

Retraction

Retracted: Application Analysis of MMC-HVDC AC Tie Line Transmission in New Energy Power Generation

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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- [1] R. Sun, X. Dang, and J. Yang, "Application Analysis of MMC-HVDC AC Tie Line Transmission in New Energy Power Generation," *Journal of Control Science and Engineering*, vol. 2022, Article ID 4301709, 8 pages, 2022.

Research Article

Application Analysis of MMC-HVDC AC Tie Line Transmission in New Energy Power Generation

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In order to solve the problem of new energy power generation, the author proposes an application analysis method based on MMC-HVDC AC tie line transmission in new energy power generation. This method analyzes the research status of the operation, protection, and control of HVDC flexible transmission systems in various countries and summarizes the advantages of flexible HVDC transmission systems compared with traditional DC, the research focus of the system protection control is explored from the research methods and research ideas. Experimental results show that: the dynamic response of the average value of the capacitor voltage when the two control systems are subjected to external disturbances, the disturbance is set as the DC side voltage rise, and the amplitude is 5%. *Conclusion.* MMC-HVDC is beneficial to improve the stability and reliability of system operation.

1. Introduction

In recent years, the automatic disturbance rejection controller (ADRC) has been widely studied as an effective method to solve the control problems of uncertain nonlinear systems. The gist of it is to treat partial changes that differ from the model as total effects, employing a continuous state observer (ESO) as a method that is estimated in real-time and eliminated in feedback control, thereby, improving the control function. When the parameters of the control product change or face unclear interference, it can still have good controllability, strong robustness, and insensitivity to control parameters, and has begun to be applied in many fields. By introducing the concept of bandwidth, the nonlinear form of ESO is linearized and parameterized to produce a linear extended state observer (LESO). Compared with traditional ESO, LESO greatly reduces the parameters used in the system and is more convenient for engineering applications.

2. Literature Review

Ji et al. said that with the rapid development of social modernization and the extensive use of fossil fuels,

environmental problems such as environmental pollution, smog, and global warming have become important factors restricting the economic development of various countries [1]. Yin et al. said that energy is the foundation of every country's economic development, and the important factor restricting economic development is the environment [2]. In recent years, Wang et al. and others said that in order to solve the contradiction between economic development, energy supply, and environmental pollution countries around the world have been actively developing various forms of clean and renewable energy applications, such as wind power generation, photovoltaic power generation, and distributed power generation, in order to replace traditional fossil energy [3]. Xiang et al. said that in the second generation of thyristor current source converter type DC transmission, the short-circuit capacity of the receiving end system is required to be large enough, and it can only work in the state of an active inverter, otherwise, it is prone to commutation failure [4]. Liu et al. This type of converter has to absorb a lot of reactive power and requires a lot of reactive power compensation devices and filters [5]. Kang et al. said that the thyristor converter station has a large investment and a large area, and the harmonics generated by the

converter have a large capacity and low frequency [6]. Farshad et al. said that with the needs of the country's sustainable development and industrialization upgrading, the country will vigorously develop renewable green energy and optimize the energy industry structure [7]. Zhao, C et al. Due to the current transformer type DC transmission technology or AC transmission technology in the context of the expansion of renewable energy; it has the characteristics of dispersion, scale, transmission distance, and so on. Such as solar and wind power, there is no profit in adopting these two technologies, not to mention the addition of heavy objects such as offshore rigs and islands [8]. Bai et al. said that the rapid increase in urban electricity load has made it necessary to continuously expand the capacity of the power grid. However, due to the rational planning of urban areas and the expansion of urban population, on the one hand, a large number of distribution network lines are required to be transferred underground; on the other hand, it requires the use of limited lines to transmit more power [9]. Therefore, more environmentally friendly, more flexible, and more economical transmission methods can better solve the above problems. Wu et al. said that renewable clean energy is geographically dispersed, and its output often has its own intermittency and volatility, such as the large-scale photovoltaic power plants and cluster wind farms described above [10]. In this case, the choice of long-term power transmission is particularly important, which affects the security, stability, economy, and development of the energy industry. The new energy application analysis is shown in Figure 1.

