Abstract:
The electric power system is witnessing significant transformations towards an integrated, active, and ubiquitously-sensed cyber-physical system. An abundance of multi-scaled data from phasor measurement units (PMUs), point on wave (POW) measurement devices, and digital disturbance recorders (DDRs) offers tremendous opportunities as well as scientific challenges to infer the state of the grid. Building on mathematical foundations and statistical analysis, this thesis aims to provide an overview of data analytic tools in the modeling and operation of modern power systems.

The key findings of this work are as follows:

1. The assumption of non-Gaussian statistical nature of noise encountered in power system is revisited. The imperfect components of the measurement and instrumentation chain are supposed to contribute to the measurement noise present in PMU data. A generic Gaussian Mixture Model (GMM) based modelling of measurement noise is proposed in this work.

2. Data-driven techniques for monitoring the health of critical power system substation components are presented. Based on the non-Gaussian nature of noise, the work develops (a) a GMM based Bayesian framework and (b) a spectral kurtosis-based index to detect equipment malfunction.

3. Traditional indices of power system situational awareness under increasing system complexity are reviewed, and robust schemes that consider the effect of realistic noise present in power systems are proposed. Towards this end, the work proposes a robust formulation of Dynamic State Estimator (DSE), taking into account the non-Gaussian nature of measurement noise.

4. Due to the modeling uncertainty of practical power systems, measurement-based power system electromechanical mode estimation is desirable in practice. The work addresses the issue of imperfect mode estimation due to low-quality measurements acquired in the field. A robust mode-metering scheme that performs fairly even in the presence of non-Gaussian measurement noise is proposed in this work.

5. Complementary to the dynamic frequency indices used for planning against transient frequency excursions, the study of steady-state frequency deviation encountered due to continuous and random power system perturbations like load and renewable power injections is also essential. The present work reports the effect of these stochastic input perturbations on power system frequency fluctuations under ambient conditions using a physics-informed data-driven method of frequency dynamics.

The analytics mentioned above are supported with rigorous mathematical treatment and simulation studies on benchmark test systems, field data, and data acquired from laboratory- scale PMU.

Keywords: Power system measurements, statistical power system modelling, Gaussian Mixture Model, frequency fluctuations, stochastic power systems, power system data analytics.