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Probabilistic Harmonic Performance Assessment in the Future UK Power Grid

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Outline

- Introduction
- Network Model
- Harmonic Source Modelling
- Probabilistic Harmonic Load Flow Results
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Introduction

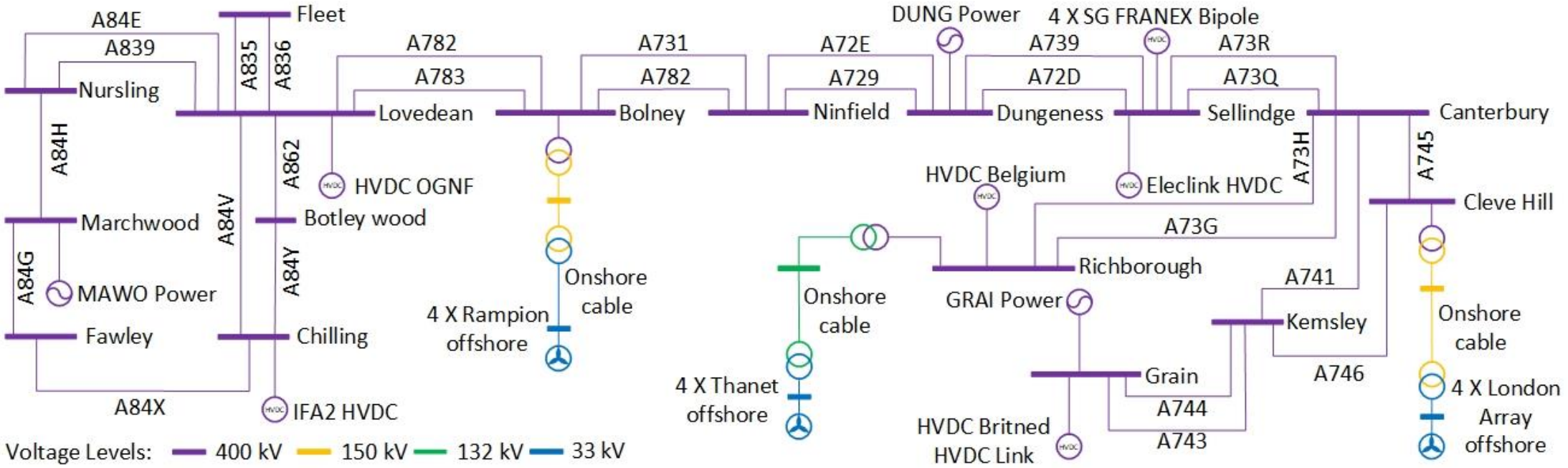
- Wind and solar generation will reach approximately 63% of total installed capacity in 2050 in the UK. The growing number of Inverter-based Resources (IBRs) may lead to adverse impacts on the system, such as poor power quality.

- An increase of harmonic levels has been highlighted by transmission and distribution system operators in recent years, and there is a concern that harmonics will grow to unacceptable levels in the future.

- It is necessary to investigate the impact of increasing IBRs on harmonic level on the future power grid to provide an insight on infrastructure reinforcement and thus managing the harmonics within standard.

Network Model - 2020

- A reduced network model has been developed, based on the full GB transmission and distribution system model provided by National Grid Transmission Owner (NGTO) UK.



Network Model - 2050

- A 2050 scenario was built by scaling the total installation capacity and power flow of 2020 scenario 3 times and 1.73 times, respectively, according to National Grid Future Energy Scenario 2021 Report.

Generation Installation, Peak Demand and Power Flow for 2020 and 2050 Scenario[1]					
Generation technology	2020 reduced network (GW)		2050 reduced network (GW)		Power flow ratio 2050/2020
	Installation	Power flow	Installation	Power flow	
Synchronous machine	3.77	2.12	3.44	2.94	1.38
HVDC Interconnectors	4.23	2.69	8.28	5.25	1.95
Solar PV	0.24	0.24	1.43	0.41	1.72
Offshore wind	1.38	0.93	12.32	1.77	1.90
Onshore wind	0.55	0.55	1.79	0.94	1.72
Energy storage	0.47	-0.47	4.62	-0.81	1.72
Total	10.64	6.06	31.89	10.50	1.73
Peak Demand	5.99		10.27		1.72

1: Z. Deng, G. Todeschini and K. L. Koo, “Harmonic Performance Assessment on Future UK Power System”, to be submitted.

