A Control Strategy for MMC-Statcom under Unbalanced Voltage System

Jimin Jing[1,*],Jingze Wang[1],Yanchao Ji[1]

Harbin Institute of Technology
Harbin China

***Abstract* — This paper develops a control strategy for Modular Multilevel Converter (MMC) static synchronous compensator (STATCOM). We describe the working principle and mathematical model of MMC, compare it with the multilevel converter modulation strategy of several commonly used systems, and the nearest level strategy and MMC STATCOM AC-DC control strategy. We build a simulation model of MMC STATCOM in the PSCAD/EMTDC environment to verify the research on the control strategy. The results show that MMC - STATCOM control strategy has very good control effect. With the development of power market, users require more strictly quality and reliability of power supply. Therefore there is a need for the corresponding device to ensure grid reliability and improve electric energy quality. Static synchronous compensator (STATCOM) as a flexible AC transmission system is an important reactive power compensation device, has excellent control performance and good compensation effect. Multilevel topology structure means the STATCOM device can be used in high voltage and high power systems.**

Keywords - STATCOM ; MMC; the nearest level modulation; decoupling control

I. INTRODUCTION

With the development of electronic technology, the emergence of a compensation device of full controlled power electronic devices based on static var compensator, than SVC is more advanced, called static synchronous compensator (STATCOM) [1]. Compared to SVC, STATCOM, adjust the speed of faster running a wider range, in the output current harmonic content is less, and the use of the capacity of capacitance and inductance device should be less than SVC, greatly reducing the occupied area of the equipment and the equipment cost, has great application prospect in the field of reactive power compensation [2, 3].

The rapid development of society, the industrial economy, the city scale is expanding constantly, make the power system network began to more geographic regional development and broad distribution, regional cooperation and coordination between the need to run, to form a complete network system [4-7]. According to the national development plan, the construction of China's electric power system is divided into two stages, the goal in the near future to will power resource transportation, the western rich power resources to the eastern developed regions of North and south, the realization of the construction of the sharing of power plants and transmission network, and separate management of nationwide power system network; and long term objectives is intelligent power grid construction an information, digitization, automation, interactive [8]. To accomplish this goal, Internet will inevitably relates to the electric power system, the interconnection makes the various disturbances in power systems, fault and abnormal operating conditions are more prone to the operation of the whole grid impact caused by power quality, reduce, serious and even lead to system collapse, resulting in large area blackout [9, 10].

In recent years, MMC-STATCOM as a novel var compensation technology, the rapid development of. Compared with the traditional transformer of multiple STATCOM, the structure of the STATCOM eliminates the need for multiple transformers, greatly reduces the size and cost of the unit [11]. At the same time, the application of cascade multilevel and PWM modulation technology, significantly reducing the switching frequency of the switching element, reduce the content of harmonic compensation current, can better the device used in high voltage system. Therefore, studies key technologies of MMC-STATCOM fast current tracking control, DC capacitor voltage balance control, to shorten the advanced countries and China power has important implications for quality level gap, control technology and equipment to achieve MMC-STATCOM industrial applications [12].

MMC-STATCOM reactive power compensation principle and mathematical modeling. According to the structure of MMC-STATCOM, the principle of its operation mode and the reactive power compensation is analyzed; the gradual establishment of the mathematical model in ABC coordinates system and DQ rotating coordinate system of a single MMC unit, MMC-STATCOM. Study on technology and modulation control strategy of MMC-STATCOM. Based on the analysis of the characteristics of existing control technology, by selection of the state feedback control as the decoupling of AC side control technology, the DC side capacitor voltage balance control is used to control technology based on active power voltage vector superposition, which combines hierarchical control thinking.

II. RELATED THEORY

A. *The research status of Current MMC-STATCOM control technology*

According to the different controller structures can be divided into: composite control open-loop control, closed-loop control and the combination of the two; at present, all kinds of MMC-STATCOM control methods more mainstream, in accordance with the different controller controlled physical quantity into two categories: direct current control and the current indirect control [13]. Direct current control refers to the controller to change the reactive current as the control object to the direct control and indirect current control, the principle is to use the change of electric current is obtained, the converter output voltage reference value regulated by PI, and then use PWM modulation control modulation of multilevel converter [14].

Compared with the direct current control method, the indirect current control is easy to realize constant switch frequency, so in practical application of MMC-STATCOM, often using the indirect current control. Voltage oriented control (VOC) is a common method of indirect control of current, the method to calculate the current reference value difference with the current actual value, and through the PI regulator output voltage value of the reference converter [15-17].

