Journal of Applied Science and Engineering Innovation Vol.2 No.3 2015 pp. 67-70
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

The Brittleness Analysis Based on the Rule of Brittleness being Motivated and its Application

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Abstract: Based on the theory of self-organized criticality, by using the cellular automata method to build the brittle model, and obtain the rule of brittleness being motivated by simulation of 6 nodes system. We can see that the brittleness being waken has the characteristic of weedy from near line to outer. Thus it may be known, the brittle occurrence is proportional to the load degree, the greater the load degree, the higher the probability of brittleness occurrence. The happening of brittleness is relative to the load condition. Only seldom element can lead to the cascading collapse.

Keywords Brittleness Analysis, Self-Organization Criticality, cellular automata

INTRODUCTION

In the recent several dozen years, along with the electrical power system development scale unceasing expansion and gradually increasing the complexity, in the worldwide scale, the electrical power system have the big dangers of power cut increase along with them inevitably, which have created the huge loss for the country ,he people and the society[1]. The system brittle theory is one kind of theory which studies chain-reaction phenomenon of the system, and is one effective method which analyzes the system chain-like sex breakdown, if the system is in from the organization critical state, it will be able to initiate the chain-like collapse of the system. Therefore the organization critical state will be the root which system brittleness will occur. At present, there are many reports about the system brittle research, Literature [2] analyzed the collapse process about the connected characteristic of the complex system subsystem between; Literature [3] has carried on brittle analysis based on the glide inspection method; Literature [4] has carried on the brittle analysis based on the brittle potential function to the complex system; Literature [5] has carried on the reason analysis about complex the system collapse based on the brittle relation entropy; Literature [6] has carried on the analysis to the system brittleness using the FAHP method. The electrical power system big power cut mainly is result of the chain-like sex breakdown causes [7], Therefore, it may revaluate big power cut mechanism of the electrical power system through the brittle analysis to the electrical power system. Therefore, this research analyzed brittle root and process of electrical power system based on critical from self-organization's theoretical, and provided the reference taking the time as the electrical power system chain-like six breakdown prevention.

COMPLEX SYSTEM BRITTLE DEFINITION AND CHARACTERISTIC

The brittle theory is the theory causing the system collapses by researching phylogeny chain-like sex breakdown. Generally, as a result of internal or exterior disturbance factor function, some part of system (subsystem) collapses because of the breakdown, thus the subsystem is influenced and even collapses. Like this, the system will occurrence chain-like breakdown, and finally causes the overall system collapse. The system collapse is the result of system brittleness which is stimulated.

System brittleness is not produces, it exists in the system. As the system attribute brittleness is recessive. When certain stimulation conditions were satisfied, system brittleness can demonstrate. The system chain-like collapse is the manifestation after system brittleness being stimulated.

Brittleness is the systematic one kind of attribute, its main characteristics are following: 1, Latent; 2, Chain-like; 3, Huge hazardous nature; 4, Stimulation initial period confidentiality; 5, Emergence;6, The system function may not the automatic restitution; 7, Integrity;⑧Non-cooperation gambling.

RESEARCH PRESENT SITUATION OF SELF-ORGANIZED CRITICALITY

Self-organized criticality (short for SOC) theory is proposed by Bak in 1987 [8].Self-organized criticality refers to the open, dynamic, far from equilibrium, the complex system composed of a number of modules. And through a long process of a self-organized it can evolve to a critical state, and in this critical state, the small incident could cause a chain reaction accident, which can have an impact on some components of the system. The chain-reaction throughout the whole system is the nature of system dynamic behaviors, and the macroscopic performance is that occurrences of the small incidents are more than the major accidents. The system in self-organized criticality has fractal structure in space, but in time it shows "1/f noise" and the time scale invariance and long-term time-correlated. Its low frequency power spectrum performance behavior conforms to the index rule (f^{β}).

