Power Grid Development Planning Based on Small World Model

Wei-hua CHEN* and Sheng ZHANG
China Energy Equipment Co., LTD., Beijing, China
*Corresponding author

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Abstract. There are two main directions of the further development of power grid. One is the construction of higher voltage power grid. The other is strengthen power grid by keeping the original voltage grade. The current research of the two power grid directions focuses on comparing of specific project. The essence laws of power grid and its boundary conditions are less researched. In view of the above problems, this paper proposes a development simulation method of power grid based on small world evolution model. The method is based on the small world characteristics of power grid. And adaptability index for power grid are built. They can reflect adaptability of power grid to boundary conditions of essence laws. The grid development direction is established based on the adaptability index. It is fit to power grid situation and external environment. The simulation results of power system development show that proposed method is effective.

Introduction

At present, most of China's power grid has formed a 500 kV backbone grid. In developed areas such as East China and South China, 500 kV power grid has developed rapidly. Some local saturation phenomena such as short-circuit current exceeding the standard have appeared. How to determine the next stage of development direction of 500 kV power grid is one of the hot issues of current research [1-3]. Reference [4] puts forward a scheme to solve the saturation problem of 500 kV power grid by constructing UHV AC power grid, and demonstrates the rationality and security of the scheme. Reference [5] further discusses some controversial issues in the field of UHV transmission in China, and draws a conclusion that the development and application of UHV transmission and transformation technology in China must be strengthened. However, literature [6] thinks that 500 kV power grid can solve the saturation problem of 500 kV power grid technically by improving the regional backbone grid and other measures on the basis of the existing grid structure. And this case has more economic advantages. Above all, there are two main development directions in the next stage of 500kV power grid. One is to upgrade to high voltage level. The other is to maintain the original voltage level to optimize and strengthen. At present, the two directions of development are often discussed from their respective perspectives. The research content is mostly focused on the analysis of specific technical aspects. While the research on the essential law of power grid development is less.

For different areas of the grid, the grid structures are different. These grid all are large-scale artificial network which belongs to the category of complex networks. They are in line with the general law of complex networks [7]. With the expansion of the grid scale, it will generally evolve into a small world network. Documents [8-10] confirm this trend and point out that some power grids in China, the western United States, Italy and Brazil have developed into small-world networks. References [11] and [12] considered the characteristics of the small-world network of the power grid based on the small-world model. The above studies confirm the small-world nature of the grid. But the above studies are mostly limited to the performance analysis of the specific state of the grid. While, the small-world dynamic evolution of the grid is seldom studied.

In view of the above problems, this paper first establishes the evolution model of small-world network. Then, the two main directions of the evolution of small-world network are compared and
analyzed. The choice of evolution direction depends on the internal characteristics and external conditions of the network at that time. Based on these, the development model of power grid is established using the adaptive index to analyze the internal characteristics and external conditions of the grid. The development direction of the grid is determined. Finally, the development of the grid is simulated in this paper. The simulation results of power grid development show the effectiveness of the model and the feasibility of the simulation method.

Small World Model

In 1998, Watts and Strogatz first proposed the small world network model [13] in Nature magazine. Compared with stochastic networks, small-world networks have similar characteristic path lengths, but have much larger clustering coefficients, i.e. they satisfy both expressions (1) and (2).

\[
L \geq L_{\text{random}} \quad (1)
\]

\[
C >> C_{\text{random}} \quad (2)
\]

where, \( L \) and \( C \) represent the characteristic path length and clustering coefficient of small-world network respectively, and \( L_{\text{random}} \) and \( C_{\text{random}} \) represent the characteristic path length and clustering coefficient of random network with the same number of nodes and the same degree of averaging as small-world network respectively.

With the popularization of the research, it has been found that small-world networks widely exist in the biological field such as neural system, gene network, social field of scientific collaboration network, interpersonal network. Small-world networks also widely exist in artificial system such as world aviation network, the Internet, power grid and so on. In order to establish a more accurate specific network model in the application process, the small-world network has also been modified and supplemented accordingly [14]. This paper will optimize the evolution principles of small world networks, and establish a more realistic grid development model.

