Research on Power Control Strategy for 35kV Medium Voltage Transformerless PCS

Bo Yang¹, Guanjun Li¹, Dan Li¹,² and Haojie Yu¹

¹ Renewable Energy Research Center, China Electric Power Research Institute, No.8 Nanrui Road, Nanjing, China
² Corresponding Author
Email: lidan1@epri.sgcc.com.cn

Abstract. The continuous growing generating capacity of new energy power has brought more and more serious impact on the stability of electrical power system. As an important method to compensate the fluctuating power of new energy plant, highly efficient large-scale power storage system has played a more and more important role in helping stabilizing electrical power system. In this paper, a topological structure of 35kV transformerless power storage system is designed, and an active and reactive decoupling control system against this system is proposed. Concerning the application scenario of primary frequency regulation, an active support frequency response control technology for power grid with changing the droop coefficients based on three response modes is put forward. Finally, the control strategy designed is simulated and verified by using PSCAD system. The simulation result shows that the system and control strategy can do very well in active support frequency response control for power grid.

1. Introduction

In recent years, new energy power generation, such as wind power and solar power, has met its rapid development, which has given an increasingly larger proportion in the whole power system. In 2018, China's grid-connected solar power generation and wind power generation were 177.5 billion and 366 billion kWh respectively, increasing by 50.8% and 20.2% respectively over the same period last year. However, the new energy power generation is also growing with series of problems: intermittence and fluctuation of output power of new energy have brought more unstable factors for electrical power system; using power electronic devices as interfaces has caused the new energy power system to lack of enough equivalent moment of inertia, thus resulting in a poor anti-interference ability; the continuous growing penetrance has made the electrical power system insufficient in its capacity of primary frequency regulation; weak capacity of frequency and voltage withstanding of the new energy plant; the capacity of wind power will not be fully used due to its anti-peak regulation character, etc.

On the basis of the above problems when new energy enters into power grid, large-scale power storage system is proposed as a solution. It can control the release and absorption of energy in energy storage device to rapidly provide dynamic power support after disturbance occurs in the electric power system, to improve the rotational inertia of the system, and to work together with new energy plant to actively support the power grid response. It is of great significance in improving the absorption of new energy and ensuring the power grid a stable operation.

Nowadays, in the engineering applications, large capacity PCS usually operates in parallel with several low-voltage converters and connects to medium and high-voltage network through boost transformers. Although the technology of this method is mature, the control between converters is
independent, which makes the coordination and coherence of the whole system worse. A huge management system and complex control strategy are needed to coordinate the control. And the response speed of the system is slow. In addition, the different output voltages between parallel converters will cause "circulation" and additional losses. In this paper, several low-voltage sub-modules are adopted. The series structure divides the voltage. This scheme does not need transformer and reduces the loss. The centralized control mode is conducive to the implementation of the control strategy, and the response speed of the system is greatly improved.[1].

At present, the research on medium and high voltage direct-mounted energy storage systems mainly focuses on topology design and optimization, power control, battery state-of-charge balance control, fault-tolerant control and grid response control [2]. Laxman Maharjan from Tribhuvan University has a brief discussion on a battery energy storage system based on a multilevel cascade pulsewidth-modulated (PWM) converter for its practical use. The Experimental results obtained from a 200-V, 10-kW, 3.6-kWh battery energy storage system verify the effectiveness of the presented active-power control [3-5]. Noriko Kawakami et al. developed a real-scale (500 kW) single-star-bridge-cell-based MMCC for BESSs. They reports successful test results obtained from a downscaled grid model and a 6.6-kV real-scale distribution line [6].

2. The Over All Designer of System
In this paper, the 35kV/5MVA large capacity energy storage system is used as the research object [7]. The cascaded H-bridge energy storage power conversion system topology is shown in Fig. 1. Each phase is connected in series by a number of low-voltage cascaded units. The three-phase star type connection is connected by the reactor to the 35kV power grid. The AC side of the system is equipped with an AC precharge circuit, and each cascade unit consists of a single-phase H bridge power conversion module, a LC filter circuit, a DC precharge link and a battery unit [8].