3. Methods

When the DC line of the flexible HVDC transmission system is disconnected and only operates as a single station STATCOM, the startup strategy of each converter station is the same, and the startup process is shown in Figure 2:

After a short-term bipolar disturbance on the DC side of the MMC; the DC bus current and the bridge arm current increase rapidly, the main components being the capacitor discharges current of the power supply submodule and the three-phase short-circuit current. Alternating current power, the capacitor discharge current increases rapidly. When the monitoring and protection system detects a short-circuit fault, blocks the converter immediately. Submodule capacitors discharge. The fault current gradually decreases. After the AC circuit breaker has operated. Only the DC component of the fault current remains zero [11, 12]. Therefore, in order to simplify the analysis process, the MMC DC side bipolar short-circuit fault is usually divided into two processes for analysis before the converter is blocked and after the converter is blocked. The MMC phase unit is composed of $2N$ submodules and two bridge arm inductances connected in series, so the equivalent inductance value of the output loop is $2L_0$. The loss of the equivalent loop, the equations of line inductance and capacitance, and the resistance of the device, etc., are related to R_{eq} to represent [13]. Due to the role of the submodule voltage sharing control strategy, it is generally considered

that the capacitor voltages of all submodules in the phase unit are equal, so the submodule capacitors in the entire phase unit can be equivalently replaced by a capacitance value of C_{ph} , and the following relationship is obtained. (1) shows:

$$\frac{1}{2}C_{ph}U_{dc}^2 = 2N\frac{1}{2}C_0U_c^2. \quad (1)$$

According to $U_{dc} = NU_c$, the equivalent capacitance value can be obtained, as shown in the following formula:

$$C_{ph} = \frac{2C_0}{N}. \quad (2)$$

The equivalent circuit is an RLC second-order circuit with a known initial state, so that the loop differential equation can be listed, as shown in the following equation:

$$2L_0\frac{di_0}{dt} + R_{eq}i_0 = u_c, \quad (3)$$

where i_0 is the discharge current of the equivalent capacitor of the phase unit, and the expression is shown in the following formula:

$$i_0 = -\frac{2C_0}{n}\frac{du_c}{dt}. \quad (4)$$

Substitute formula (4) into formula (3) and get it as formula (5).

$$\frac{4L_0C_0}{n}\frac{d^2u_c}{dt^2} + \frac{2R_{eq}C_0}{n}\frac{du_c}{dt} + u_c = 0. \quad (5)$$

Assuming that the moment when the fault occurs is $t = 0$ s, the initial conditions of the equation are shown in the following formula:

$$\begin{cases} u_c(0+) = u_c(0-) = U_{dc}, \\ i_0(0+) = i_0(0-) = I_0, \end{cases} \quad (6)$$

where I_0 is the DC component of the bridge arm current at the moment of the fault, solve the differential equation formula (5) and substitute the initial conditions of the equation to obtain the analytical expressions of the equivalent submodule capacitor voltage u_c and capacitor discharge current i_0 , such as formulas (7) and (8) shown:

$$u_c(t) = e^{\tau 1} \left[\frac{U_{dc}\omega_0}{\omega} \sin(\omega t + \alpha) \right], \quad (7)$$

$$i_0(t) = e^{\tau 1} \left[\frac{1}{\sqrt{nL_0}} U_{dc}^2 + I_0^2 \sin(\omega t + \beta) \right]. \quad (8)$$

In the above formula, ω_0 is the resonant angular frequency of the discharge circuit, $\tau 1$ is the time constant of the capacitor discharge current, the angle α is the initial phase angle of the discharge current caused by the initial current, ω is the angular frequency of the oscillating discharge current, and the expressions of each variable are shown in formulas (9) and (10):

