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Performance of STATCOM Based on Hybrid Cascaded Multilevel Converter in Power System

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ABSTRACT

A novel static synchronous compensator (STATCOM) based on hybrid cascaded multi-level converter (HCMC) is presented in this study, i.e HCMC-STATCOM, which combines the advantages of the traditional two-level converter and cascaded H-bridge converter. However, the topology and control system are relatively complex. It is difficult to coordinate the two key parts in steady operation. This study firstly introduces topology and working principle of the HCMC-STATCOM. In order to achieve the coordinated control of two key parts, a control strategy is proposed to achieve the coordination and synchronization between the two parts of the HCMC-STATCOM. The HCMC-STATCOM simulation model is built by using MTLAB software.

Keywords : Two-Level Converter, Cascaded H-Bridge Converter HCMC-STATCOM, Control Strategy

I. INTRODUCTION

At present STATCOM (static synchronous compensator) is found with a multiple transformer and a multilevel converter. A multiple transformer structure requires the phase-shifting transformers, which result may be expensive, loss, large area. Multi-level converter structure contains the topology such as diode clamped converter, flying capacitor-clamp converter and cascaded H-bridge converter. Generally it has been found that the diode-clamped converter and flying capacitor-clamp converter use to avoid the disadvantages of the multiple transformer structure. If level increases, the result of which clamping diode will increase the number of floating capacitors and it is very difficult to the design the device. The cascaded H-bridge STATCOM has the advantages of low harmonic content and high efficiency. Although the high-voltage cascaded H-bridge STATCOM requires sub-modules and requires more large and bulky DC capacitors. This paper presents a hybrid cascaded multi-level converter (HCMC) type STATCOM called as HCMC-STATCOM. It has topology which consists of a two part wave-shaping circuit, which is a cascade of conventional two level converters and H-bridge sub-modules. Compared with the STATCOM with two levels, the HCMC-STATCOM with a wave-shaping circuit formed by cascading H-bridge sub-modules does not have any additional filter and due to which it greatly reduces the loss. HCMC-STATCOM does not need to use transformers to increase the device capacity and reduce the output voltage harmonics as compared to the STATCOM based on multiple transformer structure. the output AC voltage of HCMC-STATCOM is shared by the two level converters and wave-shaping circuit due to which it significantly reduce the number of sub-modules and DC capacitors. Hence, it can greatly reduce the size of the device and cost. This paper based on the topology, working principle and coordinated control strategy of HCMC-STATCOM.

II. Circuit topology and working principle

2.1 Circuit topology

The topology of HCMC-STATCOM is shown in Fig. 1.

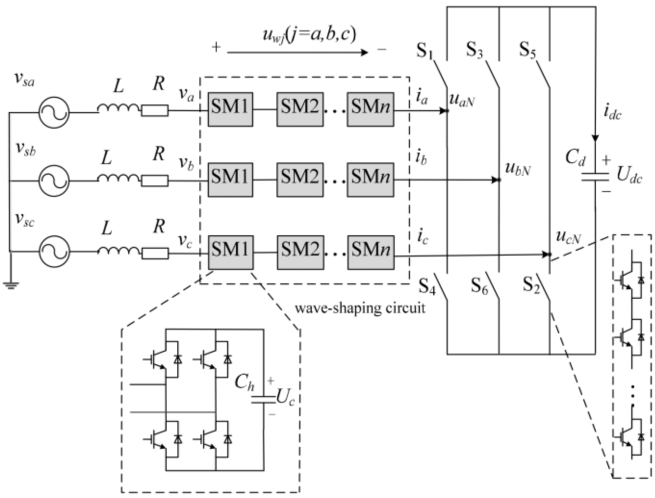


Fig. 1 Topology of the HCMC-STATCOM

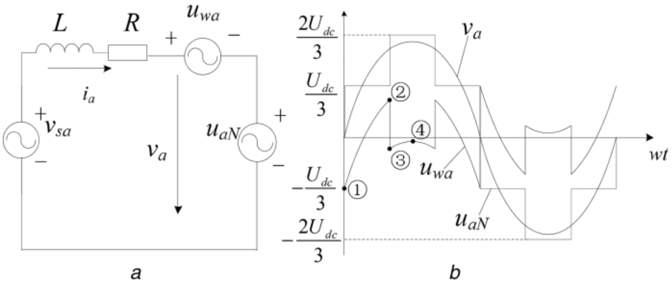
The topology consist of two parts first is a two-level converter with IGBT and an anti-parallel diode in series and second is a wave-shaping circuit cascaded with the H-bridge sub -module.

