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Probabilistic Voltage Stability Analysis of Renewable-rich Power Systems

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Presentation Outline

- Motivation
- Conceptual Framework of Probabilistic voltage stability Analysis
- Simulation Results
  - Impact of Uncertainties on the P-V and Q-V Curve.
  - Impact of Probability Distribution Characteristics for Modelling Wind Speed on the P-V and Q-V Curves.
  - Implementing an Efficient Sampling Technique for Voltage Stability.
- Conclusions and Future Work

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Motivation

- ❖ Worldwide targets to increase RESs and new technologies (Electric Vehicles)
  - ➢ Environmental Concerns
  - ➢ Higher Demand
  - ➢ Sustainable Energy
- ❖ In terms of Australia [1];
  - ➢ RESs from 6% (2008) to 25% (2020) expected to be 34% (2030)

1. Saddelr H, National Energy Emissions Audit Report, 2020, Providing a comprehensive, up-to-date indication of trends in Australia's energy combustion emissions.

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Motivation

- **Uncertainties increased in the power networks**
  - Intermittent nature of the RESs (e.g. solar-PV and Wind generation)
  - Variability of the system loads
- **These uncertainties can have a major impact on voltage stability**
- **Voltage stability:** the ability the of the power network to maintain and recover the system voltage in an acceptable range after a small or large disturbance.
- **Traditional deterministic methods** do not reflect the actual system behaviour

Probabilistic Methods are Required!!

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Conceptual Framework of Probabilistic Voltage Stability Analysis

Part 1

Probabilistic input:

- Probability distributions
- Uncertain system parameters

Part 2

Probabilistic simulation:

- Computational methods
- Application to power system voltage studies

Part 3

Probabilistic output:

- Output indices
- System loadability and reactive power margin

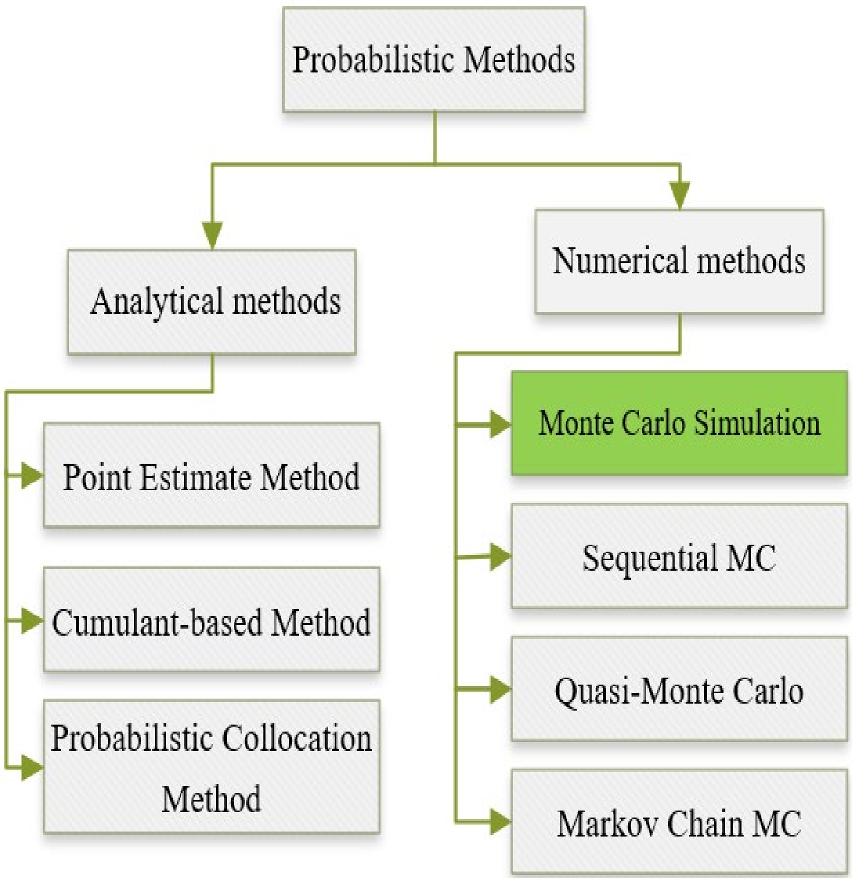
Challenging:

- Identify an appropriate probability distribution to model wind speed uncertainty, **especially for low wind speed**, and their impact on the P-V and Q-V curves.
- Implement/propose an efficient probabilistic method to **accurately and efficiently** evaluate the uncertainty on voltage stability.

