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Research on Modeling Control and Protection Strategy of Supplying Power to Passive Network of MMC-HVDC System

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Abstract: This paper is based on the EL mathematical model of the MMC synchronous rotating coordinate system, derived the MMC passive control law, the inner ring current passive controller is designed and the AC voltage controller is set. In order to restrain the negative sequence current caused by the network voltage unbalance or asymmetric AC system fault, the positive and negative sequence of independent passive controller and the control of failure protection strategy were proposed. Finally 21st level supply power to passive network-MMC HVDC system model was set up under the PSCAD/EMTDC, the response characteristics of various working conditions is the controller and the control protection strategy has been carried on a simulation, and the characteristics of the positive and negative sequence of passive control and vector control were comparative analyzed.

Keywords: Modular multilevel converter, high voltage DC, transmission, passive Network, mathematical model, passive control, control and protection strategies

1. INTRODUCTION

In recent years, with the mass development and utilization of renewable clean energy such as wind power and solar energy, a kind of more economical, flexible, and environmental transmission way is urgently needed for new energy network. Based on voltage source converter (VSC) and pulse width modulation technology of flexible HVDC technology is a new generation of HVDC technology, it not only solved the commutation failure problem of the traditional HVDC, but also realized the independently decoupling control of transmission of active power and reactive power, also, it has black start function, which can realize the long-distance power supply to passive network. Thus VSC-HVDC transmission system, has rapidly become the ideal connection mode of the interconnection among wind farm network, network-connected photovoltaic (pv) and asynchronous AC network between with its technical advantages [1- 2].

VSC is the core of VSC-HVDC transmission system parts, which has a number of different topologies, now 2 or 3 level topology of VSC are widely used in the VSC-HVDC project, there are problems high switching loss caused by too high switch frequency, the static, dynamic average voltage and electromagnetic interference caused by a large number of insulated gate bipolar transistor (IGBT) devices in cascade[3]. Modular multilevel converter (MMC) was a new topology put forward in 2002 by Marquardt and Lesnicar [4]. MMC has the advantages of low switching loss, modular design, small output voltage harmonic content, easy to expand electrical level, and it can also work in a passive inverter mode as same as the VSC, therefore, MMC HVDC system has a wide application prospect in renewable clean energy network, power supply to passive network and city over a long distance, and other fields [5-6].

MMC HVDC power transmission system supplying power to passive network is the an important application field of MMC-HVDC transmission and distribution technology. At present, the research of the control strategy of VSC-HVDC system of power supply to the passive network is mainly aimed at 2 or 3 level topology structure of the VSC, and mostly are the modeling and control under steady-state case of VSC-HVDC system in the network voltage balance. This topic puts forward the control strategy of feedback linearization control strategy based on discrete mathematical model, and carried on the simulation verification, and to supply power to passive network MMC-HVDC system fault control and protection research. In actual operation, the AC network voltage balancing can't completely, the failure probability of asymmetric AC system is also very big, so it is necessary to research the control protection strategy supply power to passive network of MMC-HVDC system.

2. MATHEMATICAL MODEL OF MMC

Working Principle

The AC side of MMC is connected to the AC network by the coupling transformer. There are a total of six bridge arm of three-phase MMC, each phase unit is consisted of upper and lower two bridge legs, each bridge arm is cascaded by theidentical n half bridge structure of sub module (SM) and a bridge arm reactance. The port output voltage u_{sm} is decided by the working state of the SM. When Sp breakover, Sn turn-off, the output voltage u_{sm} is equal to the unsharp mask SM capacitance voltage Uc, and SM input right now, the bridge arm current charge or discharge to subsidiary module capacitance. When Sp turn-off, Sn breakover, output voltage u_{sm}=0, the by-passed of SM is resected at this time.