B. *MMC-STATCOM reactive power compensation principle*

MMC-STATCOM reactive power control mode refers to the reactive MMC-STATCOM instruction size, the reactive power command can be formed by the reactive power dispatch instructions given, can also be a reactive real-time detection of power grid load. This control mode is mainly used for power transmission network, because for transmission system, which can be through the integrated automated scheduling, so that the reactive power real-time online distribution on each line.

MMC-STATCOM way: through the application of the control system and the modulation strategy to make the four switching devices of each MMC unit was opened in continuous conversion and off, that each unit of DC side voltage on the output capacitor energy storage and conversion to the ladder type modulation wave, AC voltage modulation wave and the converted with the same with the grid voltage frequency. Therefore, when considering only the fundamental frequency, MMC-STATCOM can be equivalently viewed as amplitude and phase can be controlled, and the power of an AC with the frequency of the voltage source. Figure 1 shows the single phase equivalent circuit diagram for the connection reactor assumption regardless of loss and loss of the converter. In this equivalent assumption, the phase adjustment of power grid side voltage and the output voltage of MMC-STATCOM to the same. Regulation of the specific process is shown in Figure 1b. Seen from the figure, with the change of the amplitude of UC, MMC-STATCOM I and UC compensation current phase difference can take two values, are 90 DEG and 90 DEG lead lag, amplitude specific lead and lag relationship with UC and US were compared with correlation.

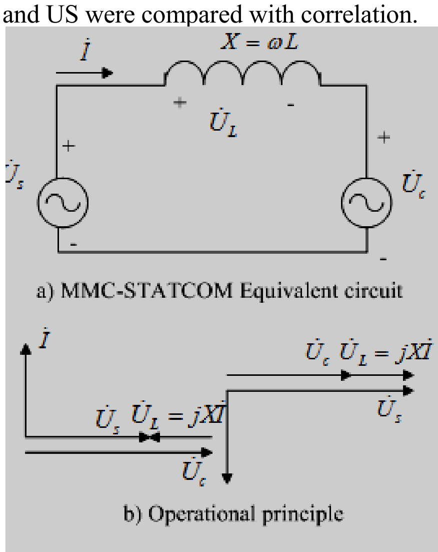


Figure 1. The single phase equivalent circuit diagram for the connection reactor

III. MMC TOPOLOGICAL STRUCTURE AND WORKING PRINCIPLE

Three-phase modular multilevel converter consists of 6 arms of the bridge and the bridge arm reactors. Each bridge arm consisting of N identical sub module. The topological structure was shown in Figure 2 of the three-phase modular multilevel converter.

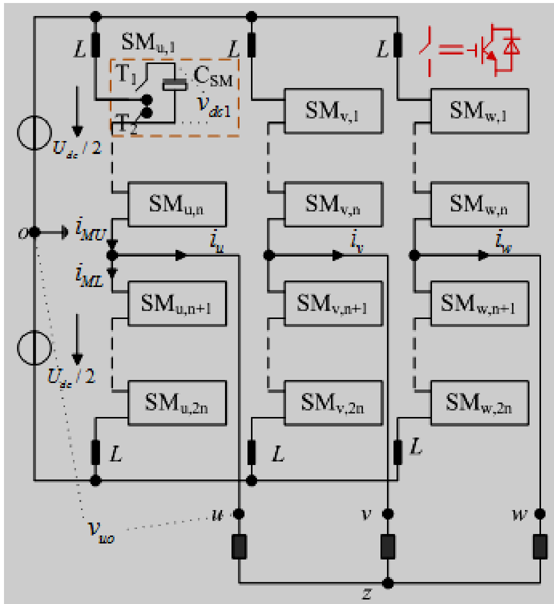
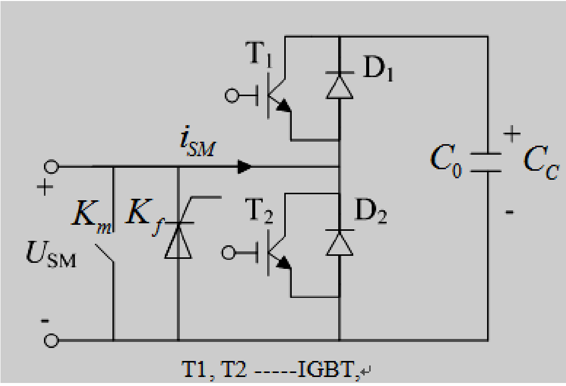


Figure 2. The topological structure

MMC through the orderly guide control module on and off, realizing AC power to DC power transformation. The topological structure of MMC module was shown in Figure 3.



