Deployment of single-phase BESS inverters for voltage unbalance mitigation in distribution systems with high penetration of low-carbon technologies

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Overview

- Introduction
- Control of single-phase BESSs for voltage unbalance mitigation
- Probabilistic framework
- Simulation results
- Conclusion

Introduction – background

- Increase of novel single-phase loads and generating units (EVs and PVs) on distribution systems.
- Voltage unbalance (VU) ↑ due to their cumulative large power rating and variable output => power quality issues [1]:
  - ➢ Zero-sequence fundamental currents ↑
    - ❑ Neutral conductor overloading.
    - ❑ Transformer overheating.
  - ➢ Voltage rms values ↑↓.
  - ➢ Network losses ↑.
  - ➢ Effective utilization of line capacity ↓.

[1] Mexis, I.; Todeschini, G. Battery Energy Storage Systems in the United Kingdom: A Review of Current State-of-the-Art and Future Applications. *Energies* **2020**, *13*, 3616. https://doi.org/10.3390/en13143616

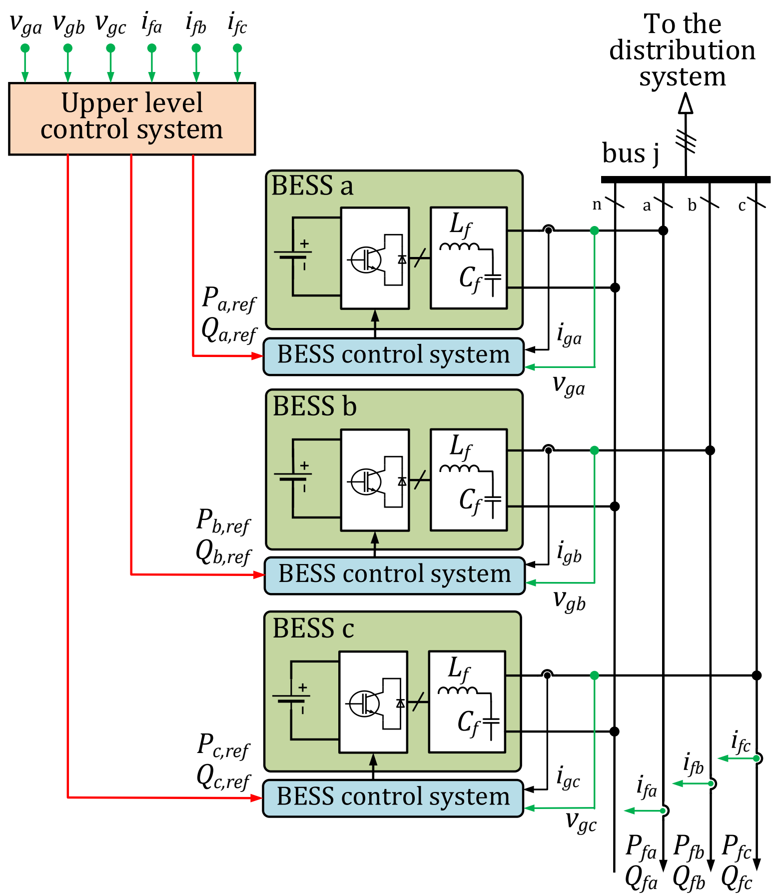
Introduction – VU mitigation methods

- Common solution: maintain load symmetry on the three phases => challenging in systems with large penetration of single-phase equipment.

- Active mitigation techniques: three-phase VSCs or CSCs (Series or shunt Active Filters, STATCOM devices etc.)

- Distributed Generation inverters: utilization of their available power rating, since not operating at full rating all the time.

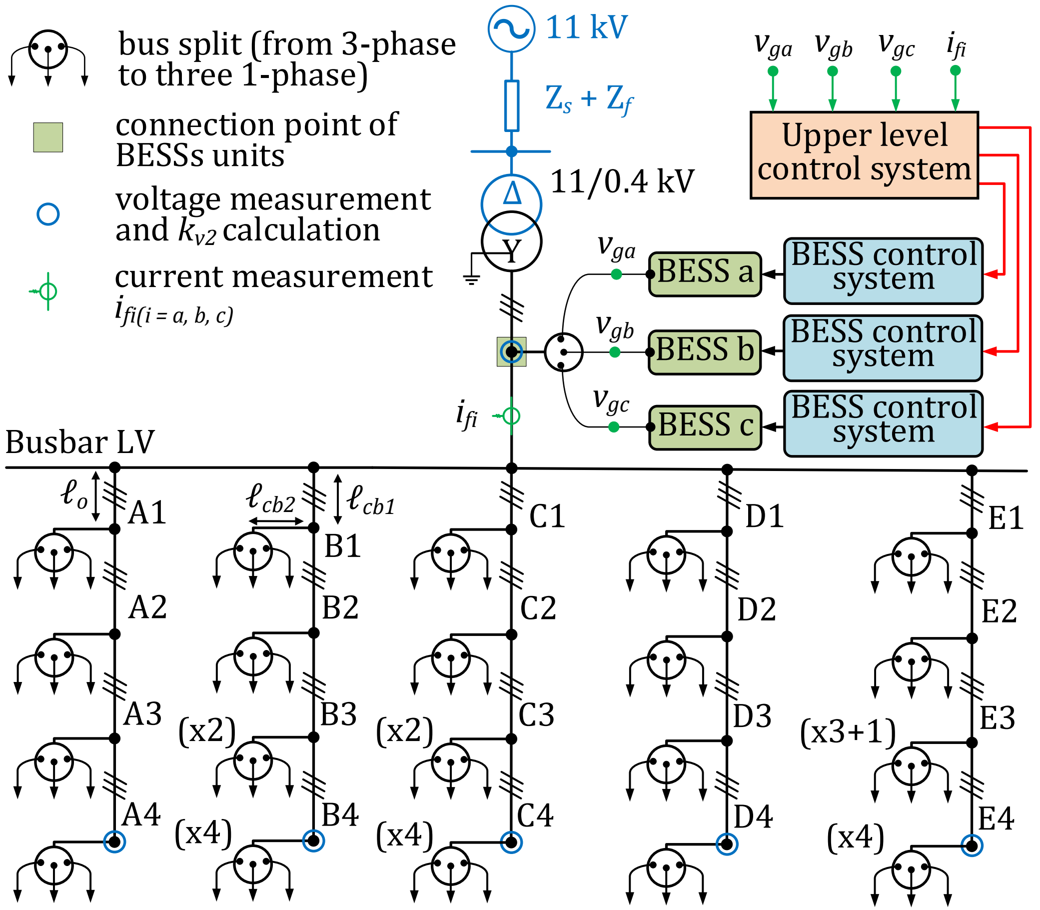
Control of single-phase BESSs for voltage unbalance mitigation



