Initial Evidence for Self-Organized Criticality in Electric Power System Blackouts

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Abstract

We examine correlations in a time series of electric power system blackout sizes using scaled window variance analysis and R/S statistics. The data shows some evidence of long time correlations and has Hurst exponent near 0.7. Large blackouts tend to correlate with further large blackouts after a long time interval. Similar effects are also observed in many other complex systems exhibiting self-organized criticality. We discuss this initial evidence and possible explanations for self-organized criticality in power systems blackouts. Self-organized criticality, if fully confirmed in power systems, would suggest new approaches to understanding and possibly controlling blackouts.

1. Introduction

Electric power transmission networks are complex systems that are commonly run near their operational limits. Such systems can undergo non-periodic major cascading disruptions that have serious consequences. Individually, these disruptions or blackouts can be attributed to specific causes, such as lightning strikes, ice storms, equipment failure, shorts through untrimmed trees, excessive customer demand, or unusual operating conditions. However, an exclusive focus on these individual causes can overlook the global dynamics of a complex system in which repeated major disruptions from a wide variety of sources are a virtual certainty. Indeed, large scale disruptions can be intrinsic to the global system dynamics as is observed in systems displaying Self-Organized Criticality (SOC) [1]. A SOC system is one in which the nonlinear dynamics in the presence of perturbations organize the overall average system state near to, but not at, the state that is marginal to major disruptions. SOC systems are characterized by a spectrum of spatial and temporal scales of the disruptions that exist in remarkably similar forms in a wide variety of physical systems. 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 Gaussian systems in which the probability decays exponentially with event size. Therefore, the application of traditional risk evaluation methods to SOC systems is bound to underestimate the risk of large events.

It is difficult to directly determine whether a system has SOC type dynamics. However, we can explore the existence of correlations of events over long time scales to indicate whether the system has non-trivial complex dynamics with non-Gaussian properties. We also consider the probability distribution function of disturbance sizes.

2. Detecting long time correlations in time series

A time series is said to have long-range dependence if its autocorrelation function falls off asymptotically as a power law. This type of dependence is difficult to determine because the noise tends to dominate over the signal for long time lags. Over the last decade, several techniques have been developed to overcome this problem. One such technique, and chronologically the first one, is the rescaled range statistics (*R/S* statistics) proposed by Mandelbrot and Wallis [3] and based on a previous hydrological analysis by Hurst [4]; another is the scaled window variance technique [2].

The *R/S* statistics or the scaled window variance technique considers blocks of m successive points in the integrated time series and measure how fast the range or standard deviation of the blocks grows as m increases. In the case of the scaled window variance technique, we begin by considering a time series $X \equiv \{X_t : t = 1, 2, \ldots, n\}$. We then construct the associated series of the Brownian motion, $Y \equiv \{Y_t : t = 1, 2, \ldots, n\}$; that is, the original series integrated in time: $Y_t = \sum_0^t X_t$. For the Brownian motion series Y and for each $m = 1, 2, \ldots, n$, a new series $Y^{(m)} \equiv \{Y_u^{(m)} : u = 1, 2, \ldots n/m\}$ is generated. The elements of this series are blocks of m elements of