DC Voltage Control Strategy for CHB-STATCOM

Capacitive-Inductive Transition

Weiming Zhao1*, Yong Wang1, Bo Zhao2

1School of Automation Science and Electrical Engineering
Beijing University of Aeronautics and Astronautics, Beijing 100191, PR China
2China EPRI Science & Technology Co, LTD
China Electrical Power Research Institution, Beijing 100191, PR China
*corresponding author, e-mail: zhaoweiming.cat@163.com

Abstract

Fluctuation of DC capacitor voltage of CHC-STATCOM(Cascaded H-Bridge Converter Based STATCOM) during capacitive-inductive load transition affects the dynamic response of the equipment and, with combination of other factors like \(\frac{\partial}{\partial t}\) of the switching devices, can degrade the stability of the equipment. This paper illustrates the cause of the voltage fluctuation and proposes a novel and practical control strategy to suppress it. A simulation was conducted to testify its effectiveness.

Keywords: Load Transition, STATCOM, DC voltage, voltage fluctuation

1. Introduction

Static Synchronous Compensator (STATCOM) is a novel power quality controller which has gained so much attention and developed rapidly during recent years for its fast response and flexibility of usage including reactive power compensator[1], dynamic voltage restorer [2, 3] and unbalance compensation [4].

Among different topologies of STATCOM, CHC-STATCOM excels for its physical consistency, less use of components, better quality of output current and lower difficulty in controller designing especially when the cascaded level gets larger [5].

But, for the simplicity and reliability consideration, combined with the fact that during compensation, capacitive or inductive, there is almost no active power consumption, the old school non-efficient DC voltage source for the individual H-bridge module is simplified, and the DC voltage can be maintained by the rectification working state of the H-bridge converter. Ideally there is no problem, while in practice, due to the disparity of active power consumption of components like switching loss and distributed resistance loss, the DC voltage will differs and results in shortened life circle and damage of the equipment.

Reference[6] develops the mathematical model of CHC-STATCOM and illustrates a well-developed control strategy including the DC voltage control part. Reference [4] and [7] introduces negative sequence and zero sequence factors to control the active power flow of STATCOM and achieve the DC voltage control objectives. Reference [8] offers a different DC voltage control strategy by choosing a particular group of H-bridge module to output and thus, control the active power flow of STATCOM.

But none of them talks enough about the dynamic control of the DC voltage of CHB-STATCOM, and with their simulation and/or experiment results, we can see that the dynamic response of DC voltage control can be improved if an appropriate strategy is introduced.

This paper illustrates a novel control strategy aims at improving the dynamic response of the DC voltage of CHB-STATCOM by choosing a particular electrical angle to follow the reactive current reference signal. With a simulation conducted in Matlab/Simulink, the effectiveness of this control strategy is testified.

2. Problem Analysis

The DC voltage of CHB-STATCOM will be affected the most during the procedure of load transition between capacitive and inductive (cases of faults are not considered for their
extreme). During the transition, phase of output voltage and current of STATCOM will be shifted by almost 0° and 180° respectively due to the operating principle. Though the phase difference of them remains 90° before and after the transition, there will be a time period that the DC capacitor is charged or discharged constantly. The transition procedure is shown in Figure 1 and Figure 2.

![Figure 1](image1.png)

**Figure 1** Output current and voltage waveform of STATCOM During load transition

![Figure 2](image2.png)

**Figure 2** DC voltage waveform of an arbitrary phase of CSTATCOM with three H-bridge module

From figures shown above, we can see that from 2.49(s) to 2.50(s), the active power is constantly flow out of the STATCOM and result in a sag of DC voltage.

This constant charge or discharge of DC capacitor can affect the stability of STATCOM in different ways as follows.

1. **Overvoltage or undervoltage of H-bridge module.** The overvoltage is more troublesome since this voltage swell can combine with $\frac{di}{dt}$ of the switching device and result in damage of the switching device itself or the DC capacitor.

