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Constructing core backbone network based on survivability of power grid

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ABSTRACT

Constructing core backbone network is beneficial to strengthen the construction of grid structure, raise the ability of withstanding natural disasters, as well as realize power grid's differentiation planning reasonably and scientifically. Based on the index system of survivability, a method of constructing core backbone network with the target of the smallest line total length and the largest integrated survivability index is put forward with constraint conditions of network connectivity and power grid safe operation. The cosine migration model, the premature judgment mechanism, and the mutative scale of mutation strategy by Chaos and Cauchy optimization are introduced into the improved biogeography-based optimization algorithm (BBO) to search for the optimal solution of the core backbone network. Comparison with the traditional BBO algorithm, particle swarm optimization (PSO), binary ant colony algorithm (BACA), genetic algorithm (GA) shows that the proposed method is accurate and effective, and it has advantages in fast convergence speed and high convergence precision.

Introduction

For the past few years, power grid is constantly damaged by extreme natural disasters, which is due to that the past standard of power facilities could not resist the increasingly frequent natural disasters [1,2]. Therefore, it is necessary that the resistant standards of disasters should be designed differentially, with different lines' geographical location and climate conditions taken into consideration. The goal of differential planning design is to confirm the core backbone network, which is made up of important lines that can guarantee the continuous power supply of the important load when the major natural disasters attack [3,4].

Take the differential planning carried out for the large area blackout accident because of the ice disaster by electric power company in Quebec, Canada in the late 1990s for an example, the strategic guarantee route designed for 735 kV substation played an important role in early 2009 north American ice storm, which managed to avoid a large area blackout accident [5,6]. Therefore, constructing core backbone network is meaningful to improve the stability of the power grid's structure, reduce the secondary investment of repairing and rebuild the harm of power grid caused by natural disasters, as well as guarantee power grid's safe and reliable operation under severe natural disasters.

The concept of survivability is firstly put forward by Barnes and others in 1993 [7]. Survivability of system is refers to the ability that the system can complete its critical services in a timely manner, and restore its basic services as soon as possible when it is subjected to the attack, failure or a sudden accident [8]. Survivability has been widely concerned in the complex network and information system as a new research direction [9,10], but its application in the related fields of power system is relatively small. Considering survivability is helpful to keep the system alive with supportive network structure, in that case, the constructed core backbone network has strong resistance, restorative and connectivity. A key line identification method based on network survivability evaluation was proposed in the literature [11], a search model and a search method of backbone grid are also present, which has certain enlightening significance. But the survivability index of this method is relatively single, and the search algorithm is easy to fall into local optimal.

The survivability index system that can systematically reflect information system is proposed in the literature [12], the formalized description and mathematical model are also given. It has a certain guiding role in establishing power system's survivability index system.

Search of core backbone network belongs to nonlinear and discontinuous optimization problem, which relies on artificial intelligence algorithm [13,14]. As a kind of new artificial intelligence algorithm, BBO algorithm based on species migration patterns

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has achieved good results in parameter identification [15], fault diagnosis [16], and image classification [17], as well as transmission network planning [18], and other fields. It is reflected that the algorithm has advantages of less set parameters, simple calculation, fast convergence speed and good stability. But there are problems in traditional BBO algorithm that the linear migration model cannot accurately simulate the migration process, search ability is not strong, as well as it is easy to fall into local optimum by premature [19,20]. Therefore, the cosine migration model, the premature judgment mechanism, and the mutative scale of mutation strategy by Chaos and Cauchy optimization were introduced into the improved traditional BBO algorithm, to strengthen its search ability, and make it search the optimal solution of core backbone network rapidly and accurately.

A new method of constructing core backbone network considering survivability is put forward in this paper. The indexes of survivability are built from aspects of resistibility, recoverability, and connectivity. The largest integrated survivability index and the minimum total length of the backbone grid's lines are regarded as the objective function, with network connectivity and power grid's safe operation as constraint conditions. The improved BBO algorithm provided with strong search ability is used to search backbone grid. The simulative results show that the method can quickly and accurately search the optimal solution of core backbone network considering survivability, and its convergence speed and convergence precision are higher than that of the traditional BBO algorithm, PSO algorithm, BACA algorithm, and GA algorithm.

