Research on Dynamic Reactive Power Optimization of Receiving Terminal Network Based on Voltage Infeasible Node

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Abstract. A dynamic reactive power optimization method for receiving end power grid with voltage infeasible nodes is proposed. Firstly, the reactive power compensation nodes are classified, and the basic concept of the system reactive compensation node is proposed. Then, on the basis of whether a voltage constraint unfeasible node is presented in a certain period, all the days are divided into feasible period cluster and infeasible interval cluster. On this basis, the receiving terminal of an unfeasible node with voltage is constructed. Dynamic reactive power optimization model of power grid. The model includes two sub models of dynamic reactive power optimization, which are unfeasible period cluster and feasible time interval cluster. In the former, a two phase algorithm based on homotopy interior point method and parallel coevolution algorithm is proposed, and the latter is solved by immune genetic algorithm. Finally, the effectiveness of the proposed method is verified by simulation analysis of the actual 25 node 110 kV high voltage distribution network.

1. Introduction
In order to solve the problem of the failure of dynamic reactive power optimization model, which is caused by the lack of voltage regulation capability caused by main variable voltage locking in substation and capacitor maintenance, [1] it can still be studied from two angles of planning and operation. On the aspect of planning, the weak link identification method, [3] is used to identify the weak reactive compensation nodes of a single period of peak load, and to solve the dynamic reactive power optimization failure through reactive power Compatibilization of the weak node of reactive power compensation. [2] From the point of view of the operation, the dynamic reactive power optimization is optimized by 24 h a day, rather than a single period of time as the optimized section. [3, 4] The mathematical model cannot be solved by using the mathematical model of the static reactive power optimization unfeasible problem. Therefore, taking the receiving power grid as the research object, the dynamic reactive power optimization model with voltage unfeasible nodes is established in the case of heavy load or reactive power compensation, which can effectively reduce the number of voltage lower limit nodes and the degree of remission limit, at the same time reduce the power consumption of the whole network in the available period. [5, 6] The ability to ensure the safe and economic operation of the power grid.
In view of the above problems, a dynamic reactive power optimization model of receiving end power grid with voltage infeasible nodes is proposed in this paper. First, the basic concept of the reactive power compensation node and the difference from the voltage infeasible node are given. Then, based on whether a voltage unfeasible node is found in a certain period of time, all the days are divided into feasible period cluster and infeasible interval cluster. Finally, the end grid dynamic of an unfeasible node with voltage is built on this basis. State reactive power optimization model. In order to solve the dynamic reactive power optimization model of infeasible interval clusters, the 2 phase algorithm based on homotopy interior point method (Homogeneous Interior Point Method, HIPM) and parallel coevolution algorithm (Parallel Cooperative Co-evolutionary Differential Evolution Algorithm, PCCD-EA) is used. The Immune Genetic Algorithm (IGA) is used to solve the dynamic reactive power optimization model for feasible time series clusters. Finally, the results of the feasible period cluster and the infeasible time cluster are combined to form the final optimization scheme.

2. Dynamic reactive power optimization algorithm for receiving end power grid with voltage constrained infeasible nodes

2.1. Algorithm flow of dynamic reactive power optimization for terminal power grid

The specific steps of the whole algorithm for solving the dynamic reactive power optimization model of the receiving terminal are as follows.

1) Homotopy interior point method is used to conduct cyclic detection for each time period to get clusters and feasible time clusters.

2) For the period I of the J infeasible time series, the relaxation of dynamic constraints is adopted to solve the static reactive power optimization one by one.

3) Until the solution of all the periods of clusters in the J infeasible period is completed, the results of cluster J dynamic reactive power optimization model are obtained.

4) Repeat step 2~ step 3 until all dynamic reactive power optimization models of all infeasible time clusters are solved.

5) Using the infeasible time cluster as the central coordination strategy, the maximum allowable action times of the capacitor switch, the maximum allowable action times of the load regulating main transformer, and the maximum adjusting gear of the feasible boundary period are updated.

6) Several feasible interval clusters are merged, 1 feasible interval clusters are formed, and the immune genetic algorithm is used to solve the conventional dynamic reactive power optimization model by using the immune genetic algorithm.

7) Combine the dynamic reactive power optimization results of the feasible time cluster and the infeasible time cluster, and obtain the action plan of all the voltage regulating devices in the whole day.