Basic Principles of Evolution. In the process of generating small world networks from regular networks, Watts and Strogatz define that the edges connecting two nodes are unique and non-repetitive. In the actual development of power grid, the connection of important nodes is usually more than the connection of general nodes. The definition of Watts and Strogatz will not distinguish the different parts of the grid. Based on the above considerations, the basic principle of allowing multiple edge requirements between two nodes will be adopted in the evolution of regular networks to generate small-world networks, as shown in the following figure. This principle reflects the different demand of different parts of the power grid. And it is more in line with the actual development law of the power grid.
Evolutionary Pattern. There are two evolutionary patterns for the need for multiple edges between two nodes in evolution, as shown in the following figure:

1) One evolutionary mode is to add new edges on existing networks to enhance.
2) The other way of evolution is to replace the original multiple edges with higher level edges.

The evolution modes of these two small world networks correspond to the two development directions of the actual power grid.

Result Analysis. For a network with 1000 nodes and an average of 10 edges per node, the characteristic path length and clustering coefficients of the two evolutionary patterns are calculated by averaging 20 stochastic processes. The results are compared with the corresponding stochastic networks and the small-world networks defined by Watts and Strogatz. The results are shown in the following table (Table 1).
The enlightenment of the two basic laws of the evolution of the small world to the power grid development lies in: the direction of power grid development can be different, but the development goals and requirements must be met. It needs to consider the network characteristics, external environment, as well as the timing of construction and other factors to determine the specific direction of power grid development.

**Transmission Network Development Model**

**Analysis of Influencing Factors.** The purpose of power grid construction is to meet the needs of national economic and social development. Power grid development is restricted by security, economy, environment, technology and other factors. From the view of power grid, these factors can be divided into external and internal factors [15].

External factors affecting the development mode of power grid are numerous and complex, including load demand, power supply, national economy, social development, energy resources, technological progress and many other aspects. These factors affect the development mode of power grid by affecting the whole society's electricity consumption, the maximum load or the installed capacity of power supply and the construction of power grid structure.

The internal factors of the power grid directly affect the development mode of the power grid. In the process of power grid development planning, power grid security generally considers system stability, "N-1" and short-circuit current. To a certain extent, the reasonable structure and proper scale of the power grid are the necessary conditions to ensure the safe development of the power grid.

**Adaptability Index.** Adaptability index is recently applied to the evaluation index of power system. Compared with the traditional indicators, the advantage of adaptive indicators is that it reflects the interaction between the power system and the external environment more comprehensively. When establishing the evaluation index system of power grid development adaptability, we should not only consider the actual situation of power system operation, but also consider the difficulty of data acquisition, feasibility and the actual situation of data post-processing and calculation.

**Case Studying**

A regional power grid from 2000 nodes to 3000 nodes is set up. There are two development modes: one is to expand the scale on the basis of maintaining the original voltage level of the grid; the other is to expand the scale based on the use of higher voltage level. The adaptability of the target grid is evaluated.

The development of power grid is restricted by internal and external factors, and the constraints on each index are shown in the following table (Table 2).

<table>
<thead>
<tr>
<th>Constraint condition</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-circuit current</td>
<td>&lt; 2.5%</td>
<td>&lt; 2.3%</td>
<td>&lt; 2.3%</td>
</tr>
<tr>
<td>High risk nodes</td>
<td>&lt; 0.5%</td>
<td>&lt; 0.5%</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Cost</td>
<td>&lt; 5050</td>
<td>&lt; 5050</td>
<td>&lt; 5050</td>
</tr>
<tr>
<td>Transformation rate</td>
<td>&lt; 1.1%</td>
<td>&lt; 1.1%</td>
<td>&lt; 1.0%</td>
</tr>
<tr>
<td>Coordination rate</td>
<td>&lt; 5.5%</td>
<td>&lt; 5.5%</td>
<td>&lt; 5.0%</td>
</tr>
</tbody>
</table>
The results of this example can be used for reference in the development of 500kV power grid in China. At present, the problems of short-circuit current exceeding the standard have appeared in the fast-developing areas of 500 kV power grid in China. It is necessary to determine the future development direction of the power grid in time. If the time of upgrading and transforming the power grid is missed, the similar work will face many unfavorable factors, such as coordination difficulties, construction blackouts and so on, which will cost more people strength and financial resources.

Summary

The evolution rule of small world network is an abstract summary of the development law of large-scale artificial networks such as transmission network. In this paper, two basic modes of small-world network evolution are proposed, which correspond to two directions of power grid development more accurately. Based on the evolution law of small-world network and the adaptability index of power grid development, this paper establishes a transmission network development model. It can simulate and evaluate the development process of power grid. The model will be helpful to solve the disputes of power grid development mode. The example analysis shows the effectiveness of the model.

References

