Probabilistic Small-Disturbance Stability Analysis of Renewable-rich Power Systems

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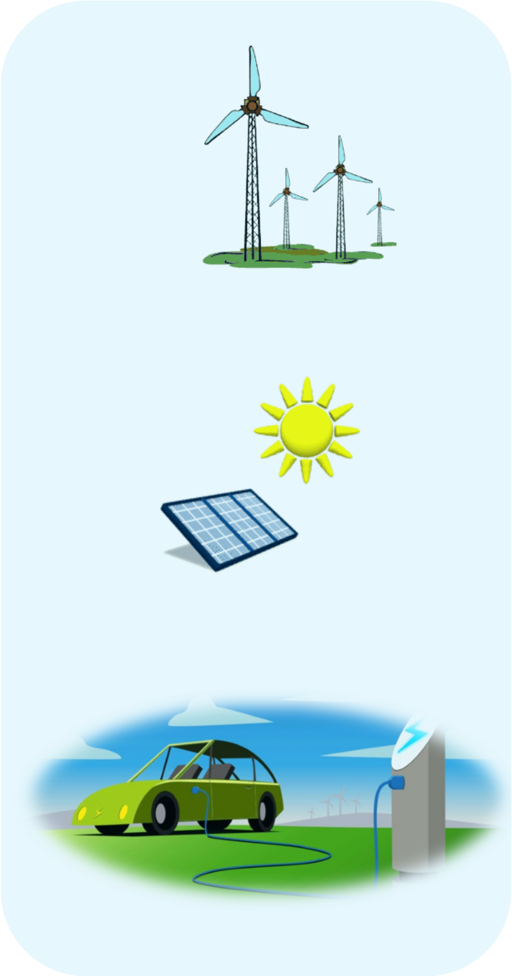
Acknowledgement: **Dr. Robin Preece, Prof. Jovica Milanović**, The University of Manchester, UK

Outline of the Presentation

- Motivation for Probabilistic Stability Studies
- Uncertainty Modelling and Probabilistic Analysis Framework
  - Input Modelling
  - Computational Techniques
  - Applications to Power Systems
- Conclusions
  - Accuracy vs. Efficiency

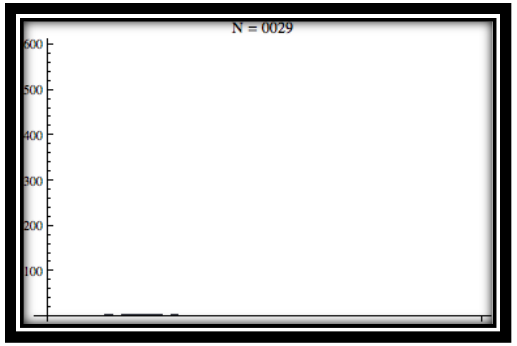
Motivation for Probabilistic Stability Analysis

- **Operational uncertainty** is increasing in power systems due to the integration of new energy resources
- As a short-term phenomenon, **system stability is significantly affected** by the intermittent **generation** and behind-the-meter **demand** variability
- **Probabilistic analysis** is highly required

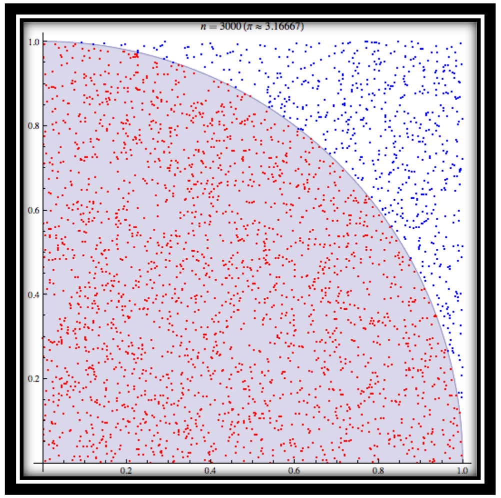


- KN Hasan, R Preece, JV Milanović, Priority ranking of critical uncertainties affecting small-disturbance stability using sensitivity analysis techniques, ***IEEE Transactions on Power Systems***, 32 (4), 2016.
- KN Hasan, R Preece, JV Milanović, The Influence of Load on Risk-based Small-Disturbance Security Profile of a Power System, ***IEEE Transactions on Power Systems***, 33 (1), 2018.
- KN Hasan, R Preece, Influence of Stochastic Dependence on Small-Disturbance Stability and Ranking Uncertainties, ***IEEE Transactions on Power Systems***, 33 (3), 2018.
- B Qi, KN Hasan, JV Milanović, Identification of Critical Parameters Affecting Voltage and Angular Stability Considering Load-Renewable Generation Correlations, ***IEEE Transactions on Power Systems***, 34(4), 2019.
- KN Hasan, R Preece, JV Milanović, Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation, ***Renewable and Sustainable Energy Reviews***, *vol 101, 2019.*
- RF Mochamad, R Preece, KN Hasan, Probabilistic multi-stability operational boundaries in power systems with high penetration of power electronics, ***International Journal of Electrical Power & Energy Systems***, 135, 107382, 2022.

