Research and Application of Three Phases Balance Technology in China Rural Power Distribution Network based on the Fast Phase Selection Method

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Abstract. In this paper, the objectivity and unpredictability of the three-phase load unbalance (TPLU) for the rural distribution network are proposed. Firstly, the influences of TPLU on the power quality and power loss are analyzed. And then, based on the common managements and governance measures of TPLU, whose typical problems are also introduced. Furthermore, based on the fast phase selection, the concept of the three-phase load balance is defined to describe the basic structure and complementation principles in detail. Lastly, the operating points and control strategies of the commutation equipments are proposed. The verification results show that proposed method is accurate and effective.

1. Introduction
The three-phase four-wire system was used widely in urban and rural low-voltage distribution networks, the loads are mostly single-phase or hybrid single three-phase. Because loads and system’s parameters are imbalance, the unbalanced currents among the three phases exist. At the same time, the loads’ irregularity and unpredictability lead to imbalance of three-phase load in a long time for the low-voltage grids. The National Standard “the maximum unbalanced degree of power quality of three-phase voltage” (GB/T 15543-2008) clearly explained: in normal circumstances, the three-phase unbalanced degree of the negative sequence voltage is less than 2% and with no more than 4% in short-term. When the common points were connected, the unbalance degree of negative sequence voltage must less than 1.3% and with no more than 2.6% in a short time. The imbalance of three-phase will lead to additional heat and vibration of the rotating motor, transformer leakage flux and local overheating, large neutral current [1], the increasing power line loss and so on.

According to statistics, more serious presence of the three-phase imbalance exceeds 85% for the low voltage distribution. Using the experience to distribute the load reasonably is the main management method at present [2-4]. In addition to the above approaches, there are few effective solutions but to take some protective measures such as increasing the neutral line section, etc. in order to reduce the three-phase unbalanced over potential problems. A classification method based on fuzzy C-means clustering is proposed [5], which divides the users based on the daily load curve so as to make the users of the same class have higher similarity and then divides each user evenly into A, B and C phase. The simulation results shows that the three-phase imbalance problem can be alleviated better.

2. Analysis on the Principle and Effect of Regulation
The three-phase unbalanced tune up device (TPUTD) is used to overcome the low-voltage three-phase unbalanced problems. The device is based on the capacitor adjustment principles, which has wide range of products[6-10], and whose working theory is similar, as shown in Figure 1.

![Figure 1](image)

**Figure 1.** Schematic diagram of reactive power Compensator adjustment device

Tune up device is built with 12 single-phase 400V power capacitors. Under the terminal’s control, each capacitor can connected both the phase-phase lines and phase-null lines, which can be put into operation all the angle capacitors or star capacitors. Each connection ways of angular and star capacitors have 5 types: 1) all the capacitors operate; 2) capacitors do not operate; 3) phase A and B are in the same group; 4) phase B and phase C are in a group; 5) phase A and C in a group. There are two sets of triangles and two sets of star wiring within the device, based on the permutations and combinations method, a total of 625 kinds of switching modes can be calculated. And for different capacity of the distribution transformer, capacitor banks can be increased or decreased. By properly connecting the different number of capacitors between phase-phase lines and phase-null lines, the use of the inductive characteristics of the load can not only achieve the compensation power factor but also adjust the unbalanced active current. Which the actual amount of compensation is the same with the needed reactive compensation.

However, due to the complex operating conditions of the inductive load in the low-voltage distribution network, it is difficult to achieve the desired effects as the compensation from the relatively fixed capacitors, which often results in the reverse problem of reactive power. On the other hand, in the conventional SVC TCR branch wiring use 6-pulse form, which contains the line current harmonics $6k \pm 1$ ($k$ is a positive integer), you need to install filtering while the cost increase. If the advanced STATCOM technology was used, because of the high cost, it is unreasonable in the low-pressure system. Thirdly, the TPUTD has an effect only installed on the supply side. And this product has no effect when it was installed at the outlet of the distribution transformer, which can cause enormous safety problems and low voltage line loss reduction and space. So this method has great limitations, which is not three-phase imbalance in the direction of governance research trends.