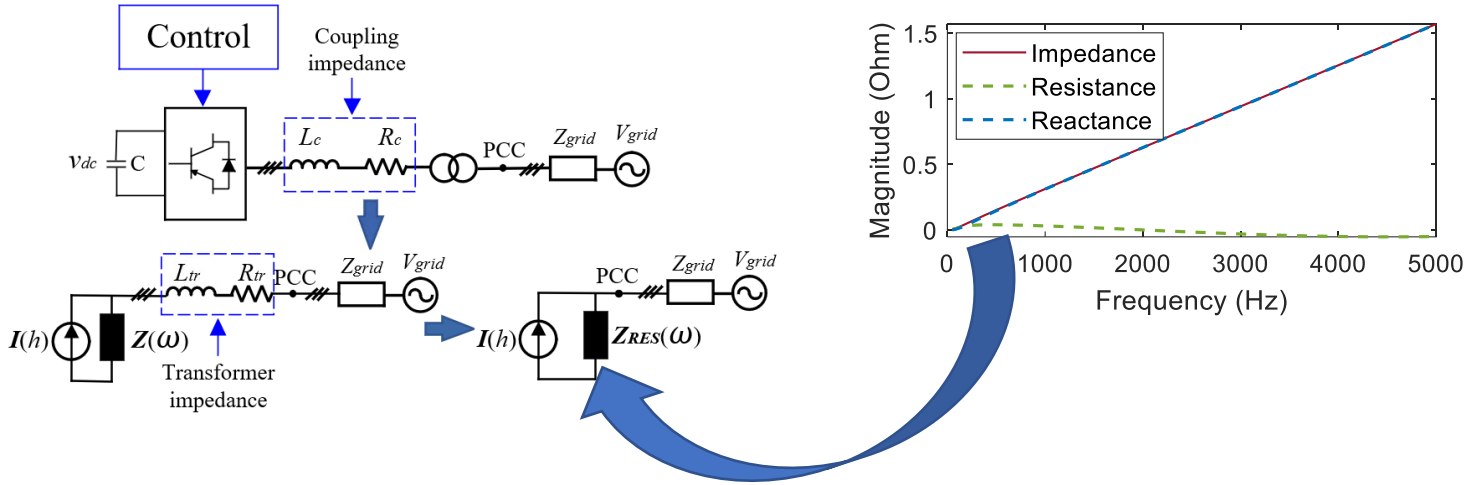
Modelling of Harmonic Injection

- An extensive work was carried out to collect harmonic injection magnitude data for loads and IBRs from the literature.

- The average collected data for different harmonic sources were applied to this work. The data can be retrieved from the project website:
- https://nms.kcl.ac.uk/future-power-grid/

Modelling of Inverter-Based Resources

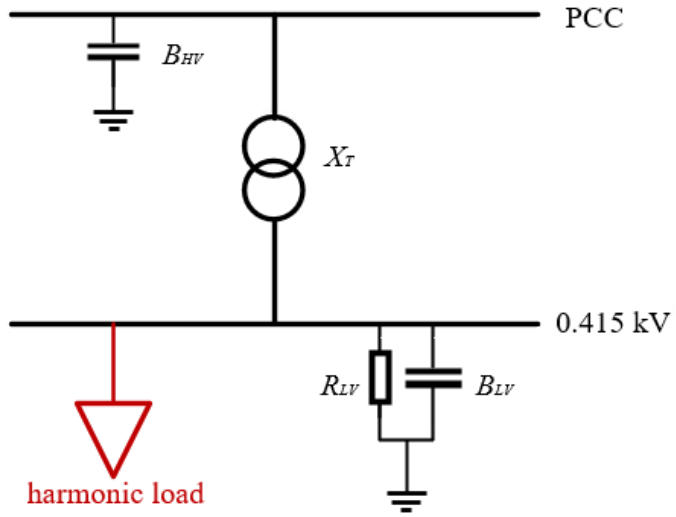
- In the practice, an Ideal Norton equivalent model (where the IBR impedance is neglected) is used for harmonic studies.
- In this project a linear frequency dependent impedance model[2] is used. It captures IBR control impedance and the step-up transformer impedance.



2: Z. Deng, G. Todeschini and K. L. Koo, "Comparison between Ideal and Frequency-dependent Norton Equivalent Model of Inverter-Based Resources for Harmonic Studies," *2021 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia)*, 2021, pp. 1-5.