2. **From simulation shown later in this paper,** we can see that the DC voltage fluctuation will be restored at different speed according to the initial value. The bigger the initial fluctuation value is, the slower the DC voltage will be restored.

3. **The harmonic performance and balance degree of output current will be downgraded.** Because the sag and swell of the DC voltage of all three phases are different, the output current will be different and result in the imbalance. As to the harmonic performance, reference[9]show that bigger DC voltage ripple can affect the harmonic performance stronger.

4. **Sometimes, during the transition,** there will be an overcurrent occurs. The causes are mostly the discharge of the connecting inductor between STATCOM and PCC (Point of Common Coupling) or the design of controller, but both of them can be avoided by choosing an appropriate time for three phase to follow the reactive current reference signal.

5. **A relatively larger range of DC voltage fluctuation will also lead to a higher requirement to the switching power source design for the controller since most of the time we gain power for the controllers from the DC side of the converter. This will cause an extra increase in cost.**

In conclusion, by introducing an effective method to suppress the DC voltage fluctuation can be of benefit and meaningful for both the stability of the equipment itself and the quality of output of STATCOM.
3. Control Strategy Development

Here we use the most well-developed control strategy called dq decouple control strategy to control the STATCOM [5], and we add an extra control to it to achieve the suppression of voltage fluctuation of DC voltage during transition.

From the analysis above, it is easy we can think that by giving the reactive current reference signal at an appropriate time during load transition, the DC voltage dynamic response may be improved. From Figure 3 we can see that during capacitive working state, the compensate current is Capacitive Current and the active power flow sequence is $A \rightarrow B \rightarrow C$ while during inductive working state, the compensate current is Inductive Current and the active power flow sequence is $A \rightarrow C \rightarrow B$ instead.

![Figure 3. Pharos diagram of STATCOM output current and voltage at inductive and capacitive state](image)

If we don’t give the reactive current reference signal at the same time, the active power flow sequence will be disturbed and may result in desirable or undesirable phenomena. Thus, by finding the electrical angle at which the transition happens and the output current of STATCOM can be mostly stabilized, maybe we can achieve the desirable result.

![Figure 4 The equivalent circuit of STATCOM with connection to the Grid](image)

![Figure 5 Equivalent circuit of STATCOM with connection to the Grid after Laplace transformation](image)
To find the time when the output current of STATCOM can be mostly stabilized during load transition, we use the equivalent circuit of STATCOM and the grid shown in Figure 4.

In the figure, $\bar{U}_g$ is the grid voltage, $\bar{U}_c$ is the STATCOM output voltage, $R + j\omega L$ is the connecting inductor. After the load transition, the phase of $\bar{U}_g$ is shifted and we can easily gain the equivalent circuit of Figure 4 after Laplace transformation and it shows in Figure 5.

The grid voltage and STATCOM output voltage after the transition can be expressed as follows.

$$
\begin{align*}
U_c' &= U_m^2 \sin (\omega t + \varphi_2) \\
U_s &= U_m \sin \omega t
\end{align*}
$$

Then we can have the expression of STATCOM output current shown as follows.

$$
I(s) = \frac{U_m^2 \omega}{s^2 + \omega^2} - \frac{U_m^2 s \sin \varphi_2 + \omega \cos \varphi_2}{s^2 + \omega^2} - \frac{L (0 -)}{sL + R}
$$

Then we perform inverse Laplace transform and get the final expression of STATCOM output current shown in Eq. 3.

$$
\begin{align*}
i(t) = -e^{\frac{-Rt}{L}} i(0-) + \\
& \frac{\left[-U_m^2 \sin \omega t \sin \varphi_2 + \left(U_m - U_m^2 \cos \varphi_2\right) \left(-\cos \omega t + e^{\frac{-Rt}{L}}\right)\right] \omega L}{R^2 + \omega^2 L^2} \\
& + \frac{R \left(U_m - U_m^2 \cos \varphi_2\right) \sin \omega t + \left(-\cos \omega t + e^{\frac{-Rt}{L}}\right) \left(U_m^2 \sin \varphi_2\right)}{R^2 + \omega^2 L^2} \\
& \ln \left(1 + \frac{\sin \varphi_2}{1 - \cos \varphi_2}\right)
\end{align*}
$$

