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Modeling power grids

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Abstract

We present a method to construct random model power grids that closely match statistical properties of a real power grid. The model grids are more difficult to partition than a real grid.

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1. Introduction

Power grids are prime examples of the interconnected networks that make life in technological societies possible. It is therefore of paramount importance to develop methods to prevent cascading failures that manifest themselves in widespread, catastrophic blackouts. One such defensive strategy is Intentional Intelligent Islanding [1, 2], which aims to prepare for the rapid isolation of parts of the grid where instabilities arise before they can spread further. This problem of network partitioning [3, 4] involves determining subdivisions of the grid that are tightly internally connected, but weakly connected to the rest of the grid. At the same time, each such island should be close to self-sufficient with power.

In previous papers [5, 6] we have considered network-theoretical methods to achieve this goal, using the high-voltage network in the U.S. state of Florida as a test example. Here we continue this endeavor by constructing model power grids that share important statistical properties with a real one. Such models provide opportunities to study the effects of specific network modifications, as well as to perform scaling analyses in terms of the network size.

2. Model construction

The Florida high-voltage power grid [7] consists of $N = 84$ vertices, 31 of which are generators and the rest are distribution substations that act as loads. The vertices are connected by $M = 200$ edges, some of which are parallel power lines connecting the same two vertices. We use a simplified representation of the grid as a weighted, undirected graph [3], defined by the

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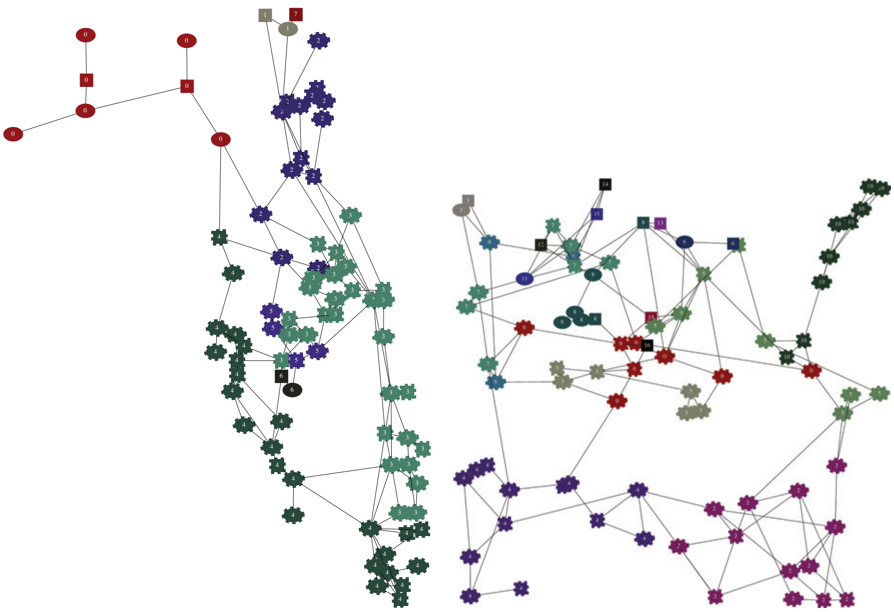

Figure 1: The Florida high-voltage power grid (left) and a representative model network (right). Generators are represented by squares and loads by ovals. The partitions shown are in each case the "best" ones obtained in ten independent runs with the bottom-up partitioning algorithm of Ref. [6]. Islands are identified by different colors and by numbers that can be seen if viewed at high magnification. See text for discussion.

$N \times N$ symmetric weight matrix $\mathbf{W}$, whose elements $w_{ij} \geq 0$ represent the "conductances" of the edges (transmission lines) between vertices (generators or loads) i and j,

$$w_{ij} = (\text{number of lines between vertices } i \text{ and } j)/(\text{ normalized geographical distance}), \quad (1)$$

where the "geographical distance" is the length of the edge connecting i and j. To obtain a model independent of any specific systems of length units, the distances are normalized such that the areal density of vertices is unity. In Fig. 1 we show a map of the Florida network together with a representative model network. Model networks were produced by the following procedure.

1. We placed the $N = 84$ vertices randomly in a square of area N.
2. Following the standard "stub" method [8], we attached $2M = 400$ stubs or half-edges randomly to the N vertices. (Actually, to ensure that no vertices in this small network should be totally isolated, we first attached one stub to each vertex, and then distributed the remaining $2M - N$ stubs randomly between the vertices.) The resulting degree distribution for the particular model grid discussed in this paper is shown together with that of the real Florida grid in Fig. 2(a).
3. We connected the stubs randomly in pairs, with the restriction that self-loops (two mutually connected stubs at the same vertex) were forbidden.
4. To obtain an edge-length distribution with the same average as that of the real Florida grid ($\approx$ 1.09 in our dimensionless units), we employed a Monte Carlo (MC) "cooling" procedure using a "Hamiltonian" in which the total edge length L plays the role of the