

Grid Transmission Expansion Planning Model Based on Grid Vulnerability

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Abstract. Based on grid vulnerability and uniformity theory, proposed global network structure and state vulnerability factor model used to measure different grid models. established a multi-objective power grid planning model which considering the global power network vulnerability, economy and grid security constraint. Using improved chaos crossover and mutation genetic algorithm to optimize the optimal plan. For the problem of multi-objective optimization, dimension is not uniform, the weight is not easy given. Using principal component analysis (PCA) method to comprehensive assessment of the population every generation, make the results more objective and credible assessment. the feasibility and effectiveness of the proposed model are validated by simulation results of Garver-6 bus system and Garver-18 bus.

1. Introduction

With the large-scale access of new energy and load, power system will face with more uncertainties. The traditional power grid planning system which is dominated by economy and security, can no longer meet the needs of the current power grid construction, and needs to be supplemented and improved[1]. As an extension of the security and stability of power grid, the power system vulnerability will be introduced into the power grid planning, which will have guiding and referential significance for planning and building a strong grid.

Most of the traditional researches on vulnerability just from the viewpoint of grid components, and only consider the relative vulnerability of single component of power grid, which can't measure the degree of vulnerability between different power grids simply and effectively[2]. Therefore, this paper proposes the concept of global structure and state vulnerability of power grid, and applies it to power grid planning effectively.

Existing researches have pointed out that the non-uniformity of power grid is the important reason that the grid tends to self-organized criticality[3-4]. Therefore, it is necessary to consider the uniformity of power grid structure and state at the beginning of transmission network planning, which can effectively prevent the grid from entering the self-organized criticality, and reduce the system vulnerability[5].

Firstly, based on the traditional grid vulnerability assessment method, combining the power system uniformity theory and the Gini coefficient index, the global vulnerability factor model of power grid structure and state is put forward to assess the global vulnerability of power grid. Secondly, the multi-



objective grid planning model is constructed on the basis of considering the economy of power grid, the global vulnerability factors of power grid structure and state, and the constraint set of grid security. Then, in the process of solving the problem, because of the dimensions of each objective are not uniform, the weight is not easy to obtain. In this paper, PCA is used to evaluate the individual population in each generation, and then the improved chaotic crossover and mutation genetic algorithm is used to optimize the planning scheme. Finally, the Garver-6 node system and the Garver-18 node system are used to analyze and prove the rationality and effectiveness of the proposed model.

2. Power Grid Planning Index and Model

2.1 Gini Coefficient

The Gini coefficient is an index used to judge the fairness of income distribution^[6]. As shown in Figure 1.

Define Gini coefficient,

$$G = \frac{A}{A+B} \quad (1)$$

The larger the Gene coefficient is, the poorer the uniformity of the distribution of the system.

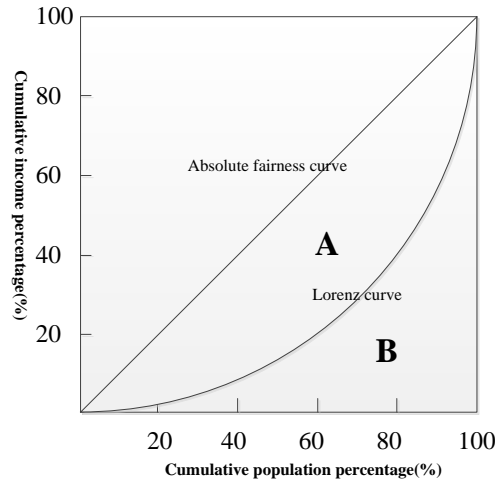


Figure 1. Gini coefficient curve

2.2 Global Vulnerability Factor of Structure

The electrical betweenness of nodes effectively quantifies the importance of nodes in the topology of the power grid. The model of electrical betweenness is available in the paper[7]. The uniform distribution of the node electrical betweenness can effectively reflect the uniformity of the topology of the power network. Therefore, based on the Gini coefficient theory, the index of the Gini coefficient of the nodes electrical betweenness G_n is established to measure the uniformity degree of the network topology.

