Simulation study on capacity planning and allocation of island microgrid

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Abstract. In this paper, the energy storage capacity planning problem of a real island microgrid is deeply simulated. In the beginning, the overview and basic data of the island microgrid are described in detail, including the composition of the grid and its key parameters. Then, with the help of modeling and simulation technology, the operation of microgrid in various scenarios is comprehensively simulated and analyzed, focusing on how to optimize energy storage planning in the case of wind energy removal to ensure the smooth operation of the grid. The research deeply reveals the core role of stable power system in ensuring the reliability of power supply and the normal operation of the system. Among them, frequency stability is regarded as the cornerstone of power system operation, which is indispensable for maintaining the overall stability of the power grid and ensuring the continuous and stable power supply of users. Through this simulation study, we not only provide feasible schemes and suggestions for the energy storage capacity planning and allocation of island microgrids, but also verify that reasonable energy storage schemes have a positive effect on the overall stability and reliability of the power system.

1. Introduction

With the transformation of global energy structure and the continuous development of distributed energy technology, microgrid, as a new energy supply mode, has been widely used in remote areas, islands and other off-grid environments. The application of microgrid can combine traditional power sources, new wind energy and energy storage equipment and load for coordinated control and operation. Effectively alleviate the impact of various distributed power sources directly connected to the grid. As a special type of island-type microgrid, due to its unique geographical location and energy demand, it puts forward higher requirements for energy storage capacity planning, energy scheduling and system stability. Therefore, it is of great significance to carry out the modeling and simulation research of island-type microgrid for improving the reliability, economy and sustainability of power supply in the island area. Island-type microgrids usually contain a variety of distributed energy sources, such as renewable energy sources such as wind and solar, as well as traditional energy sources such as energy storage systems and diesel generators. The complementarity and synergy of these energy sources are essential for the stable operation of the microgrid.

However, due to the complexity of the island environment, it may cause fluctuations in wind speed and instability in load demand, which brings great challenges to the operation and control of island-type microgrid. The microgrid model in this paper is derived from a real operating island microgrid, and is modeled and analyzed based on PSCAD platform to observe the influence of wind energy removal on the frequency variation of the grid. By adding a certain capacity of energy storage, it is verified that a certain amount of energy storage in the microgrid has a positive effect on the frequency stability of the grid. Through multiple sets of simulation experiments, the optimal energy storage capacity in line with the grid operation is explored.

2. Construction of micro-grid simulation model

\[
\begin{align*}
\dot{u}_c &= X_i - r_i, \\
\dot{u}_c &= E' - X'i - r_i.
\end{align*}
\]
The stator current equation of synchronous generator:

\[ i_s = \frac{E'_q - V_i \Delta \delta}{X'_q + X_q} \]

\[ i_q = \frac{X'_q}{X'_q + X_q} \]

The rotor excitation winding voltage equation of synchronous generator:

\[ \frac{dE'_q}{dt} = \frac{1}{T'_q} \left[ E'_q - E''_q - (X'_q - X_q) \left( \frac{E'_q - V_i \Delta \delta}{X'_q + X_q} \right) \right] \]

\[ J \frac{d\omega}{dt} + D(\omega - \omega_m) = P_e - P_m \]

\[ \frac{d\Delta}{dt} = \omega - \omega_m \]

Where \( r_a \) is the stator resistance; \( X_q \) is the Q-axis reactance and \( q' \) E is the Q-axis transient electromotive force; \( d0 \) T is the time constant of the excitation winding; \( E_f \) is the stator excitation electromotive force; \( J \) is the rotor's moment of inertia; \( D \) is the damping coefficient of the generator; \( P_m \) is the mechanical power; \( P_e \) is electromagnetic power; \( V_s \) is the system voltage; \( X_l \) is transformer and line impedance; \( \Delta \) is the electrical angle between the q and x axes.

As known by formula (3-4), the speed of the synchronous generator is determined by the rotor motion equation, and the power balance relationship determines the speed of the synchronous generator, and the speed of the synchronous generator determines the frequency of the microgrid. In order to study its speed characteristics, a mathematical model of the excitation system of the gas turbine is established, as shown in Figure 3.1.

