Research on STATCOM control strategy of Cascaded H-bridge considering unbalanced conditions

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Abstract: STATCOM, a star cascade H bridge, usually uses zero-sequence voltage injection to achieve inter-phase DC voltage balance. Different from negative sequence current injection, the phase-to-phase DC voltage balance control based on zero sequence voltage injection does not generate zero sequence current in three-phase and three-wire systems, which is beneficial to the power quality of the system. In the traditional control algorithm, the zero sequence voltage is calculated by the unbalanced active power and current. The control algorithm contains a large number of complex operations and matrix operations, which need to consume a lot of controller resources and is not conducive to system design and expansion. Moreover, in order to improve the dynamic performance under voltage imbalance, the positive and negative sequence separation is introduced into the feedforward control to increase the complexity of the control algorithm. In order to simplify the control algorithm, a PI regulator is proposed to linearly adjust the DC component of zero sequence voltage in DQ coordinate system. At the same time, through theoretical analysis, it is found that the zero-sequence voltage in feedforward control is equal to the zero-sequence voltage in power grid, so the positive and negative sequence separation can be removed, further simplifying the algorithm.

1. Introduction

As a large number of distributed power sources such as photovoltaic and wind power are connected to the power grid, the stability of the power system is greatly challenged. Cascaded H-bridge STATCOM(CHB STATCOM) has the advantages of modularity, strong expansibility and good harmonic characteristics, and is widely used in power system to regulate the power factor of the system and stabilize the power grid voltage [1]. The three-phase DC side of the cascaded H-bridge converter is independent of each other, so it has two typical connection structures: star connection and triangle connection. Because the three phase active power exchange strategies of the two connection modes are different, they have different applications. Star-shaped cascade H bridge STATCOM is suitable for generating positive sequence reactive current and supporting grid voltage. Triangle cascade H bridge STATCOM is suitable for generating unbalanced reactive current to compensate unbalanced load [2]. In this paper, the compensation characteristics of STATCOM, a star cascade H bridge, under voltage sag are studied.
The dc side voltage equalization of STATCOM of the cascaded H bridge is a prerequisite for the installation and operation of the system. In order to improve the working ability of STATCOM of the cascaded H bridge under unbalanced conditions, scholars at home and abroad have carried out a lot of relevant studies and proposed two methods: Negative sequence current injection method [3-5] and zero sequence voltage injection method [6-9]. Both methods achieve three-phase DC voltage balance by redistributing the active power of three phases. In contrast, the zero-sequence voltage injection method can achieve inter-phase DC voltage balance without generating unbalanced current, because the negative sequence current injection method will produce unbalanced current and affect the power quality of the grid. Therefore, this paper focuses on the realization of three-phase DC voltage balance by zero-sequence voltage injection method.

In order to derive the required injected zero-sequence voltage, the relation between zero-sequence voltage and active power is established in the ABC coordinate system in literature [6-9]. The operation process contains a large number of division and inverse trigonometric functions, resulting in extremely complicated operation.

Literature [9] proposed a phase-to-phase DC voltage balance control strategy based on zero-sequence voltage injection. By using feedback control, PI controller was adopted to directly adjust the D and Q axis components of zero-sequence voltage according to the deviation of inter-phase DC voltage, avoiding indirect calculation of zero-sequence voltage after unbalanced power was generated by PI controller in the traditional method. Therefore, the proposed feedback control method eliminates complex operations such as division, open square root and inverse trigonometric function, but the control algorithm is still complex. In combination with the feedback control in literature [9], this paper also proposes feedforward control, deducing that the zero-sequence voltage is equal to the grid zero-sequence voltage, so it can be directly extracted from the grid voltage without introducing complex positive and negative sequence separation algorithm, greatly simplifying the control algorithm. Therefore, the proposed phase-to-phase DC voltage balance control algorithm based on zero-sequence voltage injection is more simple, easy to implement, and convenient for system design and development. Finally, the feasibility, effectiveness and robustness of the control strategy are verified by RT-Lab simulation.

2. System model analysis
The topological structure of STATCOM power unit of star cascade H bridge is shown in Figure 1. Three phases A, B and C adopt star connection mode. L is the connection reactance. E_a, E_b, E_c are the power grid voltage of each phase. U_a, U_b, U_c are the output voltage of each STATCOM phase. I_a, I_b, I_c are the output current of each STATCOM phase. I_{ra}, I_{rb}, I_{rc} are the three-phase load current.

![Fig.1 Topological structure of STATCOM power unit of star cascade H bridge](image-url)

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3. Cascade H bridge STATCOM interphase DC voltage control strategy

According to the method proposed in literature [8], after the three-phase power grid voltage is converted to the DQ0 coordinate system, the zero-sequence voltage delay can be introduced and the dc expression of the zero-sequence voltage can be obtained through peck transformation, which can be expressed as:

\[
\begin{bmatrix}
E_0 \\
E_{0,dlay}
\end{bmatrix} =
\begin{bmatrix}
\cos(\omega t) & -\sin(\omega t) \\
\sin(\omega t) & \cos(\omega t)
\end{bmatrix}
\begin{bmatrix}
e_{d0} \\
e_{q0}
\end{bmatrix}
\]  

(1)

In the formula, the subscripts p, n and 0 respectively represent the positive, negative and zero ordered components; Subscripts d and q are d-axis and q-axis components respectively.

