Research of auxiliary frequency modulation in smart microgrid

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Abstract. In this paper, the component model of bidirectional converter and inverter is established, and the precise control of input and output power of the energy storage system is realized by using dual loop control strategy and PQ control strategy. The control strategy of the energy storage system is proposed to improve the performance of the primary frequency modulation process. The grid interconnection model of offshore oil platform is established. The frequency variation in primary and secondary frequency modulation is simulated to verify the effectiveness of the control strategy.

1. Introduction

In the current energy situation, fossil energy consumption still accounts for a large proportion. The exploitation of marine oil and gas resources is an important way to solve the energy crisis. China is rich in marine resources. The proven but unexplored oil and gas resources in the four major sea areas are very rich. In order to carry out offshore engineering, it is necessary to equip corresponding offshore platforms. The offshore power system is an important source for power supply of offshore platforms. To study the power supply scheme and comprehensive benefits of the power system of offshore platforms is an important measure to promote the development of offshore engineering [1-5]. With the development of society, the demand of fossil energy is increasing. To solve the problem of energy crisis, human beings build offshore platforms in the ocean to exploit the abundant fossil resources in the ocean, so as to alleviate the energy crisis. As the main power energy of offshore platforms, the stability of offshore power system is the guarantee for the production and life of offshore platforms. However, most offshore platforms are equipped with a single power station for independent power supply, and the grid reliability of a single platform is poor. To solve this problem, offshore platforms are networked to expand the overall capacity of the power system and improve the stability of the system against large load shocks. Offshore platform networking is a special microgrid. Gas turbines are located on different platforms and have the characteristics of distributed power supply. Combined with the control strategy of energy storage and frequency modulation in micro-grid, this paper mainly studied the gas turbine model, offshore platform micro-grid model, energy storage system model, energy storage system control strategy and the role of energy storage and frequency modulation [6-16]. This paper summarizes the current development of ESS and discusses its infrastructure and frontier applications. According to the genetic strategy is adopted to control the ESS, thus effectively improving
the stability of power grid. For private large-scale ESSs, a real-time optimal scheduling algorithm is proposed to maximize revenue through FM service transactions in the power market. The virtual drop control is applied to the ESS in the micro grid, resulting in reduced energy consumption of energy storage and generator fuel consumption in the micro grid. In offshore oil platform auxiliary power grid frequency modulation energy storage device, the study of energy storage unit AFM is not enough in-depth, model combining with the structural characteristics of the unit itself, control method and the capacity of ESS configuration in-depth research, it is necessary for each part of the unit and the ESS model respectively, set up regional power grid frequency modulation of the whole model, studies the optimal control method by means of simulation.

2. Structure of smart microgrid

2.1 Structure of micro-turbine system

The structure of the single-shaft micro-gas turbine power generation system is shown in Figure 1. Gas Turbine in the main flow of air and gas, only Compressor, Combustor and Turbine composed of three components gas Turbine cycle.

![Figure 1. Structure of the single-shaft micro-turbine power generation system](image)

2.2 Structure of offshore oil platform microgrid

The offshore oil platforms are interconnected by 35kV cables. Each offshore oil platform contains multiple transformers and loads, most of which are inductive loads. The connection mode is shown in Figure 2, it is the location of offshore oil platform group power grid. G1-G4 are central platform.

![Figure 2. Structure of offshore oil platform microgrid](image)

2.3 Inverter circuit structure and control strategy

The main structure of the inverter is a three-phase bridge inverter circuit composed of three pairs of thyristors. The topology of the inverter circuit is shown in Figure 3.
According to the characteristics of the circuit, the three-phase voltage and current relationship is analyzed, and the equation is obtained as equation (1)(2).

$$L \frac{di_{abc}}{dt} + Ri_{abc} + e_{abc} - V_{abc} = 0 \quad (2)$$

The process of orthogonal Park transformation of equation (2) is shown in equation (3) and (4).

$$\bar{C}L\bar{C}^{-1} \frac{di_{dabc}}{dt} + \bar{C}R\bar{C}^{-1} \bar{C}i_{abc} + \bar{C}e_{abc} - \bar{C}V_{abc} = 0 \quad (3)$$

$$\bar{C} \frac{di_{abc}}{dt} = \bar{C} \frac{d}{dt} (\bar{C}^{-1}i_{dq0}) = \bar{C} \frac{d\bar{C}^{-1}}{dt} i_{dq0} + \frac{di_{dq0}}{dt} \quad (4)$$

According to equation (4), equation (5)(6) can be obtained.

$$L(\frac{di_{dq0}}{dt} + \bar{C} \frac{d\bar{C}^{-1}}{dt} i_{dq0}) + Ri_{dq0} + e_{dq0} - V_{dq0} = 0 \quad (5)$$

$$L \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} R & -\omega L \\ \omega L & R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} e_d \\ e_q \end{bmatrix} - \begin{bmatrix} V_d \\ V_q \end{bmatrix} = 0 \quad (6)$$

Take the Laplace transform and get the result as shown in equation (7).

$$\begin{cases} i_d = \frac{V_d - e_d + \omega Li_d}{R + sL} \\ i_q = \frac{V_q - e_q + \omega Li_q}{R + sL} \end{cases} \quad (7)$$

This is the constraint equation of the inverter's physical characteristics.