2. Hasan, K.N., Preece, R. and Milanović, J.V., 2019. Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation. Renewable and Sustainable Energy Reviews, 101, pp.168-180.

3. Milanović, J.V., 2017. Probabilistic stability analysis: the way forward for stability analysis of sustainable power systems. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 375(2100), p.20160296.

Probabilistic Methods



❖ **The MC method:**

- Very flexible and it can be easily extended and developed.
- It needs a large number of samples to accurately capture the uncertainties in the power network.
- The accuracy of the MC method is increased by increasing the number of random samples.
- Thus, the **MC stopping rule** is usually applied to determine the number of samples!

$$\varepsilon = [\{\emptyset^{-1}(1-(\delta/2)).\sqrt{(\alpha^2(x)/N)}\}/\bar{X}]$$

- Where, ε is the sample error, $\emptyset^{-1}$ is the inverse Gaussian with a zero mean and one standard deviation, $\bar{X}$ is the sample mean, $\alpha^2(x)$ is the sample varianc, and δ is the confidence level.

Impact of Uncertainties on the P-V and Q-V Curves

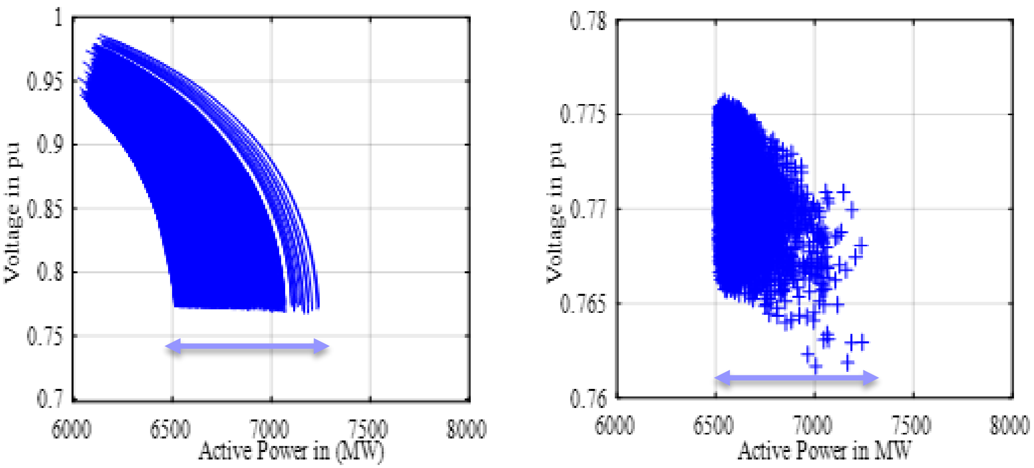


Fig.1 : The P-V curve and the nose points of the P-V curve based on 8760 MC samples

