Spatial-temporal propagation characteristics of large power grid interlocking faults based on complex network theory

Jiahao Wu

ABSTRACT

In recent years, the cross-regional interconnection of power grid is gradually strengthened, and this large-scale network interconnection ensures electricity

But it increases the complexity of the dynamic process of the power grid, and small local faults may occur in chain

The response was extended to the entire power grid. Traditional linkage fault analysis methods usually use differential equations, and their solving process is very simple

In some defects, complex network theory opens up new ideas and methods for the study of grid chain faults.

This paper introduces the basic concepts, parameters and models of complex networks, and analyzes the characteristics and modes of each parameter

The characteristics of each type. The degree is taken as the index to identify the vulnerability of the line, and two methods are used: random attack and deliberate destruction

In this paper, a new load loss ratio index is established to evaluate the impact of faults on the power grid and analyze the linkage

Temporal and spatial characteristics of fault propagation.

A 1029 node system of Zhejiang Provincial Power grid and a 197 node system of Northwest Power Grid were built by matpower

The validity of the study is guaranteed. Through the analysis, the random attack pattern is obtained for the power grid when the attack proportion is low

The extent of the impact is small, while the mode of deliberately destroying several nodes and lines is adopted, although the proportion of attacks is relatively high

Low, the power grid could still suffer significant impacts. This shows that the high-degree nodes and the high-degree lines are on the grid

The safe and stable operation plays an important role.

Keywords: Complex network,Power system, Interlocking failure,Structural vulnerability

1. INTRODUCTION

1.1 Background and significance of the research

Due to the imbalance of regional resource distribution and the continuous improvement of science and technology development, in order to achieve long-distance power transmission,

The power generation cost is reduced and the interconnecting grid structure of power system is established. Its influence mainly includes: first, demand

With the continuous growth of the level, the scale of the power network is gradually expanded, and the topology structure of the power grid is increasingly complex

Grid interconnection can reduce the reserve capacity of the regional grid and reduce the system operation cost, thus ensuring the regional

The power grid can support each other in the event of emergency failure, thus improving the reliability of the power system. Second, many

Potential destabilizing factors such as device aging, extreme weather, and protection misoperation events can also contribute to grid operation

As soon as one point in the system is disturbed, a chain reaction of failures can occur

Can spread to the whole network , causing huge losses. For example, in July 1996, the electric grid of Idaho, USA

The system broke down into five isolated islands, affecting more than 200 people in parts of Canada and Mexico

The lives of 10,000 people were seriously affected. In China, Hainan blackout in 2005 and Central China Power Grid blackout in 2006.

It is of great significance to identify and protect the vulnerable lines in power system to prevent the occurrence of chain faults.

In order to effectively prevent the frequent occurrence of large power outages, relevant scholars at home and abroad have done a lot of points on the chain fault

Analysis. For a long time, the traditional fault analysis method of power system is based on reductionism, using mathematical model to analyze the fault

The fault behavior of the barrier device is analyzed numerically by solving the differential equation function of the system . By many external things

Under the dual influence of factors variation (high temperature, rain and snow, lightning, etc.) and a large number of internal electrical factors (line load rate),

The load of the whole intelligent interconnected power system is analyzed synthetically only by establishing a set of high-order equation models

The various dynamic characteristics of the change is quite difficult. Complex network theory formulates a unified model for such complex systems

It is helpful to analyze the macro state of the system and to study the internal characteristics and development of the power system by using complex network theory

Change law, with rationality and feasibility.

1.2.1 Research status

At present, there are two kinds of research on grid chain fault. One is based on reductionism, by building elements

Equation model combined with higher order differential equations. Another approach is complexity science, complexity

It is easy to study the mechanism of grid chain failure systematically from the perspective of grid as a whole scientifically. Reductionism is more focused on

The behavior relationship and dynamic characteristics of the system components have been evolved in the long run of complex power grid

It is often difficult to fully elucidate the behavior of the system in the study of the rapid transmission of interlocking fault signals

System and dynamic characteristics. This paper studies complex power grid from a new perspective of complex system science analysis

The linkage of failures can be directly related to complex systems, statistical physical methods and system risk analysis and prediction

In this paper, the power grid fault is studied comprehensively from top to bottom. Analyze the occurrence of local chain faults

Relationship between the mechanism of, and the global characteristics of the system . Therefore, in recent years, from the perspective of scientific theory of system complexity

Some important developments have also been made in the research of the linkage fault mechanism of smart grid.

1.2.2 Development trend of domestic and foreign research

As far as China is concerned, the related research on power system interlocking fault mechanism is only in progress

At the beginning of the study. However, foreign scholars have used pattern search method to simulate and analyze the interlocking faults of power system

Mechanism, the application of complex theory to study the power system chain fault has also made a preliminary attempt.

1.2.3 Analysis method of grid chain fault

At present, the fault analysis and treatment methods proposed by scientists can be basically divided into three categories:

The method of pattern search, the method of computer modeling and processing based on the theory model of complex system, the method based on complex network

Computer modeling method of theoretical model .

1. Pattern search method

Mode search method by simulating the occurrence of the initial fault, secondary protection equipment such as circuit breaker automatically jump open,

The process of automatically finding a development path for faults. It mainly uses analytical method and stochastic simulation to find grid chain fault

The failure mode of. The former takes N-1(or N-K) as the criterion, which is simple and clear in concept and fast in operation, but difficult

Meet the actual operation requirements; Stochastic simulation is based on the Monte Carlo probability sampling algorithm   to search all initial conditions

Under the permutation and combination of running state and all possible random faults, the computational load is large and the operation time is too long. guide

In this simulation method, only the probability expectation value is used to represent the random risk index parameter, which is difficult to accurately understand and be realistic

It is not suitable for large - scale online test application because of the long time consuming of international calculation.

