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Complex Dynamics of the Power Transmission Grid (and other Critical Infrastructures)

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Our modern societies depend crucially on a web of complex critical infrastructures such as power transmission networks, communication systems, transportation networks and many others. These infrastructure systems display a great number of the characteristic properties of complex systems. Important among these characteristics, they exhibit infrequent large cascading failures that often obey a power law distribution in their probability versus size. This power law behavior suggests that conventional risk analysis does not apply to these systems. It is thought that much of this behavior comes from the dynamical evolution of the system as it ages, is repaired, upgraded, and as the operational rules evolve with human decision making playing an important role in the dynamics. In this talk, infrastructure systems as complex dynamical systems will be introduced and some of their properties explored. The majority of the talk will then be focused on the electric power transmission grid though many of the results can be easily applied to other infrastructures. General properties of the grid will be discussed and results from a dynamical complex systems power transmission model will be compared with real world data. Then we will look at a variety of uses of this type of model. As examples, we will discuss the impact of size and network homogeneity on the grid robustness, the change in risk of failure as generation mix (more distributed vs centralized for example) changes, as well as the effect of operational changes such as the changing the operational risk aversion or grid upgrade strategies. One of the important outcomes from this work is the realization that "improvements" in the system components and operational efficiency do not always improve the system robustness, and can in fact greatly increase the risk, when measured as a risk of large failure.