Improved Voltage Control Strategy for Multi-terminal Flexible DC System

Xingwei Liu*, Shixiong Fan, Zechen Wei, Tianjiao Pu
China Electric Power Research Institute, Beijing 100192, China

*Corresponding author e-mail:xw_liu554@163.com

Abstract. This paper presents an improved Voltage Droop control strategy, which updates the reference of DC link voltage by adding the difference between reference and actual voltage, which also adopts a dynamic P-V droop coefficient to improve the DC voltage level. By applying this method, we can eliminate the steady-state deviation of DC link voltage caused by ignoring the power loss in converter. In this paper, in order to demonstrate the reduction of deviation of DC link voltage, an improved control strategy is implemented for a three-terminal flexible DC power system modelled in PSCAD/EMTDC.

1. Introduction

Recently, environmental pollution and energy shortage are becoming more and more serious. In order to alleviate the problems, lots of distributed generations connect into the distribution network, such as PV and wind power. Compared with AC network, DC power system has nothing to do with synchronization stability and three-phase unbalance. In addition, DC power system can reduce the number of converter for distributed generation connecting as [1] explains. Thus DC power system will be the main research direction of this area in the future.

In multi-terminal flexible DC system, DC link voltage acts as an important role. There are three kinds of DC link voltage control strategies in existing literature, including Master-Slave, Voltage Margin and Voltage Droop control. For Master-Slave control, only one VSC station is responsible for the DC link voltage. Once there is something wrong with the voltage-control VSC station, the whole system will break down. The drawback of Voltage Margin control is that it’s difficult to determine the priorities among all the VSC stations. However, when using Voltage Droop control, all VSC stations operate according to the pre-set curve of active power and DC voltage. All VSC stations will play a part in DC link voltage adjustment and active power balance. As [2] indicates that Voltage Droop control is considered as the most suitable method in multi-terminal flexible DC system.

There is always a deviation between the actual and reference DC voltage caused by ignoring the power loss in converter. Hence, an improved DC voltage control strategy need to be complemented to alleviate the difference. Results from [3] show that a secondary control strategy can reduce the power deviation, but the DC link voltage is not improved.

In this paper, an improved Voltage Droop control strategy is proposed to reduce the difference between the actual and reference DC voltage. The improved control strategy is implemented for a three-terminal flexible DC power distribution system modelled in PSCAD/EMTDC. By comparing the simulation results with and without the improved control strategy, the validity is proved.
2. Control Strategy of Flexible DC System

Double-loop control is always used in the control unit of flexible DC system. Outer loop is aimed at accomplishing different control targets, and then it can generate the current reference for inner loop. Inner loop is devoted to improving the power quality. The structure of control system is illustrated as in Figure.1. Where $U_{abc}$ and $I_{abc}$ are AC system voltage and current, $U_{d}$ and $I_{d}$ are voltage and current on d-axis and q-axis. $\theta_s$ is lock-in angle of AC system voltage. $P_{con}$ and $Q_{con}$ are active and reactive power of converter. $U_{dc}$ is DC link voltage.

![Figure 1. The structure of control system.](image)

DC voltage control mainly relies on the double-loop control. Firstly, Adopt the Park transformation to change the signal $U_{abc}$ and $I_{abc}$ into $U_{d}$ and $I_{d}$ on d-q axis. Then active power and reactive power can be calculated as (1).

$$\begin{align*}
P_{con} &= U_d I_d + U_q I_q \\
Q_{con} &= U_d I_q - U_q I_d
\end{align*}$$

When using Voltage Droop control strategy, the outer loop control structure is as Figure.2. Where $U_{dref}$ is reference of $U_{dc}$, $P_{ref}$ and $Q_{ref}$ are references of $P_{con}$ and $Q_{con}$, $I_{dref}$ and $I_{qref}$ are references of $I_d$ and $I_q$. 

