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Study on self organized criticality of China power grid blackouts

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ABSTRACT

Based on the complex system theory and the concept of self organized criticality (SOC) theory, the mechanism of China power grid blackouts is studied by analyzing the blackout data in the China power system from 1981 to 2002. The probability distribution functions of various measures of blackout size have a power tail. The analysis of scaled window variance and rescaled range statistics of the time series show moderate long time correlations. The blackout data seem consistent with SOC; the results obtained show that SOC dynamics may play an important role in the dynamics of power systems blackouts. It would be possible to propose novel approaches for understanding and controlling power systems blackouts.

1. Introduction

Modern power systems are large, complex interconnected structures that are commonly run near their stability limits. Such systems can undergo non-periodic major cascading disturbances, or blackouts, that have serious consequences. Between August and September, 2003, the world power grids experienced a series of large blackouts, happening in the USA and Canada (August 14), in London (August 28), in Sydney and Malaysia (September 1) and in Italy (September 28) [1]. The loss of a large blackout is usually huge; thus, people have to ponder on why the blackout happens, how to predict and prevent its happening. Individually, these blackouts can be attributed to special causes, such as equipment failure, overload, lightning strikes, or unusual operating conditions. However, an exclusive focus on these individual causes can overlook the global dynamics of power systems.

In recent years, the phenomenon of self organized criticality (SOC) has been attracting much interest. These phenomena reveal the essentially holistic characteristics for the crashes of large complex systems. According to the blackout data over a period of 10–15 years in the North American power transmission system, Carreras et al. [2–5] investigated these blackout data and suggested that SOC may govern the complex dynamics of these blackouts.

As an introduction to the concept, a SOC system is one in which the nonlinear dynamics in the presence of perturbations organize the overall average system state near, but not at, the state that is marginal to major disruptions. SOC systems are characterized by a spectrum of spatial and temporal scales of disruptions that exist in remarkably similar forms in a wide variety of physical systems [2]. In these systems, the probability of occurrence of large disruptive events decreases as a power function of the event size, this is in contrast to many conventional systems in which this probability decays exponentially with event size. Therefore, the application of traditional evaluation methods to SOC systems is bound to underestimate the risk of large events. In considering the global dynamics of power systems, the complex system theory and related branches should be involved. Global complex system analysis of power system blackouts is to provide new insights and approaches that could address these challenges.

In this paper, we analyze the criticality related properties of the China power grids and provide some new insights and approaches that study the mechanism of blackout of power systems in China.

2. Self organized criticality

In the natural world and human society, there is a kind of dissipative system expanded in space, and this system can evolve to a critical state through the process of spontaneous self organization; in this state, a small disturbance will trigger chain reactions and lead to catastrophe. Bak et al. [6] in the United States Brookhaven National Laboratory presented SOC to explain the dynamical behaviors of dissipative system. The complex dissipative dynamical system is driven to the critical state due to the opposing forces among the components of the dynamical system. In the critical state, a small event may induce catastrophe and have effects on the part of components; the essence of system dynamical behavior is chain reactions throughout the whole system. A system in a critical state is characterized by a spectrum of spatial and temporal scales of disruptions, and the relationship between size and frequency is a power law. The dynamics of an idealized sand pile model can be used to illustrate SOC.

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Nomenclature

X	time series	$R(\tau)$	range of data
$<X>\tau$	average value series of data with different τ	$S(\tau)$	standard deviation of data
Y	Brownian motion series	α,k	constants
$Y(t,\tau)$	cumulative deviation of data	r	characteristic scale (power lost)
m,n	positive integer	$N(r)$	object number
σ_u^m	standard deviation	D	fractal dimension
H	hurst exponent		

3. Time series of blackout data and analysis

3.1. Description of blackout data

We have analyzed the full 22 years of data from 1981 to 2002 that is publicly available from Refs. [7–9]. There are 219 blackouts in 22 years and 9.95 blackouts per year. The average period of time between blackouts is 36 days; the statistical data is shown in Table 1 (the data of serious blackouts are only included in district power grids).The blackouts are distributed over the 22 years in an irregular manner. It is not clear how complete this data is, but it is the best documented source that we have found for blackouts in the China power system.