- Coordinated operation of three independent single-phase power converters [2].
  - <u>Upper level control system</u>: coordinate the three units by sending active and reactive power reference signals.
  - <u>BESS control system</u>: regulate active and reactive power exchange between each single-phase inverter and the grid.
- Modelled as controlled current sources in the probabilistic study – inject negative- and zero-sequence fundamental current components.
- Limit the voltage unbalance factor $k_{v2} = V_2 / V_1 < 2\%$ (based on IEC 61000-2-2) where V_2, V_1 the negative-sequence and positive-sequence voltage fundamental component.

[2] I. Mexis and G. Todeschini, "Voltage Unbalance Mitigation by Novel Control of BESS Single–phase Inverters," *2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, 2020, pp. 146-150, doi: 10.1109/ISGT-Europe47291.2020.9248770.

Probabilistic framework - overview



- Typical UK distribution system consisting of 100 single-phase loads - system parameters (equivalent impedance, transformer, line impedance) retrieved from [3].
- Data for the time-series profiles (residential demand and LCT) is retrieved from a public database [4], [5].
- Various penetration levels of low carbon technologies, i.e. single-phase PVs (P_{pv} = 1-4 kW) and EVs (P_{ev} = 3 kW), are considered.

[3] I.Hernando-Gil, H. Shi, F. Li, S. Djokic, and M. Lehtonen, "Evaluation of Fault Levels and Power Supply Network Impedances in 230/400 V 50 Hz Generic Distr. Syst.," IEEE Trans. on Power Delivery.
[4] Electricity North West, "Low Voltage Network Solutions (LVNS) - Project literature," https://www.enwl.co.uk/lvns.
[5] A. Navarro-Espinosa and L. F. Ochoa, "Probabilistic Impact Assessment of Low Carbon Technologies in LV Distribution Systems," IEEE Trans. on Power Systems.

Probabilistic framework - overview

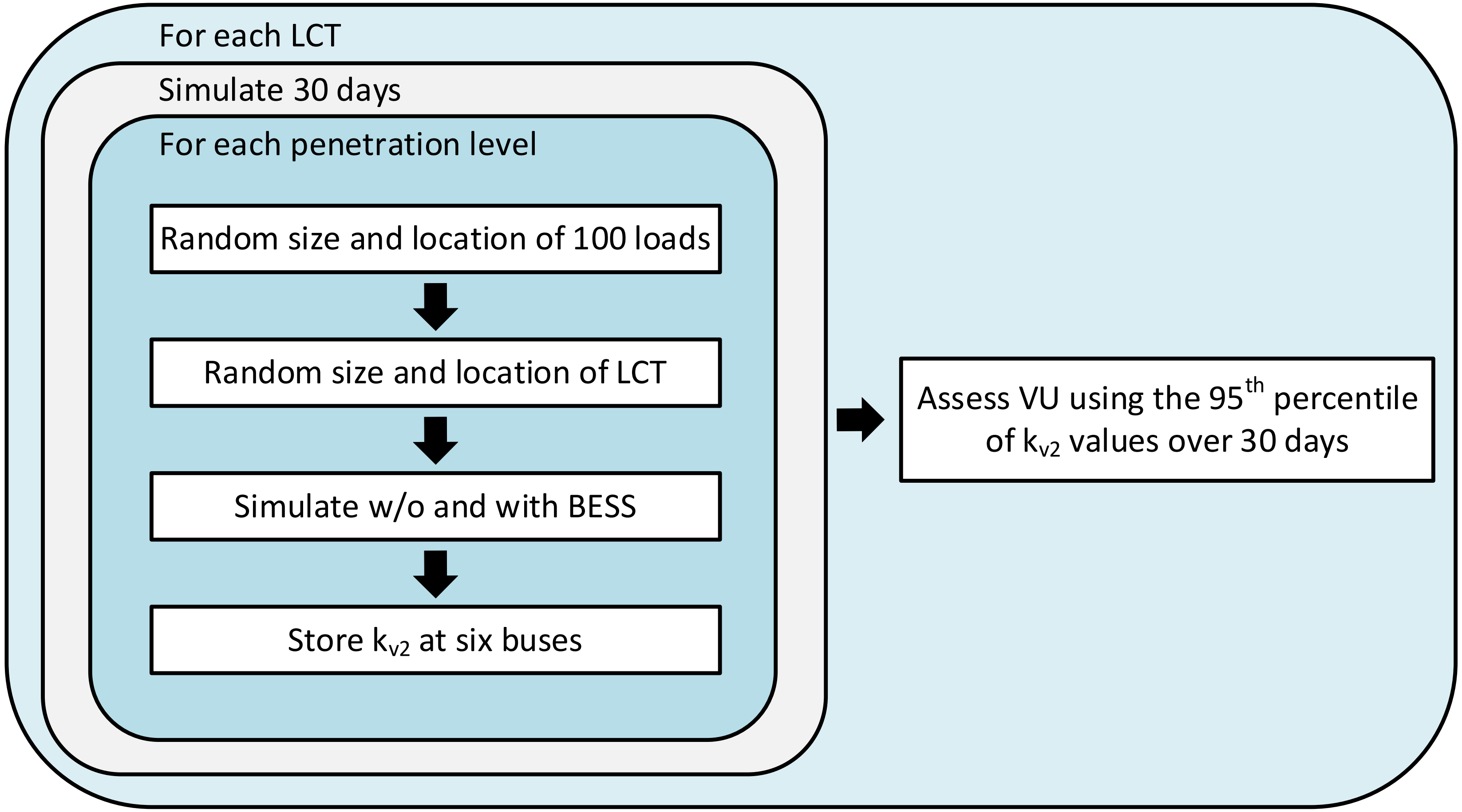
- Assess the impact of varying LCT penetration levels on VU in the distribution system:
  - busbar LV.
  - end of the distribution feeders.