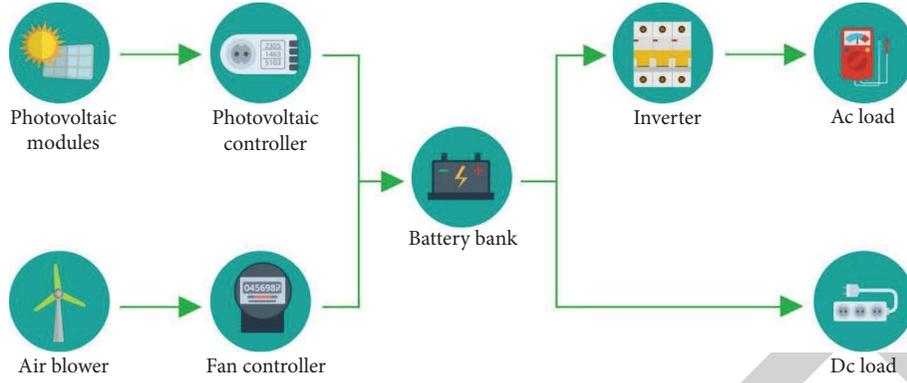


FIGURE 1: Application analysis of new energy power generation.

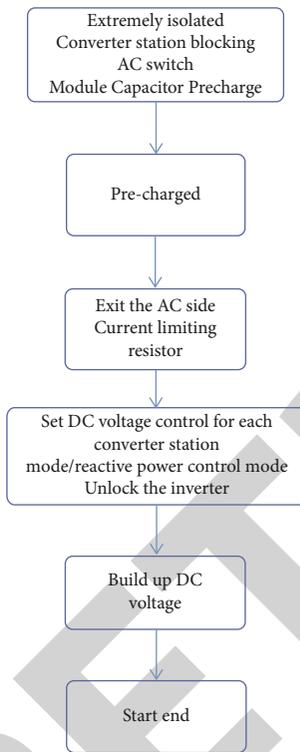


FIGURE 2: Single-station STATCOM startup process.

$$\tau_1 = \frac{4L_0}{R_{eq}},$$

$$\omega_0 = \frac{1}{2} \sqrt{\frac{n}{L_0 C_0}},$$

$$\omega = \frac{1}{2} \sqrt{\frac{n}{L_0 C_0} - \left(\frac{R_{eq}}{2L_0}\right)^2},$$

$$\alpha = \arctan\left(\sqrt{\frac{4nL_0}{C_0 R_{eq}^2} - 1}\right).$$

The capacitor discharge current of the submodule plays a major role in the bridge arm fault current before closing the converter. There are usually a few milliseconds between when the monitoring system detects a system failure and takes action to shut down the converter. Due to the symmetry of three-phase voltages on the network side, the entire MMC topology is three-phase symmetrical, therefore, the three-phase voltage on the grid side cancels the current fed into the DC short-circuit point, and the grid current flowing into the DC line is zero. The feeding current of the AC system only affects the bridge arm current. When the control system detects two-phase blocking on the DC side, it causes the converter to immediately enter the blocking state, and at the same time, the AC circuit breaker is disconnected to interrupt the injected fault current. AC side referred in [14]. The capacitor output circuit of the sub-module is closed; the cut-off current decays continuously and the arm inductance of the bridge drain energy from the free-rotating diode VD2 until the current is zero [15]. The speed of the inductor current decay depends on the equivalent resistance R_{eq} of the DC loop, when a certain bridge arm current in the converter first decays to zero, the bridge arm current appears discontinuous, and the current in the opposite direction cannot pass due to the blocking effect of the diode, and then the system gradually enters a steady state, and the converter is equivalent to an uncontrolled rectifier circuit from the AC side [16, 17]. At the actual operation process, the grid voltage fluctuation will affect the operation of some rectifiers and cause the DC side voltage to change, at the same time, other external disturbances may also affect the system. The dynamic responses of the average value of the capacitor voltage when the two control systems are subjected to external disturbances, the disturbance is set as the DC side voltage rise, the amplitude is 5%, and for the active disturbance rejection controller, the disturbance is an external disturbance [18]. It can be seen from the figure that when the control system proposed by the author is subjected to external disturbance, the output has obvious fluctuations, and the oscillation is about 0.05 s before returning to stability. It can be seen that the proposed control system has good robustness. The effect of parameter changes on the control system is shown in Figure 3:

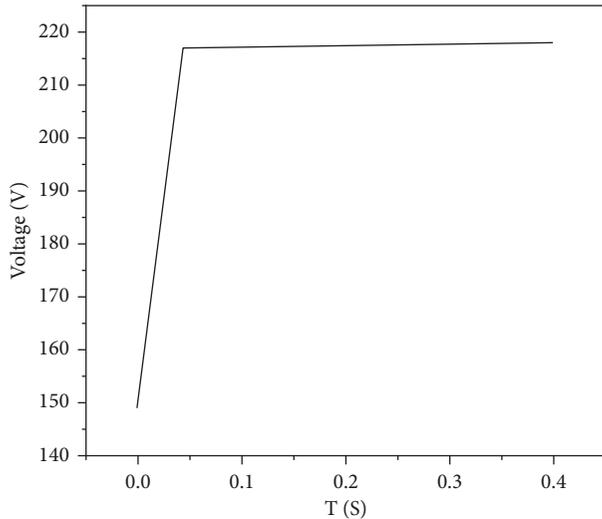


FIGURE 3: The influence of parameter changes on the control system.

In the operation mode of flexible DC transmission at both ends, the third should be in a DC isolation state, and its DC isolation knife needs to be disconnected.

There is no big difference between the startup of the two-station flexible HVDC transmission system and the ordinary two-terminal HVDC project. First, set one station to control the DC voltage and one station to control the active power. Its startup process is shown in Figure 4:

The startup control of the multi-terminal HVDC project can refer to the startup method of the systems at both ends. Since each station is an active network, the converter station can adopt an active startup control strategy. In the specific implementation, one of the stations in the normal mode is used as the DC voltage control station, and the reactive power control is selected as the reactive power control, and the reactive power parameter is set to zero. Stations additionally choose energy management and energy management, and set energy efficiency and energy efficiency parameters [19]. The implementation process is shown in Figure 5:

In summary, the startup process of multi-terminal variable DC transmission does not require special control strategies. Variable DC transmission is similar to conventional DC transmission, and the inverter station is locked into the DC voltage control for the first time. It generates DC voltage that can lock other stations, control transmission and blackouts [16, 20]. The outage strategy of the three-terminal flexible DC transmission system is similar to that of the two-terminal system. First, the power command is reduced below the allowable value, and then, the active power station is first blocked, then the fixed DC voltage station is blocked, and finally, the AC incoming line switch is turned off. As shown in Figure 6:

4. Experiments and Analysis

DC bus bipolar short circuit is one of the biggest defects of MMC-HVDC system. The half-bridge submodule's MMC-

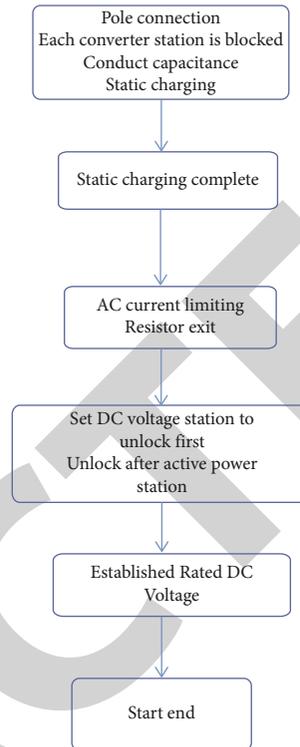


FIGURE 4: Startup process of the flexible DC system at both ends.

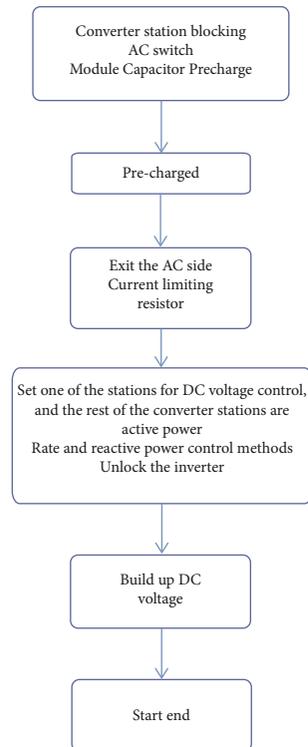


FIGURE 5: Startup process of the three-station HVDC transmission system.