3. Adjustment Principle Based on fast phase selection technique

A new low-voltage three-phase balance monitoring system was developed for the low-voltage rural distribution network structure in China. The control terminal and commutation switch were used to realize low-voltage data acquisition and three-phase balance monitoring, while the complex management can be implemented. Three-phase load adjustment program is shown in Fig.2.
3.1. Control terminal
The control terminal mainly comprises a core unit, a man-machine interface, a power supply module, a control module and a communication module. The terminal basic structures are shown in Figure 3.

![Diagram of Control Terminal](image)

**Figure 3.** Structural Representation of Control Terminal

From the above Figure, firstly, the core unit usually completes the related data acquisition, the breakdown monitoring as well as the control instruction output and so on. Secondly, man-machine interface can be set the main terminal parameters. Thirdly, the power module provides DC power for the terminal. Also the control module is used to control the commutation switch to display the switch status. Lastly, the communication module can be connected with the core unit through the serial port, and the external system can be connected with the back system or the commutation switch. The control flow chart is shown in Fig.4.
3.2. The communication switch
The communication switch can adjust the three-phase load quickly and safely. It is installed in the low voltage table box or the head of line on 220V. The incoming feeder is three-phase four-wire or two-phase three-wire and outgoing feeder is single-phase two-wire. Commutation switch received the commutation command, which can be completed under the load conditions. And commutation does not affect the normal operation of electrical equipment. the three-phase four-wire incoming feeder is shown in Figure 5.
4. Actual Applications

In order to verify the effect of research results, combined with regional load characteristics, a typical district of transformer in China’s western regions were selected. The three-phase voltages before deployment are shown in Table 1.

| Value of the whole point | A phase voltage (V) | B phase voltage (V) | C phase voltage (V) | Three-phase unbalance degree (%) |
|--------------------------|---------------------|---------------------|---------------------|----------------------------------|
| 1h                       | 224                 | 231                 | 227                 | 3.08%                            |
| 2h                       | 223                 | 221                 | 230                 | 4.01%                            |
| 3h                       | 227                 | 224                 | 233                 | 3.95%                            |
| 4h                       | 221                 | 219                 | 229                 | 4.48%                            |
| 5h                       | 228                 | 217                 | 225                 | 4.93%                            |
| 6h                       | 226                 | 216                 | 223                 | 4.51%                            |
| 7h                       | 218                 | 221                 | 211                 | 4.62%                            |
| 8h                       | 220                 | 227                 | 207                 | 9.17%                            |
| 9h                       | 217                 | 230                 | 197                 | 15.37%                           |
| 10h                      | 215                 | 237                 | 196                 | 18.98%                           |
| 11h                      | 220                 | 236                 | 190                 | 21.36%                           |
| 12h                      | 222                 | 228                 | 192                 | 16.82%                           |
| 13h                      | 218                 | 219                 | 200                 | 8.95%                            |
| 14h                      | 215                 | 212                 | 196                 | 9.15%                            |
| 15h                      | 215                 | 223                 | 191                 | 15.26%                           |
| 16h                      | 221                 | 230                 | 193                 | 17.24%                           |
| 17h                      | 217                 | 229                 | 189                 | 18.90%                           |
| 18h                      | 211                 | 224                 | 187                 | 17.85%                           |
| 19h                      | 209                 | 217                 | 192                 | 12.14%                           |
| 20h                      | 203                 | 219                 | 199                 | 9.66%                            |
| 21h                      | 214                 | 202                 | 217                 | 7.11%                            |
| 22h                      | 221                 | 211                 | 225                 | 6.39%                            |
| 23h                      | 231                 | 219                 | 224                 | 5.34%                            |
| 24h                      | 250                 | 220                 | 229                 | 4.42%                            |

Note: (1) Three-phase imbalance is calculated according to IEEE std 936-1987 [11]; (2) The bold part of the figure is the time when the voltage crosses the line.