Category	Simulated profiles	Time period [h]	Penetration levels	Number of days
PV	summer load, PVs	8:00 – 16:00	0%, 20%, 60%, 100%	30
EV	winter load, EVs	16:00 – 4:00	0%, 20%, 60%, 100%	30

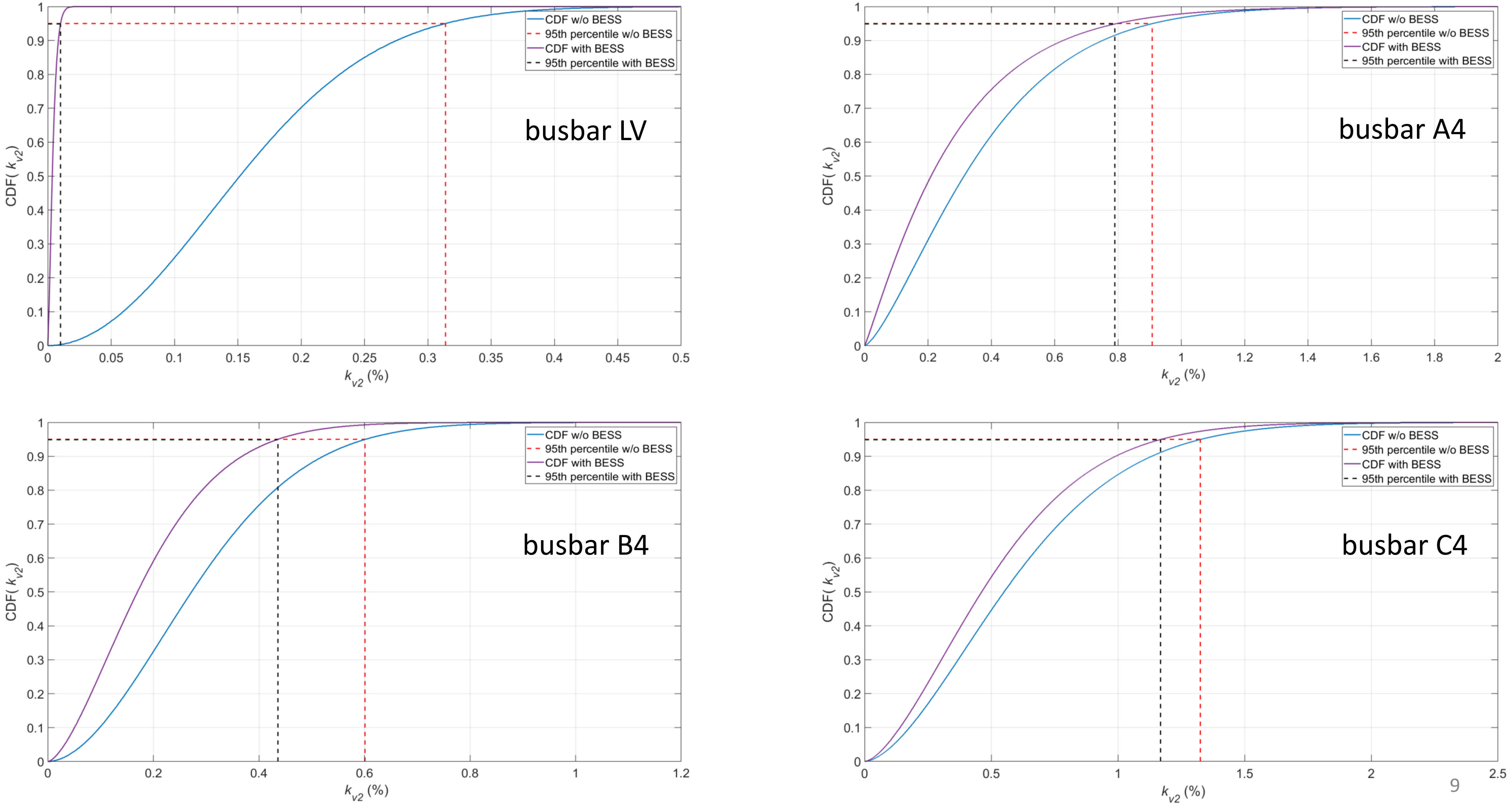
- For each day, randomization of the LCTs:
  1. Size
  2. Location

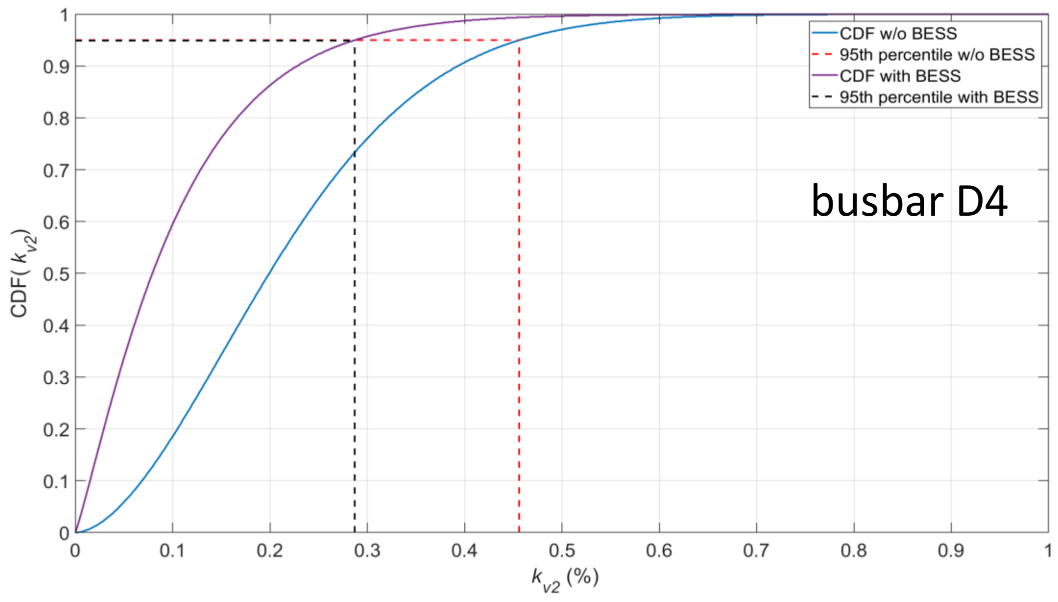
- For each busbar, VU levels are evaluated using the 95th percentile k_{v2} values (based on IEEE Std 1250-2018, VU < 2% for 95% of the 10-min samples in 1 week) and compared:
  1. without compensation
  2. with compensation (placed at busbar LV)