2. Model method based on complex system theory

Complex systems theory often combines systems holism with systems reductionism

The important representative works are "dissipative Structure Theory", "Chaos Theory", "coordination theory" and "self-organizing criticality theory"

On "and so on. In 1987, Buck et al. in the United States formally proposed a dynamic concept of self-organized critical states

In order to explain the dynamical behavior of the system in the space-time dissipative dynamical system, it is in a self-organizing criticality

For complex systems under state, there is always a power-law relationship between the accident scale and the interference frequency

A level of disruption could quickly set off a massive chain reaction that could lead to a systemic catastrophe. Therefore, to use

Self-organized criticality model and so on to simulate and explain the electricity caused by interlocking grid failures and other phenomena

Sudden large-scale power outages within the force system will become more and more common. On the basis of these studies, this paper puts forward

It includes several mainstream research models as follows: OPA(ORNL-Pserc-Alaska) model ,

CASCADE(Cascade fault) model , implicit fault model , branching process model , AC-based most

OPF model , synergetic prediction model, etc. OPA model research is a self-organizing study

Under the guidance of bound theory and based on the analysis and calculation of DC power flow model, various kinds of current time are studied

Organizational evolution mechanism and organizational behavior characteristic model in complex power system with inter-scale variation; CASCADE

The model imposes an arbitrary initial load on a random number of identical lines and imposes an initial disturbance on one or more lines

On the line, according to the set load distribution principle, the power flow is redistributed on the line without fault

Should be used to explain the possibility of grid equipment itself under different load initial failure conditions and under disturbance conditions

The manifestation form of the chain fault, the law of fault behavior, and the scale of the fault outage and the accident

The probability of occurrence and other factors, but the model makes a lot of simplification of the network structure,

The dynamic redistribution of power flow under an initial fault is studied directly, which does not reflect the change of equipment on the power side.

The branching process model is a simple numerical approximation of the CASCADE model. These models are very useful for power systems

A large number of simplifications and approximations have been made to the topology structure, which only focuses on the grid load that describes and affects the dynamic characteristics of the grid

The interplay between change and network chain failure is therefore limited.

3. Model method based on complex network theory

Complex network theory is derived from graph theory, which abstracts power grid into a grid model from the perspective of grid structure

Investigate its bearing capacity under various failure states. The grid is abstracted as a group of m nodes and K edges

Then by studying the network topology model of the whole power grid system, the dynamic line of the power grid is predicted

For and structural change, the essence is to study the fragility of macro structure. Based on complex network theory, many kinds are proposed

Grid chain fault models, representative of which are: small-world model, Watts structural model , phase

Septum centrality model, Motter and Lai model , effective performance model of Crucitti and Latora

And so on.

1.3 Main work of this paper

On the basis of in-depth research on the methods of analyzing the chain fault at home and abroad, this topic is based on the complex network theory

The main contents of the power system chain fault research are as follows:

1. Search and discuss the current research status and main research methods of power system interlocking faults, and analyze the ratio

On the basis of its advantages and disadvantages, the research method of power network model based on complex network theory is selected.

2. This paper briefly introduces the historical evolution of two basic models in complex networks: regular network and random network

Cheng, analyzes the development of scale-free networks and the phenomenon and characteristics of small worlds. The common use in complex networks is introduced in detail

The evaluation parameters of: degree and degree distribution, average path length and clustering coefficient index.

3. On the basis of considering the structure and parameters of the power system itself, the degree is selected as the identification of system fragility

Indicators of weak links, set up a 1029 node system of Zhejiang Province network and a 197 node system of Northwest power grid to power

Network linkage fault simulation, and define the network load loss ratio index, by comparing the negative before and after the fault

The change of transmission capacity after network failure is measured by the percentage of load decline, and the fault imitation is carried out according to the two fault modes

True, confirmed the correctness of the method.

4. Research on power system chain faults based on complex network theory, and analyze according to fault simulation results

Temporal and spatial characteristics of fault propagation.

2.AN OVERVIEW OF COMPLEX NETWORK THEORY

2.1 The development of complex network theory

The development of network benefits from graph theory and topology theory. Graph theory began with Euler's Goni in 1736

The Spartan Seven Bridges problem, by transforming the problem into a mathematical problem, abstracts the land into points, abstracts the seven Bridges

For edge, innovatively created a new branch of mathematics - graph theory. In the years that followed, graph theory developed

It's always stuck. It was not until 1960 that ER stochastic graph theory was proposed, which provided the basis for constructing networks

A new way of thinking. In this theory, whether or not two nodes are connected by an edge is determined by a probability,

The resulting network is called a random network. Then, to further verify that human society has complex network characteristics

Sex. Stanley Milgram, a social psychologist at Harvard University in the United States, conducted the six degrees of separation experiment. (think

The average distance between any two people on Earth is 6), and scientists have since done a lot of small-world experiments,

For example, "Kevin Bacon Game" and Watts' Small World experiment are used to verify the correctness of the six-degree separation inference.

in 1999, Barabasi and his PhD student Albert's article Emergence of Scaling in SCI

Random Networks proposes a scale-free network model (degree distribution is power-law distribution) to characterize the actual network

The ubiquitous phenomenon of "the rich get richer" opened a new era of complex network research .