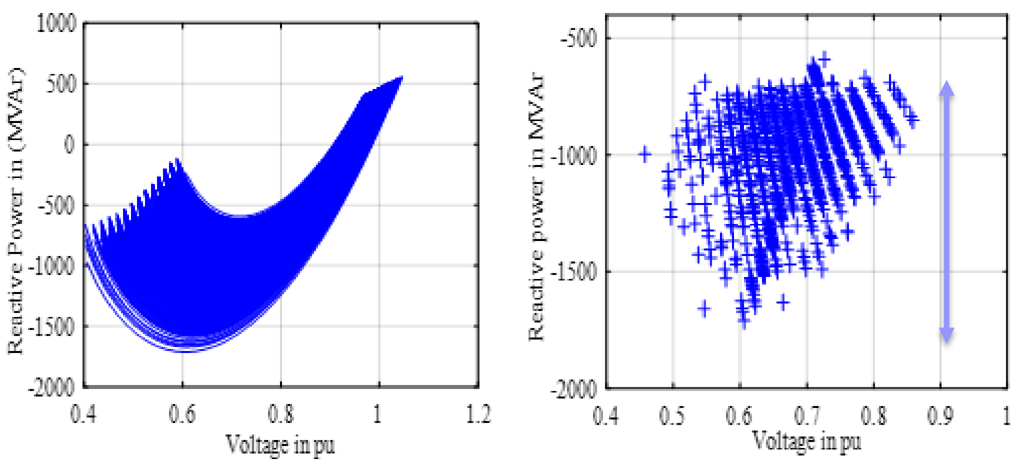


Fig.2: The Q-V curve and the nose points of the Q-V curve based on 8760 MC samples

- The nose point locations of the P-V curve are significantly impacted, which are change in range between 6,500 to 7,250 MW.
- Also, the same trend is found for nose point locations of the Q-V curve (from -1,700 to -600 MVAr).
- These outcomes show the importance of considering the uncertainties in the network and their impact on voltage stability.
- These probabilistic outcomes can support system planning, operation, and security by performing a wide range of scenarios.

4. Alzubaidi, M., Hasan, K.N., Meegahapola, L. and Rahman, M.T., Probabilistic Voltage Stability Analysis Considering Variable Wind Generation and Different Control Modes, *Australasian Universities Power Engineering Conference (AUPEC), Perth, Australia, 26 Sep- 30 Sep 2021, IEEE.*

5. Alzubaidi, M., Hasan, K.N., Meegahapola, L. and Rahman, M.T., Probabilistic Voltage Stability Assessment Considering Load and Wind Uncertainties, *IEEE PES ISGT-Asia 2021, Brisbane, Australia, 5 Dec - 8 Dec 2021.*

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Impact of Probability Distribution Characteristics for Modelling Wind Speed on the P-V Curve