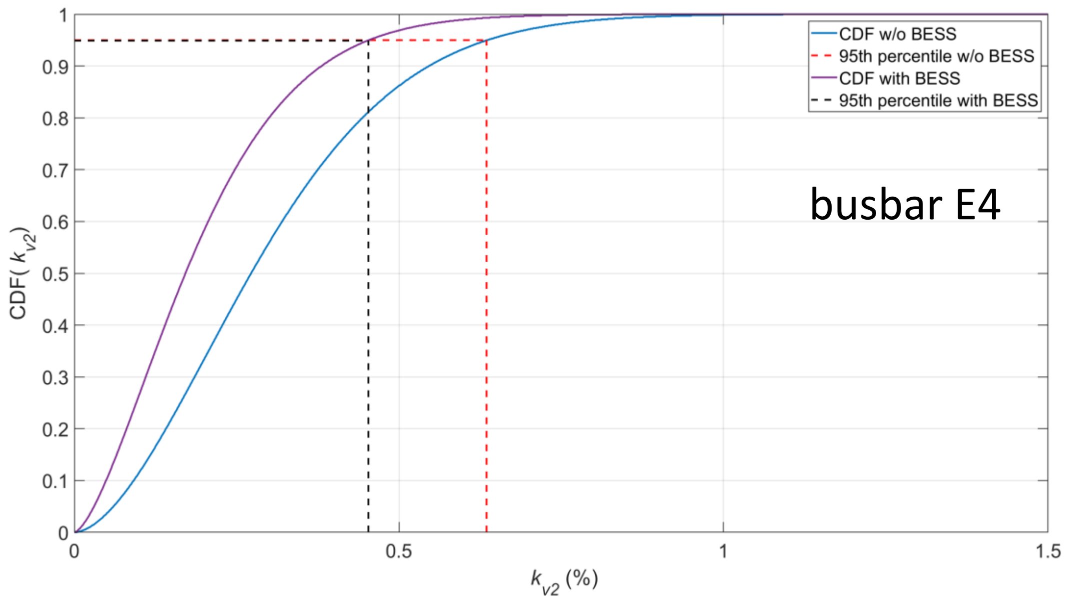
Probabilistic framework – flowchart



Simulation results for 0% PV

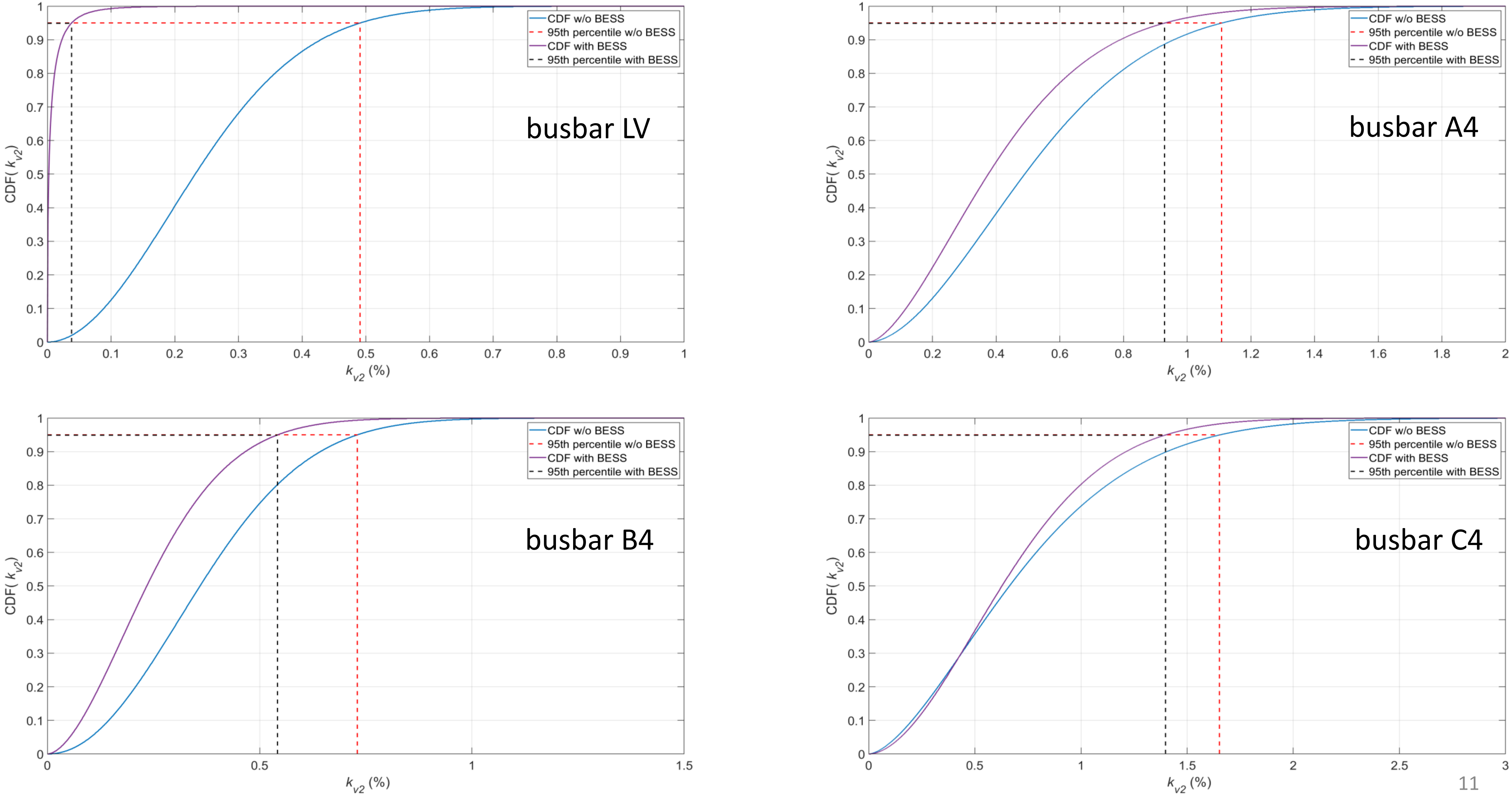


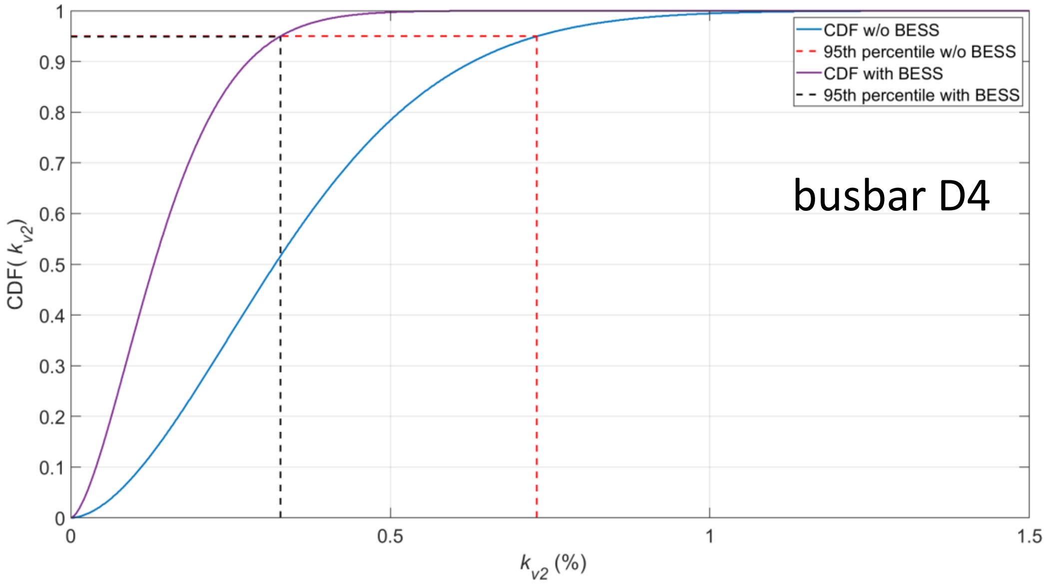


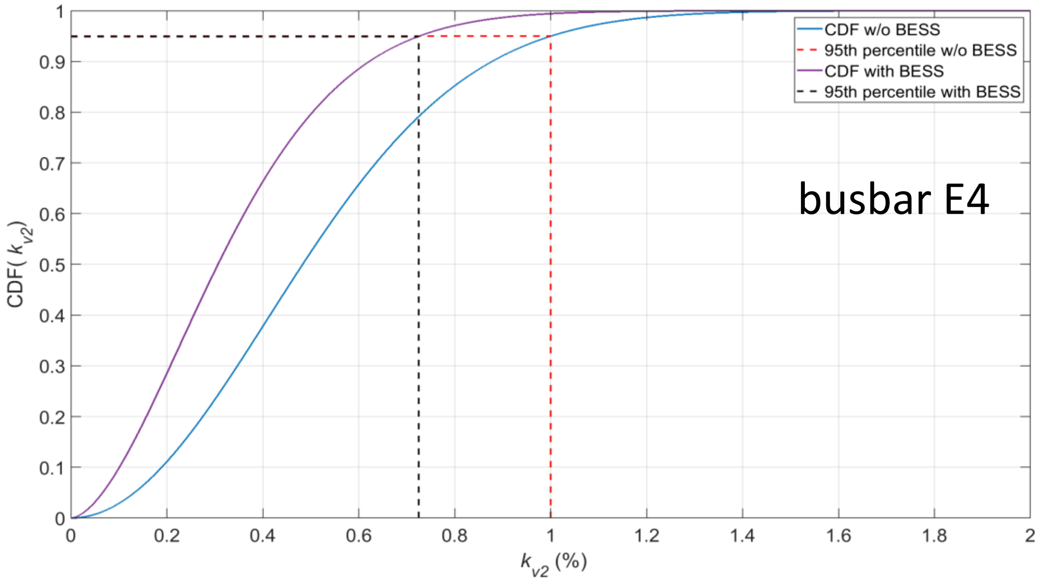


- The 95th percentile is well below the limit of 2% for all busbars, with and without compensation.
- The compensating units fully mitigate VU at busbar LV and reduce VU at the other busbars.
- Highest voltage unbalance levels at busbar C4, with k_{v2} = 1.4 %.

