SFI working paper

Complex Systems Techniques applied to Power Transmission Expansion Planning.

Introduction

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Choosing how new lines should be installed in a power grid, or Transmission Expansion Planning (TEP) is a problem of considerable complexity. Any power grid has a large number (hundreds to tens of thousands) of components, meaning that any upgrades must take into account the current infrastructure. Additionally, there are many possible additional lines that one could add to an existing power grid. Furthermore, any design must be weighted by investment and operation cost. This requires analyzing the optimal use of generation and transmission assets using optimal power flow models that simulate the physical laws governing power flows (Kirchhoff's Laws) as well as infrastructure limits.

Given the importance of this problem, many approaches have been tested. However, we found that there were still some tools, related to the Complex Systems environment, which have not yet been applied in this field. We therefore undertake the project of exploring the possibilities of some of these tools. The research we have completed while at CSSS has allowed us to write three working papers, each detailing a different application of Complex Systems tools to TEP:

- Part I: Generating Random Networks that are Consistent with Power Transmission
- Part II: An Agent-Based Model for Transmission Expansion Planning
- Part III: Using Topological Information to Build More Robust Networks

These working papers represent the first steps we have taken, highlighting what new techniques can do when applied to well-known problems. We have enjoyed this research and intend to expand and publish our results in the near future.

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I. Case Study

We tested our developments using data from the Spanish power grid, which we were lucky enough to have due to the participation of some members of the team in previous research projects. The generators in this network have a peak supply of 8321 MW in total. In addition, there is 7534 MW of intermittent sources of energy. The total peak demand in the network is 15,140 MW, meaning that the power generated in excess demand at peak generation and peak demand is 715 MW. The basic topological structure of the network can be seen in Table 1. Data from the Spanish power system is compared with data from the power system in the western U.S. (Watts & Strogatz, 1998), and a random graph of the same size with the Spanish system. The average path length of our network is 5.36 while average distance of the power grid of the western United States is 18.7 (Watts & Strogatz, 1998). The average clustering coefficient is 0.128 while that of the western United States is 0.08 (Watts & Strogatz, 1998). Watts and Strogatz (1998) found that the average path length of the power grid in the western U.S. was roughly equal to that of a random graph of the same size and average degree, but that the power grid's clustering coefficient was much higher. The Spanish power grid has the same property. Our average path length is 5.36 while the average path length of a random graph of the same size and mean degree is 13.26. Our clustering coefficient is 0.128 while the clustering coefficient of a comparable random graph is 0.00053 (Tale 1).

Table 1: Comparison between the power systems in Spain and the western U.S., and a random graph of the same size.

Indicators	Spain	The western U.S.	A random graph
Number of Nodes	1,176	4,941	1,176
Number of Edges	1,820	1,850	1,820
Average Path length	5.36	18.7	13.26
Average Clustering Coefficient	0.128	0.08	0.00053

Figure 1 shows the entire network of the power grid topologically. Each node represents a generator, a demand, generator and demand, and others (substations).. Demand nodes account for more than 50% and other nodes for 36%. Generators account for only 5% of all the nodes.

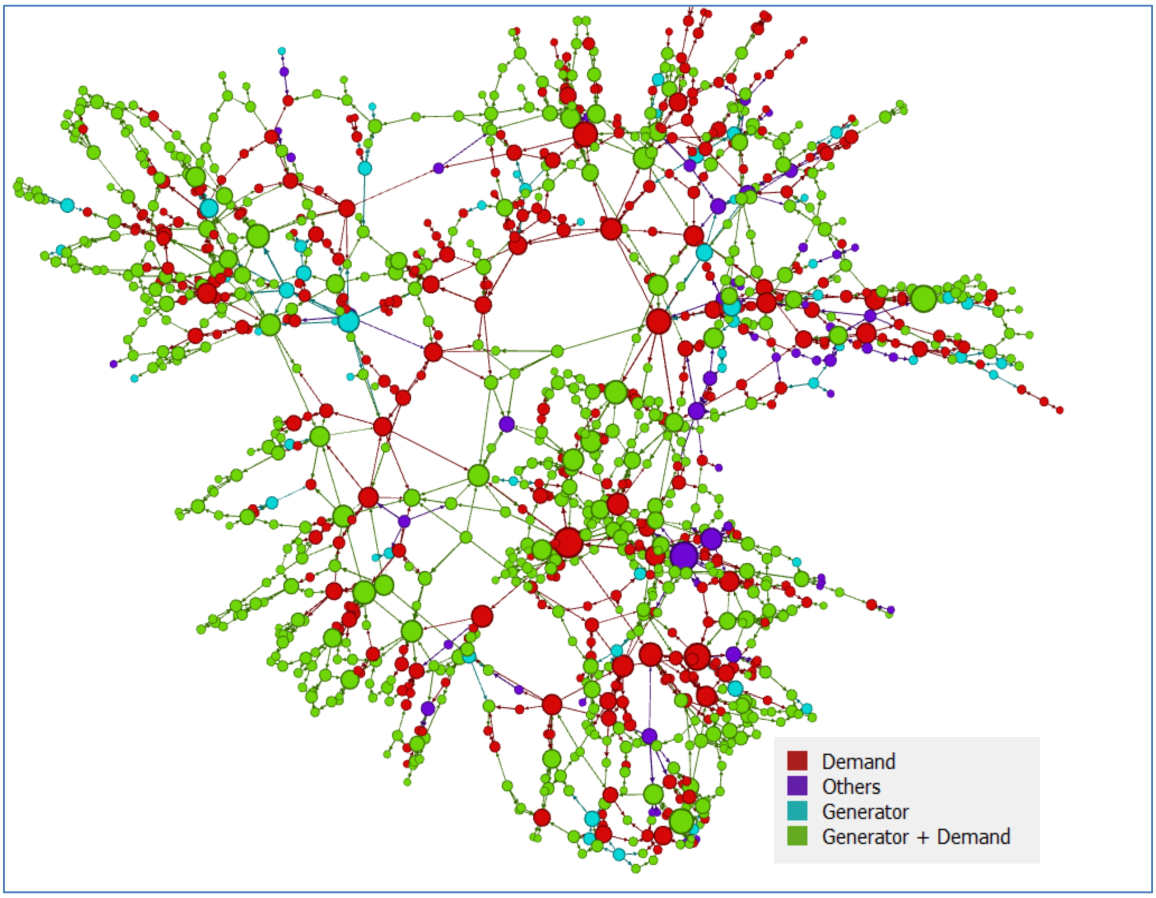

Figure 1: The entire network of the power grid

Watts, Duncan J., and Steven H. Strogatz. "Collective dynamics of 'small-world'networks." nature 393.6684 (1998): 440-442.