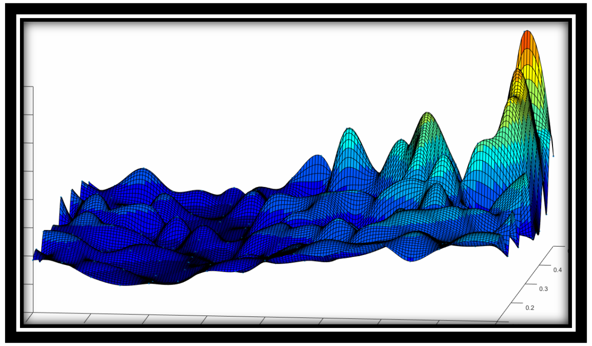
Framework for Probabilistic Stability Analysis



1 Input parameter modelling



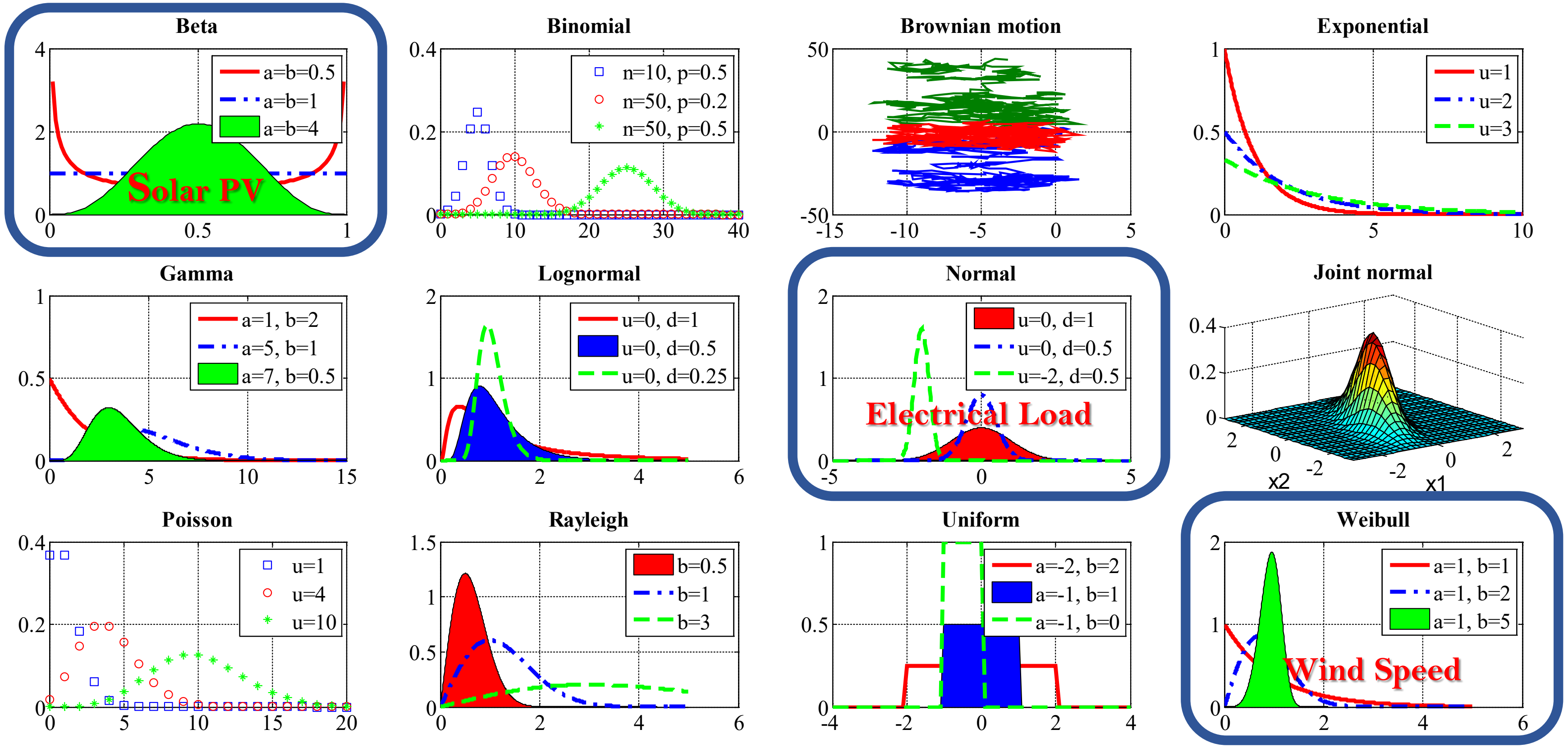
2 Computational methods



3 Defining output indices

- KN Hasan, R Preece, JV Milanović, Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation, ***Renewable and Sustainable Energy Reviews***, *vol 101, 2019.*

1 Probability Distribution of Power System Input Parameters



1 Probability Distribution of Power System Input Parameters

Variables	Independent Probability distributions
Operational variables	
Power system load	Normal [19-40], Gumbel [41, 42], discrete Normal [43] , pdf of past data [44, 45], joint Normal [46-48], Brownian motion [49]
Wind speed/power	Weibull [20, 21, 24, 27-34, 36, 41, 50-53], Normal [22, 35], discrete Normal [43, 54], joint Gaussian [55, 56], log-normal [52, 53, 57], gamma [52]
Solar power	Beta [27-36], Weibull [21, 58], pdf of past data [44]
Power generation	Normal [20, 23], historical system data and statistics [47]
EV demand	Normal [15, 20]
EV charging time	Exponential [15, 20]
EV customer arrival	Poisson [20]
Generator fuel price	Geometric Brownian motion [21]
Disturbance variables	