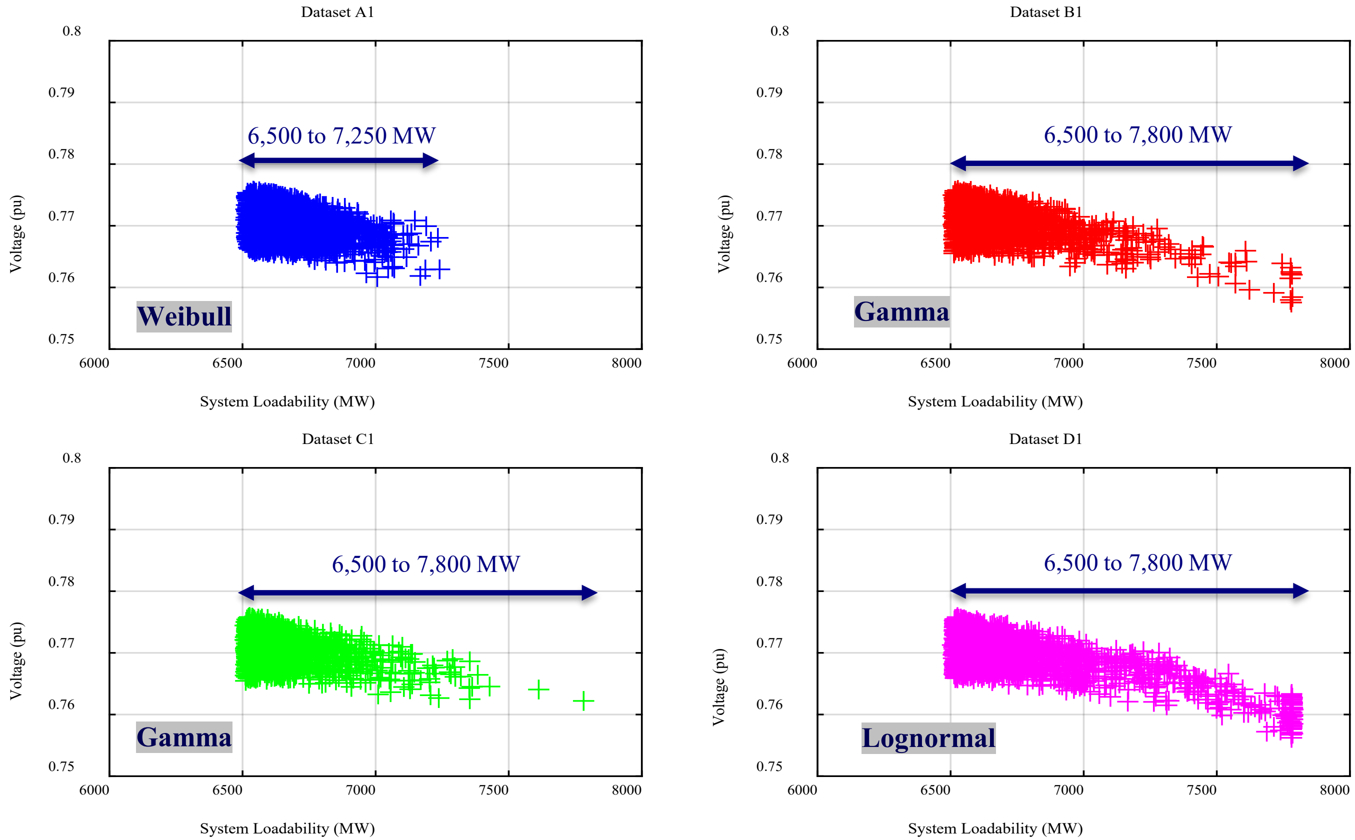

Fig. 3. The nose points of the P-V curve for the A1, B1, C1 and D1datasets modelling by Weibull, Gamma, Gamma, and Lognormal distributions, respectively.

6. .Alzubaidi, M., Hasan, K.N. and Meegahapola, L., Impact of Probabilistic Modelling of Wind Speed on Power System Voltage Profile and Voltage Stability Analysis. *Electric Power Systems Research, vol. 206, p. 107807, May 2022.*

Impact of Probability Distribution Characteristics for Modelling Wind Speed on the Q-V Curve

