

Modeling, Assessment and Control of Power Systems in Presence of Stochasticity

Abstract

Modern power systems, among the most complex engineered dynamic systems, are increasingly influenced by stochastic effects arising from uncertain loads, renewable generation, measurement noise, and unmodeled dynamics. Conventional deterministic approaches fail to capture the time-varying nature of such uncertainties, which critically affect system dynamics.

This thesis develops a stochastic framework for dynamic analysis by representing uncertainties using stochastic differential equations (SDEs), leading to a stochastic differential-algebraic equation (SDAE) formulation. A semi-implicit integration scheme is proposed to improve numerical stability and enable efficient simulation of stochastic dynamics.

Stochastic nonlinear Monte Carlo time-domain simulations (MC-TDS) and stochastic small-signal analysis are formulated to extend conventional stability assessment. To reduce computational burden, steady-state variances are computed using a stochastic-calculus-based approach via the Lyapunov Equation Method (LEM), eliminating the use of tedious time domain simulations.

The proposed stochastic framework is applied to DFIG-based wind energy conversion systems, which serve as a representative model of stochastic behaviour in modern power systems. The analysis quantifies how stochastic wind variations propagate through system dynamics under different operating conditions, demonstrating that neglecting their dynamic nature can lead to inaccurate stability assessment and suboptimal control performance.

To mitigate wind-induced stochastic oscillations, a modified LQR-based control strategy is proposed to enhance robustness. Additionally, a constant-gain linear controller, independent of the operating point, is developed by learning from LQR actions. The proposed controller suppresses stochastic oscillations with significantly reduced control effort and is suitable for practical implementation.

The thesis consolidates key insights into stochastic power system dynamics, identifies limitations, and lays a foundation for extension to large-scale systems.