based DC-to-DC converter is indistinguishable from DC. Now, it is wrong. In order to ensure the stable operation of the MMC-HVDC system before and after the fault and the safety of key equipment in the power grid, it is necessary to

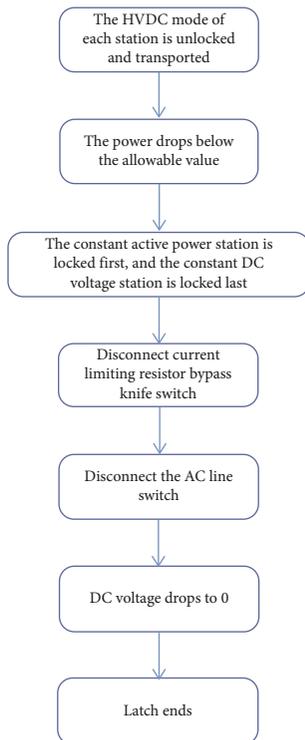


FIGURE 6: The normal shutdown process of the flexible HVDC transmission system.

analyze and study the bipolar short-circuit fault mechanism of the flexible HVDC transmission system, and to master the interpole short-circuit fault process and the evolution law of fault overcurrent. They provide theoretical methods for overcurrent suppression strategies and system protection measures during faults. Based on the analysis of bipolar short-circuit damage, the analytical expression of the bridge arm current and DC bus current is derived, and the main factors influencing the short-circuit current are evaluated. For this reason, relevant short-circuit protection measures are recommended. In the Matlab/Simulink simulation environment, a simulation model of the DC-side bipolar short-circuit fault of an eleven-phase MMC-HVDC system was built. The simulation results show the accuracy of short-circuit current analytical expression and the effectiveness of the fault current suppression strategy. After a bipolar short-circuit fault occurs on the DC side of the MMC, the DC bus current and bridge arm current increase rapidly, and the main components are the submodule capacitor discharge current and the three-phase short-circuit current of the AC power supply. The discharge current of the capacitor increases very quickly. When the monitoring and protection system detects a short circuit, the converter is immediately closed, the capacitors of the submodule are discharged, and the fault current begins to gradually decay. After the AC circuit breaker trips, the fault current has only a DC component, which remains zero [21, 22]. Therefore, in order to simplify the analysis process, the MMC DC side bipolar short-circuit fault is usually divided into two processes for analysis: before the converter is blocked and after

the converter is blocked, the monitoring system detects a bipolar short-circuit fault on the DC side. The converter must be put into the blocking state immediately, and at the same time, the AC circuit breaker will interrupt the fault current injected on the AC side. The capacitor discharge circuit of the submodule is closed. The fault current decays for some time, and the inductance of the bridge arm discharges energy through the free-wheeling diode VD2 until the current becomes zero. The rate of decay of the inductor current depends on the equivalent resistance of the DC loop R_{eq} . When some of the bridge currents coming out of the converter first drop to zero, the bridge arm currents will continuously appear and the opposite side will not be able to pass. Diode blocking effect, then, the system gradually reaches a steady state, and the converter is equivalent to an uncontrolled rectifier circuit on the AC side. From the analysis of the bipolar short-circuit fault mechanism, it can be seen that the development of the fault is divided into two stages: the rise of the fault current before the submodule is blocked and the decay of the fault current after the block. Therefore, the suppression strategy of fault current should be comprehensively considered from two aspects: reducing the rising level of fault current before submodule blocking and speeding up the decay rate of fault current after blocking. The author introduced an overcurrent suppression method based on virtual resistance combined with neutralization resistance; that is, the virtual impedance control strategy includes a DC circuit in the damping impedance before blocking MMC. Accelerate the tripping of the fault current to quickly clear the DC-side two-pole short-circuit fault [23]. Within a few milliseconds from the occurrence of the fault to the blocking of the converter, the control still has nearly 10 to 20 control cycles of the MMC system, and the effective control at this time can reduce the fault current. The phase of the bridge arm and the DC side, from the analysis of the influence of fault current, it can be seen that the larger the bridge arm inductance L_0 in the output voltage, the more obvious the influence on the increase of fault current, but it is not good for attenuation. Fault current after blocking; therefore, it is considered to add a virtual inductance at the outlet of the DC bus, and the inductance characteristics are mathematically modeled, and then, mapped into the controller to play a corresponding role. In this way, the process of fault current can be affected. After the MMC is blocked, the controller fails, and the decay process of the fault current after blocking is not affected. A brief bipolar fault occurs on the DC side of the MMC. After a few milliseconds, the converter is blocked and the fault current rises to a maximum value and starts to decay with constant time around the circle. Because the value in the circuit is small, the fault current decays slowly, and it usually takes a long time to decay to zero, which is easy to cause the device to be in an overcurrent state for a long time, which is unfavorable. System fault: clear and return. Due to the existence of a large number of nonlinear links in the traditional nonlinear active disturbance rejection controller, as a result, the traditional nonlinear active disturbance rejection controller needs to face the problems of too many parameters to be debugged, ambiguous physical meaning of parameters, and being

