

Loss Reduction Strategy of Low-Voltage Distribution Network Based on Phase Swapping

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Abstract. As the low-voltage distribution network contains many three-phase unbalanced loads and single-phase loads, and the sequence of power consumption of different types of loads varies greatly, the actual power loss of the network increases more than that under three-phase balance. This paper proposes a loss reduction strategy based on phase swapping. By swapping phase of loads, it makes the three-phase transmission power of each branch realize balance in a long period, thus achieving the objective of loss reduction.

1. Introduction

The low-voltage distribution network contains a large number of three-phase unbalanced loads and single-phase loads, so that the three-phase current of the branch is no longer balanced. At this time, the active power loss on the line and power transformer will increase. According to principles of loss reduction, the current methods mainly include load compensation [1,2], network reconfiguration [3,4] and phase swapping [5,6]. Among them, phase swapping, as a method of effectively improving the network imbalance problem, has attracted people's attention. Related research has achieved some preliminary results. Literatures [7] use improved particle swarm optimization algorithm to solve the optimal loads' phase, which mainly focuses on the static phase swapping optimization problem without considering loads' dynamic change in time scale. In Literature [8], the degree of three-phase unbalance and the duration of the three-phase unbalance are taken as the basis for the operation of the phase-change switch, which has a certain hysteresis and cannot achieve global optimization over a long time.

Aiming at the deficiencies of the existing research, this paper proposes a multi-period optimization model based on phase swapping. The model takes the single-phase load and three-phase load into account, and adopts improved genetic algorithm to solve the problem, thus achieving good effect in loss reduction.

2. Optimization Model of Phase Swapping

Actually, the optimization of phase swapping is to determine a group of connection modes using a certain optimization decision method when the network topology parameters and load information are given, so that the network can reach the minimal loss during the entire period while satisfying the static security constraints. This problem is essentially a multivariable non-linear combinatorial optimization problem, which is suitable for solving with the heuristic algorithm.



2.1. Alternative Connection Modes of Load

The mapping relationship between load connection modes and genes is shown in Table 1. Capital letters represent phases of the network and lowercase letters represent phases of the load.

Table 1. Mapping Relationship Between Load Connection Mode and Gene.

Load	Load Connection Mode	Gene
Three-phase Load	Aa-Bb-Cc	1
	Ac-Ba-Cb	2
	Ab-Bc-Ca	3
	Aa-Bc-Cb	4
	Ac-Bb-Ca	5
	Ab-Ba-Cc	6
Single-phase Load	AL	1
	BL	2
	CL	3

2.2. Objective Function

This paper takes the minimal sum of unbalanced power of branch transmission within the optimization period as the objective function, which can be expressed as:

$$\min F = \sum_{k=1}^n \sum_{i=1}^b \sum_{\varphi=A}^C S_{unb,k,i,\varphi} \quad (1)$$

In the formula, n is the total number of division periods of the load curve; b is the number of three-phase branches in the distribution network; $\varphi=A, B, C$; $S_{unb,k,i,\varphi}$ is unbalanced power of a certain phase of branch i in the k th period, whose computing method is as in Formula (2), among which $S_{k,i,A}$, $S_{k,i,B}$ and $S_{k,i,C}$ are the transmission power of each phase of the branch.

$$S_{unb,k,i,\varphi} = \left| S_{k,i,\varphi} - \frac{1}{3}(S_{k,i,A} + S_{k,i,B} + S_{k,i,C}) \right| \quad (2)$$

2.3. Solution Method and Steps of Model

In this paper, the improved genetic algorithm is used to solve the optimization model. The crossover probability and the mutation probability are dynamically generated according to the individual fitness of individuals in each evolution process, thereby enhancing the search ability of the algorithm and improving its premature convergence. The solution steps are as follows:

- 1) Read the network topology and parameter information, node load information, set population size of the genetic algorithm, evolution algebra, and the upper and lower limits of the crossover and mutation probability;
- 2) Randomly generate initial population;
- 3) Calculate the fitness of all individuals in the population;
- 4) Perform selection, crossover, and mutation operations on the population to obtain the next generation population;
- 5) Save the best individuals and their fitness in the current population;
- 6) Repeat from Step 3 to Step 5 until it achieves the maximal evolution algebra.

3. Analysis of Examples

In order to verify the reduction method proposed in this paper, the 28-node low-voltage distribution network shown in Fig. 1 is used as an example. In Fig. 1, dotted branches are single-phase lines, and the

rest of the branches are three-phase lines. The network contains a total of 18 load nodes, of which 6 load nodes have single-phase loads, and the remaining load nodes have three-phase loads.

