Dynamic Reactive Power Compensation and Harmonic Suppression of Optical Storage Microgrid Control in Natural Coordinates

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Abstract. In order to solve the influence of load fluctuation on the power quality of the grid when the distributed photovoltaic power generation system is connected to the grid side, and to reduce the complexity of the control system, this paper proposes the grid-connected control of the microgrid with reactive power compensation and harmonic suppression in natural coordinates. This strategy maintains the DC bus voltage stability in a battery capacity state switching converter control method. Two kinds of grid-connected inverter power control strategies with reactive power compensation are designed for different working conditions, which realizes independent control of active and reactive power of grid-connected inverters, eliminating coordinate transformation and grid phase detection. The experimental results show that the proposed control strategy can achieve the smooth and efficient flow of the optical storage microgrid system, achieve the purpose of reactive power compensation, and has a good dynamic response.

1. Introduction
With the development of distributed power sources and microgrids, distributed generation technology is becoming more and more competitive in the power grid. As a kind of clean energy, solar power generation network has a higher proportion in the power system with its unique advantages. Photovoltaic power generation converts the DC power of the PV array into AC power that is in phase with the same frequency of the grid and feeds it to the grid, and ensures a high grid-connected power factor and improves resource utilization. However, the intermittent and random nature of solar energy itself has led to a series of problems such as large fluctuations in photovoltaic power generation voltage and frequency, power imbalance, poor power quality, and difficulty in grid connection. At present, the application scale of the optical storage power generation system is getting larger and larger. How to improve the application efficiency of the photovoltaic unit and reduce its influence on the stable operation of the system and the poor power quality are issues that must be considered.

In order to realize the unified control of grid-connected power generation, reactive power compensation and harmonic suppression, the system must be able to emit reverse-phase reactive power and harmonic current while detecting the reactive power and harmonic current of the grid load to offset the reactive power of the load. The effect of wave current on the grid. In [3], in order to reduce the influence of load reactive power and harmonics on the power grid, it is proposed to integrate photovoltaic grid-connected power generation and reactive power compensation to form a...
photovoltaic grid-connected power regulation system, but the system harmonic current is not suppressed. Literature [5] proposed a grid-connected control scheme for optical storage power generation system with reactive dynamic compensation capability. This scheme achieves the purpose of independent control of active and reactive power through Parker transformation, but its coordinate transformation and grid phase detection are relatively complicated. Literature [8] proposes a new definition of generalized reactive current and reactive power in the $abc$ coordinate system still applicable to grid voltage distortion, and gives a method for detecting and compensating generalized reactive current.

Based on the above analysis, this paper proposes the grid-connected control of the microgrid with reactive power compensation and harmonic suppression in natural coordinates. The strategy is based on the instantaneous reactive power theory to detect the reactive and harmonic currents of the system, and achieves an effective and fast response of reactive power compensation and active filtering. At the same time, in order to reduce the complexity of the system, a grid-connected control strategy of optical storage micro-grid with reactive dynamic compensation in natural coordinate system is proposed. According to the state of charge of the energy storage battery, two grid-connected inverter power control is adopted, namely $PQ$. Power control and $VQ$ power control. The independent control of the active and reactive power of the grid-connected inverter is realized, and the coordinate transformation and the grid phase detection are omitted. In this paper, the combination of photovoltaic power generation control with reactive power compensation and active filter control can not only effectively perform photovoltaic power generation, improve power supply quality and reduce power loss, but also save investment in corresponding equipment and broaden photovoltaic grid-connected power generation. The scope of application.

2. Instantaneous reactive power and harmonic current detection

There are many methods for detecting instantaneous reactive current. In [4], the principle of instantaneous reactive power and harmonic current detection in transient reactive power theory is used to detect the fundamental reactive power and harmonic current of the system. In [6], based on FFT’s high-precision harmonic detection algorithm, accurate detection of non-integer harmonics is proposed. Because the response requirements of the inverter are relatively fast and both are instantaneous values, this paper detects the reactive current of the system based on the instantaneous reactive current instantaneous current detection method, which not only meets the requirements of the fast response of the grid-connected inverter, but also reduce the complexity of the control system. For the transient current detection method of instantaneous reactive power theory, see the literature [4].

Let the three-phase grid voltage be symmetrical and positive. The three-phase currents $i_a$, $i_b$, and $i_c$ are transformed by $C_{32}$ and $C$ to obtain the current active component $i_p$ and the reactive component $i_q$ in the $P-Q$ rotating coordinate system, respectively.

$$\begin{bmatrix} i_α \\ i_β \end{bmatrix} = C_{32} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

In the middle $C_{32} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C \begin{bmatrix} i_α \\ i_β \end{bmatrix} \quad (2)$$
In the middle

$$C = \begin{bmatrix}
\sin \alpha & \cos \alpha \\
-\cos \alpha & -\sin \alpha
\end{bmatrix}$$

Where $\omega$ is the power angle frequency. Calculated by the above formula, the current components $i_p$ and $i_q$ in the $p-q$ rotating coordinate system are obtained.