2.2 Complex network model

2.2.1 Regular network model

Regular network model is the simplest complex network model, which can be divided into global coupled network model,

Nearest neighbor coupling network model, star network model. In a globally coupled network, any two points exist between them

The directly connected edges have certain clustering and small-world characteristics. In a nearest neighbor coupling network, each section

Points are only connected to neighboring nodes, and the model has periodic boundary conditions. As the name suggests, a star network has all the points

The connection is at the central point, there is no connection between that and this. Figure 2-1 shows common regular networks.
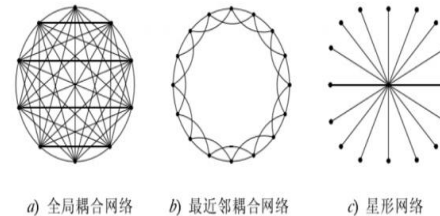

a) 全局耦合网络   b) 最近邻耦合网络   c) 星形网络

Figure 2-1 Regular network

2.2.2 Random network model

In the middle of the 20th century, the famous Hungarian mathematician Erdos and Renyo proposed the stochastic network model and established

Stochastic network theory . ER random graph is composed of N nodes, where any two points are randomly connected with probability p,

All points are equal, that is, from all possible $N(N-1)/2$ edges in the network with some probability p

The random network has the characteristics of low clustering coefficient and short average distance

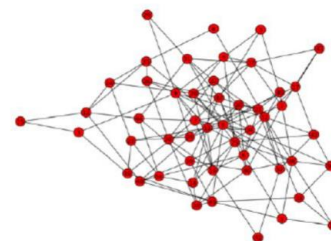Sex. Figure 2-2 shows a random network with 50 nodes.

Figure 2-2 Random network

2.2.3 Scale-free network model

In real life, the distribution of connectivity degree of many networks has the property of power law, and this power exponential form is related to the network

Is independent of the magnitude of. In 1999, Barabasi and Albert published a paper in the journal Science, proposing that

Scale-free network model, which emphasizes for the first time that network models (also real systems) have been ignored in the past

Two important characteristics of growth and merit. People call this kind of network model BA scale-free network model, which is

It is another milestone in the research of complex network theory.

Growth characteristics and preferred connection characteristics are two key factors in the evolution of scale-free network models. Growth characteristics

With the increase of time, there will be a lot of new nodes to be added to the entire network environment, and

Gradually connect to some existing nodes in the original network system. With the development of economy, the society uses electricity

With increasing demand, new traditional power plants, new energy power plants and substations are being added to the grid. In the transportation network

New tracks or Bridges are constantly being laid and built to add to the transportation network. In the information society is constantly universal

And today, on the Internet, new sites are constantly being created. The property of a preferred connection is that in a network

The higher the degree of the node, the greater the chance of connecting with the newly added node. In other words, the more the newly generated node

It is easy to connect to nodes with high degree among existing nodes. In the process of generating a scale-free network, must have

Alternate growth characteristics and preferential characteristics. At present, there are three main methods to study the degree distribution of scale-free networks: connection

Continuous field theory, master equation method and rate equation method.

2.2.4 Small-world network model

In the real world, there are many complex systems, like biological networks, social networks, and the Internet, that have one

These complex systems are defined by regularity but not regularity, by some randomness but not complete randomness

Features are somewhere in between. Combining the nature of the two networks, small world network emerged as The Times required

It was proposed by Watts and Strogatz in 1998 , and the connection between nodes is tight and the network aggregation is high

Unique characteristics of small world networks. The small world model and theory has epoch-making significance and complexity

The research of network theory has entered the stage of high development.

The small-world network model can be constructed through the following methods: taking the regular network model as the research and analysis basis,

Suppose the network has n nodes and k branches, and each node is randomly connected to its adjacent non with probability p

On repeated nodes, one end of the fixed edge is not moved, and the other endpoint is connected from a random node in the network.

No more than one edge is connected between any two nodes, and nodes are not allowed to connect with themselves, thus constructing small worlds

Network model. The characteristic path length of small-world network is smaller and the clustering coefficient is larger. As the connection probability p changes from 0 to 1, the random reconnection construction process of the model is shown in Figure 2-4. Where, p is 0 is equivalent to gauge

Then, when p is 1, the network is equivalent to a random network. The characteristics of small world network and regular network, random network
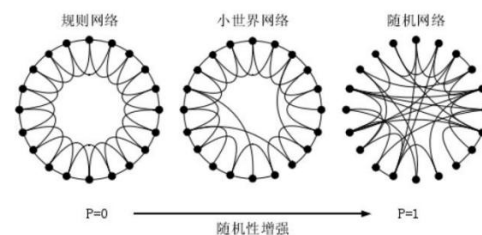
Figure 2-3shows an example

Figure 2-4 Small-world Network

2.3 Statistical characteristics of complex networks

2.3.1 Node Degree and Degree Distribution

One of the simplest and most important features in complex networks is the degree of nodes. The degree of node i ki usually Is defined as the total number of other nodes to which it is connected, namely:

$$k_i = \sum_j a_{ij}$$

Some network researchers believe that node degree can also indirectly represent the node in a network architecture

The higher the degree value of a node, the more critical the node is in the network framework. network

The arithmetic mean of all node degrees in is the weighted average degree of the whole network, and is denoted by. by

The average degree of the network composed of n nodes and E edges is:

$$\bar{k} = \frac{1}{n}\sum_i k_i = \frac{2E}{n}$$

The degree of nodes in the network is quite different. In order to well reflect the distribution characteristics of node degree, define 1

The distribution function P (k) is used to represent the distribution of degree in nodes, that is, nodes with degree k are randomly selected

Or the proportion of nodes with degree k in the network. According to the existing research results show that the completely random net

The distribution of the degree is Poisson distribution, while the distribution of the degree of scale-free network conforms to the power law property.