Simulation results for 20% PV

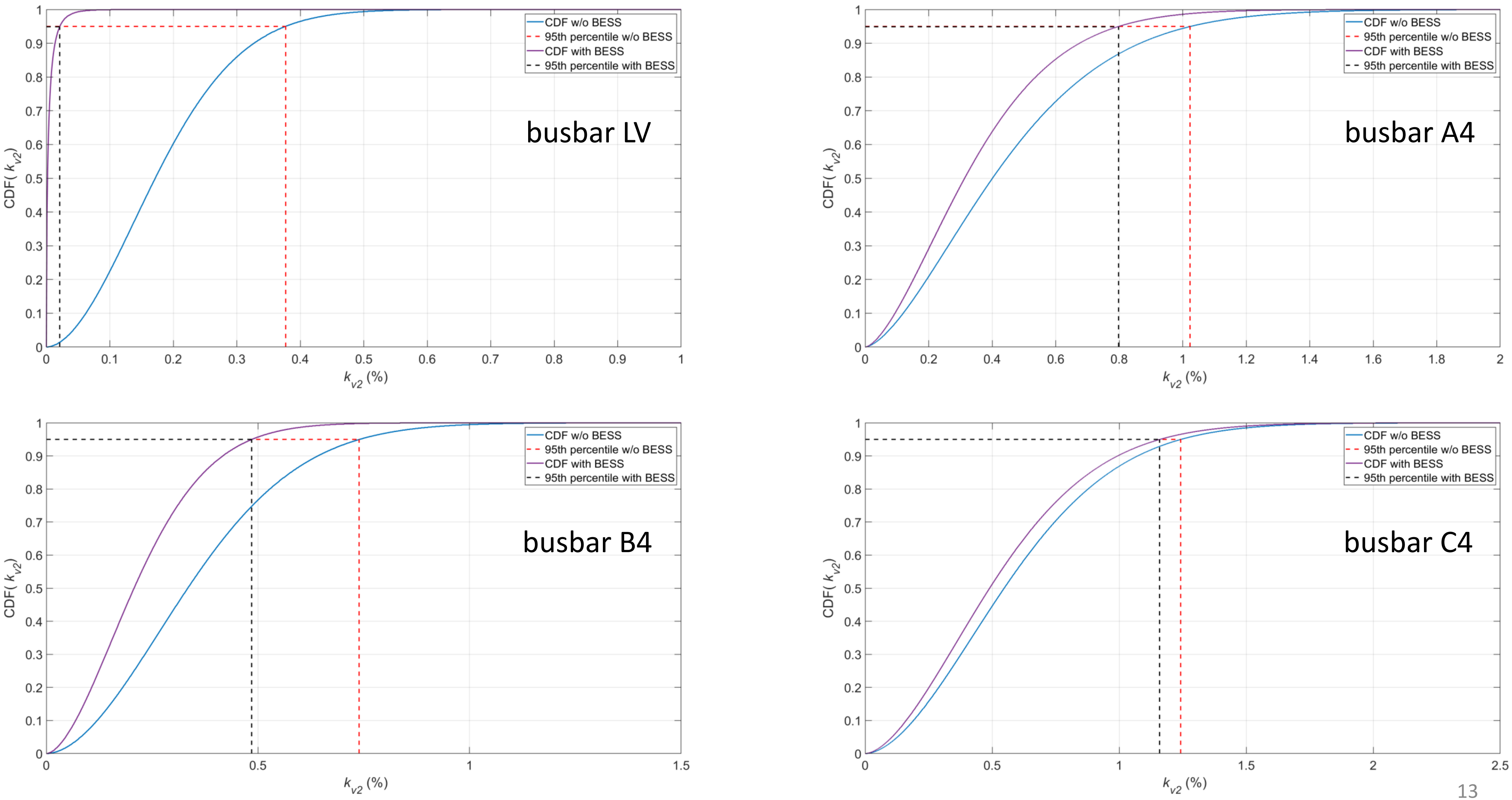


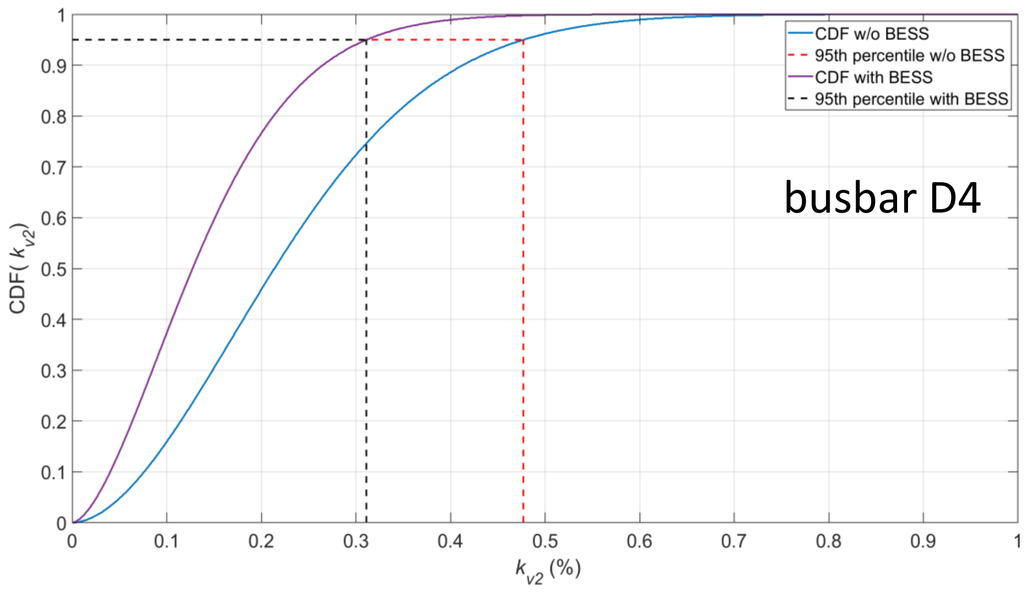


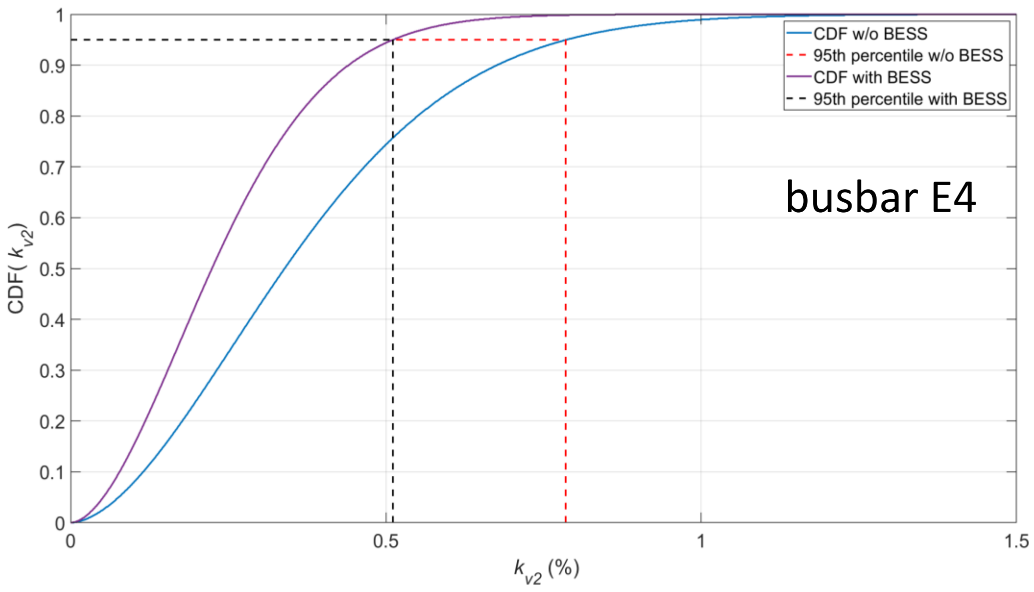


- Increase of the 95th percentile compared to the 0% PV penetration level.
- The compensating units mitigate VU at busbar LV and reduce VU at the other busbars.