According to the reference direction of various physical quantities, DC voltage equation from Kirchhoff's voltage law is:

$$U_{dc} = u_{pj} + u_{nj} + L\frac{d\left(i_{pj} + i_{nj}\right)}{dt} \qquad (1)$$

The type (1) shows that by controlling the output voltage upj, unj in each phase upper and lower bridge arm of MMC, that is the control the module number of upper and lower bridge arm in each phase of MMC, and satisfy the sum of the upper and lower bridge arm input module number identical to n, which can realize the control of the DC voltage.

3. TECHNOLOGY ADVANTAGE OF MMC-HVDC

In addition to the above introducted advantages that MMC can reduce switching loss, modular design reduces the agreed harmonic content of electricity fli and enhances its extensibility, MMC also has the following advantages:

Can Achieve Soft Switch

MMC adopts the multilevel structure, which is able to generate AC voltage with smaller level, which can control the change rangeability of the output voltage MMC in small range, so as to make the fluctuations of DC EI also limited in a smaller range, at the same time effectively reduce the electric stress converter valve that is under.

Open Phase Opearation Can be Run

Capacitance of MMC is scattered distributed in each phase of sub module, each bridge arm can be equivalent to an independent voltage source, ke phase can be run independently. Because when the one phase of system is fault, it doesn’t affect the operation of the other two phase, namely: 1 fault phase is still sustainable operation, thus ensuring the MMC-HVDC asymmetry problems in the system, to ensure uninterrupted power supply. Such as when the system is of single-phase earth fault occurs, the un-fault phase can also continue to run full power, and in the condition of guaranting system flow, the un-fault phase current can be appropriately increase, to improve the transmission capacity of system during fault.

Improve the Ability of Fault Crossing

As there is no common DC capacitor in MMC DC side, its capacitance uniform is distributed in each phase of sub module, comparing to the two level of VSC, its electrical energy storage ability is stronger. When transient fault occurs in the AC system, DC voltage can ensure the stability of MMC-HVDC system, inverter can also be sustainedly, stably running for a period of time, thus improving the through capacity of AC failure.

Voltage Sharing of Device is Easier to Implement

Traditional two level of VSC each phase is direct cascade of hundreds of IGBT, to keep the balance of IGBT power consist, the error of the driving circuit need to be controlled in a very short period of time, the average HI of device is relatively difficult to achieve. MMC uses the cascade of submodule, rather than direct cascade of switching devices, voltage of device can be realized through sub module power capacitor HI balance modulation strategy.

Improve the Ability of Fault Protection

For MMC sub-modules, through improving the structure redundancy design of converter valve can be achieved, when the module failed, standby module can be quickly put into use, which does not affect the normal work of the converter system; When some serious problems happen, such as short-circuit faults on the DC side can limit impact current rising at a lower level, which effectively protects the IGBT and the fly-wheel diode, and improves the reliability and availability of the system.

4. CONTROL AND PROTECTION STRATEGY OF MMC-HVDC SYSTEM

At present, the control strategies of MMC-HVDC systems are divided into two types: indirect current control and direct current control. Indirect current control is also known as "direct control", that is to input the difference of control target reference value and measured value directly into P_I (proportional integral) controller, by setting the appropriate control parameters, can output the modulation M and phase-shifting Angle δ . Indirect current control structure is simple, but there are disadvantages such as the AC current dynamic response is too slow, too sensitive to system parameters change and so on. Direct current control is known as the "vector control", usually adopts double closed loop control, voltage control and the inner current control loop. Outer ring voltage controller receives the system-level control of active power and reactive power reference value, the output of the inner ring current reference. Inner ring current controller receives the outer ring of inner ring current reference voltage controller, and through certain control links, output and phase-shifting Angle δ modulation M. At present the commonly used direct current control is based on d_q rotating coordinates system of the double closed loop control, the control strategy of current inner loop coupling term, need feedforward decoupling.