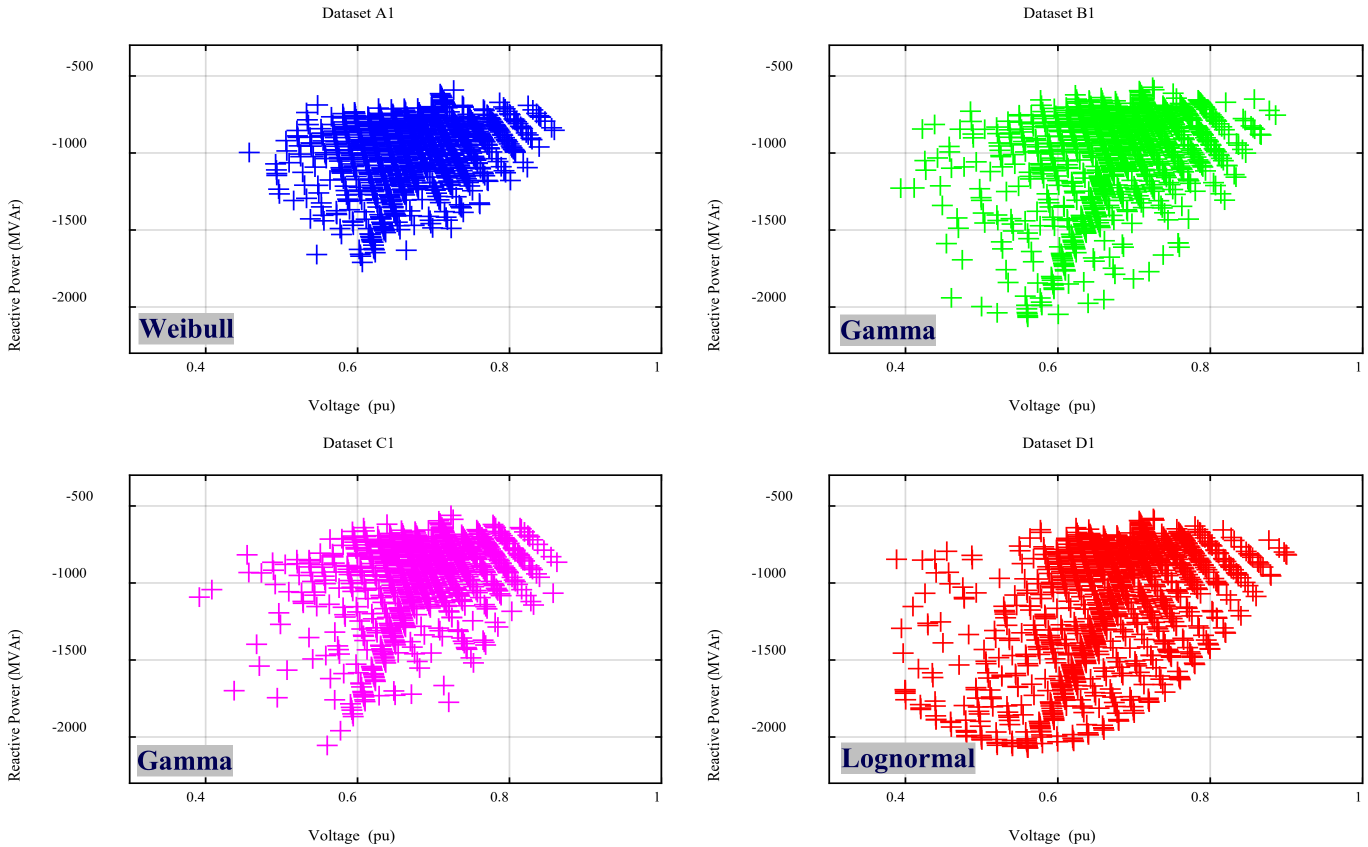

Fig. 4. The nose points of the Q-V curve for the A1, B1, C1 and D1datasets modelling by Weibull, Gamma, Gamma, and Lognormal distributions, respectively.

6. Alzubaidi, M., Hasan, K.N. and Meegahapola, L., Impact of Probabilistic Modelling of Wind Speed on Power System Voltage Profile and Voltage Stability Analysis. *Electric Power Systems Research, vol. 206, p. 107807, May 2022.*

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Implementing Six Sampling Techniques for Voltage Stability Analysis