Fault clearing time	Normal [23, 41, 48, 59-61], Poisson jump process [62]
Fault type	Historical system data and statistics [23, 41, 45, 59], pdf of past data [45]
Fault location	Historical data[41, 60], uniform [15, 23, 59], empirical pdf of data [45]
Fault incident	Poisson [59, 63, 64], binomial [64]
Fault impedance	Normal [23, 41]
Fault duration	Rayleigh [23, 41]
Load change	Poisson jump process [15, 62]
Contingency/failure	Markov model [43, 46]
Transformer failure	Arrhenius-Weibull [65], Normal [65]
Time to failure	Exponential [63]
Unsuccessful reclose	Bernoulli [62]
HVDC failure	Weibull [66]
Transformer overloading	Binomial [61, 67]

KN Hasan, R Preece, JV Milanović, Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation, *Renewable and Sustainable Energy Reviews, vol 101, 2019.*

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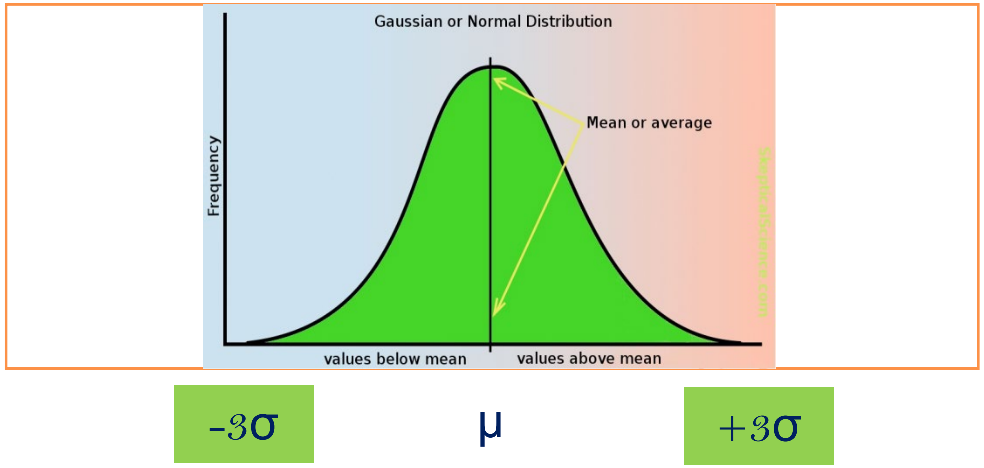
2 Probabilistic Computational Methods

Monte Carlo Simulation

The MC simulation involves,

- Defining a domain of possible inputs,
- Generating inputs randomly from a probability distribution over the domain,
- Performing deterministic computations on the inputs, and
- Aggregating the results.