T1, T2 -----IGBT,
D1, D2 ----- anti parallel diode of IGBT,
C0-----dc side capacitor of module,
UC-----capacitor voltage,
USM----- voltage at the ends of the sub module,
i_{SM} -----current into the sub module

Figure 3. The topological structure of MMC module

The sub module has 3 working states: the input state, off state and the locking state. In the converter in the process of operation, the output voltage regulation of UAP bridge arm can be by adjusting the number of sub module of the opening of the. In the ideal case, each bridge arm can be connected in series is equivalent to an ideal voltage source and resistance.

With a as an example, to ignore the pressure drop converter bridge arm reactor, available

$$u_{a1} = \tfrac{1}{2}U_{DC} - u_{ao}$$
$$u_{a2} = \tfrac{1}{2}U_{DC} + u_{ao}$$
$$u_{a1} + u_{a2} = U_{DC}$$

(1)

In a phase, the lower bridge arm current:

$$i_{a1} = -\tfrac{1}{3}I_{DC} - \tfrac{1}{2}i_a$$
$$i_{a2} = -\tfrac{1}{3}I_{DC} + \tfrac{1}{2}i_a$$

(2)

According to this principle, a single bridge arm into the number of sub module state can be 0, 1, 2,... N, that is to say, the number of level of modular multilevel converter can output up to N + 1, which is consistent with the scalability of MMC, but also through the sub module is connected in series to achieve the level of very high number.

A. DC voltage stability control

In the modular multilevel converter, the DC voltage associated with the active power, reactive power of AC voltage related, therefore the DC bus voltage is controlled by the active current output can control STATCOM. According to the DC bus voltage reference value and the actual value deviation, using PI controller to realize the stable DC voltage control, the control equation is:

$$I_{admf} = K_p(U_{DCmf} - U_{DC}) + K_t\int(U_{DCmf} - U_{DC})dt \qquad (3)$$

In the formula, I sdref output active current reference value for STATCOM.

B. The AC side control

At present, there are mainly two kinds of STATCOM used in the AC side controller strategies: one is based on pulse amplitude modulation (PAM) mode, the phase between this control method only control the system voltage and inverter output voltage difference, and then adjust the AC voltage converter output during the transient process; the other is a pulse width modulation (PWM) based on the phase between the way, this way not only control the system voltage and inverter output voltage difference, but also on the modulation ratio M control, keep the AC output voltage stability. Transient control strategy of PAM mode based on the long response time, control and subject to many factors, it is difficult to improve the dynamic response speed. The control strategy based on PWM mode by using current feedback, can improve the system dynamic response speed in a great extent. But the phase difference and modulation ratio of M interaction, the coupling relationship between big, has caused great difficulties to the construction of the controller. So it can be used under dq0 coordinate decoupling scheme, to solve the phase difference and modulation ratio of coupling relationship between M, MMC and STATCOM to realize the independent control of active power and reactive power.

In DQ coordinates, STATCOM expression

$$\begin{aligned} U_{cd} &= U_{sd} - v_d' + \Delta u_q \\ U_{cq} &= U_{sq} - v_q' + \Delta u_d \end{aligned} \qquad (4)$$

In it:

$$\begin{cases} v_d' = L_s dI_{sd}/dt + R_s I_{sd} \\ v_q' = L_s dI_{sq}/dt + R_s I_{sq} \end{cases} \qquad (5)$$

$$\begin{aligned} \Delta u_q &= \omega L_s I_{sq} \\ \Delta u_d &= \omega L_s I_{sd} \end{aligned} \qquad (6)$$

A measurement data track measuring instrument on the target trajectory parameters X, Y, Z of the partial derivative matrix Jacobi,

That is:

$$A^T = \begin{bmatrix} \frac{\partial R_1}{\partial X} & \frac{\partial A_1}{\partial X} & \frac{\partial E_1}{\partial X} & \frac{\partial R_2}{\partial X} & \frac{\partial A_2}{\partial X} & \frac{\partial E_2}{\partial X} & \frac{\partial R_3}{\partial X} & \frac{\partial A_3}{\partial X} & \frac{\partial E_3}{\partial X} \\ \frac{\partial R_1}{\partial Y} & \frac{\partial A_1}{\partial Y} & \frac{\partial E_1}{\partial Y} & \frac{\partial R_2}{\partial Y} & \frac{\partial A_2}{\partial Y} & \frac{\partial E_2}{\partial Y} & \frac{\partial R_3}{\partial Y} & \frac{\partial A_3}{\partial Y} & \frac{\partial E_3}{\partial Y} \\ \frac{\partial R_1}{\partial Z} & \frac{\partial A_1}{\partial Z} & \frac{\partial E_1}{\partial Z} & \frac{\partial R_2}{\partial Z} & \frac{\partial A_2}{\partial Z} & \frac{\partial E_2}{\partial Z} & \frac{\partial R_3}{\partial Z} & \frac{\partial A_3}{\partial Z} & \frac{\partial E_3}{\partial Z} \end{bmatrix}$$

