Research on Commutation Switch to Control Three-phase Unbalance and Azimuth Configuration

Zhenwei Li¹, Jianjun Wu¹, Kefei Long¹, Jiajun Li¹, Jiao Nie², Yu Wang² and Yi Zhang²*

¹ Enshi Power Supply Company, State Grid Hubei Electric Power Company, (Enshi, Hubei Province, 445000, China)
² Wuhan Haomai Electric Power Automation Technology Limited Liability Company (Wuhan, Hubei Province, 430074, China)
*Corresponding author’s email: sales@haomai.net

Abstract -The randomness of each phase load in the station combined with the distribution of new energy into the network has caused the three-phase unbalance to become more and more serious. The use of commutation switch to switch the three-phase unbalance load effectively solves the problem. Considering the number of commutation switches, the particle swarm algorithm is used to optimize the configuration orientation of the commutation switch and to improve the accuracy of the installation location of the commutation switch. Effectively reduces the three-phase unbalance in the platform area.

1. Introduction
Three-phase unbalance is one of the power quality problems that have long plagued the desk area. Serious unbalance will cause high line loss[1], uneven heat and output of transformer, motor vibration and heat, which endanger the safety of distribution network and electrical equipment[2]. In order to solve the three-phase unbalance problem, experts and scholars at home and abroad have done a lot of work. Literature[3] proposed a three-phase line current unbalance suppression algorithm based on distributed static series compensators (DSSCs). Literature[4] selected three-phase four-arm topology and real-time detection method of three-phase current based on instantaneous reactive power theory. Literature[5] the active unbalance control technology with power electronic properties is proposed to control the three-phase unbalance. Document[6] combines a commutation switch with an energy controller for treatment. The commutation switch is currently the most economical and effective way to eliminate the three-phase unbalance. It changes the phase sequence of the access load by switching the phase of the load mechanically, so as to switch the phase of the heavy load to the phase of the light load. In the actual installation process of a project, the number of installations in a desk area is usually preset. It is worth studying where to install it to improve the three-phase unbalance of the desk area with maximum efficiency. In this paper, the load data of the desk area is analyzed by particle swarm algorithm, the configuration orientation of the commutation switch is optimized, and the method to find the optimal location is analyzed. The three-phase unbalance of the platform can be better improved by using the commutation switch and reasonable installation position.
2. Principle of commutation switch

2.1. Overview of three-phase unbalance

In the distribution network of power system, the distribution network of 0.4kV voltage level station often uses the three-phase four-wire system to supply power to the users. After the secondary output of the three-phase transformer, the users will only use one phase, which is affected by wiring, time and season. Three-phase unbalance will occur when one phase user consumes more power while the others are smaller. The standard three-phase voltage is a three-phase symmetric sine wave as shown in figure 1. Unbalanced three-phase voltage can exhibit waveform distortion as shown in figure 2.

![Figure 1. Symmetrical three-phase voltage](image1)

![Figure 2. Unbalanced three-phase voltage](image2)

The three-phase vector diagram can directly reflect the neutral point drift distortion of unbalanced voltage, as shown in figure 3, and the power quality will be affected.

![Figure 3. Three phase voltage distortion](image3)

The most intuitive impact of three-phase load imbalance is the imbalance of three-phase current and the increase of neutral line current. Describe the unbalance degree of three-phase current mathematically:

\[
\beta = \frac{\text{max}\{I_A, I_B, I_C\} - \text{min}\{I_A, I_B, I_C\}}{\text{max}\{I_A, I_B, I_C\}} \times 100\%
\]

(1)

In equation (1) \(\beta\) is the three-phase unbalance degree, \(\text{max}\{I_A, I_B, I_C\}\) is the largest phase of three-phase current, and \(\text{min}\{I_A, I_B, I_C\}\) is the smallest phase of three-phase current. The surge of current at the neutral point will lead to high line loss. The equivalent power supply diagram is shown in figure 4.