difficult to debug when designing. Moreover, at present, there is no accurate method to calculate these parameters well, especially in power electronic systems, some commonly used tuning empirical formulas, such as the Fibonacci sequence method, and so on often cannot get a good control effect, therefore, in the design of the traditional nonlinear ADRC controller, a large number of parameters are usually obtained only by trial and error, which will lead to a lot of time and energy being wasted in the parameter adjustment process, and the debugging efficiency is extremely low. It is this significant defect of the traditional nonlinear ADRC that makes it not put into large-scale industrial applications [24]. Aiming at the shortcomings of the above traditional ADRC, the parameters in the ADRC are given physical meaning. He linearizes and parameterizes the nonlinear ESO and NLSEF, optimizes them, and gives the LESO and the linear state error feedback control law (linear state error feedback, LSEF) parameter configuration general method, thus designing the linear active disturbance rejection controller (LADRC). Then, through the frequency domain analysis, it is concluded that the linear extended state observer has higher performance than the nonlinear extended state observer (NESO) at high frequency. In general, compared with traditional ADRC, LADRC greatly reduces the parameters used in the system and at the same time gives the adjusted parameters physical meaning, and gives the general method of parameter adjustment. The parameter adjustment process is no longer a traditional trial and error process, and it takes less time and energy and is more convenient for engineering applications. Therefore, in recent years, LADRC has made some progress in the research fields of inverters, gyroscopes, superconducting RF cavities, and servo systems. At the same time, LADRC released the economic analysis of motion control in 2009; in 2010, it replaced PID control for the first time in a North American nylon pipe extrusion production line, saving a lot of energy; in 2013, Texas Instruments (TI) released the LADRC-based DSP globally chip. It can be seen that LADRC is favored by the majority of engineers and has broad prospects for industrial application. The various disturbances in the control of the bridge arm circulation are analyzed, at the same time, it can be seen from the simulation that the bridge arm circulation contains the fundamental wave component, the double-frequency component, and other AC components, therefore, it is obviously difficult for the traditional PI controller to achieve error-free tracking, so it is considered to use ADRC instead of the PI controller for control, however, the bridge arm circulation loop is used as the inner loop of the control system, the traditional ADRC, because the transition process of TD arrangement is difficult to meet the rapidity requirements of the inner loop, and in the traditional LADRC, because the general LSEF adopts the form of a PD controller, the static performance is not ideal, at the same time, the differential component in LSEF is observed by LESO, which will also generate a certain delay, reduce the static performance of the system, and also cannot fully meet the requirements. Therefore, it is considered that, on the basis of using the PI controller, an extended state observer is separately added to observe and compensate for the system disturbance, that is,