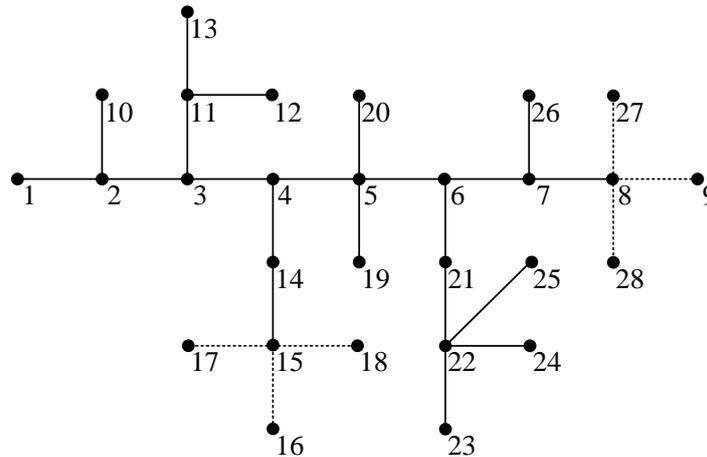


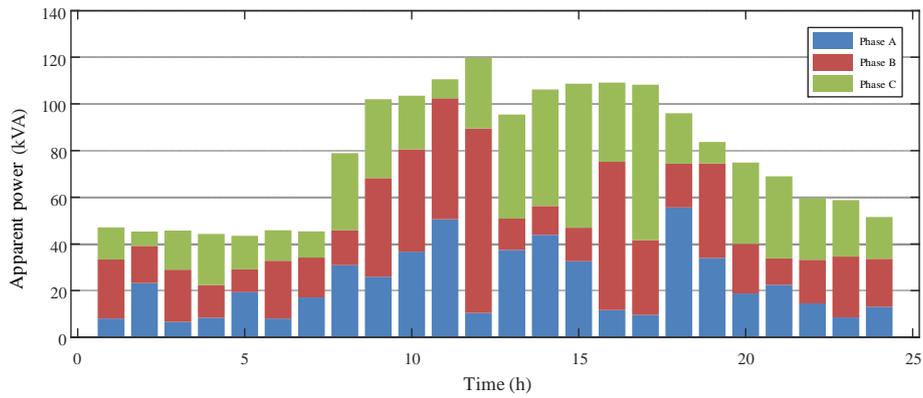
Figure 1. Topology of 28-Node Low-voltage Distribution Network.

Considering the safety of the power grid operation and the cost of the switch operation, the phase-change switch cannot be operated frequently, therefore, the continuous change of the load during the entire cycle must be considered, so that the network after phase swapping can keep the three-phase load balance as long as possible. To take the load curve characteristics of different types of loads into account, the types of load nodes in the network are shown as in Table 2.

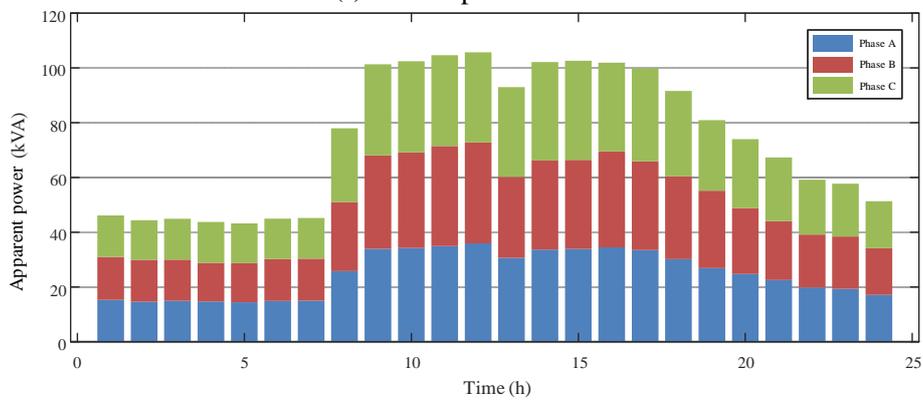
Table 2. Load Type of 28-Node Low-voltage Distribution Network.