When the system is at the critical state, small perturbations trigger chain-reactions and lead to the electric power system blackouts phenomenon. The concept of self-organized criticality, which is expected to be one of effective tools, used to reveal the complex phenomenon including electric power blackouts in the overall system behavior characteristics. In self-organized criticality, a small incident will trigger a major accident and even mutation. The basic concept of self-organized criticality views that the electric power system is always in a continuous state of non-equilibrium. Because the interaction of internal and external various system elements, they may organize into one critical stable condition, namely critical state[9] . American scholars, carriers and others[10-11],has used the data to prove that the frequent electric blackouts of North American electric power system were caused by self-organized criticality. They used 15-year-blackout-data to prove that when the electric power system blackouts happened, the loss of load had relationship with power-law of occurring frequency. But they only used probability methods to study the distribution of occurring a chain reaction collapse of the electric power system, and established several simple simulation models , but those did not apply to the actual electric power system. Therefore, this article used the cellular automaton method to establish the brittleness model of the actual electric power system, to simulate the chain collapse phenomenon of small electric power system.

SELF-ORGANIZED CRITICALITY OF ELECTRIC POWER SYSTEM

The complex system components (subsystems) states only affect the states of the neighborhood, and only small quantity and dramatic states transformation can affect (or change) the basic characteristics, and this characteristic can use “Sand pile model” to reflect. Sand pile model is a typical model of self-organized criticality. Sand pile model is to choice a even board, and make sand granules, one by one, slowly and evenly fall to the board. At the beginning, sand granules just stay near the falling location, but soon they will cover other sand granules to form a gentle slope sand pile. When somewhere in the sand slope is too steep, sand landslide will occur, leading to the "avalanche". With the increasing of sand granules, sand pile slope is more and more steep and average scale of "avalanche" increase, so some sand granules began to reach outside the disk. When sand granules amount adding to the sand pile have reached an equilibrium with the amount fallen outside the plate, the sand pile ,on the whole, will stop growing on, when the sand pile system reaches the critical state . By adding sand granules to the sand pile which has been in a critical state, the new sand granules may lead to different scale avalanches. With more sand granules falling, slope angle are bigger and bigger, when it reach the critical slope stability angle, the average collapse scale will also increase. In principle, when a sand granule falls onto the sand pile has been in the critical state, it will trigger the collapse with arbitrary scale, until the catastrophic events occur. So to know, the collapsing Dynamics mechanism is Chain reactions or "Branch processes"[9].

2D lattice models can be used to simulate the Sand pile model. On a two-dimensional lattice platform, define a lattice coordinate (x,y), and with Z(x,y) indicates the numbers of sand granules have fallen into each lattice, and also with Zcr indicates the maximum amount(critical value) of sand granules in each lattice .

Initially, the placement of sand is randomly selected, so:

$$Z(x,y) \rightarrow Z(x,y)+1 \qquad (1)$$

When the sand amount somewhere is in excess of the critical value, then:

$$Z(x,y) \rightarrow Z(x,y)-(Z_{cr}+1) \qquad (2)$$

$$Z(x\pm 1,y) \rightarrow Z(x\pm 1,y)+1 \qquad (3)$$

$$Z(x,y\pm 1) \rightarrow Z(x,y\pm 1)+1 \qquad (4)$$

Via it will subtract the critical value from the lattice in excess of the critical value, then the top and the underside, the left and the right of the lattice will increase one value. When the sand amount near the lattice exceeds the critical value, the same process would occur. Thus, when this process continues, probably the height of at least one lattice near will reach the critical value, so the initial collapse incident leads to a second collapse incident. With the same analogy, like a domino, a collapse chain-reaction will be formed.

The collapse of the electric power system is very similar to sand pile collapse[11].The similarity comparison is shown in table 1.