In order to eliminate the negative sequence current, the negative sequence voltage of the converter and the power grid should be equal on the premise of ignoring the high-frequency component. However, when STATCOM processes reactive power, the exchange of active power generated by the power grid is very small, so the positive sequence current in the dq coordinate system can be approximately considered as 0. Therefore, the dq coordinate system expression is as follows:

\[
\begin{bmatrix}
P_d \\
P_q
\end{bmatrix} =
\begin{bmatrix}
0 & -\frac{l_{qp}}{2} \\
\frac{-\sqrt{3}l_{qp}}{4} & \frac{l_{qp}}{4} \\
\frac{\sqrt{3}l_{qp}}{4} & \frac{l_{qp}}{4}
\end{bmatrix}
\begin{bmatrix}
e_{dn} \\
e_{qn}
\end{bmatrix}
\]

(2)

In the formula, \(I_{dp}\) and \(I_{qp}\) are the positive sequence current in the dq coordinate system. According to the formula, the active power of three phases is not equal, but the sum of the active power of three phases is 0. Therefore, although the active power of three phases does not affect the overall DC voltage, it will cause the imbalance of the DC voltage between phases.

According to the output reactive current, the generated active power is as follows:

\[
\begin{bmatrix}
P_{A0} \\
P_{B0} \\
P_{C0}
\end{bmatrix} =
\begin{bmatrix}
0 & \frac{l_{qp}}{2} \\
\frac{\sqrt{3}l_{qp}}{4} & \frac{-l_{qp}}{4} \\
\frac{-\sqrt{3}l_{qp}}{4} & \frac{-l_{qp}}{4}
\end{bmatrix}
\begin{bmatrix}
U_{d0} \\
U_{q0}
\end{bmatrix}
\]

(3)

In the formula, \(U_{d0}\) and \(U_{q0}\) are zero-sequence voltage of dq axis. From the formula, it can be seen that the negative sequence voltage in the power grid will cause three-phase DC voltage imbalance, while the zero-sequence voltage can achieve three-phase DC voltage balance by adjusting the active power.

4. Cascade H bridge STATCOM interphase DC voltage control algorithm

Fig.2 Interphase DC voltage equalization control based on zero-sequence voltage injection

According to literature [9] feedback control. The linear relationship between active power and phase
DC voltage deviation can be obtained as follows:

\[
\begin{align*}
P_{00,1} &= \frac{-3K_pI_{dp}}{4}(U_{d1}-U_{d0}) \\
P_{10,1} &= \frac{-3K_pI_{dp}}{4}(U_{d2}-U_{d0}) \\
U_{d0} &= \frac{U_{d1}+U_{d2}+U_{d3}}{3}
\end{align*}
\]

(4)

According to Equation (4), when deviation occurs, the feedback control will adjust the zero-sequence voltage by generating active power.

The feed-ahead control proposed in this paper can directly generate the required zero sequence voltage and offset the unbalanced active power caused by the unbalanced grid. The zero-sequence voltage generated by feedforward control is derived as follows:

\[
\begin{bmatrix}
P_{AN} + P_{A0,gg} \\
P_{BN} + P_{B0,gg} \\
P_{CN} + P_{C0,gg}
\end{bmatrix} = 
\begin{bmatrix}
0 & \frac{-I_{qp}}{2} \\
\frac{-\sqrt{3}I_{qp}}{4} & \frac{I_{qp}}{4} \\
\frac{\sqrt{3}I_{qp}}{4} & \frac{-I_{qp}}{4}
\end{bmatrix} \begin{bmatrix}
 \frac{U_{do,gg}}{2U_{d0,gg}} \\
 \frac{U_{o,gg}}{2U_{d0,gg}} \\
 \frac{U_{o,gg}}{2U_{d0,gg}}
\end{bmatrix} 
\]

(5)

Combined with Equations (1), (2) and (4), the zero sequence voltage required in feedforward control is solved as follows:

\[
U_{o,gg} = \frac{E_a + E_b + E_c}{3}
\]

(6)

5. Simulation diagram effect description

Based on RT-LAB software, the STATCOM model of cascade H-bridge was built, and the above dc side voltage balance control strategy was simulated and verified. The parameters are shown in Table 1.

| Parameter                      | The numerical |
|-------------------------------|---------------|
| The grid frequency /Hz        | 50            |
| Dc side capacitance /mF       | 4             |
| Filtering inductance /mH      | 10            |
| Carrier frequency /kHz        | 0.5           |
| Reactive power compensation capacity /Mar | 50        |
| The node voltage /kv          | 20            |

It can be seen from the simulation results in FIG.3 that within 0.1 seconds after the failure, STATCOM voltage fluctuates greatly and shows no signs of recovery. However, after injecting zero-sequence voltage through the control strategy described in this paper, the system balances the three-phase voltage rapidly and recovers stability after 0.3 seconds.
Dc side voltage between phases

| Voltage (kV) | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| U_{dgA}     |     |     |     |     |     |     |     |     |     |
| U_{dgB}     |     |     |     |     |     |     |     |     |     |
| U_{dgC}     |     |     |     |     |     |     |     |     |     |

FIG. 3 Waveform after injection of zero sequence voltage after system failure

6. Conclusion

In this paper, a new control strategy of injecting zero-sequence voltage is proposed for STATCOM of star cascade H-bridge under unbalanced conditions to realize the inter-phase DC voltage balance, which simplifies the complex operation of square root, division and inverse trigonometric function in the traditional algorithm, and eliminates the separation of positive and negative sequence. The proposed control strategy is more simple and efficient. Finally, the feasibility of the proposed strategy is verified by RT-Lab software simulation.

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