As shown in Fig. 1, vsa, vsb, vsc and ia, ib, ic shows three phase AC voltage and current; va, vb, vc denote three-phase output voltage of HCMC-STATCOM. L is inductance, R is equivalent resistance. vwa, vwb, vwc are the voltage of three-phase wave-shaping circuit. vaN, vbN andvcN used to represent AC phase voltage of two-level converter.Udc represents rated DC voltage of two-level converter, idc represents DC current of two-level converter,Cd represents capacitance of two-level converter,Ch represents Capacitance value of H-bridge sub-modules. Uc represents rated voltage of H-bridge sub-modules capacitor. Each phase wave shaping circuit having N H-bridge sub-modules in series and it is located in the AC side of the two-level converter. In normal Working each H-bridge sub-modules has three modes of operation positive input, negative input and cut off or may be called bypass respectively.

2.2 Working principle

HCMC-STATCOM is consider in steady operation then two-level converter wll turn on or turn off alternately in each bridge arm. The wave-shaping circuit input and cut-off cascade H-bridge sub modules used for making the output AC voltage approximation to the desired sinusoidal reference wave. In Fig. 2 shows the output voltage reference waveform of HCMC-STATCOM single-phase equivalent circuit and two-level converter, wave-shaping circuit and HCMCSTATCOM. in Fig. 2, the output AC voltage of HCMCSTATCOM having the two-level converter and the wave shaping circuit. Consider phase A as an example and it may conclude from Figs. 1 and 2 that the basic characteristics of HCMC-STATCOM are

Determined by (1)–(5):



$va(t) = Um\sin \omega t$ …………………………………… (1)

$ia(t) = Im\sin(\omega t + \pi/2) = Im\cos \omega t$ ……………(2)

$va(t) = uwa(t) + uaN(t)$ ……………………………(3)

$uaN(t) = MaU\mathrm{dc}$ ……………………………………(4)

$uwa(t)= \Sigma k = 1\ Gk(a)Uck(a)$ ……………………(5)

where *Um* and *Im* represents the HCMC-STATCOM export phase voltage and AC current respectively. *ω* gives angular frequency, *Ma* is used for the switching factor and it is calculated by the two-level converter switch signal , *Uck*(*a*)(*k* = 1,2,…,*N*) represents capacitance voltage of the *k* H-bridge sub-module in phase A wave-shaping circuit , *Gk*(*a*)(*k* = 1,2,…,*N*) is the switching function of the *k* H-bridge sub-modules in phase A wave-shaping circuit, with respective to its operating mode, positive inputs (*Gk* (*a*) = 1), negative inputs (*Gk* (*a*) = –1) and cut off (*Gk* (*a*) = 0).

III. Coordination control strategy

3.1 Control strategy of HCMC-STATCOM

Under the d*q* coordinate system, the mathematical model of HCMC-STATCOM AC side can be written as,

$$L\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} v_{sd} - v_d \\ v_{sq} - v_q \end{bmatrix} + \begin{bmatrix} -R & \omega L \\ -\omega L & -R \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

where *id*, *iq* use to represent active and reactive current. *vsd* and *vsq* use to represent d*q*-axis component of AC system voltage. *vd*, *vq* use to represent d*q*axis component of HCMC-STATCOM output voltage. With respective mathematical model the active-reactive current feed forward decoupling control strategy is used. The control strategy of HCMC-STATCOM is shown in Fig. 3. The *id** and *iq** used to represent active and reactive current respectively. *vj** (*j* =*a,b,c*)

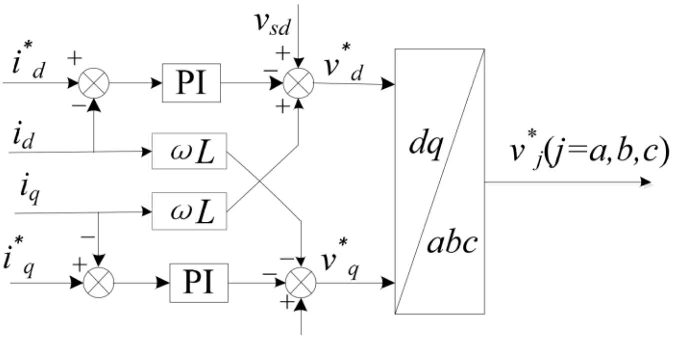


Fig. 3 *Control strategy of the HCMC-STATCOM*

3.2 Control strategy of two-level converter

For stabilizing the capacitor voltage of the two-level converter, the voltage outer loop control is used to compare the actual value of the DC side capacitor voltage with the set value and the active current reference value *id** is obtained through the proportional integral (PI) controller, as shown in Fig.4.