![Figure 1. The topology of 35kV cascaded H bridge energy storage system](image)

3. Power Control Strategy
The mathematical model of 35kV cascade H-bridge energy storage system in DQ synchronous rotating coordinate system is as follows:
where \( u_d \) is the d axis component of grid voltage, \( u_q \) is the q axis component of grid voltage, \( u_d \) and \( u_q \) are the d axis and q axis components of PCS output voltage. To decouple the voltage and current components in formula (1), two new variables \( \Delta u_d \), \( \Delta u_q \) are introduced and are satisfied with \( u_d \), \( u_q \):

\[
\begin{align*}
\Delta u_d &= u_d + \omega L i_q - \Delta u_d \\
\Delta u_q &= u_q - \omega L i_d - \Delta u_q
\end{align*}
\]

(2)

Formula (1) and (2), can be obtained:

\[
\begin{align*}
L \frac{d i_d}{dt} + R i_d - \Delta u_d &= 0 \\
L \frac{d i_q}{dt} + R i_q - \Delta u_q &= 0
\end{align*}
\]

(3)

From the formula (3), we can see that there is a first order differential relation between \( \Delta u_d \), \( \Delta u_q \) and \( i_d \), \( i_q \). In order to realize the steady state difference tracking control of \( i'_d \), \( i'_q \), the PI control link can be used, and \( \Delta u_d \), \( \Delta u_q \) are defined as follows:

\[
\begin{align*}
\Delta u_d &= k_{d}\int (i'_d - i_d)\,dt + k_{d}\int (i'_d - i_d)\,dt \\
\Delta u_q &= k_{q}\int (i'_q - i_q)\,dt + k_{q}\int (i'_q - i_q)\,dt
\end{align*}
\]

(4)

When the grid voltage oriented dq synchronous rotating coordinate system is adopted, when \( u_d = u_d \), \( u_q = 0 \), the system feed forward decoupling control model as shown in Figure. 2 can be established; \( K_{dq} \), \( K_{di} \), \( K_{qp} \) and \( K_{qi} \) are the adjustment parameters of PI controller; \( i'_d \), \( i'_q \) are the given values of active current and reactive current. The left half of Figure. 2 is the feed forward control model.

**Figure 2.** System model with feedforward decoupling control

Based on the control block diagram shown in Figure.2, the independent control of the system output current can be completed, and then the decoupling control of active power and reactive power can be realized.

4. Frequency Response Control of Active Support Grid

An important application scenario of large-capacity energy storage system in power system is auxiliary frequency modulation. For the 35kV Transformerless energy storage system, this paper
designs an active support grid primary frequency response control strategy. Unlike the traditional frequency modulation strategy with fixed droop coefficient, this control strategy can continuously change the droop coefficient according to the real-time operation state of the energy storage system and the upper limit of output power. Then, the output power of the system is adjusted according to the frequency deviation degree of the grid to realize the active response of the grid frequency, which can make full use of the regulating ability of the energy storage system and make the system response more accurate. The adjustment capability of the energy storage system can be fully utilized to make the system response more accurate.

The frequency deviation of the system is defined as:

$$\Delta f = f_s - f_N$$  \hspace{1cm} (5)

where $f_s$ is the real-time frequency of the grid and $f_N$ is the rated frequency of the grid. The frequency response of the energy storage system is divided into three modes: a given power operation mode of the frequency modulation dead zone, an active support frequency deviation response mode, and a maximum power operation mode of the overrun zone. The operating ranges of the three operating modes are divided according to the response threshold $\Delta f_r$ and the frequency deviation threshold $\Delta f_l$. Where $[-\Delta f_l, \Delta f_l]$ is set to the FM dead zone, when the grid frequency deviation changes within this range, the energy storage system does not actively act to avoid system loss and performance degradation caused by frequent response; $(\Delta f_l, \Delta f_r)$ and $(-\Delta f_l, -\Delta f_r)$ are set to actively support the frequency response of the energy storage system. In the region, when the grid frequency deviation changes within this range, the energy storage system simulates the droop characteristics of the traditional generator set to adjust the frequency to achieve active power compensation for the grid; $[-0.5, \Delta f_l]$ and $[-0.5, -\Delta f_r]$ are set to the frequency deviation limit zone, and the grid frequency deviation reaches In the range, the energy storage system is charged and discharged at maximum power immediately and unconditionally according to the needs of the power system.