![Figure 4. Equivalent circuit diagram of three-phase four wire power supply](image4)

The impedance values of phase A, B and C lines are respectively \(Z_a, Z_b, Z_c\). \(U_a, I_a\), \(U_b, I_b\), \(U_c, I_c\) indicates that the current on the neutral line is expressed by \(I_N\) denotes impedance, and \(Z_n\) denotes impedance represents the line loss per unit length, which can be expressed by the following formula:
\[ \Delta P = I_a^2Z_a + I_b^2Z_b + I_c^2Z_c + I_n^2Z_n \] (2)

\( \Delta P \) represents line loss, \( I_n \) in case of three-phase balance the value is zero, and the loss is the basic line loss. However, when the three-phase is unbalanced, the value of the neutral line is not zero, and the value is large. Because the radius of the neutral line is generally smaller than that of the phase line, the resistance will be much higher, resulting in more line losses.

2.2. Management of commutation switch

The commutation switch is internally composed of thyristor and relay, as shown in figure 5. A single thyristor and relay are connected in parallel to form a group of change-over switches. Three groups are connected in parallel to form the core components of the commutation switch. The switch is input by the three-phase incoming lines of A, B and C, and outputs any one of the three phases of A, B and C to the user.

![Figure 5. Equivalent circuit diagram of commutation switch](image)

When phase A load is too heavy and phase B load is light, the three-phase unbalance in the bench area is serious. In the setting area, phase a flows through 80A, phase B flows through 30A, and phase C flows through 50A. According to formula (1), the unbalance degree of three-phase current is calculated as 

\[ \beta = \frac{\max(|I_A|,|I_B|,|I_C|) - \min(|I_A|,|I_B|,|I_C|)}{\max(|I_A|,|I_B|,|I_C|)} \times 100\% = \frac{80-30}{80} \times 100\% = 62.5\% \] at this time, commutation measures shall be taken to switch part of the load of phase A to phase B. It is detected that the installation position of the commutation switch is a single-phase user. At present, phase A power supply mode is used, and the effective value of current flow is 25A. The user shall be switched from phase A power supply to phase B power supply. At present, the switch of phase A circuit is on, and then give a command to the thyristor of phase a to turn it on; In order to better disconnect phase A, disconnect phase A relay while maintaining the conduction of phase a thyristor; The magnetic holding relay has been disconnected, and all the current flows through the thyristor. At this time, the trigger signal of phase A is removed, and then the thyristor of phase A will be turned off when the current crosses zero. Turn on the phase B thyristor for the phase B trigger signal. The magnetic holding relay undertakes the normal working current to complete the positive sequence commutation, and completely turn off the phase A thyristor before giving the phase B trigger signal.

Commutation is to forcibly change the user's access phase sequence with a mechanical switch. If the commutation time is too long, it will lead to power failure or even phase to phase short circuit, which is absolutely unacceptable. According to relevant regulations of the State Grid, the commutation voltage loss time shall not exceed 20ms. The commutation process is closely coordinated by thyristor, relay and control signal. As shown in figure 6, the waveform capture of oscilloscope in the commutation process is shown, and the single commutation time is 6.52ms, meeting the requirements.
After 25A of phase A is switched to phase B, the current of phase B is 55A, the current of phase A is 55A, and the current of phase C is 50A. The calculated three-phase unbalance after phase commutation is 9%, which meets the relevant provisions of national standards and the requirements of power quality.