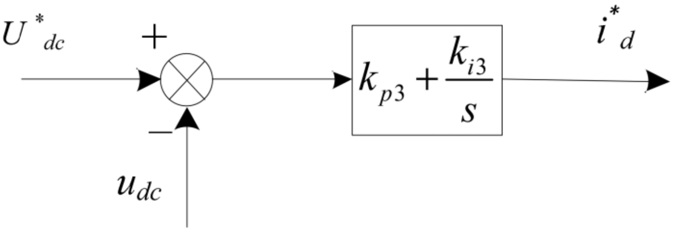


Fig. 4 Control strategy of the two-level converter

*U*dc is the actual DC voltage of two-level converter, and *U**dc is the reference value of DC voltage. The PI controller creates a phase difference between the HCMC-STATCOM output voltage and the AC system Voltage for compensating the active loss of the HCMC-STATCOM. So, stabilizing the capacitor voltage.

3.3 Control strategy of wave-shaping circuit

Wave-shaping circuit and its capacitor voltage stability control strategy are shown in following Fig. 5.

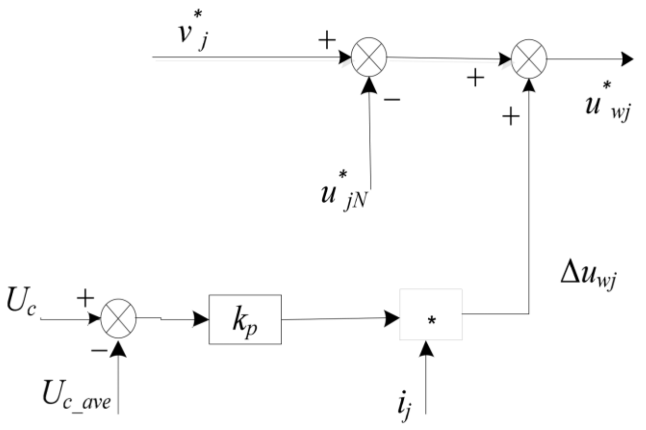


Fig. 5 *Control strategy of the wave-shaping circuit*

uwj^*, ujN^*($j = a,b,c$) represents the output reference voltage of wave-shaping circuit and two-level converter. Uc represents rated voltage of sub-module capacitor; Uc_ave denotes average of all sub-module capacitor voltages in three-phase wave shaping circuit. The output voltage uwj ($j = a$, b, c) of WSC(three phase wave shaping circuit) can be written as

$uwj(t) = vj(t) - ujN(t)$ ……………………………….(7)

From (7), the output reference voltage uwj^* of the wave-shaping circuit is calculated by the HCMC-STATCOM output reference voltage vj^* and the two-level converter output reference voltage ujN^*. When the two-level converter switch signal is calculated then the output line voltage depends simply on the converter itself and the output voltage is affected due to the voltage across the wave-shaping circuit. Therefore, the output voltage can be found by two-level converter ujN^*.

Uc_ave is the average of the capacitor voltages of all the submodules in the three-phase wave-shaping circuit, Uc_ave can be expressed as

$$U_{c\_ave} = \frac{1}{3N}\left(\sum_{k=1}^{N} U_{ck(a)} + \sum_{k=1}^{N} U_{ck(b)} + \sum_{k}^{N} U_{ck(c)}\right)$$

Instantaneous active power ΔPj which produced can be expressed as

$$\Delta Pj = \Delta uwj * ij = kpij2\,(Uc - Uc\_\text{ave})$$

When $Uc > Uc$_ave then $\Delta Pj > 0$ so, the active power ΔPj flows into the wave-shaping circuit from the AC system to charge the capacitor voltage upto the rated value Uc. When $Uc < Uc$_ave then ΔPj < 0 so, the wave shaping circuit delivers the active power ΔPj to the AC system so that the capacitor voltage discharge drops to the rated value Uc. Hence, through the control strategy as shown in Fig. 5 the wave shaping wave shaping circuit sub-module capacitor is charged and discharged, and the capacitor voltage in the WSC can be kept stable.

3.4 Coordination control strategy between wave-shaping circuit and two-level converter

To ensure output AC voltage of HCMC-STATCOM is sine waveform with low distortion rate, there is need of twolevel converter and wave-shaping circuit coordinated with each other Two-level converter using square wave modulation strategy. The two-level converter output voltage *ujN* will change only when output voltage of HCMC-STATCOM *vj* is across zero. The shaping circuit output voltage *uwj* must be synchronized with the two-level converter output voltage *ujN* to obtain HCM-STATCOM output voltage *vj* smooth without mutation. When *ujN* decreases *uwj* should rise synchronously and if ujN increases uwj should decreases synchronously .Otherwise, the HCMC-STATCOM output voltage *vj* spikes which will affect the output voltage. Wave-shaping circuit calculates nearer level modulation strategy. Once is calculate the number of levels which should be in the output of three phases, the modulation controller obtained the sub-modules to put or removed according to the equalization control algorithm of the sub-modules. Nearer level modulation strategy (NLM) sub-module voltage-sharing control algorithm basically a control strategy which works on the direction of current and voltage of submodule for selective switching control strategy. the two-level converter output voltage *ujN* instantly change the control signal generated at the same time in such away that wave-shaping circuit output voltage *uwj* synchronous the changes In order to prevent the HCMC-STATCOM output voltage *vj* spikes.