2.3.2 Shortest Path and Average shortest path Length

The shortest path is the longest distance among all possible paths from a specified start point in the network to the destination end point

A short path. The shortest electrical path is the path with the shortest electrical distance. The shortest path is calculated as follows

There are many kinds, such as Dijkstra algorithm, Floyd algorithm and Johnson algorithm. dij Is the number of edges in the shortest path connecting two nodes i and j in the network. According to the

define dij ≥1 and dij =1 indicates that node i is directly connected to node j.

The maximum distance between any pair of nodes in the network is defined as the network diameter D. Pairs all nodes in the network

The average shortest distance is equal to the average shortest path length L, also known as the characteristic path length, namely:

$$L = \frac{1}{N\ ((N-1)}\sum_{i \neq j} d_{ij}$$

The average shortest path length reflects the depth of information transmission between any two nodes. The smaller L is, the information is in the network

The deeper the network transmission, and from the global perspective of the network to analyze the degree of interconnection between nodes, helps

Solve the structural properties of the network. Recent research has shown that although the number of nodes in most real networks is very large,

However, the average shortest path length is very small, showing strong small-world characteristics.

2.3.3 Clustering coefficient

In many networks, if there is A connection between A and B, between B and D

If there is A connection, then there is likely to be a connection between nodes A and D, and this property is called a network

The clustering coefficient C is defined as an index to measure the degree of network connection clustering.

2.3.4 betweenness

At the end of the 20th century, Freeman first proposed the concept of intermediates. With the further development of research work, intermediates

The number is divided into node interface and edge interface. The interface describes the effect and influence of nodes or edges on the global information flow of the network

Noise, which can be a criterion of the importance of a node or edge in the network, has great practical value. You can pass

The intermediate index evaluates the importance of various resources, technologies and other information in their corresponding production relations, so as to

Effectively monitor and protect these key objects.

The number of shortest paths passing through this node in all shortest paths in the network is defined as node medium

$$B_i = \sum_{j \neq k} \frac{d_i(j,k)}{d(j,k)}$$

3 ANALYSIS METHOD OF POWER SYSTEM CHAIN FAULT

3.1 Power system complexity

A power system is a typical complex network connected by thousands of nodes, and each section

The connection relationship between points presents a high degree of complexity. The complexity of power system can be summarized as the following aspects

Surface.

1. Large scale

A power system consists of a large number of generation, transmission, distribution, transformation, and electrical components, which pass through

The network is interconnected and spread over a vast area, and the number of nodes is huge tens of thousands.

2. Complexity of connection structure

Power plants, substations, transmission lines, distribution systems and loads in the power system have their own differences

And these components have different voltage levels. They are not only structurally interconnected, but also

They are interconnected in the way of currents, information flows.

The power system often has different faults, which can have different effects on the power system,

The power system has certain planning property but also exhibits obvious self-organized criticality. Every failure of the power system

Obstacles are likely to cause large-scale power outages, the load in the grid changes in real time, coupled with unified scheduling

So the power system is a dynamic system.

3. Failure unpredictability

Power system failures can be affected by many factors, including earthquakes, thunderstorms, misoperations, and aging equipment.

These factors are likely to cause large-scale power outages in a very short period of time, and these factors have not

Predictive.

4. Complexity of spatio-temporal evolution of network

With the development of the economy, the power grid is constantly being planned, built, transformed, etc., and every process is

Can be affected by unpredictable factors, which not only promote the formation and development of the grid, but also cause electricity

Spatial and temporal evolution complexity of the net.

3.2 Grid chain fault analysis method based on complex network theory

3.2.1 Basic mechanism of grid chain fault

The basic mechanism of grid chain fault is that when one or a few components in the grid are overloaded

Or after a fault, the relay protection device acts to remove the faulty element, and the power flow will be unbalanced and transferred to other non-faulty components

If other components cannot bear the added load, it will cause overloading again.

The relay protection continues to act tripping, so that there will be a knock-on effect if the initial load of the component is large

A large number of nodes or even the entire network may collapse due to the failure.

3.2.2 Topology principles of the power grid

The topological characteristic parameters of the network are the basis for the study of complex networks. The complex network theory is used to study the power grid.

Firstly, topology modeling of power grid is required. The topology principle can be simply described as: the generator, transformer and transformer

Power stations are abstracted as nodes, and high-voltage transmission lines above 110KV are abstracted as edges. The total number of grid nodes is n,

The number of lines is k.

3.2.3 Component removal method and fault index

1. Component removal method

The methods of removing network elements can be divided into random attack and sabotage. The value can be specified by attack object

It is divided into removing nodes and removing edges. Assuming that the proportion of the number of removed nodes to the total number of nodes in the network is P, then

The vulnerability of power grid can be studied by the relationship between network failure index and. Different element removal modes are used

The purpose of this paper is to simulate all kinds of faults that may occur in the actual network, so as to study the network resistance from different angles

The ability of obstacles. The two component removal modes used in this paper are as follows:

Random attack: Randomly select n lines from the network and remove them.

Sabotage: The purposeful removal of the n lines with the highest degree in the network.

The results show that random attacks have less impact on small world networks and scale-free networks, while the random attacks have less impact

The damage will have a serious impact. For regular networks and random networks, random attacks and sabotage

Similar effects.

2. Fault indicators

The load loss ratio is used as the fault index of this simulation to evaluate the vulnerability of the network, and its formula is determined

Just as

$$\overline{P_{loss}} = \frac{\sum_{i=1}^{n} P_{lossi}}{n}$$

The number of remaining subcliques was used Cleft Represents the grid split into several regions after restoration of stability, and the final set number of solitary points I last Represents the equilibrium of the tidal current after the generation of several solitary points, the maximum residual subcluster Cmax When the grid is stable again Ploss = 50% Ploss <s:1> 50% Ploss = (initial negative initial load – negative maximum final load)

Divided the largest area, integrated three indicators to evaluate the power grid after the attack of the fragmentation situation and the degree of collectivization.