When detecting reactive current and harmonics, $Bip$ can calculate the fundamental active current components $i_{apf}$, $i_{bpf}$ and $i_{cpf}$ of the detected current.

$$\begin{bmatrix}
i_{apf} \\
i_{bpf} \\
i_{cpf}
\end{bmatrix} = C_{23} C^{-1} \begin{bmatrix}Bip \\0\end{bmatrix} \quad (3)$$

In the middle

$$C^{-1} = \begin{bmatrix}
\sin \alpha & -\cos \alpha \\
-\cos \alpha & -\sin \alpha
\end{bmatrix} \quad C_{23} = \frac{1}{\sqrt{3}} \begin{bmatrix}2 \\1 & -\sqrt{3} \\1 & -\sqrt{3}
\end{bmatrix}$$

The sum of the harmonic component of the detected current and the fundamental reactive component is:

$$i_{aq} = i_a - i_{apf} \quad i_{bq} = i_b - i_{bpf} \quad i_{cq} = i_c - i_{cpf} \quad (4)$$

On the basis of the completion of reactive power and harmonic current detection, the detected value of each phase is used as the command value of the reactive current component. The current feedback control of the system satisfies the reverse phase requirement of the phase of the control current, and the system generates reversed reactive power and Harmonic current, which in turn achieves reactive power compensation and harmonic suppression.

3. Grid-connected control of optical storage microgrid

3.1. System structure of optical storage microgrid

![Figure 1 System structure of optical storage microgrid](image)

The system structure of the optical storage microgrid system connected to the grid is shown in Figure 1. The system consists of photovoltaic system, energy storage system, converter, transformer, load and distribution network.
3.2. Energy storage system

The energy storage system is connected in series through a plurality of battery modules to obtain a higher voltage level, and is boosted and regulated by a bidirectional DC/DC converter. The energy storage system has two control modes, namely voltage regulation control and constant current control. The voltage regulation control adjusts the power balance of the energy storage battery charging and discharging power control system to maintain the constant DC voltage; the constant current control passes a given small As the reference value of the energy storage discharge current and the reference value of the charging current, the value is charged and discharged by the constant current of the energy storage battery to ensure the normal use of the battery. In this paper, a general-purpose battery is used as the energy storage device. The output voltage of the energy storage battery is:

\[ V_b = V_0 + R_b i_b - K \frac{Q}{Q + \int i_b dt} + C \exp \left( B \int i_b dt \right) \] (5)

\[ SOC = 100 \left( 1 + \frac{\int i_b dt}{Q} \right) \] (6)

Where: \( R_b \) is the resistance of the battery; \( V_0 \) and \( V_0 \) are the battery output voltage and open circuit voltage; \( i_b \) is the charging current, \( K \) is the battery polarization voltage; \( Q \) is the battery capacity; \( K, B \) and \( C \) are constant.

3.3. Control of reactive power compensation system in natural coordinates

1) Assume that in a three-phase symmetrical AC system, the grid direction is defined as the active power direction, and its instantaneous amplitude is selected as the reference value. The instantaneous amplitude of the grid voltage is:

\[ U_s = \sqrt{\frac{2}{3}} (u_a^2 + u_b^2 + u_c^2) \] (7)

Then the three-phase active unit components are:

\[ v_a = \frac{u_a}{U_s}, \quad v_b = \frac{u_b}{U_s}, \quad v_c = \frac{u_c}{U_s} \] (8)

Figure 2 Phasor relationship between unit active and reactive components

The unit reactive component orthogonal to the active component is:

\[ w_a = \frac{1}{\sqrt{3}} (v_c - v_b), \quad w_b = \frac{1}{\sqrt{3}} (v_a - v_c), \quad w_c = \frac{1}{\sqrt{3}} (v_b - v_a) \] (9)

The three-phase active current components are:

\[ i_{pa} = i_p v_a, \quad i_{pb} = i_p v_b, \quad i_{pc} = i_p v_c \] (10)
The three-phase reactive current components are:

\[ i_{qa} = i_{qy}w_a, \quad i_{qb} = i_{qy}w_b, \quad i_{qc} = i_{qy}w_c \quad (11) \]

Then the three-phase reference value of the microgrid grid-connected inverter output is:

\[ i_a^* = i_{pa} + i_{qa}, \quad i_b^* = i_{pb} + i_{qb}, \quad i_c^* = i_{pc} + i_{qc} \quad (12) \]

2) Operation control of grid-connected inverter

In order to convert the direct current output from the photovoltaic power generation system and the energy storage system into an alternating current through an inverter to realize grid-connected power generation, the inverter should adopt a corresponding control method.

