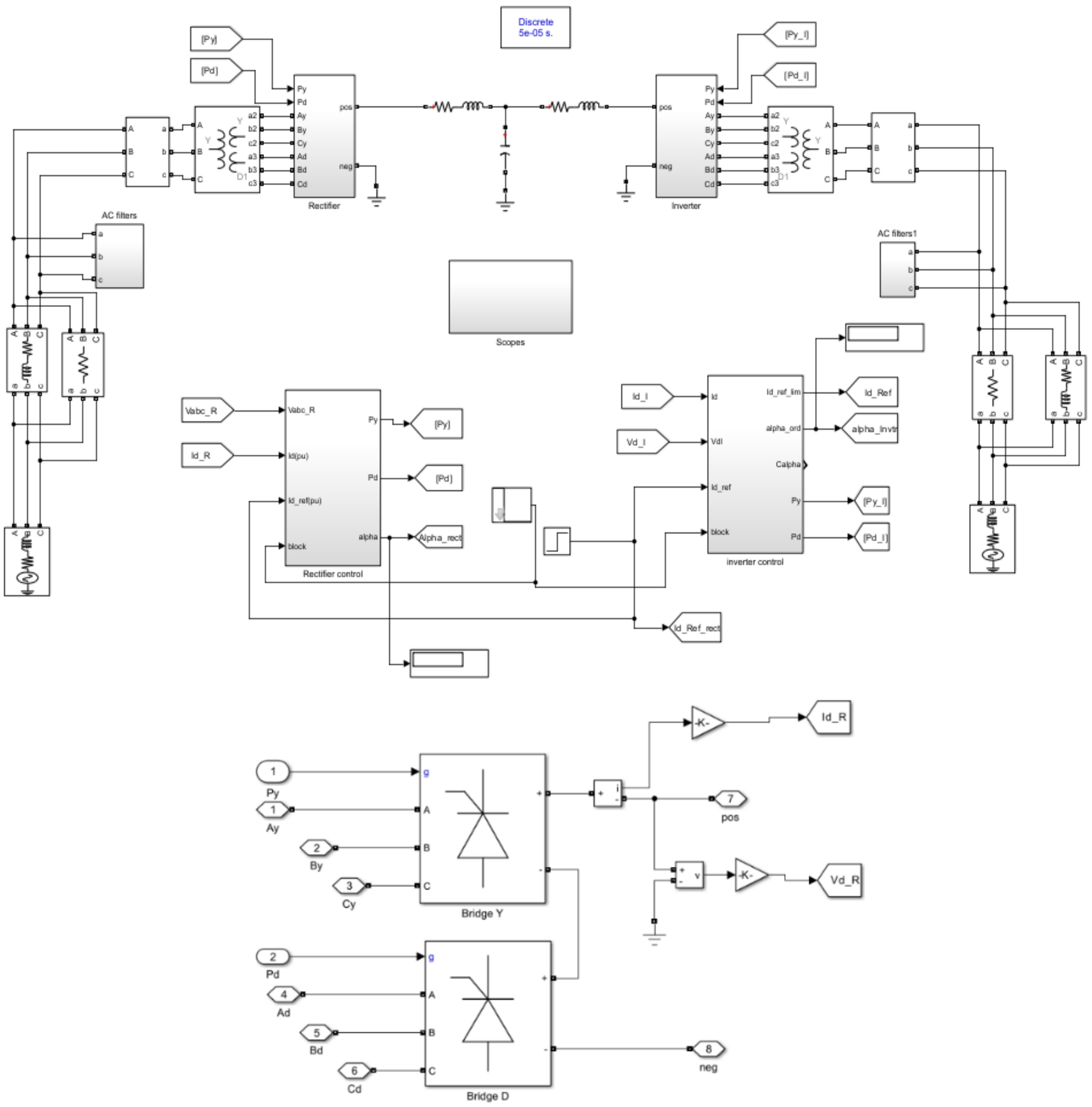

Figure 9. 12 pulse bridge rectifier station

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As shown in Fig 10, since α of the model designed in this paper is 60° during stable operation, when a ground fault occurs on the DC side, the triggering Angle of the converter valve will rapidly increase to more than 70°, so the threshold value of the fault judgment module is set as αref=70°, and α=60°&lt when the model runs stably. αref, so the fault judgment module will not act, when the DC side of the HVDC module is grounded fault setting, the fault judgment module will act immediately, so that the fast current module can be put into operation quickly.