1. $P_{con}$ and $Q_{con}$ are active and reactive power of converter. $U_{dc}$ is DC link voltage.
The output of outer loop ($I_{dref}$ and $I_{qref}$) then will be put into the inner loop. The inner loop is responsible for adjusting the current injected into the network. The inner loop control structure is as Figure 3. Where $\omega L$ is coupling reactance of system.

The Voltage Droop Control can be drawn by (2), where $k (k > 0)$ is droop coefficient.

$$P_{con} = P_{ref} + k(U_{dcerr} - U_{dc})$$  \tag{2}$$

When the power loss of converter is not taken account into the reference of DC voltage control, there will be a big difference between the actual and reference DC link voltage. So, an improved control strategy need to be applied to adjust the reference of the outer loop, thus reducing the deviation of DC link voltage.

3. Improved Voltage Droop Control Strategy

This paper proposes an improved DC voltage control strategy to reduce the deviation between the actual and reference DC link voltage. The reference DC link voltage must be updated constantly. At the meantime, the droop coefficient also need to be dynamic. The method of updating the reference of DC link voltage is shown as (3).

$$\begin{align*}
U_{dcref,new} &= U_{dcref} + \Delta U_{dc} \\
\Delta U_{dc} &= U_{dcref} - U_{dc}
\end{align*}$$  \tag{3}$$

When the actual DC link voltage is lower than reference, $\Delta U_{dc} > 0$, the updated reference $U_{dcref,new}$ is higher than before. It will make the DC link voltage increase. Otherwise, $\Delta U_{dc} < 0$, the updated reference $U_{dcref,new}$ is lower than before, the DC link voltage will droop.

The droop coefficient is dynamic, which will increase along with the deviation of active power. It can be calculated as (4), where $s$ is the coefficient to update $k$. The value of $s$ need to fit the order of
magnitude of \( k \). If the value of \( s \) is too small, the effects of regulation is not obvious. On the other hand, if the value of \( s \) is too high, it may result in system instability.

\[
k_{\text{new}} = s \cdot |P_{\text{con}} - P_{\text{ref}}| + k
\]  

The improved DC voltage control strategy changes the reference of outer loop. Now the improved DC voltage control structure is illustrated as Figure 4.

**Figure 4.** Improved DC voltage control structure.

4. Case Study

A three-terminal flexible DC system is simulated in PSCAD/EMTDC as example. The structure of the system is shown as Figure 5.

**Figure 5.** Structure of three-terminal flexible DC system.

During the simulation, the parameters set as below. The positive direction of power is from AC system to DC system. AC system voltage is 10kV. Transformer ratio is 10/0.38kV. \( U_{\text{dcref}}=800V \), \( P_{\text{ref1}}=-500\text{kW} \), \( P_{\text{ref2}}=200\text{kW} \), \( P_{\text{ref3}}=300\text{kW} \), \( k=1\text{kW/s} \), \( s=15 \). VSC1 is a rectifier station, VSC2 and VSC3 are inverter stations. The simulation results are illustrated as Figure 6 and Figure 7.

**Figure 6.** The actual and reference active power of converter.
From Figure 6, we can see that the active power doesn’t reach the reference because of the power loss in converters. The actual power of the three converters are: $P_1 = -510$ kW, $P_2 = -183$ kW, $P_3 = 289$ kW. It can be observed from Figure 7 that without the improved Voltage Droop control, the DC link voltage is 785 V. The difference between the actual and reference DC voltage is up to 15 V. It will affect DC load and DC power’s efficiency. After adopting the improved control strategy, the DC voltage rises to 798 V. The operation level of DC link voltage is improved effectively.

5. Conclusion
This paper proposes a dynamic Voltage Droop control strategy in order to alleviate the deviation of DC voltage caused by ignoring the power loss in converter. By adopting the dynamic droop coefficient and adding the difference between the reference and actual DC voltage into the reference, the droop coefficient will change with the difference of DC link voltage. As a result, the DC link voltage can be improved effectively. The simulation results prove the effectiveness of the strategy.

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