(7)

Type (7) can be used to realize the PI controller to compensate the voltage loss, flat wave reactor on the compensated, by introducing the DQ voltage coupling compensation term delta UD, delta UQ, can realize the current axis DQ solution coupling control, but also can improve the stability of the whole system, the control equation is:

$$\begin{aligned} v_d' &= K_p(I_{sdref} - I_{sd}) + K_t\int(I_{sdref} - I_{sd})dt \\ v_q' &= K_p(I_{sqref} - I_{sq}) + K_t\int(I_{sqref} - I_{sq})dt \end{aligned} \qquad (8)$$

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Feedback control structure diagram was shown in Figure 4 MMC STATCOM state.

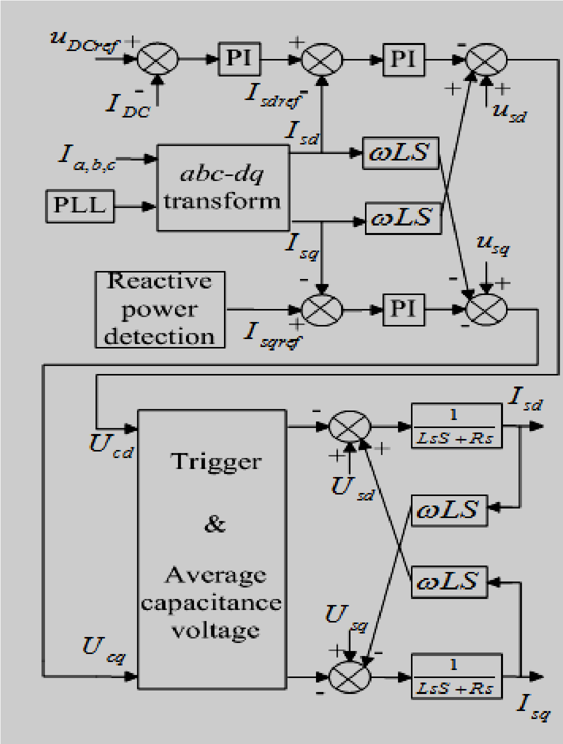

Figure 4. Feedback control structure diagram in MMC STATCOM state.

C. The control strategy of AC side

MMC-STATCOM communication control using decoupling method based on dq0 coordinate, can send out of MMC STATCOM reactive power control effectively. Set up simulation model of the capacity of 5 MVA, can send out the inductive reactive power and capacitive reactive power. In the simulation model, a 4 s reactive power from 4 MVA to 3 MA to observe the change of slope, MMCSTATCOM dynamic response characteristics. No such as shown in Figure 5 response of reactive power dynamic.

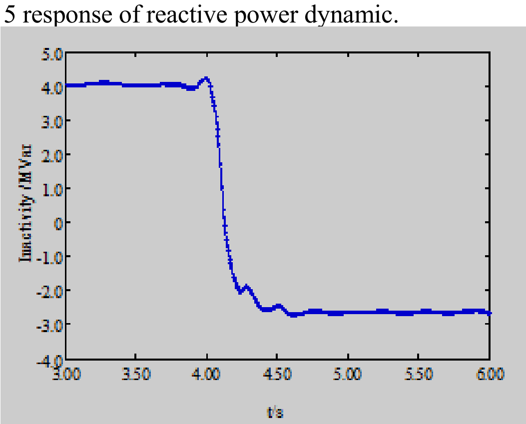

Figure 5. Response of reactive power dynamic.

In Figure 5, the command is issued, the system can response quickly to the power change, instantaneous reactive power stability in the new reactive power setting, that strategy has good dynamic response characteristics of the AC control.

Analysis of the topological structure and working principle of MMC, according to the working characteristics of MMC, compares several commonly used modulation strategy, the final choice of the nearest level as the modulation strategy of MMC. On this basis, the MMCSTATCOM control direct current control strategy and the direct current control strategy in the strategy are studied, and in the PSCAD/EMTDC environment to build the capacity of MMC STATCOM simulation model of 5 MVA, verify the control strategy, results show that, the control strategy has very good control effect.