The iteration number of power flow calculation is taken as the index to evaluate the frequency and time of the occurrence of chain faults

The more iterations, the longer the failure time.

4 IS AN EXAMPLE ANALYSIS

4.1 Analysis Process

(1) Input the parameters of each load node, generator node and line into the matrix, and set the node type,

Node and line number, line capacity, and initial power flow.

(2) Calculate the degree of each node according to the degree definition, and statistically arrange the degree of nodes from high to low

As a form.

(3) Select the attack mode of the line. If sabotage is used, the n nodes with the highest node degree value will be selected

The k lines connected to the node are removed, so that the nodes at both ends of the k lines fail, that is, the node load is set to 0.

If random attack is used, the same number of k lines are randomly selected to cut off the two ends of the k lines

Points fail and the load of the remaining edge is recalculated.

(4) According to the initial fault, determine whether there is an over-limiting branch, and determine whether there is an island and a solitary point. If there is

If the branch exceeds the limit, the branch with the most serious overload is disconnected and recorded as a first-level linkage; If the fault of this level is isolated

Island, the island power balance; If this level of fault forms a solitary point, change the node type to solitary

If the node does not have a generator, set its load to 0.

If the node has a generator, it is an autonomous node

Point so that its electricity production equals the local load. Return to step (4) and loop until all edges are negative

The charge value is less than its capacity value. If there is no off-limit branch, the load loss can be calculated according to formula (1-1)

The proportion.

(5) Record each simulation result, and draw a curve of load loss ratio with attack line ratio.
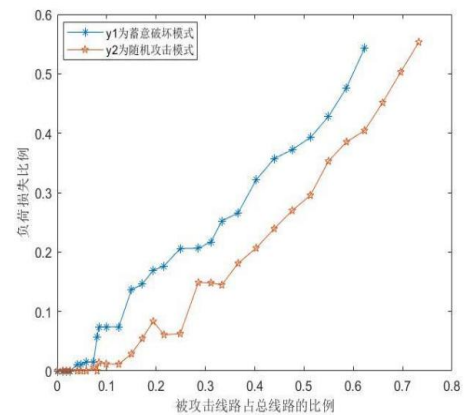

Figure 4-1Curve of load loss ratio of 197-node system in Northwest Power grid with proportion of attacked lines
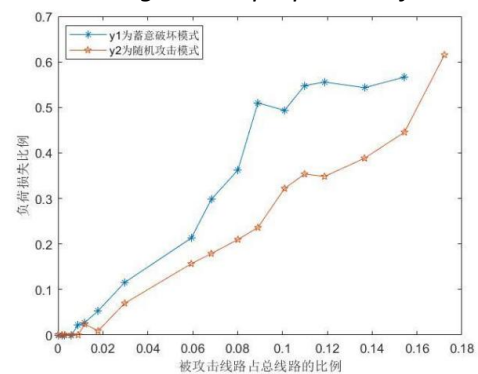

Figure 4-2 Change curve of load loss ratio of 1029 node system in Zhejiang power grid with proportion of attacked lines

As the proportion of the attack line to the total line increases, the load of the two grids

The proportion of losses showed a positive correlation trend. Compared with the 1029 nodes of Zhejiang Power grid, Northwest Power

The scale of network 197 node system is small and the degree of each node is similar, which makes it difficult to reflect the importance of individual nodes and lines

And under the two attack modes of random attack and deliberate destruction, the fault graph lines are close to each other and are attacked

After the failure of the situation is not much different. However, the scale of Zhejiang power grid 1029 node system is large, and the degree between nodes is different

It can clearly distinguish that some nodes are in the central position in the whole power grid and have high importance

Sex, in the sabotage mode, showed a far greater degree of failure than in the random attack mode.
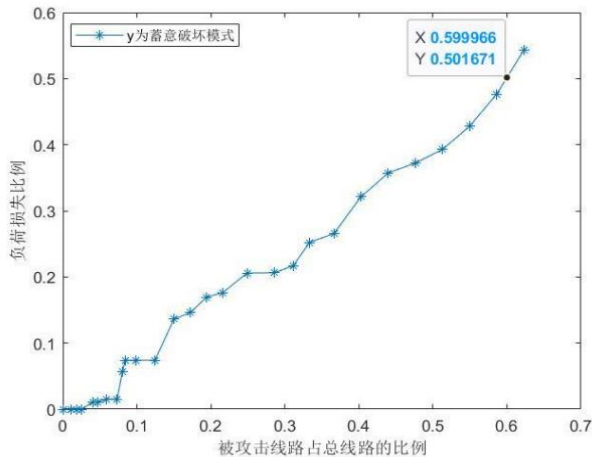

Figure 4-3 Load exceeding-limit boundary diagram of the 197-node system in the sabotage mode of Northwest Power Grid
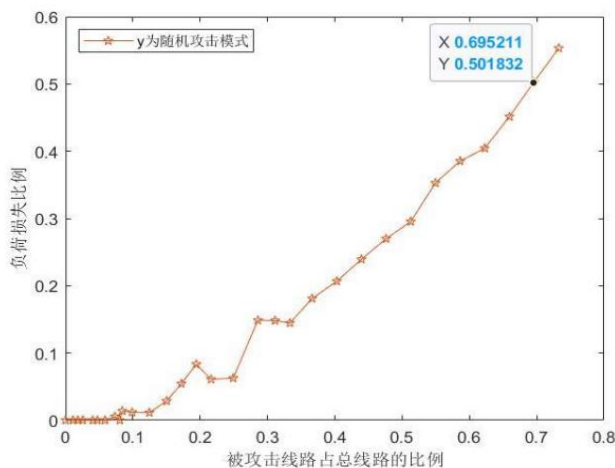