According to equation (8), the relationship between active and reactive power and dq axis voltage and current can be known. The phase-locked loop is used so that the rotating voltage vector is always on the d-axis, eq=0. At this point, since the inverter is connected to the bus, Ed remains basically unchanged, so the active and reactive power output of the inverter is determined by $i_d$ and IQ respectively.

According to equation (7), there is coupling between the $d$ and $q$ axis currents, and corresponding decoupling control strategy is required to realize the independent control of the $d$ and $q$ axis currents. The current closed-loop decoupling control strategy introduces the opposite quantity to the PI control result of the current closed-loop to offset the influence of the coupling quantity on the control, so as to make the $d$ and $q$ axis current consistent with the set value in the steady state. After introducing the opposite quantity to generate the $d$ and $q$ axis reference voltage, the inverse Park transformation is carried out to
change it into the mid-point reference voltage of ABC three-phase bridge arm, and PWM control is carried out according to the obtained reference voltage, so that the inverter can operate in the set state and the output active and reactive power can be more accurate and fast controlled.

3. Simulation research of AFM system

3.1 Simulation model of microgrid in PSCAD
A single region power grid model is established in PSCAD. In order to simplify the situation, the single-region power grid is set as the single-unit with load, and the PSCAD model is shown in Figure 4.

![Figure 4. PSCAD model of unit](image)

In Figure 4, 1 is the speed control link, whose function is to maintain stable speed when load changes within a certain range; 2 is the temperature control link, the main role is to limit and maintain the turbine generator inlet temperature; 3 is acceleration control link, and temperature control link and speed control link together to produce a minimum fuel reference, so as to obtain the actual fuel semaphore; 5 and 6 are exhaust temperature functions and torque functions.

Pref generates the ESS power instructions for the energy storage auxiliary FM controller. Internal resistance of the storage battery voltage is set to 600 v, 0.001 Ω, dc bus voltage of 800 v, keep the inverter ac terminal voltage 380 v. Connect to AC bus through 380V/10kV transformer.

3.2 Simulation results of AFM in microgrid
The simulation is carried by energy storage systems on two platforms, namely, G1 and G2 platforms, G1 and G3 platforms and G2 and G3 platforms respectively. In the simulation, the gas turbine set is started with load at 0.4s, with a load capacity of 30MW, which is 30% of the total capacity of the generator set.

The primary FM speed curve of the gas turbine set equipped with the energy storage system on the dual platform is shown in the Figure 5, Figure 6 and Figure 7.

When G1 and G2 platforms are equipped with energy storage systems, the two frequency deviations are reduced, and the adjustment time is reduced compared with the state without energy storage, which plays a certain role in energy storage frequency modulation. The frequency improvement of G1 and G3 platforms with energy storage systems is similar to that of G1 and G2 platforms with energy storage systems. After the G2 and G3 platforms are equipped with energy storage systems, both frequency parameters have been reduced, and the adjustment time has been greatly reduced on the original basis of the three methods, the energy storage system is the most effective in G2 and G3 platforms.
Figure 5. Auxiliary frequency modulation in G1 and G2

Figure 6. Auxiliary frequency modulation in G1 and G3

Figure 7. Auxiliary frequency modulation in G2 and G3
Figure 8. Variation curves of frequency reduction of different energy storage capacities

In the process of frequency modulation, the ESS takes the first action after the AGC instruction is issued, and the output changes rapidly with the jump of the AGC instruction, so that the speed changing due to load fluctuation rapidly returns to the direction of the rating value, and then the energy storage output slowly decreases to zero. When the AGC instruction changes suddenly, the input and output power required is the maximum, because the output of the ESS changes rapidly. Therefore, the maximum input/output power of the ESS mainly affects the speed of speed regression after the AGC instruction is issued, and therefore affects the time for the system to reach steady state. Figure 8 shows the simulation curve of frequency modulation speed under different energy storage capacities.

4. Conclusion

In this paper, the component model of bidirectional converter and inverter is established, and the precise control of input and output power of the energy storage system is realized by using dual loop control strategy and PQ control strategy. the control strategy of the energy storage system is proposed to improve the performance of the primary frequency modulation process. The grid interconnection model of offshore oil platform is established. The frequency variation in primary and secondary frequency modulation is simulated to verify the effectiveness of the control strategy.

5. References

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