As to the VSC-HVDC system which supply power to passive network, the outer control of sending end usually uses constant DC voltage and reactive power control mode. Select the inner ring current reference as follows:

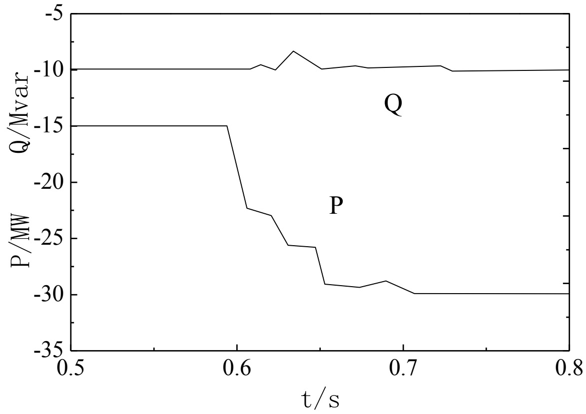

Fig. (1). Simulation Wave of Active and Reactive Power Load.

Table 1. Parameters of the Simulation System.

The Parameter Value	40
Capacity S/MVA	40
Dc voltage Udc/kV	20
The bridge arm module number n/	10
AC voltage of sending end/kV	1
Reactance of AC system /mH	1
Resistance of AC system /Ω	0.1
Leakage of resistance Transformer LT (pu)	0.1
Rated voltage of valve side/kV	22
Rated voltage of network side/kV	10
Rated capacitance voltage of submodule/kV	2
Capacitance of submodule/μF	9 000
Commutation reactance value L/mH	8
Filter capacitor of receiving end of C/μF	20
DC cable length/km	10

$$i_d^* = k_{p3}\left(U_{dc}^* - U_{dc}\right) + k_{i3}\left(U_{dc}^* - U_{dc}\right)dt \tag{2}$$

$$i_q^* = \frac{-Q^*}{1.5u_d} + k_{p4}\left(Q - Q^*\right) + k_{i4}\int\left(Q - Q^*\right)dt \tag{3}$$

Voltage control on the outer ring fixed of receiving end. Receiving end of the connection is passive network, and its outer loop control must adopt AC voltage control [7]. This is the characteristics of power supply to passive network of VSC-HVDC system, passive inverter controller design is also the focus of this article.

Because the grid synchronous phase is needed by the transformation of dq, but the recieving end of the passive network has no power, which can not obtain the synchronous phase by phase-locked loop (PLL), the synchronous phase needs to be given directly:

$$\theta = 2\pi f^* t \tag{4}$$

In order to get better current response needs to retain the current inner ring, and AC voltage control should be taken as the outer loop control. This will need to give the relationship between the AC voltage and ac current. However, due to the variability and complexity of load, it is impossible to get the general accurate load model, the design of the control system for the end is with great difficulty, supply power to passive network is the control difficulty of VSC-HVDC system.[8] cancelled the inner ring current negative feedback, only the AC voltage feedback control, belong to the phase of the control (indirect current control).

5. SIMULATION RESEARCH

In PSCAD/EMTDC has established the supply power to passive network type MMC VSC-HVDC simulation system, the structure of system is shown in Fig. (**1**), the system parameters are given in the table below. Normally, the

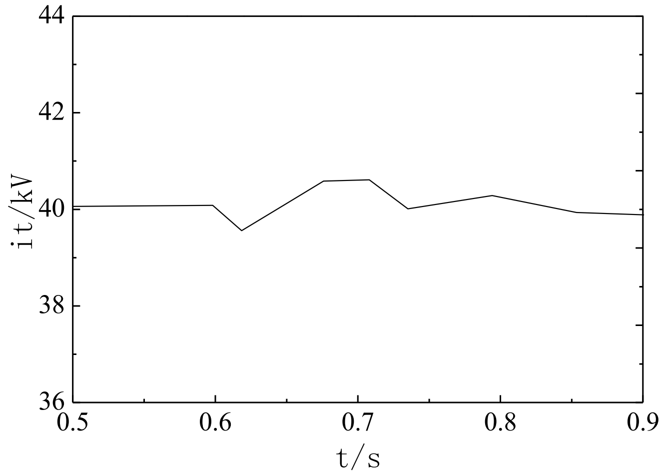

Fig. (2). Simulation Wave of Dc Voltage of Rectifier Side.