Since both the phase difference between STATCOM output voltage and grid voltage and the resistance of the connecting inductor are very limited, we can have Eq. 4.

$$
\begin{align*}
\sin \varphi_2 &= 0 \\
\cos \varphi_2 &= 1 \\
R &= 0
\end{align*}
$$

And the simplified STATCOM output current can be seen in Eq. 5.

$$
\begin{align*}
i(t) = -e^{\frac{-Rt}{L}} i(0-) + \\
& \frac{\left(U_m + U_m^2\right) \left(-\cos \omega t + e^{\frac{-Rt}{L}}\right) \omega L + R \left(U_m - U_m^2\right) \sin \omega t}{R^2 + \omega^2 L^2}
\end{align*}
$$

With the expression of output current of STATCOM above, we can draw the waveform with different initial current $i(0\_)$ and get Fig. 6 which suggests that the larger the initial output current is, the more stabilized the STATCOM output current can be.

In order to make sure that the transition procedure will not last too long that affect the active power flow between different phases too much and with consideration of the stability of output current, we can decide that the reactive current reference signal can be given respectively at the phase current maximum point. Thus, three phase reactive current reference signal will be given with a time interval of 30° electrical angle.

In additional, according to the characteristics of STATCOM that active power flow will be larger at capacitive working states and smaller at inductive working states, it is easy to find that only the voltage fluctuation caused by transition from inductive to capacitive working state should be suppressed for the sudden increase of active power.
4. Simulation Verification

According to the control strategy development, we can conduct a simulation to verify the effectiveness. Figure 7 shows the transition procedure from which we can see that the reactive current reference has been changed at 1.4s but the transition is hold until the phase current reaches its maximum. The time delay of reactive current reference signal is ignored since during that period of time, the reference signal remains the same as that of it at 1.4s.

Figure 6: Different STATCOM output current with different initial current

Figure 7: Inductive Capacitive working state transition of phase A

Figure 8: DC voltage of phase A of STATCOM during transition with control strategy applied

Figure 9: DC voltage of phase A of STATCOM during transition without control strategy applied
The DC voltage waveform can be seen in Figure 8 and by comparing it with Figure 9 which is the DC voltage waveform during transition without the compensation control, we can see that the DC voltage fluctuation is suppressed.

The voltage restore speed is also observed in the simulation. Figure 10 and Figure 11 shows the voltage restore speed of DC voltage of STATCOM with and without the control strategy applied and we can see that it is effective.

Figure 10 DC voltage of STATCOM of three phase without the control strategy applied

Figure 11 DC voltage of STATCOM of three phase with the control strategy applied

Figure 12 DC voltage waveform when STATCOM is transform from capacitive to inductive

Also we can see from Figure 12 that if the working state is transformed from capacitive to inductive, the DC voltage will be relatively smooth and there is no need to apply any extra control strategy to suppress the DC voltage fluctuation.
5. Conclusion and Future Work

This paper proposes a novel control strategy which focuses on suppressing the DC voltage fluctuation of STATCOM during load transition. The cause of the fluctuation is firstly analyzed and a control strategy which gives three phase reactive current reference signal at different time is designed. Finally, a simulation is introduced to verify the effectiveness of this control strategy. From the simulation result one can see that the DC voltage fluctuation can be effectively suppressed, and also there is a conclusion that only during the working state transition from inductive to capacitive should an extra control strategy be applied.

In the future, the unbalance of the load will be considered also will the grid fault. Because of the unbalance of the load, three phase output current will be different, thus the active power flow will be different and the electrical angle at which the reactive current reference is given will be affected during transition. Grid fault should also be considered.

References