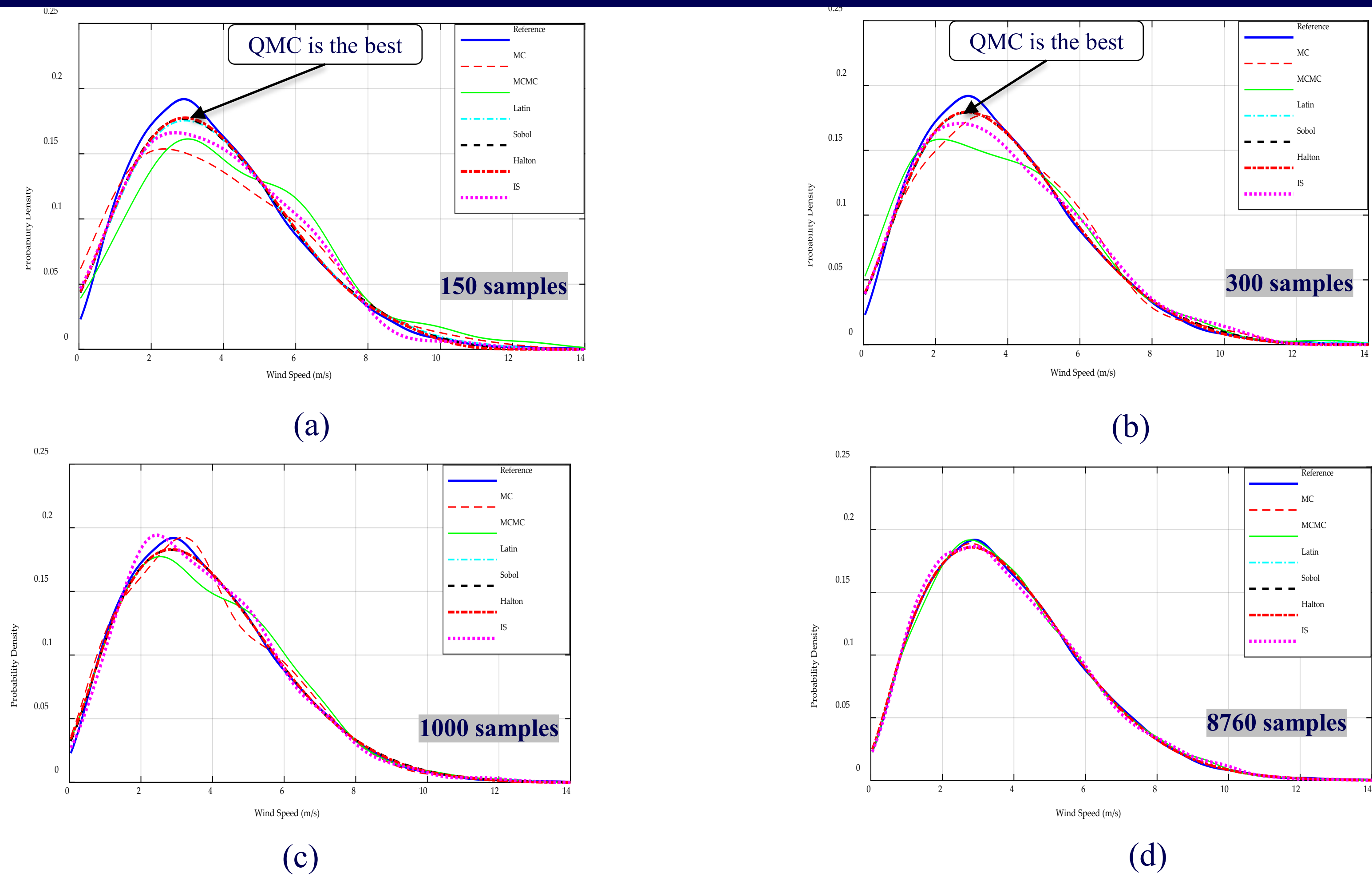

Fig 5: The pdf of the wind speed datasets generated by the six sampling techniques compared to the reference dataset: (a) 150 samples; (b) 300 samples; (c) 1000 samples; (d) 8760 samples

7. Alzubaidi, M., Hasan, K.N., Meegahapola, L. and Rahman, M.T., Identification of Efficient Sampling Techniques for Probabilistic Voltage Stability Analysis of Renewable-Rich Power Systems, *Energies, April 2021.*

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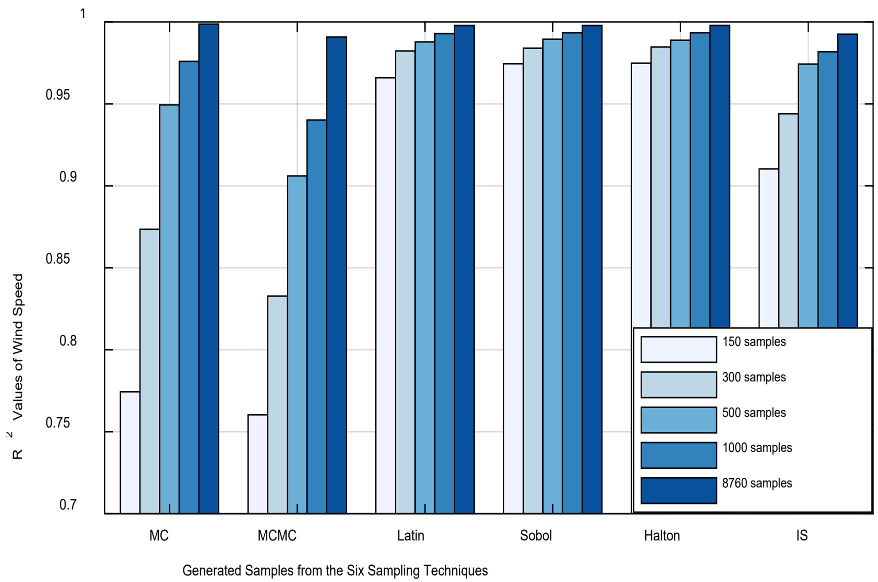
R^2 Criteria for Evaluating the Six Sampling Techniques