Load Type	Node Number
Industrial Load	23,24,25
Commercial Load	10,12,13,14,15,19,20,21,26
Residential Load	9,16,17,18,27,28

It is assumed that the power factor of each load is taken as 0.9, and the set of nodes in the network that can perform phase swapping are {9,12,13,14,15,19,20,21,23,24,25,27}. Set the genetic algorithm population size to 100, the evolutionary algebra to 50, the maximum and minimum crossover probability were 0.8 and 0.2, and the maximum and minimum mutation probability were 0.4 and 0.2 respectively. The three-phase apparent power of the system before and after the optimization is shown in Fig. 2, and the system network loss and the minimum voltage change of the node are shown in Fig. 3 and Fig. 4 respectively.



(a) Before Optimization



(b) After Optimization

Figure 2. Three-phase Apparent Power of the System before and after Optimization.

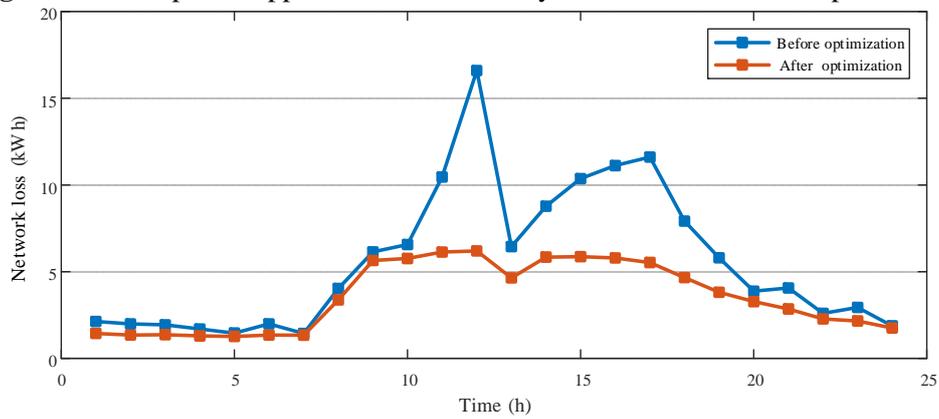


Figure 3. Network Loss Curve before and after Optimization.

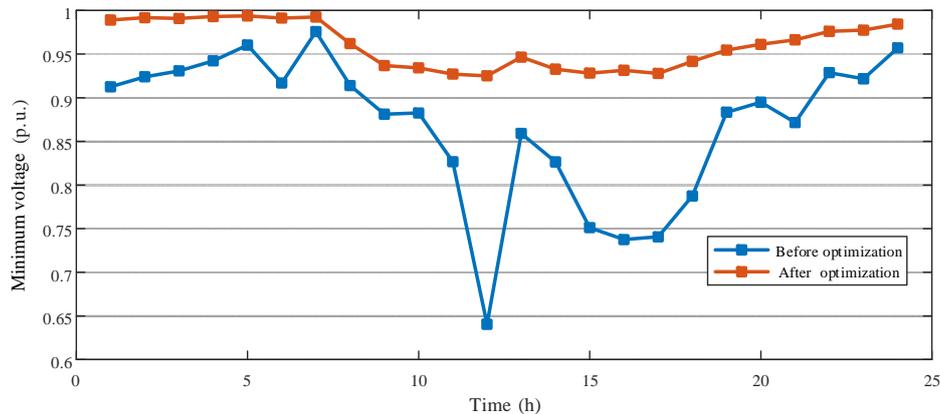


Figure 4. The Minimum Voltage Curve before and after Optimization.

After optimization, the network power loss decreased from 133.7914 kWh to 84.9480 kWh, and the reduction rate was 36.51%. According to Fig. 2, it can be seen that the apparent power of each phase of the original network varies greatly. By phase swapping, the three-phase load of each period is basically balanced. Since the network loss after three-phase load balancing is significantly reduced, the apparent power consumed by the network during each period is also reduced. Taking 12th period with a higher load level as an example, the sums of three-phase apparent power consumed before and after optimization are 119.74kVA and 105.74kVA. In addition, from Fig. 3 and Fig. 4, it can be seen that during the period when the load level and the three-phase imbalance degree are relatively high, the network loss reduction after optimization is large, and the voltage quality of the network is significantly improved.

4. Conclusion

This paper proposes a method to reduce the loss of low-voltage distribution network based on phase swapping. The single-phase load and three-phase load in the network are taken into account, and the improved genetic algorithm is used to solve the problem. The results of the example show that the proposed method can balance the three-phase load better, the loss reduction effect is more obvious, and it can greatly improve the voltage quality of the network.

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