the ADRC control architecture of PI + ESO. It can be seen that compared with the traditional ADRC controller, the bridge arm loop current control using the PI + LESO controller reduces the TD arrangement transition process, the rapidity of the system is enhanced, and the PI control with easier parameter setting is used instead of NLSEF, and LESO is used instead of ESO in traditional ADRC, which reduces the parameters used in ESO, design difficulty of the ESO link is reduced. Since the PI + LESO controller simplifies and improves the structure of the conventional ADRC controller, the number of parameters that need to be adjusted is greatly reduced compared with the traditional ADRC controller, enhanced its practicability. Compared with the traditional PI controller, it increases the antisturbance performance while ensuring the rapidity of the system. Compared with the traditional LADRC controller, the control architecture uses the PI controller to replace the PD controller commonly used in the LSEF in the traditional LADRC, avoiding the system delay caused by the differential component observed by the LESO in the LSEF, so that the control system has better quickness. Based on the evolution process of fault current, an analytical mathematical model of bipolar short-circuit fault transient current is established, and the main factors affecting the fault current are analyzed. On this basis, corresponding short-circuit fault current suppression measures are proposed. Finally, a related MMC converter station bipolar short-circuit fault model is built in the Matlab/Simulink environment for simulation analysis, which verifies the accuracy of the fault current analytical model and the effectiveness of the overcurrent suppression measures [25]. The details are as follows: the evolution of the bipolar short-circuit fault mechanism is divided into two stages before and after the converter shutdown; Based on this, a single-phase equivalent circuit model is obtained before and after blocking. A mathematical analytical expression of the a-phase upper and lower arm fault current and DC side short-circuit current is derived, and the correctness of the analytical expression of fault current is confirmed by simulation. The three main system parameters affecting the DC side fault current are mainly analyzed: the bridge arm inductance L_0 , the submodule capacitance C_0 and the loop loss resistance R_{eq} , respectively, as a single variable to analyze the change process and influence degree of the fault current. An overcurrent suppression method based on virtual impedance and damping resistance is introduced, before blocking, the virtual impedance control strategy is used to restrain the rising level of fault current, and after blocking, the DC circuit is put into damping resistance to speed up the attenuation of fault current; Finally, the effectiveness of the overcurrent suppression strategy based on virtual impedance and damping resistance is verified based on the bipolar short-circuit fault model [26, 27]. The topology structure of MMC modular multilevel converter and its submodule working principle, modulation method, submodule capacitor voltage equalization control strategy, interphase circulating current suppression strategy, etc. are combed in detail. The analysis shows that the recent measurement has the characteristics of a low frequency of change wave, small change, and fast tracking; the capacitor

voltage sorting algorithm can perform good voltage equalization control; the main element of rotation is the double-frequency negative temporary component, and the opposition based on the dq rotation coordinate will meet. Interference are affected by intersections. The mathematical model of the abc three-phase static control system and the MMC converter in the dq rotating coordinate system is deduced, and it is proved by verification that the inductance of the upper and lower arms of each phase of the MMC is infinite in the connection of equal points. Therefore, in the case of stable operation, the MMC control operation is designed to be useful; in addition, the entire controller of the MMC consists of two loop-decoupled control concepts, the current inner loop and the outer loop. By using the DC side grounding method through large resistance, the AC and DC side fault simulation model of the 11-level MMC-HVDC system was developed in the Matlab/Simulink environment. At this point, the failure mechanism; the evolution of fault formation and fault currents are simulated and analyzed. During various failures, the system has different levels of overvoltage and overcurrent. This indicates a threat to the security of the system. An analytical model of the transient current of the MMC DC side bipolar short-circuit fault is established. On this basis, the main system parameters that affect the fault current are analyzed: the analysis shows that the bridge arm inductance L_0 suppresses the fault current, the capacitor C_0 promotes the growth of the fault current, and the loop resistance R_{eq} plays a role in accelerating the decay of the fault current. Finally, the author proposes an overcurrent suppression method based on virtual impedance and damping resistance, and simulates and analyzes the suppression degree of fault current.

5. Conclusions

Flexible DC transmission technology is a research hotspot that has attracted much attention in China in recent years. However, flexible DC transmission is only in the initial application stage in China, and the feasibility of its work has not been confirmed. The new technology business and lack of operational experience have added many doubts about the long-term stable operation of the DC transmission potential behind it when it is connected to the real power grid. Connecting the AC transmission to the AC power grid creates new problems in power grid operation, especially changing the protection mode and creating new differences between the control mode and the normal DC transmission. Studying the protection and control algorithms of the MMC-HVDC DC system is helpful to improve operational stability and reliability.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

Research on Agricultural Equipment Innovation based on New energy and Internet of Things Technology (no. 2018YJ51).

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