Fig. 1. Gas turbine excitation system model

Where, \( T_1 \) and \( T_2 \) are the time constant of the circuit of the integrated amplifier unit; \( K_p \) is the amplification factor of the proportional amplification circuit; \( T_a \) is the time constant of the adaptive unit. Gas turbine generator set has the characteristics of high adjustment capacity, so the offshore oil and gas field platform is basically used gas turbine generator set. The gas turbine speed control system is the main part of the gas turbine control system, which realizes the purpose of controlling the gas turbine speed by controlling the fuel output signal. The simplified model of gas turbine and speed control system is as follows:
Where, $K^*$ is the per unit value of the unit regulating power of the offshore oil and gas field power system; PI regulator is for secondary frequency modulation, so that the frequency back to 50Hz; $K$ is the proportion of fuel flow required by the gas turbine to maintain self-support under no-load conditions; $a$, $b$ and $c$ are parameters that reflect the characteristics of the fuel system; $W_F$ is the fuel flow output ratio. The included gas turbine-generator set model is shown as follows:

3. Simulation model of island microgrid
4. Simulation analysis

This chapter will run the simulation models of each component of the microgrid in Section 3, establish the mathematical model of the sea island microgrid as shown in Figure 3-1, set the total load capacity to 27MW, and conduct the following sets of experiments.

1. When the fan is not connected to the power grid, the running frequency of the power grid under normal operation is obtained by simulation.

2. When the 12.5MW fan is connected to the power grid, the fan is cut out immediately during normal operation, and the frequency fluctuation of the power grid is observed.

3. When a certain amount of energy storage is connected to the power grid, the fan is cut out instantly, whether the frequency of the power grid is within the normal allowable range, and multiple sets of simulation experiments are set to verify the minimum energy storage capacity to ensure the safe and stable operation of the power grid.
When the grid without wind turbine new energy to join, the grid model as shown in Figure 3 at this time the grid operation results as shown in the following waveform.

Fig. 6. Generator set 1 power and voltage waveform

Fig. 7. Generator set 2 power and voltage waveform

Fig. 8. Generator set 3 power and voltage waveform

Fig. 9. Generator set 4 power and voltage waveform

The above simulation waveforms for each generator set in the wind turbine generator set is not connected to the voltage and power waveforms, as well as at this time the grid frequency waveforms, it can be seen in the initial operation of the grid, when the start of operation, this time the generator is in the initialization stage, this time the fluctuations are larger, when the generator is running stably, this time the grid frequency tends to be stable, and at this time, each generator set power is also relatively stable, the system to provide the power is equal to the load of the system.
On the basis of Scene 1, wind energy is connected to the grid, the power of the turbine is set to 1.25 MW, and the wind energy is completely removed at the 8s. At this time, the grid is powered by gas turbines and wind turbines simultaneously on the load side of the grid, and when the turbines in the grid are suddenly cut off at the 8th s, the frequency and power changes in the grid are shown in the figure below.

**Fig. 10.** Frequency waveform of the grid when no new wind energy is connected

**Fig. 11.** Frequency variation waveform (excised 12.5 MW turbine, no energy storage)

**Fig. 12.** Wind turbine power waveform (excision of 12.5 MW wind turbine, no energy storage)
Fig. 13. Waveforms of the power variation of each generating unit (12.5 MW of wind energy excised, no energy storage).

Fig. 14. Grid frequency waveform (turbine removed, with 5MW energy storage).

Fig. 15. Waveforms of power variation of each generating unit (excision of 12.5 MW turbine, storage of 5 MW).
At this point in time, the energy storage facility provides a certain amount of power supply to the grid, and the grid operation, that is, at this time, the grid frequency exceeds the normal range of fluctuations allowed, the power grid will be out of control and even experience a major accident. Therefore, in order to ensure the safety and stability of the power grid, it is necessary to install a certain amount of energy storage facilities in the power grid. When the wind turbine is removed from the grid, the grid is supplied with power from four synchronous generators, and their automatic chemistry is required to provide the grid with power. After comparing the frequency fluctuation of the grid and the change of synchronous generator set output under the conditions of adding four different energy storage capacity configurations of 2MW, 5MW, the following conclusions can be obtained:

- Once the wind turbine is removed from the grid, the grid is supplied with power from four synchronous generators, and their automatic chemistry is required to provide the grid with power. After comparing the frequency fluctuation of the grid and the change of synchronous generator set output under the conditions of adding four different energy storage capacity configurations of 2MW, 5MW, the following conclusions can be obtained:

5. Conclusions

In this paper, PSCAD is used to construct the overall model of the power grid and carry out simulation experiments to simulate the adverse impact of wind power removal on the grid frequency and select the optimal energy storage capacity.

References


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