Self-organized criticality can completely be used to consider chain-reaction failures research in the electric power system .The electric power system collapse can be regarded as performance of the electric power system in a self-organized critical state. When some component of the electric power system a system has a overload, the electric power system will cut the circuitry to protect itself, which will lead to a redistribution of current in the transmission-line system of electric power. Therefore, the loads of other circuitries associated with this circuitry will be increased to varying degrees. When increased capacity over certain circuitry endure, it is possible to make this circuitry be cut for protection. This again will cause the current redistribution in the transmission-line system of electric power, thus, a chain of failures occurs, at last it possibly makes the entire electric power system be in the collapse state.

Table 1. The Analogy between Power System and Sand Pile

System characteristic	Power system	Sand pile
System state	loading pattern	Gradient profile
Driving force	Customer load	Addition of sand
Relaxing force	Response to blackout	Gravity
Event	Limit flow or trip	Sand topples

ELECTRIC POWER SYSTEM BRITTLENESS SIMULATION BASED ON CELLULAR AUTOMATON

Based on self-organized criticality theory, the following steps are used for the electric power system brittleness model:

Using one-dimensional cellular automaton to represent a electric power system, and each cell represents a certain electric power system component, such as a branch circuit, generator or loads. M represents the number of nodes in the electric power system, so the components maximum of the electric power system is M×M. Each cell has only one coordinates(x,y). The electric power system components coordinates corresponding to are classified as: When x=y, which is a representative of one power system node, and this node may be generator or load; When x≠y, which is on behalf of a branch circuit connecting two nodes.

When the coordinates(x, y) contains a electric power system component, it makes C(x,y)=C(y,x)=1;Conversely, if not, it makes C(x,y)=C(y,x)=0.

To make P(x,y) as tidal current quantity of electric power system components .Parameters set as below : When x=y, and if P(x,y)>0, then this component stands for a generator, if P(x,y)<0,it stands for the load; When x≠y, and if P(x,y)>0, it represents the branch circuit tidal current of components from x to y is positive; If P(x,y)<0,it represents the branch circuit tidal current of components from x to y is negative.

To make Pmax(x,y) as tidal current limit value of electric power system components, and Pmax(x,y)= Pmax(y,x). If exceeding this value, the element exits from the operation, and C(x,y)=C(y,x)=0.

If a component meets the requirements exiting from the operation, in order to guarantee electric power system's power to be invariable, then to assign this component's power to its neighboring components on average. The concrete assignment means are as so: If the component exiting from the operation is a branch circuit, to make other branch circuits connecting with two nodes of this branch circuit as neighboring components; if the component exiting from the operation is a generator or load, then to make the neighboring components as branch circuits connecting with this component.

Now give the specific steps :

Step1: To assign initial values to M,C(x,y),P(x,y), Pmax(x,y).

Step2: To choose some component randomly, and make it cut, so: C(x,y)=C(y,x)=0,P(x,y)=P(y,x)=0, also count the neighboring branch circuits amount N, so tidal current quantity of each neighboring branch circuit's obtaining is so:

$$\Delta P = \frac{P(x,y)}{N} \qquad (5)$$

Here, the tidal current quantity of each neighboring branch circuit is:

$$P(x,y) = |P(x,y)| + \Delta P \qquad (6)$$

In the formula, the absolute value expresses that it does not differentiate the direction of the tidal current.

Step3: To check if all neighboring branch circuits exceed their allowable limit values, if doesn't, so to be finished, or return to step 2. If all satisfy C(x,y)=0, then to be finished.

To choose a electric power system with six nodes[12], and also use the direct-current tidal current method for solving the tidal current quantity of all branch circuits in the systems, then to simulate brittleness process. The model parameters establishment are as follows.