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2 Probabilistic Computational Methods

Monte Carlo Simulation is accurate but computationally expensive

The required number of Monte Carlo simulation can be calculated by using the stopping rule formula presented below.

$$E > \left[\left\{ \Phi^{-1}(1 - \delta/2) \cdot \sqrt{\sigma^2(X)/N} \right\} \Big/ \overline{X} \right]$$

In (1), $\Phi^{-1}(\bullet)$ represents the inverse Normal *cdf* with a mean of zero and standard deviation of one, $\sigma^2(\bullet)$ is the variance of a sample, and δ is the desired confidence level. As presented in (1), simulations can be stopped if the calculated sample mean error falls below a specific threshold, *E*. This is true assuming that the outputs follow Normal distribution (which might not be true in many cases).

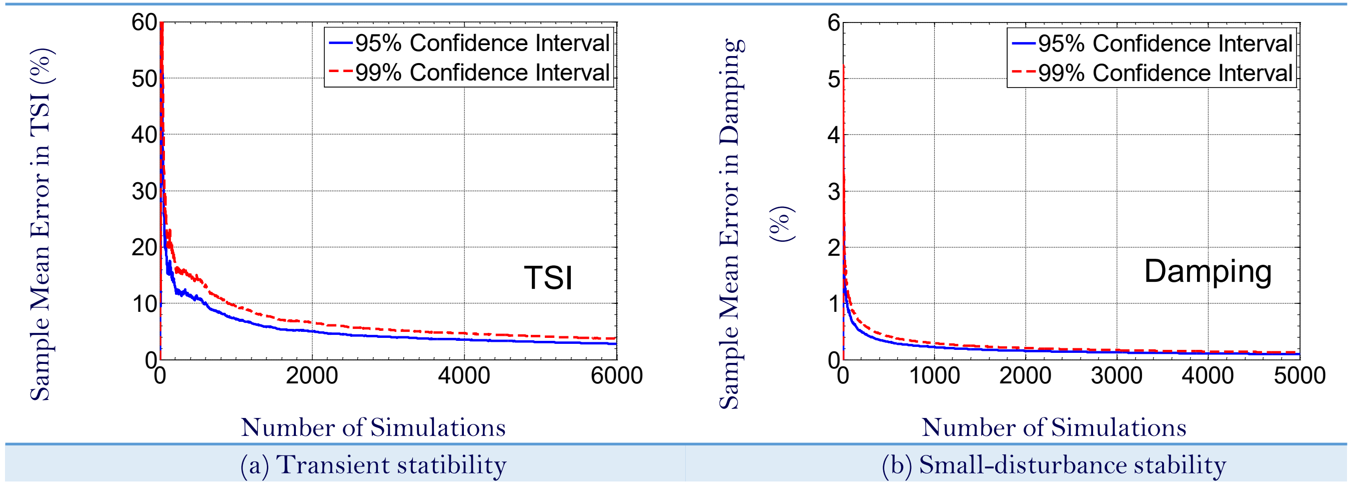

Figure: Illustrative results of Monte Carlo stopping rule.

- KN Hasan, R Preece, JV Milanović, Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation, ***Renewable and Sustainable Energy Reviews***, *vol 101, 2019.*

2 Probabilistic Computational Methods

Table: Probabilistic techniques and stability applications.

Amount of research interest of different computational methods with different stability studies				
	Transient Stability	Small-disturbance Stability	Voltage Stability	Frequency Stability
Monte Carlo (MC)	High	High	High	High
Sequential MC	Medium	None	None	Low
Quasi-MC	None	Low	None	None
Markov Chain MC	Low	Low	None	None
Point Estimate (PEM)	Low	Medium	Low	None
Cumulant-based	None	Low	Low	None
Probabilistic Collocation	Low	Medium	Low	None

- KN Hasan, R Preece, JV Milanović, Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation, ***Renewable and Sustainable Energy Reviews***, *vol 101, 2019.*