3. Example analysis

3.1. The basic data of the example

On the Matlab R2012a platform, the dynamic reactive power optimization test of a real 110 kV high voltage distribution network is carried out. The 110 kV power grid has 6 110 kV substations, 1 220 kV substations and 25 nodes in the whole network. Among them, the substation SMQ has not yet been connected to the 10 kV load, and its low voltage nodes 11 and 12 and 220 kV RD station nodes 25 are all the system reactive power compensation nodes. Therefore, RD stations and SMQ stations form 2 voltage control stations, while the other substations form 1 loss reduction control zones. All transformer substations are all on load voltage regulation, and reactive power compensation capacitors are installed at the low voltage side of the substation.
Figure 1. A 25-bus 110 kV distribution power system

The total day total load data is derived from the SCADA acquisition values of 24 periods in July 21, 2016, and 2 infeasible periods are given by the HIPM algorithm. 1 unfeasible interval clusters are composed of time periods 11 and 12 respectively. The period 19 constitutes 1 unfeasible interval clusters, and the rest period is composed of 1 feasible interval clusters. As shown in Figure 2. In the simulation, the voltage safety change range of 10 kV is 0~7% of nominal voltage, that is, 1 (pu) ~1.07 (pu), 110 kV and above voltage level is 1 (pu) ~1.1 (pu) [17]. At the same time, 220 kV RD station high voltage side power factor qualified range is 0.95~1.0 [18]. In order to simplify the problem, the capacity of each substation's single capacitor is 0.100 (pu), and the single regulating bit of the transformer is 0.025 (pu).

Figure 2. Total load curve and detection solution of infeasible time period

3.2. The calculation conditions of calculation examples

In this paper, the dual gap of HIPM algorithm and the convergence accuracy of KKT equation are set to 10^-6. For the IGA algorithm, the total number of antibodies is set to 40, and the selection probability and variation are 0.5 and 0.15 respectively, and the largest generation of immune genetic evolution is 100 generation. For the IPCCD-EA algorithm, the population number of the defined voltage control station and the loss control area is 1, the evolutionary maximum algebra is 100 generations, the evolutionary population size is 80, the population size of the genetic algorithm is 20, the mutation probability is 0.15, the selection probability is 0.5, and the genetic algebra is 10 generations.
3.3. The results and analysis of calculation examples

The results and characteristics of the dynamic reactive power optimization method proposed in this paper are compared and analysed by using the continuous static reactive power optimization as a comparison method which does not consider the dynamic constraints. For convenience, the contrast method is referred to as the overall optimization method. Table 3 gives the sum of the percentage of the voltage limit and the ∑s of the voltage limit and the ∑Ns value of active power loss at different time intervals ∑Ploss. In Table 1, as the overall optimization method fails in time 11, 12, and 19, in order to compare the effectiveness of this method, it is assumed that the overall optimization method adopts a scheme of last period 10 in time interval 11 and 12 for the control variable scheme, and the scheme of period 19 takes the last interval 18 scheme.

### Table 1. Partial solutions of the two methods

| Period /h         | This paper method | Overall optimization method |
|-------------------|-------------------|-----------------------------|
|                   | ∑Ploss (pu) | ∑s (%) | ∑Ns (pu) | ∑Ploss (pu) | ∑s (%) | ∑Ns (pu) |
| Feasible period   |              |       |          |              |       |          |
| 1~10              | 13~18       | 20~24 |           | 19.38        | 0      | 0        | 17.18    | 0      | 0        |
| Infeasible period | 11          | 12    | 19        | 0.97         | 4.0    | 0        | 1.05     | 18.7   | 9        |
|                   | 0.99        | 3.8   | 1         | 1.04         | 1.04   | 1.04     | 1.04     | 18.1   | 7        |
| Total             | 22.29       | 11.9  | 3         | 20.34        | 56.7   | 25       |

As can be seen from table 1, the total day loss of this method is 22.290 (pu), which is higher than the total optimization method (20.340 (pu)), but the number of voltage limits and the sum of the ∑Ns, the voltage limit percentage and ∑s are 3% and 11.9% respectively, which are significantly lower than the total optimization methods of 25% and 56.7%.

At the same time, the SMQ station has no access to the load of 10 kV for the time being, and the more upper limit of its voltage is allowed, it is a system reactive compensation node. It can be seen that to solve the problem of the lower voltage limit of the 9 nodes of the SP station, the upper limit of the node 11 voltage of the SMQ station is caused. Table 4 gives the control scheme of voltage and voltage regulation equipment for SMQ station and SP station.

