Study on three-phase unbalanced control of low voltage distribution network

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Abstract. Three-phase unbalance is one of the power quality problems. For the power quality problem caused by the three-phase unbalance phenomenon on the load side in the low-voltage distribution network, combined with the characteristics of the three-phase four-wire system of the distribution network in China, the three-phase unbalance adjustment is studied. The device control strategy is selected, and the three-phase four-bridge arm topology and the three-phase current real-time detection method based on instantaneous reactive power theory are selected. The experimental model is built by MATLAB/Simulink to verify the feasibility of the method.

1 Introduction

In recent years, China’s economy has flourished, and the demand for electricity consumption has also increased sharply[1]. Among them, the impact and non-linear load devices have also increased, resulting in voltage waveform distortion, voltage fluctuation, flicker and three-phase imbalance in the power grid[2]. Power quality problems sometimes occur, so three-phase unbalanced control is an important measure to improve power quality[3].

The treatment of three-phase unbalance in the low-voltage distribution network can improve the power factor of the components in the system, reduce the loss of equipment, lines and transformers, improve the power supply quality of the power grid, extend the service life of equipment in the power grid, and improve the stability of the system to avoid[4]. When the system encounters a large disturbance, a stable breakdown accident such as a voltage collapse occurs, which is of great significance for the safe, economical and high-quality operation of the power system[5].

In this paper, the power quality problems caused by the three-phase unbalance of the load side in the low-voltage distribution network are combined with the characteristics of the three-phase four-wire system of the distribution network in China[6]. Select the main topology. The hysteresis comparison method in the PWM tracking control method is used to control the compensation current. The theory of instantaneous reactive power is studied, and the method of accurately extracting positive sequence, negative sequence and zero sequence current in real time is obtained[7]. The experimental model is built based on MATLAB/Simulink for simulation analysis. The system simulation model is built according to the main system, detection system, control system and adjustment system. The selected method is verified and the simulation results are analyzed[8].

2 Three-phase unbalanced principle
2.1 Unbalance measure
In practical engineering applications, the three-phase four-wire system with zero sequence components is defined as follows\cite{9}:

\[
\varepsilon_U = \frac{U_2}{U_1} \times 100\% \tag{1}
\]

\[
\varepsilon_U^0 = \frac{U_0}{U_1} \times 100\% \tag{2}
\]

Where \(\varepsilon_U\) represents the three-phase voltage negative sequence imbalance; \(\varepsilon_U^0\) represents the three-phase voltage zero sequence imbalance; \(U_1\) represents the three-phase voltage fundamental positive sequence RMS; \(U_2\) represents the three-phase voltage fundamental negative sequence RMS; \(U_0\) represents the zero-order rms value of the three-phase voltage fundamental.

Similarly, by replacing the voltage in the above equation with a current, the negative sequence and zero sequence imbalance of the three-phase current can be obtained\cite{10}.

2.2 Three-phase load imbalance management principle
The simple power system model is shown in Figure 1. The purpose of using the adjustment device to manage the three-phase load imbalance is to transfer the unbalanced power between the power supply and the load to the load and the adjustment device, so that the system network side three-phase power balance, three-phase current symmetry, negative sequence, zero sequence current is zero. In Figure 1, \(e_s\) represents the grid voltage, \(i_s\) is the grid side current, \(i_L\) is the load current, and \(i_c\) is the output compensation current of the adjustment device. According to the symmetrical component method, the three-phase current is decomposed into a positive sequence, a negative sequence, and a zero sequence. If the amount of negative sequence and zero sequence components in the load current is injected into the grid by the device, so that only the positive sequence component is left in the current on the system network side, the imbalance treatment of the system is realized\cite{11}.

The adjustment device is mainly composed of two parts, namely a power electronic converter and an auxiliary circuit. The converter completes the function of injecting unbalanced current into the system, and the auxiliary circuit realizes the function of detecting, controlling, and driving the IGBT. The working principle of the adjusting device can be described as: detecting the negative sequence and the zero sequence component of the three-phase current through the detecting module, forming a command signal for compensating the current, forming a modulation signal of the IGBT through the control module, and controlling the IGBT after being amplified by the driving circuit, so that The device injects and directs a current with the same amplitude of the signal in the system, so that the current on the network side of the system is three-phase symmetrical.

![Figure 1. governance schematic](image-url)
This paper is to deal with the three-phase unbalanced load of the low-voltage distribution network. Considering the cost and design difficulty, the two-level structure can meet the requirements. Because the system is a three-phase four-wire system, the system needs to output a large number of zero-sequence currents. Therefore, the single-capacitor three-phase four-bridge arm single-inductor grid-connected interface structure as shown in Fig. 2 is selected as the research object.

