Research of evaluation method of auxiliary frequency modulation in gas turbine unit

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Abstract. In this paper, according to the mechanical structure of the gas turbine set and the process of primary frequency modulation, the models including the speed regulating system, combustion chamber, temperature control system, torque control system, acceleration control system and synchronous generator are established. Bidirectional DC/DC converter and inverter model are established according to the circuit structure and corresponding control strategy. According to the primary frequency modulation process of the gas turbine, the control strategy of the energy storage system participating in the primary frequency modulation is set. The energy storage system uses the traditional droop control strategy and combines the primary frequency modulation process of gas turbine to improve the frequency modulation performance of gas turbine and offshore platform microgrid. Finally, PSCAD transient simulation software is used to build offshore platform and a multi-platform interconnection micro-grid model, results of the simulation show high performance of the designed microgrid.

1. Introduction

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 [1- 4].

In this paper, firstly, according to the mechanical structure of the gas turbine set and the process of primary frequency modulation, the models including the speed regulating system, combustion chamber, temperature control system, torque control system, acceleration control system and synchronous generator are established. Bidirectional DC/DC converter and inverter model are established according to the circuit structure and corresponding control strategy. Secondly, according
to the primary frequency modulation process of the gas turbine, the control strategy of the energy storage system participating in the primary frequency modulation is set[5]. The energy storage system uses the traditional droop control strategy and combines the primary frequency modulation process of gas turbine to improve the frequency modulation performance of gas turbine and offshore platform microgrid. Finally, PSCAD transient simulation software is used to build a single offshore platform model and a multi-platform interconnection micro-grid model [6-7]. By using the control strategy of frequency modulation, the frequency fluctuation in the process of primary frequency modulation is simulated, and the role of energy storage frequency modulation in offshore platform is verified. At the same time, through different energy storage configuration schemes, a comprehensive configuration method of frequency modulation performance and economy is obtained [8-10].

2. Structure of gas turbine unit

2.1 Structure of offshore oil platform

As shown in Figure 1, micro-grid of offshore platform is a special micro-grid with low voltage level, small system scale, direct consumption of production energy by load, and high reliability of power supply. The difference is that most of the power supply of offshore platform is gas turbine generator
set. Due to the limitation of its generation capacity, it is generally generated by multiple generators with the same capacity in parallel. G1-G4 are central platform, W1-W6 are wellhead platform. The generator set platform is equipped with a gas turbine set. 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.

2.2 Structure of micro-turbine system
The structure of the single-shaft micro-gas turbine power generation system is shown in Figure 3. Gas Turbine in the main flow of air and gas, only Compressor, Combustor and Turbine composed of three components gas Turbine cycle.

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 4. 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).

\[
\begin{align*}
V_a &= \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \\
L \frac{d i_{abc}}{dt} + Ri_{abc} + e_{abc} - V_{abc} &= 0
\end{align*}
\] (1)
\[
L \frac{d i_{abc}}{dt} + Ri_{abc} + e_{abc} - V_{abc} = 0
\] (2)

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

\[
\bar{C}L \bar{C}^{-1} \frac{d i_{abc}}{dt} + \bar{C}R \bar{C}^{-1} \bar{C}i_{abc} + \bar{C}e_{abc} - \bar{C}V_{abc} = 0
\] (3)
According to equation (4), equation (5) and (6) can be obtained.

\[
L \frac{di_{dq0}}{dt} + R i_{dq0} + e_{dq0} - V_{dq0} = 0
\]

\[
L \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} R & -\omega L \\ \omega L & R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} e_d \\ e_q \end{bmatrix} - \begin{bmatrix} V_d \\ V_q \end{bmatrix} = 0
\]

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

\[
\begin{align*}
\frac{i_d}{s} &= \frac{V_d - e_d + \omega L i_d}{R + sL} \\
\frac{i_q}{s} &= \frac{V_q - e_q + \omega L i_q}{R + sL}
\end{align*}
\]

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 id and IQ respectively. According to equation (7), there is coupling between the dq axis currents, and corresponding decoupling control strategy is required to realize the independent control of the dq axis currents.

\[
\hat{S} = P + jQ = \hat{E}I = (e_d + je_q)(i_d - ji_q) = (e_d i_d + e_q i_q) + j(e_d i_q - e_q i_d)
\]

3. Evaluation method of auxiliary frequency modulation system

3.1 Simulation model of auxiliary frequency modulation in PSCAD

![Figure 5. PSCAD model of gas turbine unit](image-url)
same, for example in Figure 4, the exciter collects voltage and current data, controls the operation of the synchronous generator, and ensures the stability of its terminal voltage. In the model, the rated terminal voltage of the synchronous generator is set at 6.3kV. Area 1 is the speed control module, which accepts the speed signal of the synchronous generator as a single value and outputs the difference between the speed signal and the rated speed signal of 1.0PU through the speed regulating inertial link. This module mainly maintains the stability of the gas turbine speed. Area 2 is the acceleration control module, which accepts the speed signal of the synchronous generator as a single value and sends the acceleration signal into the low-selection link after processing. Area 3 is the fuel quantity control module. The signal of the module comes from the speed signal, temperature signal and acceleration signal. The minimum value of the three is the fuel control signal. Area 4 is the torque control module, which outputs the torque of the gas turbine. Area 5 for the temperature control module, the module of exhaust temperature function, as shown in the module receives signals fuel quantity control module and output for the turbine exhaust temperature signal, the signal after radiation shielding inertia link and thermocouple inertial link compared with reference exhaust temperature 950 °C, the temperature difference signal generation, after temperature control inertia link, produce temperature control signals. The main function of this module is to limit and maintain the inlet temperature of the turbine.

3.2 Simulation results of auxiliary frequency modulation 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.

First, all the platforms are simulated without energy storage. All three platforms are put into operation. There are a total of 9 gas turbine sets, each of which has a capacity of 16MVA and a power factor of 0.8. In the simulation, after the load of the gas turbine set with 30MW is stabilized, a load of 40WM is put into the system in 4 seconds, which is 40% of the total capacity of the generator set. The curve of primary frequency modulation speed when the gas turbine set is running with load is shown in Figure 6.

![Figure 6. Primary frequency modulation speed in G1, G2 and G3](image)

In G1, G2 and G3 platform of generating sets with energy storage system, namely in all of the generating set platform carry energy storage system, in the simulation, the gas turbine units with 30 MW load stability, after 4 seconds to spend 40 MW load of the system, for 40% of the total capacity
of generator set, gas turbine unit load when running a frequency modulation speed curve as shown in Figure 7.

The primary frequency modulation speed curve of the gas turbine set equipped with the energy storage system on the dual platform is shown in the Figure 8-9 below.

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.
4. Conclusion
In this paper, according to the mechanical structure of the gas turbine set and the process of primary frequency modulation, the models including the speed regulating system, combustion chamber, temperature control system, torque control system, acceleration control system and synchronous generator are established. Bidirectional DC/DC converter and inverter model are established according to the circuit structure and corresponding control strategy. According to the primary frequency modulation process of the gas turbine, the control strategy of the energy storage system participating in the primary frequency modulation is set. The energy storage system uses the traditional droop control strategy and combines the primary frequency modulation process of gas turbine to improve the frequency modulation performance of gas turbine and offshore platform microgrid. Finally, PSCAD transient simulation software is used to build offshore platform and a multi-platform interconnection micro-grid model, results of the simulation show high performance of the designed auxiliary frequency modulation in offshore oil platform microgrid.

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