Modelling of Distribution Network Loads

- Generally, the load is modelled as resistance and reactance connected either in series or in parallel based on the load demand (active and reactive power).
- The National Grid load model provides a better representation, which considers distribution transformers and cables.
- In this project, we added a harmonic source to the low voltage busbar to illustrated distribution system distortion[3].



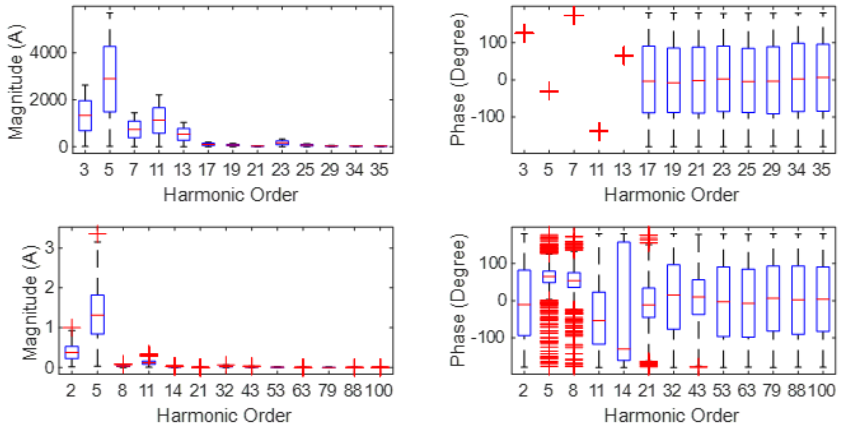
National Grid load model with harmonic injection[3]

3: G. Todeschini and Z. Deng, "Forecasting the impact of renewable energy sources on transmission grid power quality," *The 11th International Conference on Renewable Power Generation*, 2022, pp. 1-5 (submitted).

Probabilistic Harmonic Load Flow

- Probabilistic Harmonic Load Flows (PHLF) with 1,000 runs were performed on the 2020 and 2050 scenario.
- The harmonic injection magnitude and phase angles were considered as random variables.
- For harmonic magnitudes, these were uniformly random changed from 0 to 100%. For harmonic phase angles, these were changed as below:

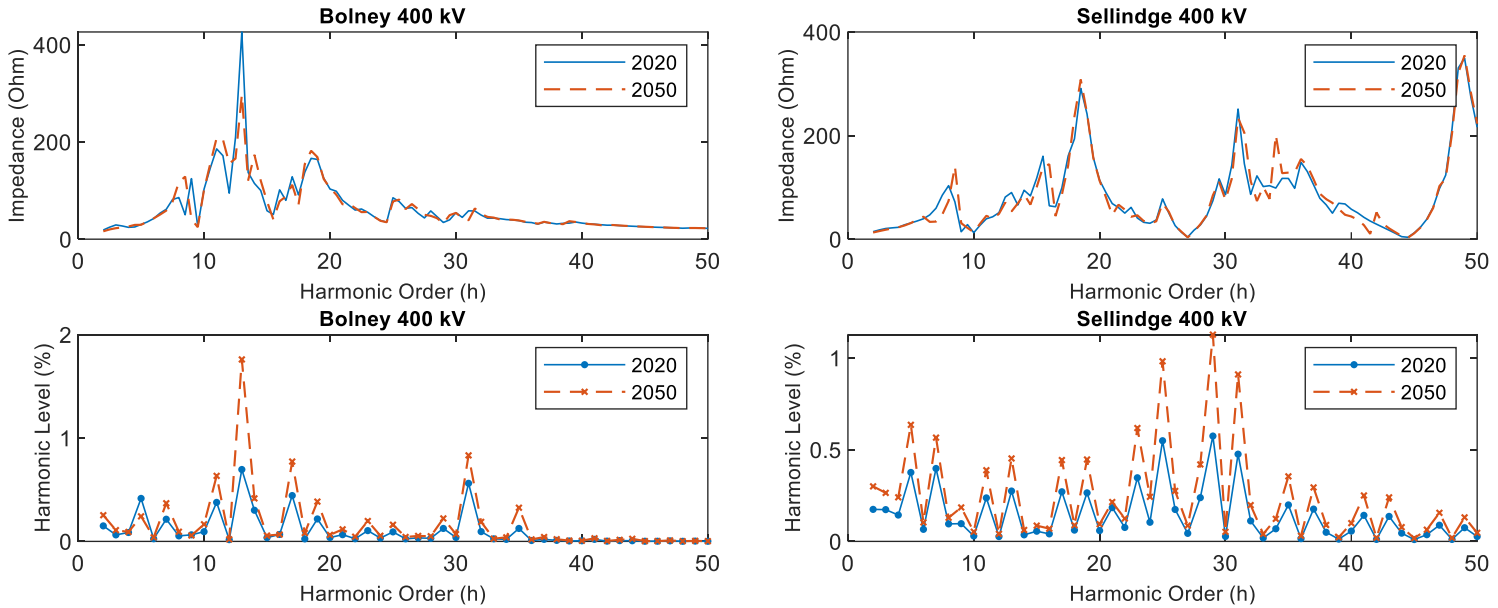
$$\varphi_h \in (h\varphi_1); \text{ for load if } h < 16; \text{ for IBR if } h < 50$$
$$\Delta\varphi_h \in (-180°, +180°); \text{ for load if } h \geq 16; \text{ for IBR if } h \geq 50$$