![Figure 3. Comparison of nodal voltage results at infeasible time period between the two methods](image-url)
Table 2. Control scheme of voltage and voltage-adjusting devices of SMQ station and SP station

| node | Voltage amplitude (pu) | Input capacitance (pu) | Main variable gear position (pu) |
|------|------------------------|------------------------|---------------------------------|
| 11   | 1.1135                 | 0.3                    | 0.925                           |
| 12   | 1.0049                 | 0.3                    | 1.025                           |
| 7    | 1.0011                 | 0.2                    | 1.000                           |
| 9    | 1.0235                 | 0.2                    | 0.975                           |
| 10   | 1.0221                 | 0.2                    | 0.975                           |
| 4    | 1.0298                 | —                      | —                               |

According to table 2, the nodes 7, 9 and 10 of the SP station are all invested in the peak load period 12 reactive compensation, and the node 11 and node 12 of the SMQ station are used as reactive compensation nodes of the system, and their reactive compensation is all invested. This indicates that the load of the SP station is heavy and its self-regulating ability is insufficient, and the reactive power compensation node is required to provide reactive power. Aid. From the main transformer position, the SMQ station node 11 is the main shift bit of 0.925 (pu), which is lower than the nominal voltage ratio of 1. This indicates that the SMQ station reduces the main shift position, returns the reactive power of the low voltage side to the high voltage side node 4, the voltage amplitude of the lifting node 4 to 1.029 (pu), realizes the reactive power support to the SP station, and solves the voltage lower limit of the SP station node 6~10, but this leads to the voltage amplitude of the node 11 to 1.113 (pu), higher than the safety limit. 1.070 (pu) is about 4.1%.

According to Fig. 2, the periods 11, 12 and 19 are the "morning peak" and the "late peak" respectively, and the corresponding periods are all infeasible. As can be seen from Fig. 4, the overall optimization method cannot be calculated at time 11, 12 and 19, resulting in no action on the capacitor and main transformer during these periods. In this paper, the number of action times of the 12 capacitor and the main transformer in the period of time is 0, the number of action at 11 in the period of time is 1 and 0 respectively, and the number of capacitors and main variable gears in the period 19 is 2 and 3 respectively.

(a) Comparison of the action times of capacitors (b) comparison of the number of action times of the main shift

Figure 4, Comparison of switch times by voltage devices between the two methods

Then the dynamic reactive power optimization is solved. As a result, the number of times that the capacitor and the main transformer are at 12 of the maximum load time are 0, while the time period 11 is not 0. The number of action times of the unworkable period 19 is determined by the difference between the 18 and the 19 control schemes, so the number of action times of the capacitor and the main transformer is 2 and 3, respectively. From the action time period, time 13~18 is between two unworkable
periods, and the number of main shift positions and capacitors is 3 times and 1 times respectively, while the total action times between 20~24 and time 1~10 are 7, 6 and 6, 10 times respectively.

In summary, the coordination strategy based on the infeasible time cluster cluster can effectively coordinate the capacitor and main shift operations in different periods. This method can give priority to ensure that the capacitor and the main variable position of the unworkable period cluster have enough adjustment times to ensure that the peak load voltage is within the qualified range as much as possible. In a feasible period cluster, this method can reasonably allocate the total number of remaining allowed actions between the "early peak", the "late peak" and the morning and evening peaks, which effectively reduces the total number of times of the device's action.

4. Conclusion
In this paper, a dynamic reactive power optimization method for receiving end power grid with voltage infeasible nodes is proposed. In the aspect of the model, this method solves the problem of failure of conventional dynamic reactive power optimization when the voltage infeasible node of the receiving terminal is invalid. The model has the following characteristics:

1) In this paper, we take the unworkable time cluster as the central coordination strategy, which can give priority to the maximum voltage and reactive power adjustment capability of the voltage regulator in the unworkable period cluster, and then consider how to allocate the total number of remaining allowable actions to every feasible time period. This strategy can guarantee the operation safety of the power grid in the "dangerous" period of higher load in the whole day, and can also reduce the number of repeated action in the "dangerous" time period of higher adjacent load, and prolong the service life of the power grid equipment.

2) This method is the extension of the traditional dynamic reactive power optimization model, which solves the problem of the traditional dynamic reactive power optimization failure when the voltage unworkable node is infeasible, and provides an effective solution to solve the low voltage problem in the case of heavy load or reactive power compensation.

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