3 Probabilistic Outputs

Output distribution is affected by the input uncertainties

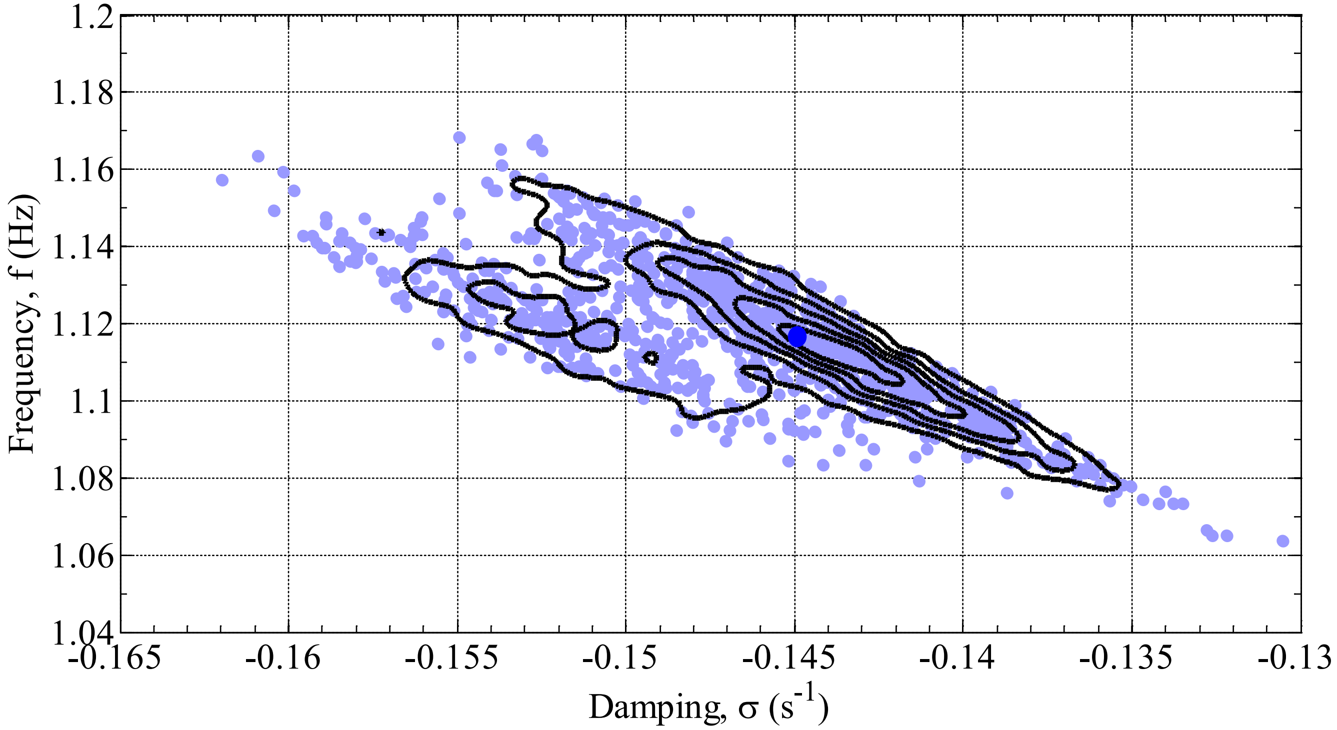

Figure: Contour plot and footprints of critical eigenvalue on the complex plane as affected by input parameter uncertainties.

Next Phases of the Work … (1/5)

Application of **sensitivity analysis** techniques

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 32, NO. 4, JULY 2017 2629

Priority Ranking of Critical Uncertainties Affecting Small-Disturbance Stability Using Sensitivity Analysis Techniques

Kazi Nazmul Hasan, *Member, IEEE*, Robin Preece, *Member, IEEE*, and Jovica V. Milanović, *Fellow, IEEE*

Next Phases of the Work … (2/5)

Application of **game theory** approaches

Electrical Power and Energy Systems 97 (2018) 344–352

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Application of game theoretic approaches for identification of critical parameters affecting power system small-disturbance stability

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Next Phases of the Work … (3/5)

Application of **risk analysis**

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 33, NO. 1, JANUARY 2018 557

The Influence of Load on Risk-Based Small-Disturbance Security Profile of a Power System

Kazi N. Hasan, *Member, IEEE*, Robin Preece, *Member, IEEE*, and Jovica V. Milanović, *Fellow, IEEE*

Next Phases of the Work … (4/5)

Application of **correlation modelling**

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 33, NO. 3, MAY 2018 3227

Influence of Stochastic Dependence on Small-Disturbance Stability and Ranking Uncertainties

Kazi N. Hasan, *Member, IEEE* and Robin Preece, *Member, IEEE*

Next Phases of the Work … (5/5)

Application of **multi-stability** operational boundary identification

Electrical Power and Energy Systems 135 (2022) 107382

Contents lists available at ScienceDirect

International Journal of Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Probabilistic multi-stability operational boundaries in power systems with high penetration of power electronics

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Summary

- Operational uncertainties are increasing
- Probabilistic analysis is required
- Efficient computational techniques needs to be applied
- A probabilistic framework may be applied to further analysis:
    - Sensitivity analysis
    - Game theory application
    - Risk assessment
    - Correlation modelling

Thank you

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