3. Optimization of installation position of commutation switch

3.1. Historical data analysis of station area

When engineers decide to use commutation switch to manage a specific station area, considering economy and construction convenience, it is impossible to install a commutation switch for each user load. Therefore, it is particularly important to consider the installation position of commutation switch. According to the relevant provisions of the state grid operation inspection, the number of commutation switches shall be limited by the rated capacity of the transformer, and the number of 100, 200 and 400kVA shall not exceed 6, 9 and 12. The change law of power consumption in the station area will not change much in a year. Select the imbalance degree analysis in several days to give the time unbalance degree change curve, as shown in figure 7.
Analyzing the historical data of the station area has important reference significance for the installation of commutation switch. Particle swarm optimization algorithm is used to analyze the historical three-phase unbalance in the station area, establish the position optimization model and iterative optimization [7]. The core formula of particle swarm optimization algorithm is as follows:

$$V_{id}(t+1) = \omega(t) V_{id}(t) + C_1 r_1 [P_{id}(t) - X_{id}(t)] + C_2 r_2 [P_{gd}(t) - X_{id}(t)]$$  \hspace{1cm} (3)

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1)$$ \hspace{1cm} (4)

$$\omega(t) = \frac{\omega_{max} - t (\omega_{max} - \omega_{min})}{n}$$ \hspace{1cm} (5)

\(\omega(t)\) is the inertia factor, \(V_{id}(t)\) represents the velocity in dimension \(d\) when the \(i\)'th particle iterates \(t\) times, \(X_{id}(t)\) represents the position of the \(i\)'th particle on dimension \(d\) when iterating \(t\) times. Similarly, \(P_{id}(t)\) represents the individual extreme value, \(P_{gd}(t)\) is the global extremum, \(C_1 C_2\) is the learning factor, \(r_1 r_2\) is a random factor with a value range of \((0,1)\).

### 3.2. Simulation analysis

![Figure 8. Load topology of station area](image)

The station area model is established. There are 24 load points in the station area, which are distributed within the power supply range of the station area, as shown in figure 8. The load power consumption difference is analyzed to judge the three-phase imbalance. The installation position of the commutation switch is iterated continuously in 24 loads to generate \(1 \times n\) based on the n-dimensional
vector matrix, analyze the measures of the optimal commutation command, compare the unbalance degree of each load after commutation, the number of times involved in commutation and the number of switching actions, constantly compare the old position with the new position, and continuously iterate according to different data in different stations to obtain the best state, and finally find the appropriate installation position, and the optimization convergence is shown in figure 9.

![Optimization fitness curve](image)

Figure 9. Optimization fitness curve

4. Conclusion
This paper introduces the basic concept of three-phase imbalance, simulates and analyzes the process of using commutation switch to control three-phase imbalance in the station area, and introduces the method of using particle swarm optimization algorithm to find the best installation position of commutation switch, which has reference significance for pursuing efficiency and economic value in engineering practice.

References
[1] Hao, S., Cui, S., Zhang, Y., Liu, H., Chen, G., Chen, X., (2021) Quantitative Analysis Between Three-phase Unbalance and Line Losses. Power System Technology, 45(04):1547-1552.
[2] Yan, Z., Lei, X., He, J., Zhou, W., Ye, H., Zhao, L., (2018) Study on the influence of three-phase unbalance on the load capacity of distribution transformer. Electrical Measurement & Instrumentation, 55(08):51-57.
[3] Yoon, H., Cho, Y., (2019) Imbalance Reduction of Three-phase Line Current Using Reactive Power Injection of the Distributed Static Series Compensator. Journal of Electrical Engineering & Technology, 14(3).
[4] Zhang, C., Fu, Z., Ye, H., Niu, D., Study on three-phase unbalanced control of low voltage distribution network. In: Proceedings of 2019 the 5th International Conference on Electrical Engineering, Control and Robotics (EECR 2019). Guang Zhou China. 2019, 77-83.
[5] Lu, Z., (2021) Research on the Three-phase Unbalanced Treatment Technology in Distribution Area. Power Electronics, 55(09):40-42.
[6] Yu, Z., Zhu, D., Meng, L., Teng, P., (2021) Research on Three-Phase Imbalance Treatment Based on Commutation Switch and Energy Controller. Applied Technology, (06):62-64+67.
[7] Yang, W., Li, Q., (2004) Survey on Particle Swarm Optimization Algorithm. Engineering Science, (05):87-94.