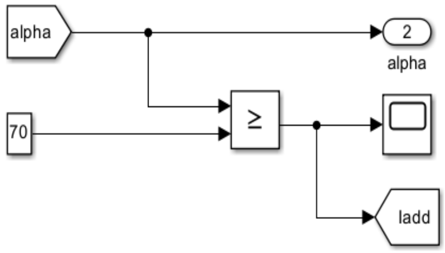

Figure 10. Fault determination module

The model diagram of DC current additional control module is shown in Fig 12. The PI values are 0.12 and 1.05.

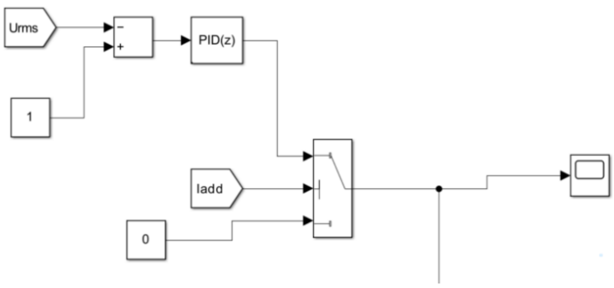

Figure 11. Dc voltage additional control link

4. Simulation result

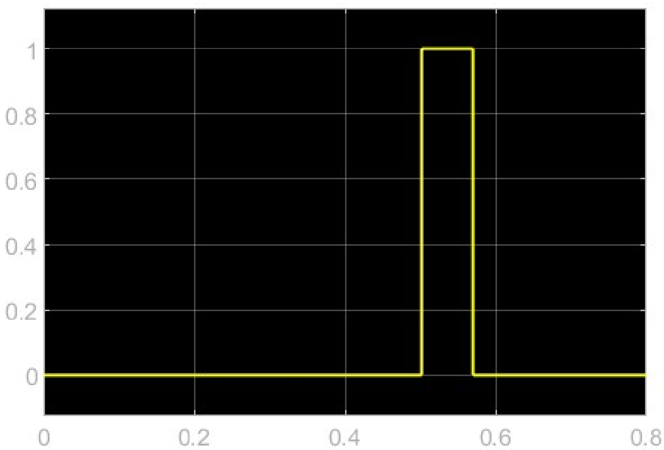

Figure 12. Running result of the fault detection module

As can be seen from FIG. 48, the fault diagnosis module operates at 0.5s, and the output signal becomes 1 during the fault period, which enables the DC current fast response module to be put into operation quickly.

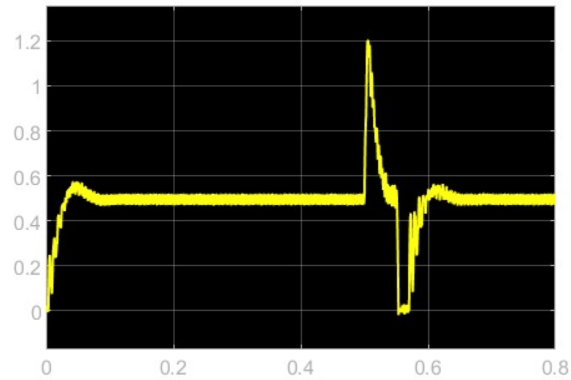

Figure 13. No additional control DC current diagram

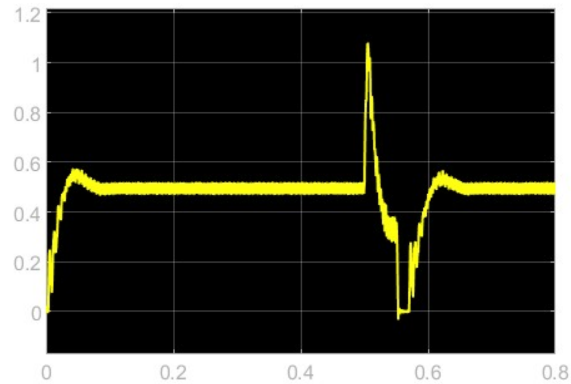

Figure 14. With additional control DC current diagram

There are additional control DC current diagramsIt can be seen from Fig 14 and Fig 15 that the maximum current is 1.2pu without additional control, and 1.12pu with additional control, the maximum current is reduced by 7.14%, effectively reducing the overcurrent, which verifies the effectiveness of this control method.

5. Conclusion

In order to solve the overcurrent problem brought on by LCC-HVDC commutation failure, this research suggests an overcurrent coordinated control technique. The following are the primary conclusions:

1) This article describes the overcurrent characteristics of the LCC-HVDC and builds one using PSCAD. It also specifies the pertinent control mechanisms in the circuit.

2) To prevent errors in judgment, these electrical parameters serve as the foundation for problem identification when LCC-HVDC fails to commutate. These characteristics are based on the rise in AC on the inverter side.

3) This study adds the voltage compensation value to the LCC-HVDC fixed current control by calculating it using the difference between the LCC-HVDC voltage and its reference value.

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