In the active support frequency deviation response mode, the droop gain (MW/Hz) is first determined according to the deadband given operating power, response threshold, maximum output power, and frequency deviation threshold:

$$K = \begin{cases} 
K_c = \frac{P_{max} - P_1}{\Delta f_l - \Delta f_d}, & \Delta f > 0 \text{(charge)} \\
K_d = \frac{-P_{max} - P_1}{-\Delta f_l + \Delta f_d}, & \Delta f < 0 \text{(discharge)}
\end{cases}$$  \hspace{1cm} (6)

Where the $P_{max}$ is the maximum output power of the energy storage system, and the $P_1$ is the given operating power of the grid frequency deviation at the FM dead zone, $\Delta f_l$ is the frequency deviation threshold of the maximum power output of the energy storage system, and the $\Delta f_d$ is the threshold value for the energy storage system to participate in the grid frequency modulation.

The droop gain and frequency deviation determined by the formula (6) can obtain the output power increment of the energy storage system (the charging power of the energy storage system is positive and the discharge power is negative).

$$\Delta P = \begin{cases} 
K_c \times (\Delta f - \Delta f_d), & \Delta f > 0 \\
K_d \times (\Delta f + \Delta f_d), & \Delta f < 0
\end{cases}$$  \hspace{1cm} (7)

According to the initial operation power of the energy storage system, a new power reference value of PCS is obtained.

$$P_0 = P_1 + \Delta P$$  \hspace{1cm} (8)

In summary, the three response modes of the energy storage system to the grid frequency fluctuation are shown in Figure.3, and the corresponding power output adjustment value is:
Figure 3. Energy storage system actively supports grid frequency response curve

5. Experiment and Simulation

Based on the topological parameters and operation control strategy of the 35kV direct-storage energy storage system, power dynamic control and frequency response simulation experiments were carried out using PSCAD.

The power dynamic adjustment simulation of the system model is performed by giving different power reference commands at different times. The rated power of the system design is S=5MVA. When the given power is 0.3s, the given control commands: P=0.5MW, 0.5s is given P=2.5MW, 0.7s is given P=5MW, 0.9s is given P=−2.5MW, given P=−5MW at 1.1s, P=−0.5MW at 1.3s.

Figure 4 and Figure 6 show the dynamic output process of the active power and reactive power of the system respectively. After the control command is given, the output current of the system enters a steady state within 10ms. It can be seen from the figure that the system achieves accurate tracking of the output power, the dynamic adjustment process is very short, and the output power does not fluctuate greatly. Tracking accuracy is maintained at a good level, reflecting the effectiveness of system control. Figure 5 and Figure 7 show that the system output current is not distorted and impacted during the power adjustment process, indicating the correctness and stability of the parameter design and control strategy.

Figure 4. System output for dynamic power adjustment (kW)
When the grid frequency fluctuates, the frequency response operation simulation of the energy storage system is carried out according to the aforementioned active support grid frequency response control strategy. The grid frequency starts at 50Hz, the energy storage is charged at 2MW power, and when t=1s, the grid frequency becomes 50.035Hz. After the control strategy calculation, the energy storage system charging power becomes 2.75MW, and the response process is shown in Figure 8 and Figure 9.
6. Conclusion
The medium voltage large capacity power storage and power converted system can connect several low voltage cascade units in series connection into the power grid, having the features of low loss, good output characteristic and easy to control etc. It is of big developing and application space in aspects of peak and frequency regulation in power grid, new energy connecting into power grid, and black startup and so on. A topological structure of 35kV transformerless power storage system is designed in this paper. The system adopts a kind of feedforward decoupling strategy to achieve the system’s active and reactive independent control. A strategy of active support frequency response control for power grid based on changing the droop characteristics is designed. The strategy can rapidly and accurately adjust the output power based on the deviation condition of power grid frequency, as well as the actual running condition of the power storage system. Finally, effectiveness and advancement of the algorithm is tested by simulation experiment using the PSCAD.

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