(1) \( PQ \) power control. The collected voltage and current signals are obtained by the \( PQ \) calculation module to obtain the real-time measured value of the power, and are respectively made to be different from the given values of the active power and the reactive power, and the inner loop active current command value and the reactive current command value are obtained through the \( PI \) link. Then, it is respectively multiplied by the active component and the reactive component of the three-phase current, and then the corresponding vectors are added to obtain the three-phase reference current value of the inner loop. The current inner loop reference current \( i_{abc}^* \) is compared with the measured current \( i_{abc} \), and the pulse signal is sent to the grid-connected inverter through the \( SPWM \) modulation link, so that the inverter active and reactive output can be realized. The active and reactive control signals of this control strategy are taken from the inverter output active and the grid side input reactive power, so that the inverter can output the active power and control the fixed input reactive power of the grid respectively. The inverter outputs the corresponding reactive power according to the fluctuation of the load reactive power. The measured value in the whole process is the instantaneous value of the power grid connected to the load side, and the dynamic real-time tracking compensation effect is achieved.

(2) \( VQ \) power control. When the optical storage microgrid system is started, if the energy storage system is in the constant current control mode and the grid-connected inverter adopts \( PQ \) control, the DC bus voltage is in an uncontrolled state, and it is difficult to ensure the input power and output of the inverter. The power is consistent, causing the system to crash. In order to ensure stable operation of the system, the DC bus voltage must be stabilized.
The power is consistent, causing the system to crash. In order to ensure stable operation of the system, the DC bus voltage must be stabilized. Therefore, when the capacity $SOC < 5\%$ or $SOC > 95\%$ of the energy storage battery is used, the control method as shown in Fig. 3 is employed. By controlling the DC bus voltage, the stability of the DC bus voltage is maintained, and the balanced flow of the grid-connected inverter power is ensured, so that the system operates stably.

4. Simulation results

In order to verify the effectiveness of the control strategy, this paper builds the optical storage microgrid system shown in Figure 1. In this model, the light intensity is $1000W/m^2$, and the maximum power output of photovoltaic power generation is $15kW$. The rated voltage of the battery is $200V$ and the capacity is $300Ah$. There is no additional reactive power compensation device, and the simulation duration is $5S$. The rated voltage of the load is $500V$. In the initial state, there is a $10kW$ work load, and the reactive load is $9kVar$. Compared with conventional unit power factor grid-connected control under the same conditions. The simulation results are shown in the following figure: Figure 5 shows the RMS effective value of the load line voltage under normal unit power factor, the reactive output on the inverter side and the large grid side. Figure 6 shows the RMS value of the load line voltage, the reactive side of the inverter side and the large grid side under the control strategy of the grid-connected inverter.

![Figure 5 results under the general control strategy](image-url)
5. Conclusion

The simulation results show that for the conventional control strategy, when the reactive load changes, the voltage of the common coupling point changes greatly due to the transmission of reactive power, which is not conducive to providing reliable power quality. Comparing the simulation waveforms obtained by using two different control strategies, it can be known that for the new control strategy, it has a certain reactive power compensation capability, which can effectively ensure the stability of the common coupling point voltage.

References

[1] Wang Zhaoan, Yang Jun, Liu Jinjun. Harmonic suppression and reactive power compensation [M]. Beijing: Mechanical Industry Press, 1998.

[2] Zhang Xing, Cao Renxian. Solar photovoltaic grid-connected power generation and its inverter control. Beijing: Mechanical Industry Press, 2013:1-26.

[3] Wang Haining, Su Jianhui, Ding Ming, et al. Photovoltaic grid-connected power regulation system[J]. Proceedings of the CSEE, 2007, 27(2): 75-79.

[4] Wang Haining, Su Jianhui, Zhang Guorong, Ding Ming. Research on Control of Photovoltaic Grid-Connected Power Regulator with Reactive Power Compensation and Harmonic Suppression[J]. Journal of Solar Energy, 2006, 27(6): 540-544.

[5] Li Bin, Fan Shoulu, Tian Xiaohe, et al. Grid-connected control scheme of reactive power compensation for optical storage power generation system [J]. Journal of Tianjin University: Natural Science and Engineering Technology Edition, 2013, 46(11): 977-983.

[6] HILLC, SUCHMC, CHEND, et al. Battery energy storage for enabling integration of distributed solar power generation [J]. Smart Grid, IEEE Transactions on, 2012, 3(2) : 850-857.

[7] Xue Wei, Yang Rengang. High-precision harmonic detection algorithm based on FFT[J]. Proceedings of the CSEE, 2002, 22(12): 106-110.

[8] Yin Bo, Chen Yunping. Definition and compensation of generalized reactive current and power in abc coordinate system[J]. Power grid technology,2003,27(7): 43-51.

[9] Cao Jun, Hu Likun, Lu Zhilin, et al. Grid-connected control of optical storage microgrid with reactive dynamic compensation[J]. Journal of Guangxi University, 2015, 40(6): 1424-1430.

[10] Cao Jun. Research on grid-connected control strategy of optical storage micro-grid with reactive dynamic compensation [D]. Guangxi: Guangxi University, 2016.