Simulation results for 60% PV

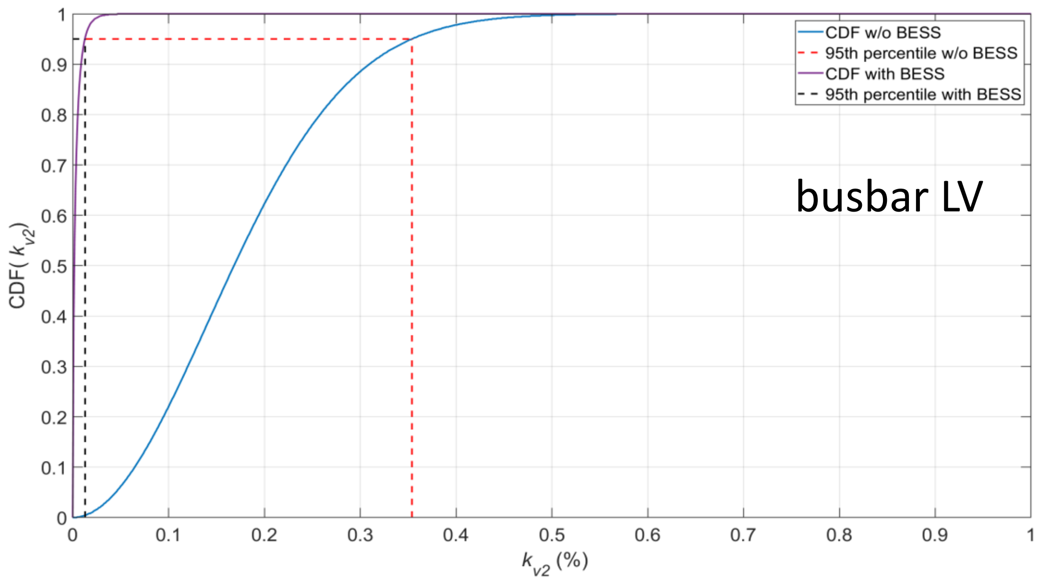


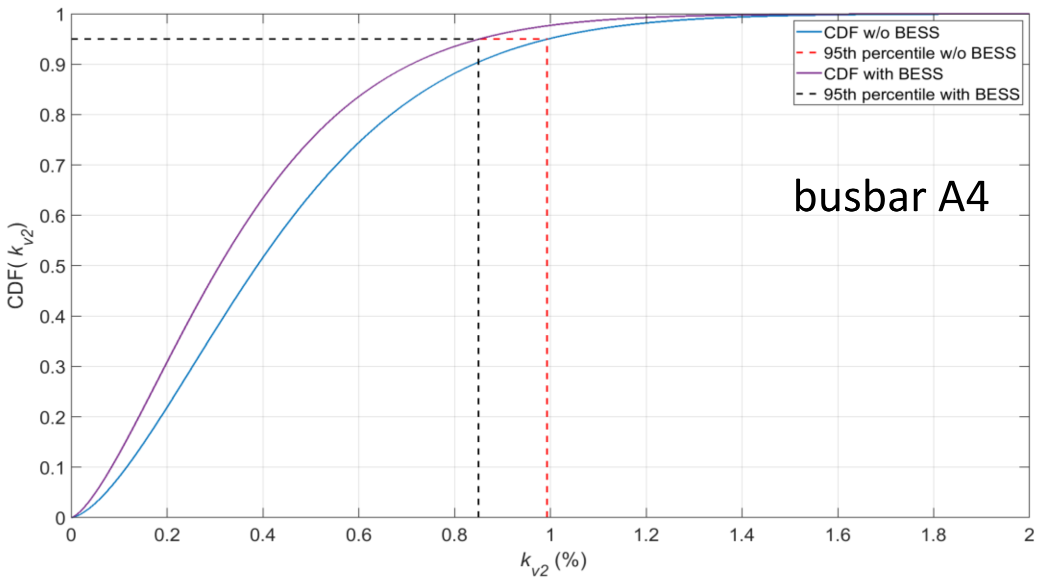


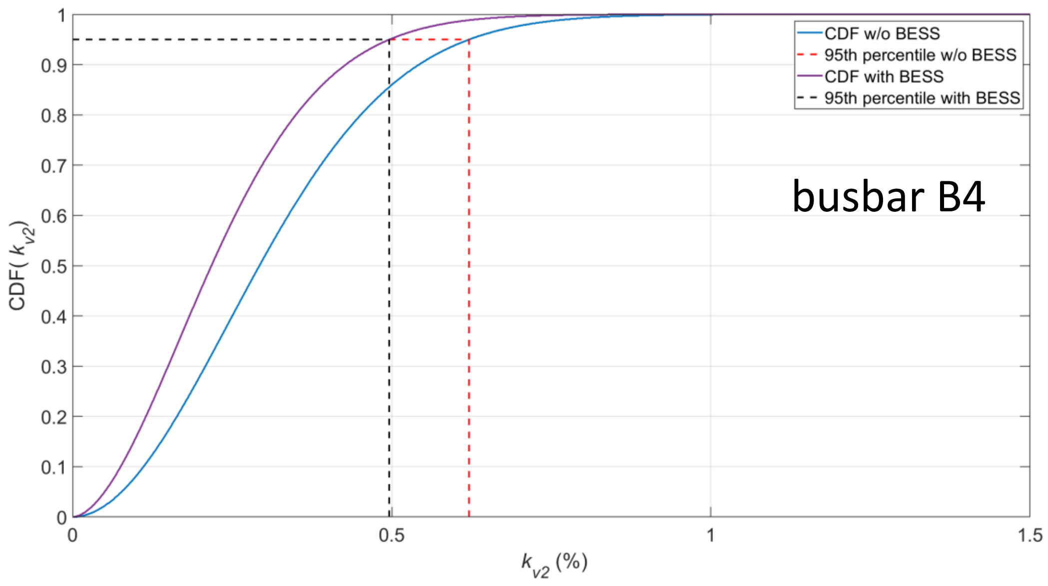


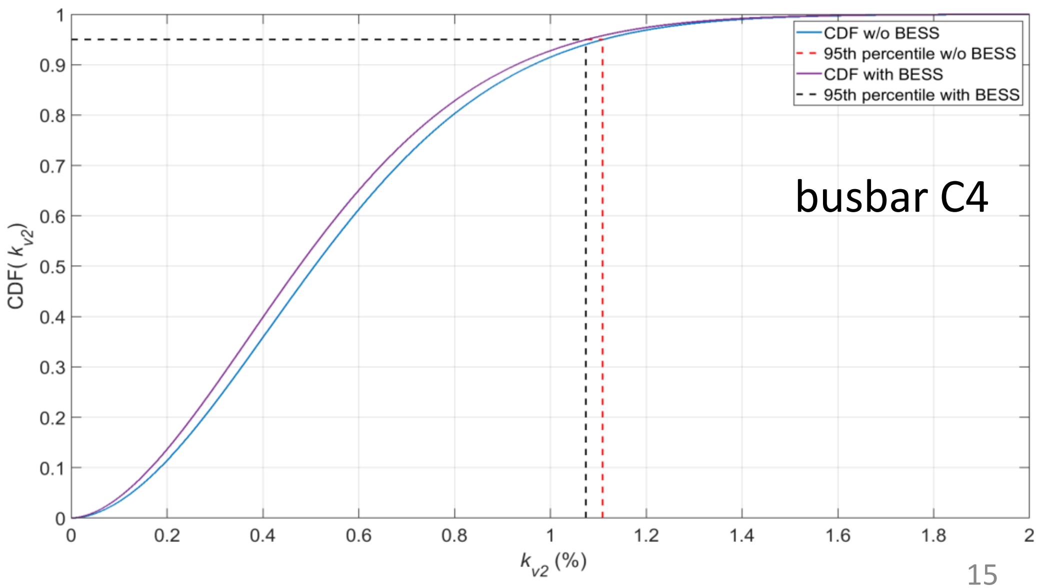
- The additional PVs have a smoothing effect, thus leading to decreased VU levels compared to the 20% PV penetration level.

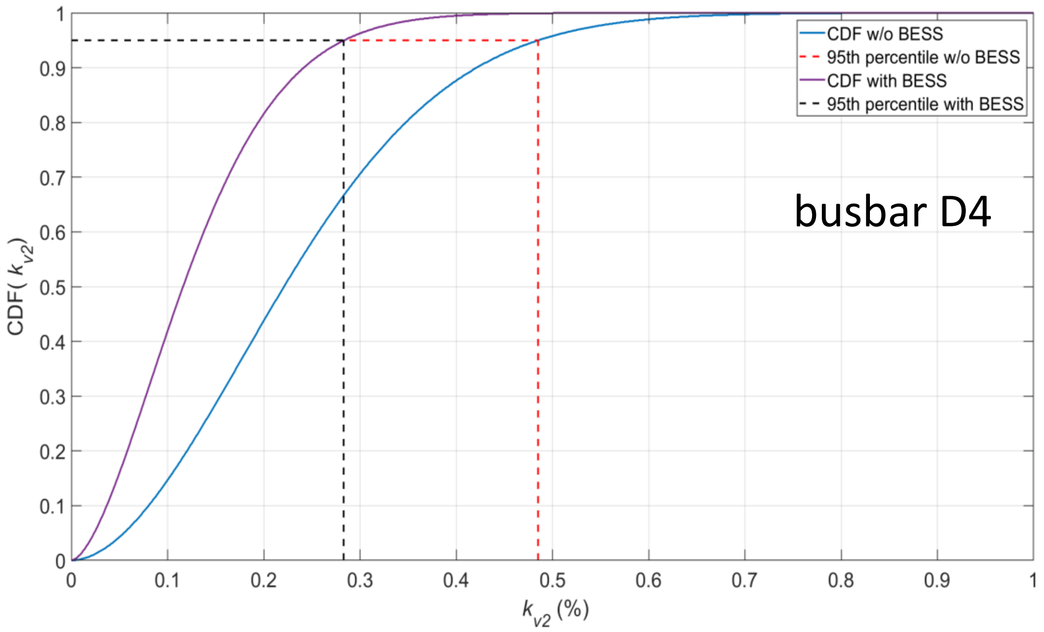
Simulation results for 100% PV

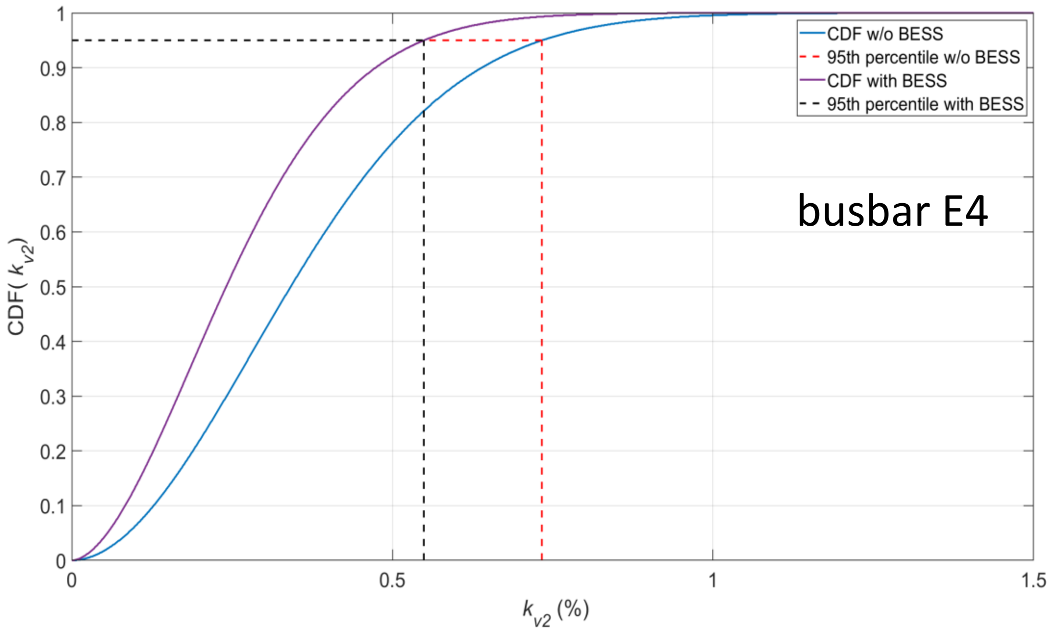












- Also in this case, the additional PVs have a smoothing effect, thus leading to decreased VU levels compared to the 60% PV penetration level.

Conclusion

- Higher VU was observed with increasing PV penetration, but above 60 % penetration, VU showed a steady decline.

- Effective mitigation of the VU levels by controlling the BESS units.

- 95th percentile is below the limit of 2% for all busbars, even without compensation.

- A cursory study involving 30 simulated days was performed. A much larger set of simulations is required to identify the probability distribution more accurately and assess the impact of varying LCT levels on VU.

Acknowledgments

- Dr Grazia Todeschini
- Dr Zhongfu Zhou

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