IV. EXPERIMENTAL RESULTS

A. MMC modulation strategy

At present, the modulation strategy of modular multilevel converter used mainly contains the fundamental frequency modulation strategy for high frequency modulation strategy based on PWM technology and switching control based on multi level. High frequency modulation refers to a power cycle of the output voltage, PWM modulation of the switching device based on high frequency on-off control, including the carrier phase shifted pulse width modulation and carrier disposition pwm. Frequency modulation refers to a power cycle, the switching device only open several times, to achieve control of multi level by level cascade way, mainly has the space vector modulation and the nearest level modulation mode.

Compared to the carrier phase shifted pulse width modulation, carrier disposition PWM modulation and space vector modulation, the nearest level modulation mode is more suitable for high voltage and high power modular multilevel converter. When MMC is used for high voltage and large power applications, each bridge arm need several sub modules in series is numerous, makes modulation strategy is complicated. Therefore, MMC STATCOM uses the nearest level modulation as MMC modulation, the nearest level modulation waveform was shown in Figure 6.

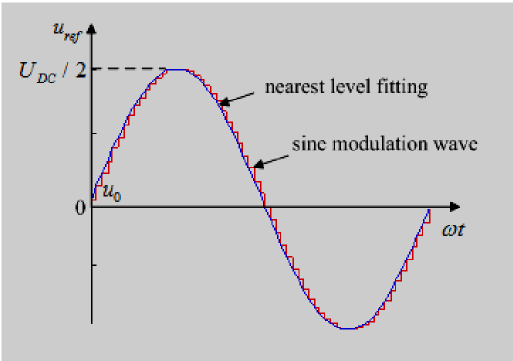

Figure 6. The nearest level modulation waveform

The number of level set of modular multilevel converter for N + 1, that is, each bridge arm of tandem N sub module, in order to ensure that no large circulation generated DC voltage stability as well as the bridge between arms at any time MMC upper and lower bridge arm guide through total module for N. Located on the bridge arm conduction module number is Np, then the lower bridge arm conduction module number Nn = N - Np. Capacitance voltage set ideal sub module for the U0 ladder ladder wave, each representing a opening of the sub module, step voltage is a discrete set of values, therefore, the need for real-time rounding operation on the modulation wave of UreF, get the step wave voltage to approximate sine wave. The number of upper and lower bridge arm module obtains the recent level modulation for

$$N_p = f_{sound}[(\frac{U_{DC}}{2} - u_{cd})/u_0]$$
$$N_a = f_{sound}[(\frac{U_{DC}}{2} + u_{cd})/u_0] \tag{9}$$

B. The simulation and verification

In order to verify the working principle, modular multilevel converter MMC nearest level modulation strategy side control strategy and control strategy of AC side and DC STATCOM based on MMC, built the MMC STATCOM simulation model in the PSCAD/EMTDC simulation environment, the simulation model of the main parameters.

Using the nearest level modulation strategy as MMC modulation, this method has the advantages of simple operation, and low switching frequency devices, converter suitable for high level number. The nearest level was shown in Figure 7 waveform strategy.

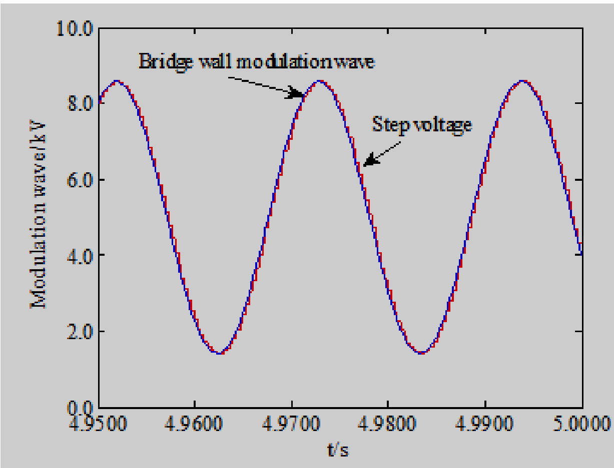

Figure 7. The nearest level in waveform strategy.

In Figure 7, was recently rounded on bridge arm modulation wave, obtained the step voltage, wherein each step into sub modules rated voltage value, the number of steps step voltage wave is a sub module of single bridge arm of the conduction number.

V. CONCLUSION

Analysis of the topological structure and working principle of MMC, according to the working characteristic of MMC and comparison of several commonly used modulation strategy, the final choice of the nearest level as the modulation strategy of MMC. On this basis, the MMCSTATCOM control direct current control strategy and the direct current control strategy in the strategy are studied, and in the PSCAD/EMTDC environment to build the capacity of MMC STATCOM simulation model of 5 MVA, verify the control strategy of the results show that the control strategy has very good control effect.

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