IV. MODEL AND SIMULATION

Three-phase 35 kV/ ± 50 Mvar HCMC-STATCOM system is simulated and verify its performance in the system.

1) The AC system voltage is 35 kV.
2) The rated reactive power is ±50 Mvar.
3) Inductance is 4.8 mH.
4) Resistance is 0.01 Ω.
5) The number of H-bridge modules per phase is *N* = 15.
6) The sub-module capacitance is 9783 μF.
7) Two-level converter DC voltage is 39.4 kV.
8) The capacitance is 126 μF.

The two-level circuit and the wave-shaping circuit adopt the square wave modulation and the NLM strategy. The simulation waveform is shown.

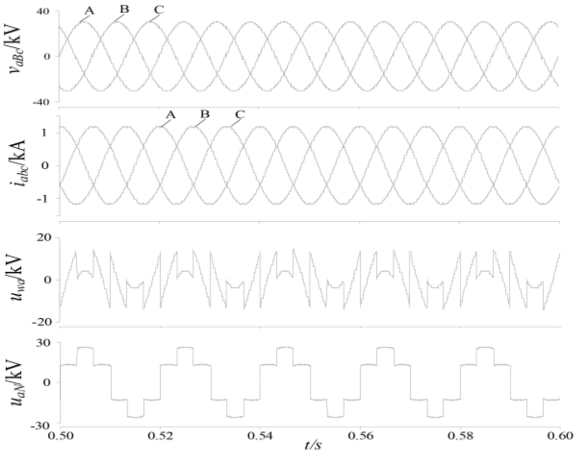


Fig. 6 *Waveforms on steady-state operation*

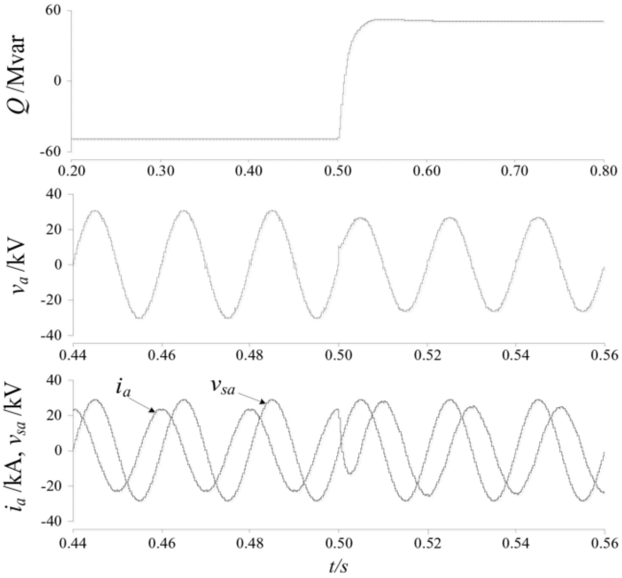


Fig. 7 *Dynamic response of the HCMC-STATCOM to reactive power demand change*

In the above Fig. 6 represents HCMC-STATCOM three-phase output voltage, three-phase AC current, A-phase wave-shaping circuit voltage and the two-level converter output phase voltage. it is also found the system gives best running performance and waveform quality. Harmonic content of HCMC-STATCOMC output AC phase voltage and current is small. In the above Fig. 7 gives the response characteristics of HCMC-STATCOM the changes of HCMC-STATCOM absorption reactive power, A-phase output voltage and current. HCMC-STATCOM absorbs reactive power from –50 to +50 Mvar at 0. Indicates its dynamic response is very fast.

V. CONCLUSION

This paper studies on HCMC-STATCOM (hybrid cascaded multi-level converter type stationary synchronous compensator. It gives the advantages of the conventional two-level converter and the cascaded H-bridge converter with different topology. For control ing the two key components, this paper represents the coordinate control strategy of HCMCSTATCOM. the three-phase 35 kV/ ± 50 Mvar

HCMC-STATCOM simulation model is built.From simulation results it is clear the performance of HCMCSTATCOM topology and effectiveness of the coordinate control strategy.

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