Figure 4-4 Load exceeding-limit boundary diagram of Northwest Power Grid under random attack mode of 197-node system
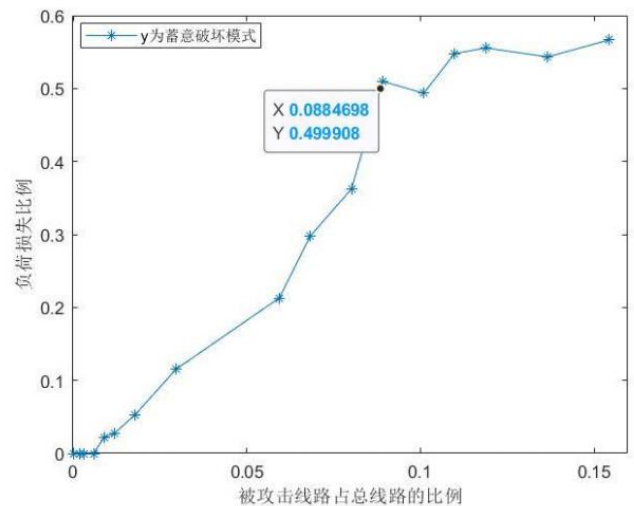
In either sabotage or random attack mode, Northwest Grid 197

The load loss ratio of node system increases smoothly with the attack line ratio, and there is no obvious spike or drop zone

Segment. When the proportion of attacked lines is less than 10% of the number of bus routes, the normal operation load can still account for the initial load

When the number of attacked lines exceeds 60% of the total number of lines, the system faces a crash wind

Risks. Using sabotage mode in which the attack ratio reaches about 60% of the line ratio, the system crashes while using with

In machine attack mode, the system will crash only when the attack ratio reaches nearly 70%, indicating that although the inter-node degree of small grid

There is little difference in the number, but damaging the lines connected by nodes with relatively high degree will still speed up the collapse of the power grid. points

The analysis shows that the distribution of each node in the 197-node system of Northwest Power grid is sparse, the node aggregation is not strong, and the network is mutual

The connection degree is not deep. The line connected to a single node has limited impact on other nodes and lines

So there is no significant ripple effect when the percentage of attacks is low and when the percentage of attacks is high

When the system uncolumns.

Figure 4-5 Load exceeding-limit boundary diagram of Zhejiang Power Grid 1029 node system in intentional destruction mode
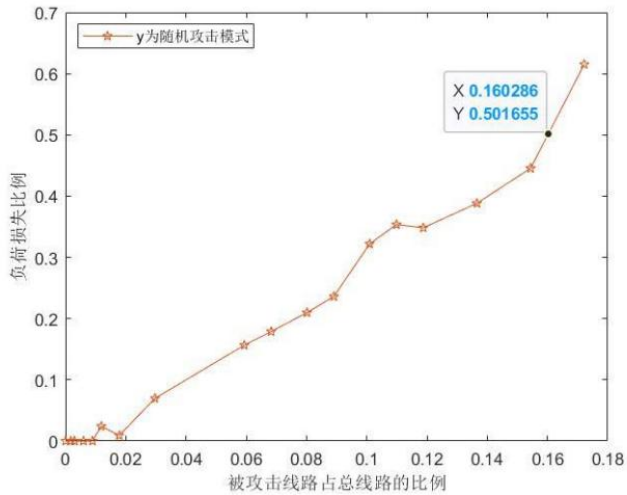
Figure 4-6 Load exceeding-limit boundary diagram of Zhejiang Power Grid 1029 node system under random attack mode

Different from the 197-node system of Northwest Power grid, Zhejiang power grid has 1029 nodes

In both attack modes, the system has an obvious fault surge section, which occurs in the sabotage mode

The time of occurrence predates the random attack mode. In random attack mode, when the proportion of attacked lines reaches the total line

At 10% of the number, the remaining normal operating load can reach about 75% of the initial load, while in the sabotage mode

At this time, the system is facing the risk of collapse, which indicates that the lines connected to the high-degree nodes in the large power grid system show

The strong correlation effect aggravates the breadth and depth of the chain fault. Compared with the northwest small power grid system, two modes

In the following equation, the system has collapsed before the attack ratio reaches 18%, indicating the connection of each node in the large power grid system

The more compact the network, the higher the degree of agglomeration, the attack of a few important nodes and lines will be to the whole system

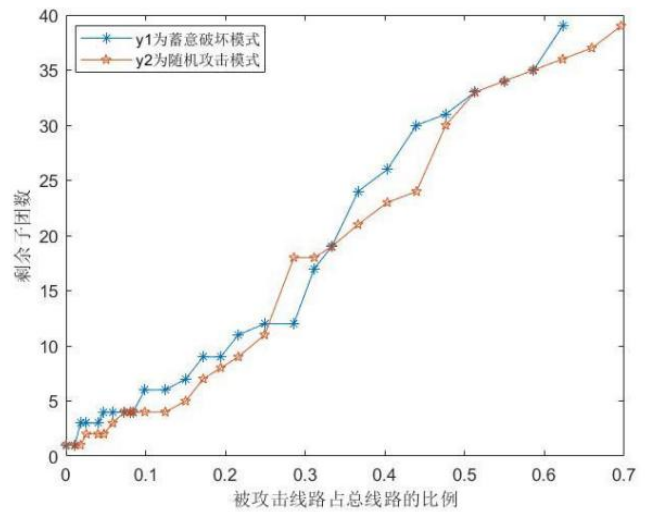Unification has a serious impact on the whole body

