

Stability Analysis and Robust Control of Power Networks in Stochastic Environment

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Abstract

The modern power grid is moving towards cleaner form of energy, renewable energy to meet the ever-increasing demand and new technologies are being installed in the power network to monitor and maintain stable operation. Further, the interactions in the network are not anymore localized but take place over a network and the control centers are located remotely, thus involving control of network components over communication channels. We model the unreliable and intermittent nature of wind energy with stochastic uncertainty to study the impact of uncertain wind on the frequency regulation and small-signal stability of power network. The challenging aspect of the stability analysis of stochastic power network is that the stochastic uncertainty appears multiplicative as well as additive in the system dynamics.

The notion of *mean square exponential stability* is considered to study the properties of stochastic power network expressed as a networked control system (NCS) with stochastic uncertainty. We develop, necessary and sufficient conditions for mean square exponential stability which are expressed in terms of the input-output property of deterministic or nominal system dynamics captured by the *mean square* system norm and variance of channel uncertainty. Overall, the theoretical contributions in this work generalize the existing results on stability analysis from discrete-time linear systems to continuous-time linear systems with multiplicative uncertainty. The stability results can also be interpreted as a small gain theorem for continuous-time stochastic systems. Linear Matrix Inequalities (LMI)-based optimization formulation is provided for the computation of mean square system norm for stability analysis and controller synthesis.

An IEEE 68 bus system is considered and the fragility of the decentralized load-side primary frequency controller with uncertain wind is shown. The critical variance value is shown to decrease with the increase in the cost of the controllable loads and with the increase in penetration of wind farms. Next, we model the power network with renewables, controllable loads and as the name suggests, these loads can be able to change their power generation based on frequency feedback to minimize the uncertainties in wind generation to an extent. The resultant system is described by a detailed higher order nonlinear differential-algebraic model.

The stochastic wind speed is shown to appear as a multiplicative parametric uncertainty in the linearized differential-algebraic equations. Stochastic stability of such systems is characterized based on the developed results on mean square exponential stability. The power fluctuations in the demand side and intermittent generation (from renewables) cause frequency excursions from the nominal value. In this context, the performance of decentralized and distributed frequency controllers are studied in the presence of stochastic wind. Finally, the time-domain simulations on an IEEE 39 bus system (by replacing some of the traditional SGs with DFIGs) are shown using the wind speeds modeled as stochastic as well as actual wind speeds obtained from the wind farm located near Ames, Iowa. It can be seen that, with an increase in the penetration of wind generation in the network, the network turns *mean square unstable*. Furthermore, we capture the mean square unstable behavior of the power network with increased penetration of renewables using the statistics of actual wind analytically and validate them through time domain simulations.