Research on Voltage and Frequency Regulation of Micro-Grid with Distributed Energy Storage

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Abstract: Aiming at the increasingly widespread use of distributed energy storage, building a model of distributed energy storage for Micro-Grid voltage regulation and frequency modulation. The waveforms of the frequency, active power, reactive power and bus voltage of the Micro-Grid are given. Firstly, the control method of distributed energy storage inverter - droop control is introduced. Secondly, based on MATLAB/Simulink platform, a Micro-Grid model with distributed energy storage system output to adjust voltage and frequency is built. Through the simulation, the role of distributed energy storage in the Micro-Grid is verified, which lays a foundation for the research of distributed in the Micro-Grid.

1. Introduction

Renewable energy reserves are abundant, clean and pollution-free, and have received widespread attentions in academic and industrial circles at home and abroad in recent years [1,2]. The Micro-Grid is proposed to achieve the integration of multiple renewable energy sources to form a small regional grid [3-6]. At the same time, with the development of social economy and increasing energy, new energy development has become an important direction of future energy strategy. Since the energy storage system (ESS) has flexible charging and discharging control functions, the grid, especially the Micro-Grid, can be used for demand side management after the introduction of the energy storage link, which can more effectively use the power equipment to reduce the power supply cost [7,8]. However, there are still many problems in the new energy power generation that affect the power stability of the Micro-Grid system. In the normal and continuous operation of the Micro-Grid, it is inseparable from the energy storage system that provides energy buffer. The energy storage device plays an important role in the Micro-Grid.

In recent years, energy storage technology has developed rapidly and is mainly divided into three categories: mechanical energy storage, electrochemical energy storage, and battery energy storage. The requirements of the Micro-Grid for energy storage devices connected to it including [9]: one, quick response, the new energy fluctuations in the Micro-Grid and the switching from the grid-connected mode pose great threats to the stable operation of the Micro-Grid. In order to ensure the stability of the transient process of the Micro-Grid, the rapid response of the energy storage device is required. Two, high power density, when the system power fluctuates greatly, in order to ensure the stability of the system, the energy storage device is required to provide or absorb the differential power. Three, high energy density, the new energy power generation process is uncontrollable, and the power flow changes relatively large, requiring a large capacity for energy storage.

Based on this, a Micro-Grid model with distributed energy storage is built under...
MATLAB/Simulink. Verify the function of the energy storage system in the Micro-Grid for voltage regulation and frequency modulation.

2. Inverter control method

The droop control is a control method for simulating the frequency static characteristics of the generator set. The control principle diagram is shown in Figure 1.

![Figure 1. Droop control principle.](image)

The initial operating point of the distributed power system is $A$, the output active power is $P_0$, the reactive power is $Q_0$, the system frequency is $f_0$, and the voltage at the AC bus connected to the distributed power supply is $U_0$. When the active load of the system suddenly increases, the active power is insufficient, resulting in a decrease in frequency; When the reactive load of the system suddenly increases, the reactive power is insufficient, resulting in a decrease in the voltage amplitude, and vice versa. Taking the frequency drop when the system active load suddenly increases, the regulation function of the inverter droop control system is: When the frequency is reduced, the control system adjusts the active power output of the distributed power system to increase accordingly. At the same time, the load power is also reduced due to the frequency drop, and finally the load self-regulating effect of the droop characteristic of the control system is reduced. The new power balance is achieved by the joint action, that is, the transition to the B point operation. Figure 1 shows that the active power $P$, the frequency $f$ and the sagging relationship between the reactive power $Q$ and the voltage $U$ are:

$$
\begin{align*}
P &= P_0 + (f_0 - f)K_f \\
Q &= Q_0 + (U_0 - U)K_U
\end{align*}
$$

Or

$$
\begin{align*}
f &= f_0 + (P_0 - P)K_f \\
U &= U_0 + (Q_0 - Q)K_U
\end{align*}
$$

Based on the above analysis, we can see that there are two basic droop control methods: One is to control the output power by adjusting the voltage frequency and amplitude, that is, the droop control of $f$-$P$ and $U$-$Q$; The second is to control the output power by adjusting the frequency of the output, that is, the droop control of $P$-$f$ and $Q$-$U$.

The principle of droop control is shown in Figure 2. Each inverter detects its output powers $P$ and $Q$, and obtains reference values $f_{ref}$ and $u_{ref}$ of the output voltage frequency and amplitude by the droop characteristic shown in Figure 1. Then each of them reversely fine-tunes the output voltage frequency and amplitude to achieve a reasonable distribution of system active and reactive power. The output active power $P$ and reactive power $Q$ must satisfy the conditions of $0 < P < P_{max}$ and $-Q_{max} < Q < Q_{max}$, that is, the output power cannot exceed the range of its rated power. When the Micro-Grid is operating in an isolated network, the active power is distributed according to the $P$-$f$ drooping system, and the frequency reaches a new value;
The inverter injection power in the Micro-Grid is shown in the Figure 3.

\[ M \rightarrow S = P + jQ \]

\[ E_1 = Z_e = R + jX \]

\[ M \rightarrow N \]

\[ E_1 \angle \delta \]

\[ E_1 \angle 0 \]

The active and reactive power of the inverter output are as follows:

\[ P = \frac{E_1 [E_1 \cos \theta - E_2 \cos (\theta + \delta)]}{Z} \]  \hspace{1cm} (3)

\[ Q = \frac{E_1 [E_1 \sin \theta - E_2 \sin (\theta + \delta)]}{Z} \]  \hspace{1cm} (4)

When the line is inductive, it can be seen from formula (3) and (4) that the phase angle mainly depends on the active power, and the voltage amplitude mainly depends on the reactive power, and the following droop equation can be used.

\[ f = f^* - m_p (P - P^*) \]  \hspace{1cm} (5)

\[ U = U^* - n_q (Q - Q^*) \]  \hspace{1cm} (6)

In the formula: “*” is the variable under the rated operating point, and \( m_p \) and \( n_q \) are the active and reactive droop coefficients respectively.