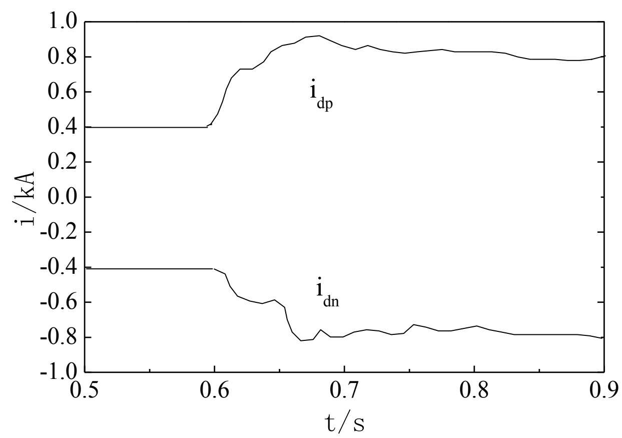

Fig. (3). Simulation Wave of DC Current.

receiving end of the outer voltage control reference of u_d* and u_q* respectively take 1.0 (pu) and 0.0 (pu), namely the coincide of d axle of the passive side AC voltage vector and rotating coordinate system.The simulation research are on the following three conditions.

Active Load Increase

The initial active and reactive power load, Dc Voltage of Rectifier Side and DC Current of receiving end are respectively 15 mw and 10 mvar; In 0.6 s, the active load of the end increased 15 mw. Fig. (**1-3**) are respectively by the end of the active and reactive power waveform and sent to the DC voltage and current waveform. Basic is three-phase symmetrical sinusoidal AC voltage and current waveform, frequency stability. Active load increases, the voltage amplitude will be a slight small drop, then returnS to the initial steady state value.

As active current greatly increased as a result of the controller, the three-phase alternating current amplitude is increased significantly. As long as the load of the three-phase AC voltage control in its rating, the load of active and reactive power demand can be satisfied, Fig. (**1**) of active and reactive power waveform well reflects the situation.Under steady state, the DC voltage stability in its rating. When by the end of the active load increases, the DC voltage drops, then send the DC voltage controller to work, to return to DC voltage to their ratings.In order to increase the active transport, a direct current flows. Transient process of DC voltage and DC current overshoot is smaller, the impact on the system is very small.

Reactive Load Increase

The initial active and reactive power load of receiving end are respectively 30 mw and mvar 5; In 0.6 s, the active load of the end increased 5 mvar. In the case of double reactive load, AC voltage and AC current will soon be able to restore to the reference value, outer ring are given in the control of reactive current reference iq* increases, the inner ring current control makes iq tracke the change of iq*, thus increasing the reactive power of the inverter output. Close to zero steady-state error of the control volume, short transient adjustment process, the control system of steady state and transient performance are ideal.

Providing passive network by the end of the three-phase AC voltage and current basic symmetry of sine waveform, the power supply quality is better. Active and reactive power measurement waveform shows that the load of active and reactive power requirements are satisfied.Dc current after the transient process of around 0.05 s return to the initial state.

CONCLUSION

This paper combines with the characteristics of passive network, designes the structure of the double closed loop type MMC type VSC-HVDC passive inverter controller, the inner ring current negative feedback has achieved the high quality of alternating current response, outer ring voltage negative feedback has achieved the high quality AC voltage output. By setting the network synchronization phase, no source inverter frequency invariant features are ensured. Above coordination strategies improve the passive inverter power supply quality of VSC-HVDC.Simulation system is built which can supply power to MMC type VSC-HVDC passive network power based on PSCAD/EMTDC software. The simulation results show that the designed controller has a good steady precision, an increase in active load, increase of reactive load and the lifting of the AC voltage transient process Chinese super small, adjust fast. Passive inverter AC voltage and current waveform of the basic is three-phase symmetrical sinusoidal waveform, frequency stability, good quality of power supply.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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