In order to understand the global dynamical properties of the China power grid, we constructed a time series with the resolution of a day for the number of disturbances for three different measures of the blackout size. The three measures of blackout size are the amount of power lost, the energy unsupplied and the restoration time. The energy unsupplied is estimated from the blackout data by multiplying the power lost by the restoration time. The time series for power lost is shown in Fig. 1.

3.2. Scaled window variance method of blackout data

The scaled window variance (SWV) method is given as follows to show the power law properties [10]. Consider the following time series.

$$X = \{X_t;\ t = 1, 2, 3, \ldots, n\} \quad (1)$$

From (1), the Brownian motion series can be constructed as follows:

$$Y = \{Y_t;\ t = 1, 2, 3, \ldots, n\} \quad (2)$$

where Y_t is the original series, X_t is integrated in time, that is $Y_t = \sum_{s=1}^{t} X_s$.

For the series Y and for each m = 1, 2,..., n, a new series $Y^{(m)}$ is generated

$$Y^{(m)} = \{Y_u^{(m)};\ u = 1, 2, \ldots, n/m\} \quad (3)$$

The elements of this series are blocks containing m elements of the initial series, that is

$$Y_u^{(m)} = \{Y_{um-m+1}, \ldots, Y_{um}\} \quad (4)$$

We can then calculate the standard deviation $\sigma_m^{(u)}$ within each of the n/m blocks that contains m elements of this series. After that, we average $\sigma_m^{(u)}$ over the blocks to obtain

Table 1
Statistics of blackouts in power system by region from 1981 to 2002.

District power grid	Blackouts times	District power grid	Blackouts times
Northwest China	53	East China	11
Northeast China	44	Fu Jian	8
Central China	40	Hai Nan	3
South China	39	Shan Dong	1
North China	19	Si Chuan	1

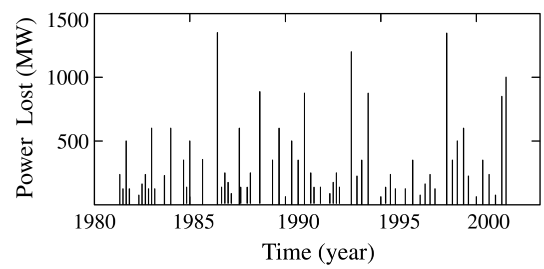

Fig. 1. Time series of power lost in China power grids.

$$\sigma_m = \frac{\sum_{u=1}^{n/m} \sigma_m^{(u)}}{n/m} \quad (5)$$

In the case of a time series X with an autocorrelation function, it can be shown that the function σ_m has an algebraic tail and scales as a power law, like $\sigma_m \propto m^H$, where H is the Hurst exponent. It satisfies

$$\log(\sigma_m) = H \log(m) \quad (6)$$

It is known that, for 1 > H > 0.5, the series X_t has long range time correlations, and for 0.5 > H > 0, the series X_t has long range time anti-correlations. If H = 1.0, the series X_t is deterministic, and if H = 0.5, the series X_t is uncorrelated [11,12].

Table 2 is the result of autocorrelation analysis of the blackout data in China power grids during 1981–2002, by using the SWV method [13,14].

The detailed results of the calculation are shown in Fig. 2 by using the SWV method.

For the numbers of blackouts, H = 0.5049 roughly indicates that there is no correlation in the individual triggers of the blackouts.

For those variables describing blackout size, such as energy unsupplied, power lost and restoration time, H = 0.6–0.7 indicates that there is a long range correlation in them.

It is necessary to point out that the sample data and the related statistical analysis are far from perfect.

3.3. Rescaled range method of blackout data

As mentioned before, we consider a group of time series:

$$X = \{X(t);\ t = 1, 2, 3, \ldots, n\} \quad (7)$$

Let us define an average value series of the data with different τ.

Table 2
Hurst exponents of blackouts.

Time series	H
Numbers of blackout	0.5049
Energy unserved (MWh)	0.6899
Power lost (MW)	0.6503
Restoration time (min)	0.6047