Figure 4-7 Curve of the number of remaining subcliques in the 197-node system of Northwest Power Grid as a function of the proportion of attacked lines Conclusions
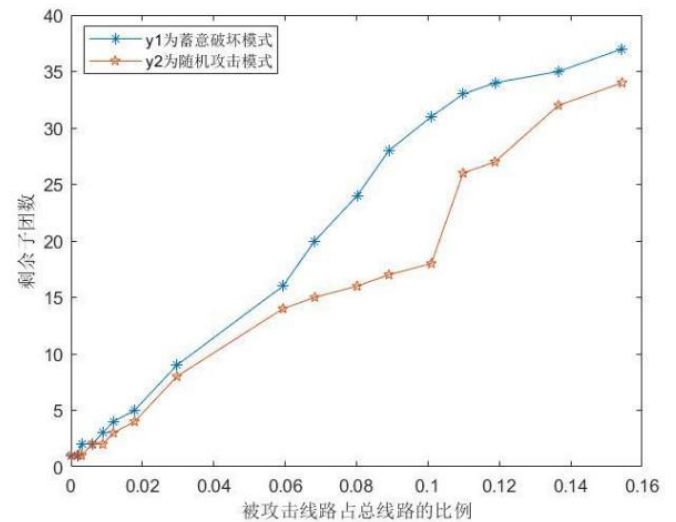

Figure 4-8 Curve of the number of remaining subcliques of 1029-node system in Zhejiang Power grid as a function of the proportion of attacked lines
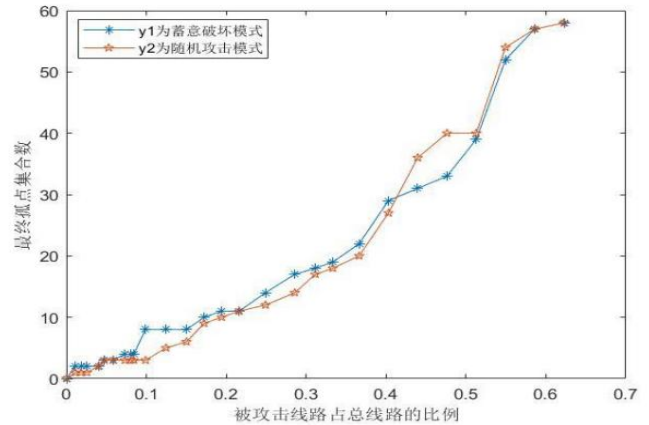

Figure 4-9 Curve of the final number of isolated points set in the 197-node system of Northwest Power Grid as a function of the proportion of attacked lines
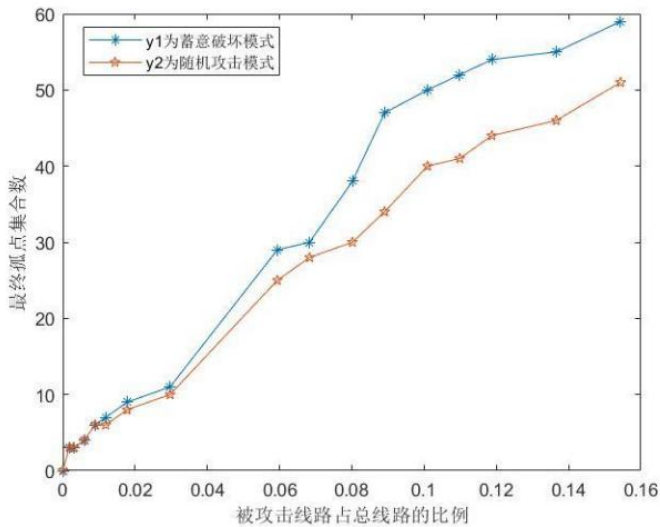
Figure 4-10 Change curve of the number of final solitary points set in 1029-node system of Zhejiang power grid as a function of the proportion of attacked lines
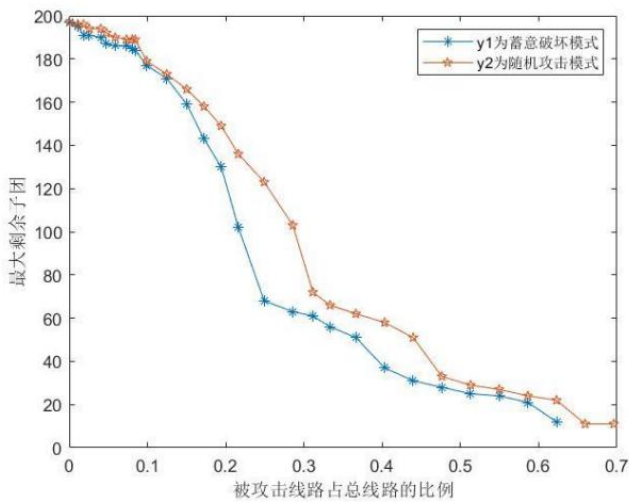

Figure 4-11 Curve of the maximum remaining subclique of the 197-node system in Northwest Power Grid with the proportion of attacked lines
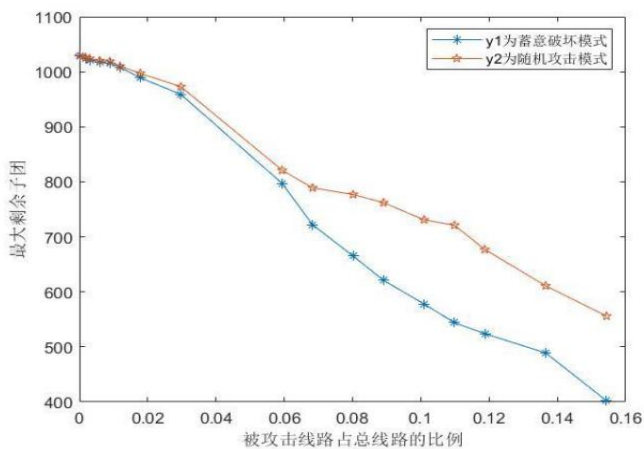