The index system of survivability

Survivability of power grid is defined as the ability of guaranteeing the electricity supply of important load relying on the high design standards of the core backbone network, as well as restoring power supply for other load gradually through the network frame when major natural disasters attacks. The index system of survivability is built from these three aspects as follows: resistibility, recoverability and connectivity.

The index of resistibility

Resistibility of power grid reflects the resistance of the basic service that the system provides power supply for the important load with all kinds of natural disasters. The two indicators, preserving rate of line and node are introduced to evaluate resistibility. The number of original rack's lines is set as dim (L), and that of the node is set as dim (B).

The number of failure line and failure node of the remain network frame after natural disasters compared to the original rack are respectively *L_failure*, *B_failure*.

Preserving rate of line is as follows:

$$\alpha_l = \frac{\dim(L) - L\_failure}{\dim(L)} \tag{1}$$

Preserving rate of node is as follows:

$$\alpha_b = \frac{\dim(B) - B\_failure}{\dim(B)} \tag{2}$$

The index of recoverability

Recoverability of power grid reflects whether the power grid can recover after suffering from natural disasters, as well as how much it can recover. The generator standby indicator and load recovery degree index are introduced to evaluate recoverability.

The generator is actual output and the largest capacity of the backbone grid are respectively set as G_i, and $G_{i\max}$. The total number of generator is m_g. The active load and the actual active load of node j in the backbone network frame scheme that meets the safe operation conditions and ensure the rack's load to be biggest are respectively S_{jm} and S_j.

The generator standby indicator is as follows:

$$\beta_g = \sum_{i=1}^{m_g}\left(\frac{G_{i\max} - G_i}{G_{i\max}}\right) \tag{3}$$

The load recovery degree index is as follows:

$$\beta_c = \frac{\sum_{j=1}^{\dim(B)-B\_failure} S_{jm} - S_j}{\sum_{j=1}^{\dim(B)-B\_failure} S_{jm}} \tag{4}$$

The index of connectivity

The relative tightness degree and the relative condensation degree of the grid are introduced to evaluate connectivity.

(1) The relative tightness degree of the grid

Assuming that node j has K_j neighbor nodes, there are at least $K_j(K_j-1)/2$ lines between these nodes, but there are actually only t_j lines, in that case, the clustering coefficient of the node j is as follows:

$$C_j = \frac{2t_j}{K_j(K_j-1)} \tag{5}$$

The relative tightness degree of the grid is the weighted average of backbone grid's all nodes' C_j. It is the characteristic parameter that shows the connected degree of neighboring nodes, and its expression is as follows:

$$C = \frac{\sum_{j=1}^{\dim(B)-B\_failure} C_j}{\dim(B) - B\_failure} = \frac{\sum_{j=1}^{\dim(B)-B\_failure} \frac{2t_j}{K_j(K_j-1)}}{\dim(B) - B\_failure} \tag{6}$$

If the tightness degree of the original grid is C_0, the relative tightness degree of the backbone grid is as follows:

$$\varphi = \frac{C}{C_0} \tag{7}$$

(2) The relative condensation degree of the grid

The relative condensation degree of the grid is the product's reciprocal of the number of nodes and the weighted average of the shortest path, namely:

$$\partial = \frac{1}{n \cdot l} \tag{8}$$

The traditional shortest path is the minimum number of edges between two nodes. Considering the actual situation of power system, the weighted average of the shortest path of backbone grid with the length of the transmission line as the line's weight is as follows:

$$l = \frac{2}{n \times (n-1)} \sum d'_{ij} \tag{9}$$

where d'_{ij} is the weighted number of edges that the shortest path passes through; n is the total number of nodes in the grid.

The formula (9) is taken into the formula (8), and then the condensation degree of the backbone grid is got as follows:

$$\partial = \frac{n-1}{\sum d'_{ij}} = \frac{\dim(B) - B\_failure - 1}{\sum d'_{ij}} \tag{10}$$