When the line is resistive, \( P \cdot f \), \( Q \cdot U \) drooping and \( P \cdot U \), \( Q \cdot f \) anti-sagging control are not applicable. The literature [10] proposes to use the new way \( R/X \) to transform, the formula (3) and (4) can be abbreviated as:

\[ \begin{bmatrix} P_d \\ Q_d \end{bmatrix} = \begin{bmatrix} \sin \theta & - \cos \theta \\ \cos \theta & \sin \theta \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} = \frac{E_1 E_2 \sin \delta}{Z} \begin{bmatrix} E_1 \end{bmatrix} \begin{bmatrix} E_1 \end{bmatrix} - E_2 \cos \delta \]  \hspace{1cm} (7)

In the formula: \( P_d \), \( Q_d \) is the transformed virtual active and virtual reactive. It can be seen from formula (7) that \( P_d \) is mainly determined by the phase angle, and \( Q_d \) is mainly determined by the voltage amplitude, so that \( P_d \cdot f \) drooping and \( Q_d \cdot U \) drooping can be used. This control method requires accurate line \( R/X \) information.
3. Simulation
In order to verify the above theoretical analysis results, a simulation Micro-Grid model based on MATLAB/Simulink was built. In the model, two distributed power supplies are connected in parallel to the grid bus through the inverter. Under the initial conditions, ESS1 and 10kW active load are connected, and ESS2 is connected in 2 seconds, and the 40 kW active load in series with 10kVar reactive load are connected in 5 seconds.

3.1 Frequency regulation in the Micro-Grid

3.1.1 From begin to the 2nd second. The ESS1 and 10kW active load are connected to the Micro-Grid. The theoretical frequency is 50 Hz. The simulation is shown in Figure 4.

![Figure 4. Frequency of the Micro-Grid From begin to the 2nd second.](image)

3.1.2 From the 2nd second to 5th second. The ESS1, ESS2 and 10kW active load are connected to the Micro-Grid. It can be known from the principle of droop control (formula (2)) that the Micro-Grid rate rises to 50.05 Hz. The simulation is shown in Figure 5.

![Figure 5. Frequency of the Micro-Grid from the 2nd second to 5th second.](image)

3.1.3 From the 5nd second to the end. The ESS1, ESS2, 10kW active load and 40kW active load in series with 10kVar reactive load are connected to the Micro-Grid. According to the droop control principle, the frequency drops to 49.85 Hz. The simulation is shown in Figure 6.

![Figure 6. Frequency of the Micro-Grid from the 5nd second to the end.](image)

3.2 Active and reactive power regulation in the Micro-Grid
From begin to the 2nd second, 10kW active load is connected to Micro-Grid, and only the ESS1 is output. It can be seen from the Figure 7 that $P_{ESS1}=10kW$, $Q_{ESS1}=0kVar$. From the 2nd second to the 5th second, 10kW active load is connected to Micro-Grid and both ESS1 and ESS2 are output. Figure 7 shows that $P_{ESS1}=P_{ESS2}=5kW$, $Q_{ESS1}=Q_{ESS2}=0kVar$. From the 5nd second to the end, the load are 10kW active, and 40kW active load in series with 10kVar reactive load, the ESS1 and ESS2 are output.
Figure 7 shows that $P_{ESS1} = P_{ESS2} = 25$ kW, $Q_{ESS1} = Q_{ESS2} = 5$ kvar.

![Figure 7. Active and reactive power of the ESS1 and ESS2.](image)

### 3.3 Voltage regulation in the Micro-Grid

When there is only one 10kW active load in the Micro-Grid, the effective value of the Micro-Grid bus voltage is about 311V. The waveform is shown in Figure 8. After 5th second, connecting 40kW active load in series with 10kVar reactive load. The bus voltage will drop. The waveform is shown in Figure 9:

![Figure 8. Voltage of Micro-Grid.](image)

![Figure 9. Micro-Grid voltage drops after 5th second.](image)

### 4. Conclusions

- Distributed energy storage has good voltage regulation and frequency modulation capability, and satisfies the theory of using distributed energy storage to adjust peak-to-valley voltage and frequency.
- Through this paper, we have further understanding of the distributed energy storage work in the Micro-Grid and the Micro-Grid, the principle of droop control and how to realize it on the MATLAB/Simulink platform, which laid the foundation for the subsequent research and study.
- In the future work, the simulation of the Micro-Grid will be further improved, and the influence of other factors will be fully considered to optimize the simulation curve. Consider how to use distributed energy storage technology to optimize system power stability when a Micro-Grid fails.

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