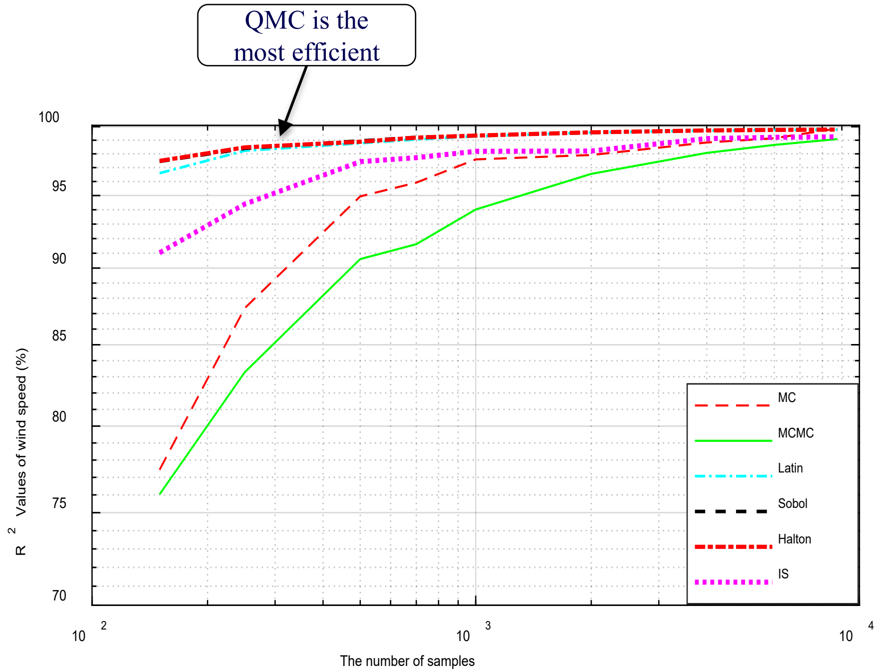


Fig 6: The coefficient of determination (R^2) values of 150, 300, 500, 1000, and 8760 generated samples from the six sampling techniques compared to the reference dataset.

Fig 7: The R^2 values vs. the number of the samples for the generated wind speed by using the six sampling techniques.

7. Alzubaidi, M., Hasan, K.N., Meegahapola, L. and Rahman, M.T., Identification of Efficient Sampling Techniques for Probabilistic Voltage Stability Analysis of Renewable-Rich Power Systems, *Energies, April 2021.*