![Figure 2. Three-phase four-wire topology main circuit topology](image)

### 3 MATLAB Simulation

#### 3.1 Establishment of simulation model for three-phase load imbalance management

The parameters for establishing the simulation model system are shown in Table 1. The model is mainly divided into main system, current detection module and control module. The overall simulation timing control of the system is as follows: the capacitor is pre-charged to 540V, the 0.05s adjustment device is put into operation, and the positive sequence active current detection module is input, the DC capacitor is charged and the DC voltage control is controlled by the ramp signal, and the slope is 6500V/s, 0.09s began to control the capacitor with constant voltage, the reference voltage is 800V. The 0.1s system manages the unbalanced current and puts into the system unbalanced current detection module. The 0.7s load is abrupt, which is twice the original load.

| Table 1. Simulation model system parameters |
|--------------------------------------------|
| element                          | parameter                        |
| System power             | 380V, 50HZ                      |
| Phase A load             | 1mH, 30Ω                        |
| Phase B load             | 1mH, 50Ω                        |
| Phase C load             | 1mH, 20Ω                        |
| DC side capacitor        | 2000uF, 540V                     |
| Step size                | 10us                            |
| On-off level             | 18kHz                           |

#### 3.2 Signal detection module

For the detection of the three-sequence current, the $i_p-i_q$ detection method based on the instantaneous reactive power theory can reduce the influence of harmonics in the current on the control current. At the same time, in order to be more realistic and cooperate with the working sequence of the main system, the step signal is used to control the input time of the detection module. The simulation results of the three-phase load current can be obtained through simulation operation as shown in Figure 3.
Therefore, the $i_p-i_q$ detection algorithm based on the instantaneous reactive power theory can detect the positive sequence and negative sequence current components of the three-phase current. The zero sequence current component can be measured directly from the center line.

### 3.3 DC voltage control module

DC capacitor voltage control is a constant value control system, as shown in Figure 4. In the simulation, the initial voltage of the capacitor is set to 540V, and the adjustment device starts running at 0.05s. In order to avoid the inrush current caused by the switching device, the slope of the DC side voltage is ramped up to 6500V/s, so that the DC voltage of the system can reach 800V after 0.04s. After 0.09s, the DC voltage is controlled by constant voltage. The control result is shown in Figure 4-8.

![Figure 4. DC voltage control simulation results](image)

### 3.4 Governance outcome analysis

![Figure 5. Three-phase network side current change process](image)
Figure 5. shows the change process of the three-phase grid side current in the process of system three-phase load imbalance. The stages are now analyzed as follows:

3.4.1 Steady state analysis. Fig 6. is a three-phase current waveform after the switching device is turned on, and Fig. 7 is a three-phase current waveform after the load is abrupt.

![Figure 6. Steady-state waveform after three-phase current imbalance treatment](image)

![Figure 7. Three-phase current waveform after sudden load change](image)

From the three-phase unbalance formula, the comparison of the three-phase unbalance before and after the treatment can be obtained, as shown in Table 2.

It can be seen that although the imbalance is not possible after the treatment, the effect of the treatment is obvious, and the three-phase negative sequence imbalance and the three-phase zero sequence imbalance are obviously dynamically stabilized in a small range. Due to the small fluctuation of the DC side voltage, there is still a certain negative sequence and zero sequence current on the system network side.

| Table 2. Comparison of three-phase unbalance |
|---------------------------------------------|
| Governanc status | negative sequence imbalance | zero sequence imbalance |
| Before governance | 106% | 287% |
| Before the load is mutated | 15% | 9% |
| After the load is mutated | 1.5% | 3.7% |
3.4.2 Dynamic Analysis. As shown in Fig. 8, (a) is a waveform of a change in current when the adjustment device is put into operation, and (b) is a three-phase grid-side current waveform when the load is abrupt. It can be seen from the figure that when the adjustment device is put into operation to start the three-phase unbalanced current, the inrush current is not large; when the load is abrupt, the transition time is appropriate and the next steady state can be quickly entered. The control system performs well.

The simulation results show that the three-phase unbalance phenomenon of the system has a good effect in the case of grid voltage symmetry.

4 Conclusion
According to the characteristics of the three-phase four-wire system, this paper selects the single-capacitor four-bridge single-inductor grid-connected interface as the main topology of the compensation device. The $i_r$-$i_q$ current detection algorithm based on instantaneous reactive power theory is used to detect the unbalanced current. Filtering is performed using a dual filter approach combining a notch filter and a low pass filter. The simulation results show that the detection algorithm has fast detection speed and high precision, which can meet the system requirements. The hysteresis comparison method in PWM tracking control theory is used to control the compensation current, and various parameters are set. The control performance is obtained by simulation. In the Simulink environment, a simulation model was built. The simulation results show that the three-phase unbalanced control effect of the system is good when the grid voltage is symmetrical. However, there are still some shortcomings in this paper that need to continue to study in future work: This paper only analyzes the three-phase unbalance phenomenon when the grid voltage is symmetrical. And the control strategy selected in this paper only compensates for the negative sequence and zero sequence component currents in the fundamental current, and the influence of harmonics in the system on the treatment effect needs further discussion.
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