Figure 4-12 Curve of maximum remaining subclique of 1029-node system in Zhejiang Power grid with proportion of attacked lines

Two systems on two attacks

The number of remaining subcliques and the final set of solitary points in the attack mode are both positive to the proportion of the attacked line in the total line

While the maximum remaining subclique is negatively correlated with the proportion of attacked lines. Both the number of remaining subcliques and the final solitary

The number of points set is still the maximum residual subcliques, and the curve of 197 node system in Northwest Power grid is 10 in both attack modes

Points close, in the sabotage mode of the system block split and random attack mode gap is not big, the reason

It is that the degree of collectivization of the system itself is weak, but it can still preliminarily infer the line connected by several nodes of the attack height

Increase the power grid fragmentation. In Zhejiang power grid 1029 node system, it can be seen that the deliberate attack mode on the system

When the attack ratio exceeds 5%, the interval between the two curves is significantly separated.

When the attack ratio reaches 15%, the maximum remaining subclique after random attack still occupies half of the initial number of nodes

However, the maximum remaining subclique drops to less than 40% of the initial node after deliberately destroying the system. Visible attack height

The lines connected by the degree nodes will quickly split the large grid system into many small grid systems, making the grid four parts

Five split, seriously affect the interconnection and common performance of power grid

4.3 Fault Propagation Feature

(1) Spatial

According to the fault simulation results, the contact line between the 197-node system and the 1029-node system was attacked

Both random and deliberate attacks will cause an increase in the proportion of load loss. When the network suffers

The change rate of load loss ratio is slow when the machine is attacked. Of these, 10 are removed in random attack mode

After the line, the load loss ratio is less than 0.01% of the initial value; Remove 10 lines in Deliberate Attack mode

The afterload loss ratio can also be as low as less than 0.1% of the initial value.

The result of random attack fully shows that the power grid has strong robustness to random disturbance. Yet a deliberate attack

The proportion of load loss increases rapidly for vulnerable lines with high values in the network, and the system splits rapidly into many subsets

Group. For 1029 node system, after the attack ratio is greater than 15%, it has a great impact on the network efficiency.

The load loss ratio is up to about 50% of the initial value, which decreases by about 50%, resulting in network crash and serious impact

Normal operation of the power grid.

The result of the deliberate attack shows that the high degree of the line to ensure the transmission efficiency of the grid and also the tenseness of the fault

Delay plays an important role in promoting the failure of these lines will cause the rapid expansion of the fault scale, and eventually lead to

The network crashes.

(2) temporality

Power system chain fault is usually caused by multiple fault events and spread, eventually leading to a blackout.

Causing great damage. The propagation of multiple faults has certain time characteristics, which are required after each fault occurs

The power flow of the next fault can be calculated only after the power flow distribution is recalculated and the power flow balance of the solitary point is carried out.

Therefore, the iteration times of power flow calculation can reflect the generation of chain faults in power system to a certain extent

The impact time. Taking Zhejiang Province Network 1029 node system as an example, when 10 lines are randomly attacked, only

It takes 4 iterations to make the power flow distribution converge. A deliberate attack on 10 altitude lines requires 8

Iteration; However, when the proportion of random attack lines reaches 15.4% of the total proportion, 58 iterations are needed

Convergence of power flow calculation; When 15.4 per cent of the routes were deliberately attacked, 92 were needed

Iteration.

5 SUMMARY AND PROSPECT

Power system blackout accidents often occur, each occurrence will bring a huge impact on production and life,

But the power system big outage accident is mostly caused by the chain fault. This paper summarizes contemporary scholars' research on power systems

The analysis method of chain fault is presented, and the performance of these methods is compared and analyzed

The analysis method of power system chain fault is suitable for the current power grid and can be simulated well

Dynamic characteristics of power systems. matpower tool is used to simulate and build the regional power grid topology

The vulnerability of attack mode and deliberate attack mode under the complex power grid theory is analyzed. The specific work content is as follows:

(1) This paper studies the current situation of Chinese electric power system interlock faults and analyses the existing interlock faults

Methods, the advantages and disadvantages of each method are analyzed, which lays a foundation for the introduction of complex network theory analysis method.

(2) Introduces the development history, concept, model and statistical characteristics of complex network theory, and determines the power system

The system is positioned as a small-world network, and the degree is selected as the parameter index to distinguish common lines from important lines.

(3) Use matpower platform to simulate the construction of a 1029-node system in Zhejiang Province power grid and a system in northwest China

197 node system, the two system node degree ranking, in the two attack mode compared with the power system

The proportion of load loss after attack, the number of remaining subcliques, the number of final solitary points set and the maximum remaining subcliques, and the result

It shows that the line with high degree can not only ensure the transmission efficiency of the power grid, but also promote the spread of faults

Function, the failure of these lines will cause the rapid expansion of the fault scale, and eventually lead to the collapse of the network, verified

Correctness of analysis.

At the same time, there are still some aspects to be improved in this paper. The following problems are ignored when writing the chain fault program:

(1) Determination of the initial fault set, external factors (high temperature, rain and snow, lightning, etc.); Internal factors (lines

Load rate).

(2) Island adjustment model: Adopt the optimization method to establish the optimal model with cutting load to make the cutting load

Minimum cost.

(3) The line failure probability should be related to the current load rate.
(4) Electricity market factors such as generation cost and operation cost are not taken into account.
(5) DC power flow method is used to analyze the problem, ignoring the network loss

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