Methods of dimensional reduction to assess rare events of blackouts in power grids

<u>Hildegard Meyer-Ortmanns</u>
Constructor University, Bremen, Germany, [2]Complexity Science Hub, Vienna, Austria

We discuss the frequency of blackout or desynchronization events in power grids for realistic data input, in particular with time correlations in the fluctuating power production. Our desynchronization events are caused by overloads. We propose and discuss different methods of dimensional reduction to considerably reduce the high-dimensional phase space. The first method splits the system into two areas, connected by heavily loaded lines, and treats each area as a single node. This corresponds to the so-called synchronized subgraph approximation, here applied to the swing equations. The second one considers a separation of the timescales of power fluctuations and phase angle dynamics and completely disregards the phase angle dynamics. Desynchronization events are truly rare either if the fluctuations are very small, too small to easily kick the system out of the fixed point that is stable in the deterministic limit, or, if the distance to the bifurcation point is still rather large, as the system is not heavily loaded. Such rare events are captured by the WKB-method for classical stochastic systems. We insert a WKB-ansatz into the differential Chapman-Kolmogorov equation for the probability to find certain voltage phase angles, frequencies, and power fluctuations at time t. This leads to a Hamilton-Jacobi equation. We then derive Hamilton's equations of motion to determine the optimal path with the smallest entropic barrier along which the desynchronization happens via an instanton. The obtained average desynchronization times obtained for the different versions of the dimensionally reduced system are compared with those obtained for the full system, simulated via the swing equations. The drastic approximation to neglect the phase space dynamics turns out to be justified to exponential accuracy in the strength of the fluctuations, which means that the number of rare events does not sensitively depend on inertia or damping for realistic heterogeneous parameters and long correlation times. Neither does the number of desynchronization events automatically increase with non-Gaussian fluctuations in the power production as one might have expected. We point out under which conditions the number of desynchronization events decreases. On the other hand, the analytical expressions for the average time to desynchronization do depend on the finite correlation time of the fluctuating power input. We also discuss subtleties in the very implementation of data in the numerical simulations if the artificially generated ones should reproduce real data as collected in histograms of power increments of wind data.