Analysis on Control Stability of STATCOM Applied on Weak Power System

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Abstract—Control stability when Multi-level STATCOM is applied on weak power system is discussed in this paper. In order to research the stability of weak system quantitatively, the current inner open-loop transfer function with system impedance is presented. Nyquist curve is used to demonstrate the relationship between the system impedance and the system control performance. Then a new control strategy - adding the current’s proportion-differential (PD) to the feed forward voltage, is proposed. This control strategy can eliminate the positive feedback action caused by system impedance. Finally, test result proves that the above theoretical analysis is correct.

1. Introduction
STATCOM is now used more widely with the development of power electronics and microcomputer technologies. In China it is mainly used for voltage control in different industries, such as wind farm power station, Photovoltaic power station, substation, mill, subway traction [1-3].

In most cases, the power system connected with STATCOM has a large capacity. But some wind farm power stations or Photovoltaic power stations are far from the strong power system. Those stations are connected to weak power system. In practical applications, weak power grids have great influence on STATCOM operating stability, and the following two cases may happen:

i) STATCOM can’t start up because of oscillations

ii) STATCOM can start up but may oscillate due to minor disturbance of system voltage.

When STATCOM starts up, the current injected into the grid may cause the voltage collapse. High amplitude oscillation may cause protection trip and converter block. So it is necessary to research the control stability of weak system quantitatively.

2. System modeling
In order to simplify the study, Circuit model includes only the PWM rectifier with output filter, and power grid.

2.1 Infinite Grid Model
First, the case of infinite grid without system impedance is researched [4]. Simplified circuit model without considering system impedance is as shown in Fig. 1.
Where $U_g$ is Voltage of infinite grid, $U$ is STATCOM output voltage, $R$ is Resistance of STATCOM interface, $L$ is Inductance of STATCOM interface.

If the system impedance is not considered, a current loop transfer function control diagram using PI regulator is shown as Fig. 2 [5]:

![Figure 2. Control diagram without system impedance](image)

Where $K_F$ is Feed forward coefficient, $K_P$ is Proportional coefficient, $K_I$ is Integral coefficient, $K_{PWM}$ is Modulation coefficient, $T_d$ is Control delay time.

Fig. 2 shows the control strategy with feed forward grid voltage. That control strategy is composite control, which can eliminate the grid voltage’s disturbance. Using composite control method, one can improve control system’s robust performance [6,7].

### 2.2 Model with System Impedance

Compared with the model without system impedance, the simplified circuit model with system impedance is as Fig. 3.

![Figure 3. Simplified circuit model with system impedance](image)

Where $U_C$ is Common node voltage, $L_g$ is Inductance of equaling power system, $R_g$ is Resistance of equaling power system. One can get the control diagram with system impedance, as Fig. 4 shows.

![Figure 4. Simplified control diagram with system impedance](image)

Fig. 4 shows that the feed forward part contains a current transfer function, and it is a positive feedback part. Positive feedback part can make the control system less stable or even unstable. There is a delay part within the control system, which is caused by sampling, modulating and communicating. So feed forward part can’t eliminate the influence caused by system impedance, instead it introduces a positive feedback part for control system.
2.3 Proportion-differential (PD) Compensation Model

From the above analysis, one can see that if the system impedance cannot be ignored, feed forward part can produce a positive feedback loop. To solve the above problem, a method with new feed forward part is proposed, which contains a current’s proportion-differential (PD) compensation. The aim of adding the PD compensation is to eliminate the effect of the system impedance. So the new feed forward part’s transfer function can be described as equation (1).

\[ U_c' = U_c + (L \cdot s + R)i \]  

(1)

Where \( U_c' \) is New feed forward voltage, \( L \) is Estimated resistance of equivalent power system, \( R \) is Estimated inductance of equivalent power system.

Adding the current’s proportion-differential compensation to the feed forward voltage, the control diagram with system impedance (as Fig. 4 shows) is changed to Fig. 5.

![Control diagram with PD compensation feed forward](image)

**Figure 5.** Control diagram with PD compensation feed forward

Under ideal conditions, if \( L = L_s, R = R_s \), the control diagram can be simplified as Fig. 6.

![Simplified control diagram with PD compensation](image)

**Figure 6.** Simplified control diagram with PD compensation

Compared with Fig. 4, PD compensation can eliminate the positive feedback part caused by system impedance. One can get system’s open loop transfer function from Fig. 6, as equation (2) shows.

\[ G(s) = \frac{K_p \cdot s + K_c}{(L + L_s) \cdot T_d \cdot s^3 + [L + L_s + (R + R_s)T_d] \cdot s^2 + (R + R_s) \cdot s} \]  

(2)

3. Further analysis and experiment

3.1 Further analysis

In order to verify that the new feed forward part with PD compensation can improve control system stability, nyquist curves of two control strategies are compared. The two control strategies adopt same parameters under same conditions. Matlab tool is used to draw the nyquist curve: Where \( G_1 \) is the nyquist curve of traditional feed forward control strategy, \( G_5 \) is that of the proposed new feed forward with PD compensation control strategy.
Fig. 7 shows that adding the PD compensation, the distance from the curve to the point (-1, j0) increases. It proves that the new feed forward with PD compensation control strategy leads to a larger stability margin than traditional feed forward control strategy.

3.2 Experiment

Take Korla Photovoltaic power station as an example. The previously mentioned when STATCOM starts up, the current injected into the grid causes the voltage collapse. The waveforms have been recorded by Waveform Recorder. Fig. 8 shows the STATCOM output voltage waveform and the STATCOM output current waveform. It causes protection trip and converter block.

To solve above problem, PD compensation is added on the basis of the original feed forward voltage. Fig. 9 shows how PD compensation is added based on the original control strategy.

In practical applications, PD coefficient need be regulated. In this case, differential coefficient $K'_L = 0.022$, proportion $K'_R = 0.01$. Fig. 10 shows the waveforms after PD compensation is added. From voltage and current waveform of STATCOM, One can see the system can work normally. It proves that PD compensation can improve system stability margin.
4. Conclusion
Control stability when Multi-level STATCOM is applied on weak power system is discussed in this paper. In practical applications, weak power grids can cause STATCOM trip. In order to research the stability of weak system quantitatively, Korla Photovoltaic power station is taken as an example, and the current inner open-loop transfer function with system impedance is presented. Nyquist curve are used to demonstrate the relationship between the system impedance and the system control performance. Then a new control strategy is proposed that the current’s proportion-differential (PD) is added to the feed forward voltage to eliminate the positive feedback action caused by system impedance. The theoretical analysis and experiment results show that PD compensation can improve stability margin.

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