The voltage curve of three-phase before Adjusting is shown in Fig.6.
Figure 6. The three-phase Voltage Values before Adjustment

It can be known from the table 1, phase B has the serious three-phase unbalance phenomenon in this supplying district. Considering the deployment principles, such as three-phase line arrival, load size step changes, and avoid critical loads, 4-5 sets of commutation switches were installed in the each low-pressure outline. The three-phase voltage results after the adjusting are listed in Table 2.

Table 2. Integral point three-phase voltage numerical after adjust

| Value of the whole point | A phase voltage (V) | B phase voltage (V) | C phase voltage (V) | Three-phase unbalance degree (%) |
|--------------------------|---------------------|---------------------|---------------------|-----------------------------------|
| 1h                       | 227                 | 225                 | 223                 | 1.78%                             |
| 2h                       | 230                 | 226                 | 230                 | 1.75%                             |
| 3h                       | 225                 | 224                 | 221                 | 1.79%                             |
| 4h                       | 226                 | 223                 | 227                 | 1.78%                             |
| 5h                       | 224                 | 225                 | 226                 | 0.89%                             |
| 6h                       | 221                 | 225                 | 222                 | 1.80%                             |
| 7h                       | 220                 | 216                 | 219                 | 1.83%                             |
| 8h                       | 221                 | 223                 | 218                 | 2.27%                             |
| 9h                       | 226                 | 220                 | 223                 | 2.69%                             |
| 10h                      | 226                 | 222                 | 225                 | 1.78%                             |
| 11h                      | 220                 | 218                 | 222                 | 1.82%                             |
| 12h                      | 231                 | 224                 | 228                 | 3.07%                             |
| 13h                      | 226                 | 224                 | 226                 | 0.89%                             |
| 14h                      | 226                 | 220                 | 219                 | 3.16%                             |
| 15h                      | 222                 | 217                 | 216                 | 2.75%                             |
| 16h                      | 221                 | 218                 | 218                 | 1.37%                             |
| 17h                      | 219                 | 213                 | 215                 | 2.78%                             |
| 18h                      | 219                 | 217                 | 213                 | 2.77%                             |
| 19h                      | 218                 | 221                 | 214                 | 3.22%                             |
| 20h                      | 224                 | 223                 | 216                 | 3.62%                             |
| 21h                      | 226                 | 220                 | 225                 | 2.68%                             |
| 22h                      | 233                 | 231                 | 224                 | 3.92%                             |
| 23h                      | 232                 | 229                 | 228                 | 1.74%                             |
| 24h                      | 231                 | 230                 | 228                 | 1.31%                             |

In order to illustrate the performance of the proposed method, three-phase voltage values are shown in Fig. 7.
Next, the unbalance degrees before and after the adjustment are compared in the 24 hours. The comparison results are shown in Fig.8

In Fig.8, it is obviously that: (1) the unbalance degree of the selected supply district is improved greatly; (2) the suppression performance is better when the unbalance degree is serious; (3) the unbalance degree is controlled around 5%, which fits in the requirements of the guidelines.

5. Conclusion
In this paper, based on the actual situation of low-voltage distribution network in China, a new three-phase load balanced control technique is proposed. The key of the proposed method is to achieve the maximum balance of three-phase load through quick selecting phase, the uninterrupted power supply must be ensured. In the realization process, the commutation optimization strategy, the action frequencies and other factors are considered, and which can be also integrated into the unified monitoring and management.

Based on the verification, the device based on the above ideas provides a new solution to solve the problem of rural low voltage three-phase load imbalance. The device also can greatly enhance the intelligent level of low-voltage three-phase management and owns the significant values.

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