Random Samples of MC and QMC

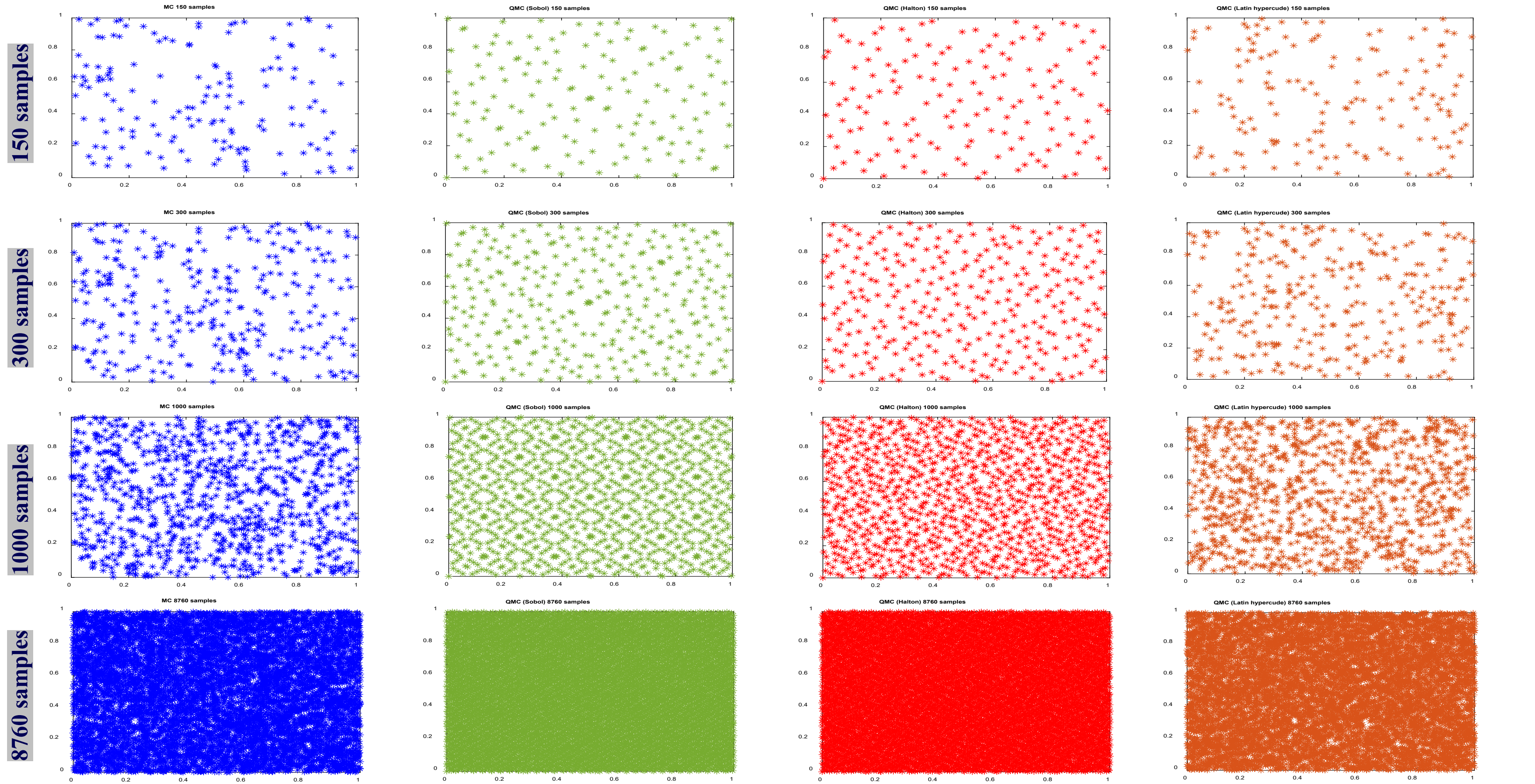


Fig 8: 150, 300, 1000, and 8760 random samples of MC method and three versions of QMC method (Sobol, Halton, and Latin hypercube).

7. Alzubaidi, M., Hasan, K.N., Meegahapola, L. and Rahman, M.T., Identification of Efficient Sampling Techniques for Probabilistic Voltage Stability Analysis of Renewable-Rich Power Systems, *Energies, April 2021.*

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Conclusions

- Based on the P-V and Q-V curve analysis, the voltage stability margin is significantly impacted by the uncertainties in the power network.
- Voltage stability needs to be investigated in the context of a probabilistic framework, which can accurately capture the variability of system parameters and characterize the voltage stability issues.

Future Works

- Proposition/development of an efficient sampling technique is an ongoing research area for their application in dynamic voltage stability.
- Identification and selection of suitable Copula function is an ongoing research area for considering the correlation among uncertain system parameters.

References

1. Saddelr H, National Energy Emissions Audit Report, 2020, Providing a comprehensive, up-to-date indication of trends in Australia's energy combustion emissions.
2. Hasan, K.N., Preece, R. and Milanović, J.V., 2019. Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation. Renewable and Sustainable Energy Reviews, 101, pp.168-180.
3. Milanović, J.V., 2017. Probabilistic stability analysis: the way forward for stability analysis of sustainable power systems. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 375(2100), p.20160296.
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Thank You

Q & A

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