M=6;N=0;

$$C = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}$$

$$P = \begin{bmatrix} -2.4 & 0.074 & 0 & -0.8 & -0.767 & -0.908 \\ -0.074 & -1.6 & 0 & 0 & -0.874 & -0.655 \\ 0 & 0 & -2.4 & -2.4 & 0 & -2.215 \\ 0.8 & 0 & 2.4 & 3.200 & 0 & 0 \\ 0.767 & 0.874 & 0 & 0 & 1.649 & 0 \\ 0.908 & 0.655 & 2.215 & 0 & 0 & 1.551 \end{bmatrix}$$

$$P^{\max}=\begin{bmatrix} -4 & 1.00 & 0 & 3.00 & 3.00 & 1.60 \\ 1.00 & -6 & 0 & 0 & 1.50 & 0.95 \\ 0 & 0 & -4 & 3.00 & 0 & 2.50 \\ 3.00 & 0 & 3.00 & 5.000 & 0 & 0 \\ 3.00 & 1.50 & 0 & 0 & 7.500 & 0 \\ 1.60 & 0.95 & 2.50 & 0 & 0 & 7.500 \end{bmatrix}$$

To choose the fourth node as the breakpoint, so other nodes cut off due to the fourth node, whose breaked sequence are in Figure 1.

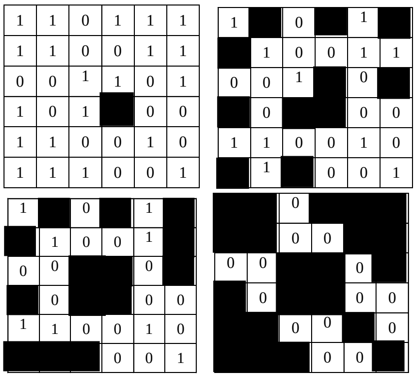

Fig.1 Cascading Failure Order after the 4th Node Break

From Fig.1, the break-off sequences in turn are :

$$(4,4)\rightarrow(4,3)\rightarrow\begin{cases}(6,3)\\(4,1)\end{cases}\rightarrow\begin{cases}(6,1)\\(6,2)\\(3,3)\\(1,2)\end{cases}\rightarrow\begin{cases}(6,6)\\(1,5)\\(5,2)\end{cases}\rightarrow\begin{cases}(1,1)\\(5,5)\\(2,2)\end{cases}$$

Above simulation has only given the result of node 4 opening and breaking, other components opening and breaking situations are similar to node 4. The calculating results reveal that node 4, node 2 and branch circuit (3,4) can produce the chain collapse, but other nodes and branch circuits have no chain collapses.

The occurrence of brittleness has relation with the load condition of the electric power circuit. If the original electric power circuit load is quite big, when it receives excess loads, relatively it is easy to reach the load maximum value, so the probability which brittleness occurs will increase. So to define the load degree of some circuit is:

$$l_k=\frac{L_k}{L_k^{\max}} \qquad (7)$$

In the formula, l_k is the load degree of Circuit k; L_k is the load of Circuit k; $L_k^{\max}$ is the load maximum value of Circuit k. Thus it may be known, the brittle occurrence is proportional to the load degree, the greater the load degree, the higher the probability of brittleness occurrence.

CONCLUSIONS

The electrical power system brittle analysis is an important method preventing the electrical power system chain-like collapse. From the simulation result, the electrical power system brittle occurrence has following characteristic: (1) Has mostly the characteristic which along the toward line outward spreads when brittleness occurs; (2) Brittle occurrence is relative to power circuit load condition; (3) Not all parts can cause the brittle occurrence, only then little the partial parts can stimulate the system brittleness. This also is precisely reason that the electrical power system has the big power cut omen is not very obvious.

As shown in the above analysis, preventing the electrical power system brittle stimulation should adjust suitably the line load, and cause the overall system active status far away critical from the self-organization condition; Discovering part causing the chain-like collapse is most important, which can suppress electrical power system brittle stimulation from the headstream. Simultaneously, the path which chain-like occurs must real-time seek, While which chain-like occurs shut off the chain-like line as soon as possible, and avoid the accident's expansion.

ACKNOWLEDGMENT

This work is supported by the Foster Fund of Northeast Petroleum University (XN2014110).

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