2.3 Global Vulnerability Factor of State

The load rate of the power network branch can effectively measure the occupancy of the branches. The Gini coefficient of the branch flow load rate can effectively measure the uniformity of the system running state. Supposing the maximum active transport capacity of the branch i is $P_{i,max}$. When the system is running, the actual load flow of the branch i is P_i , and the load rate of the branch i can be as follows,

$$\eta_i = |P_i / P_{i,max}|, i = 1, 2, \dots, N \quad (2)$$

N is the number of branches

The Gini coefficient model for the load flow rate of the branches is established to measure the uniformity degree of the power grid state G_f .

2.4 Power Grid Planning Model

In this paper, the new lines is taken as the planning variable, Meeting the prerequisites of the number constraint of the new-built lines ω_i and grid security constraint set X , considering the investment of construction cost C , line operation loss cost P_{loss} , global structure vulnerability factor G_n , global state vulnerability factor G_f and safety constraint penalty O . The grid expansion planning model is as follows,

$$F = \min\{f_1(C), f_2(P_{loss}), f_3(G_n), f_4(G_f), f_5(O)\} \quad (3)$$

$$s.t. \ h(x) = 0 \quad (4)$$

$$g(x) \leq 0 \quad (5)$$

Formula (3) is the objective function vector, formula (4) and (5) are the grid security constraint sets where x is running state variable.

3. Simulation Analysis

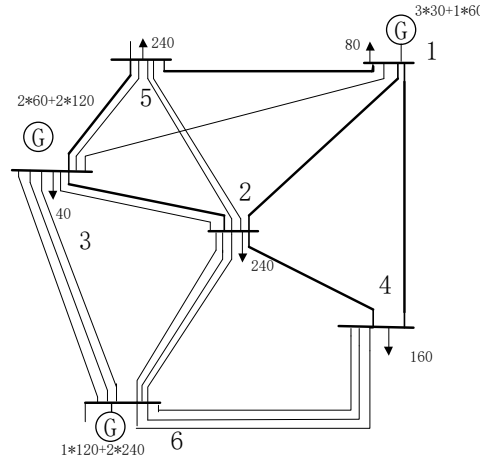


Figure 2. Planning route map

In this paper, the Garver-6 node system is taken as an example to simulate. It is considered that the 6 nodes can be connected with each other. In order to solve the problem that the weights of multi-objective programming are difficult to select, this paper uses PCA to evaluate the power grid planning comprehensively. Genetic algorithm is used to optimize the model. The wiring diagram of the optimization results is shown in Figure 2. The thin line is the added line.

It can be seen from table 1, first of all, the construction cost of model 1 is 71097.95 thousand yuan, which is slightly larger than model 2. This is mainly because of the model 1 considers the uniformity of the structure and the state of the grid, more branches are needed to share the power flow of heavy load lines, and to make the topology of power network more reasonable. Then the vulnerability of planning model is reduced, and the ability of grid to resist various uncertain risks is enhanced. Simulation results also have proved this point; Secondly, the cost of grid loss of model 1 is obviously lower than that of the model 2, because of the rationality of the network topology and power flow distribution. In conclusion, the planning model established in this paper sacrifices the cost of a part of construction cost to achieve the optimal overall goal. Such a grid is more economical and reliable.

Table.1 The optimization simulation results comparison chart of Garver-6 node system

Parameter	Model 1	Model 2 ^[8]
Number of expansion lines	2-3(1), 3-5(1), 1-3(1), 2-5(2), 2-6(3), 3-6(3), 4-6(3)	2-3(1), 2-6(4), 3-5(2), 4-6(3), 3-6(2),
Construction expenses (Thousand yuan)	71097,95	63007,7
Global structure vulnerability factor	0.146	0.249
Global state vulnerability factor	0.315	0.386
Grid loss (Thousand yuan)	30472,76	31711,4

4. Conclusion

In this paper, a mathematical model of multi-objective power grid planning is proposed. Firstly, the global vulnerability factor model of power grid is constructed based on the uniformity of power grid topology and operation state. It can effectively measure the structure and state vulnerability of power grid. Secondly, the principal component analysis is used to comprehensively evaluate the economic, security constraints and global vulnerability of the planning model. Finally, the genetic algorithm is used to optimize the selected scheme, and the optimal scheme is obtained. Simulation results show the feasibility and effectiveness of the proposed model. At the same time, the planning model proposed in this paper can solve the problem that the constraint condition and the objective function of the power grid planning are difficult to deal with, meeting the needs of the actual project.

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