Harmonic current magnitude and phase distribution for Bolney load (top) and Ashford PV (bottom)[1]

Frequency Scans and Individual Harmonic Levels

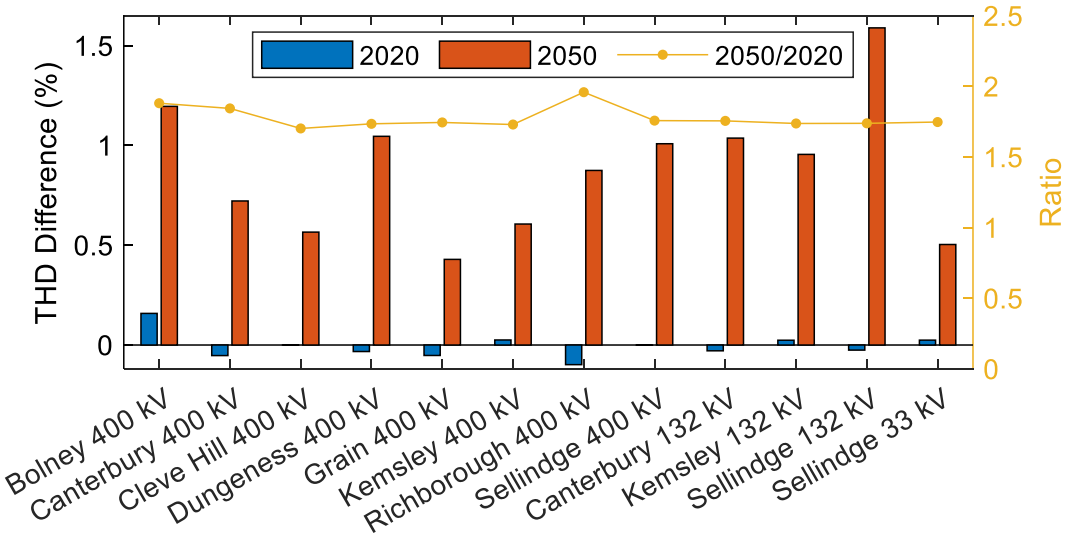
- The scans at the transmission side were similar for the 2020 and 2050 scenario. As a result, harmonic levels in 2050 linearly increased following the generation change ratio (1.72).



Frequency scans and 95th percentile individual harmonics at 400 kV busbars[1]

Voltage Total Harmonic Distortion

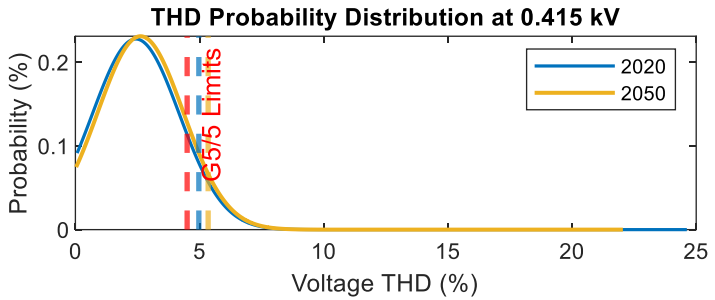
- The simulated 95th percentile voltage Total Harmonic Distortions (THDs) at measurement busbars for the 2020 and 2050 scenario were compared with the measurement data provided by NGTO.

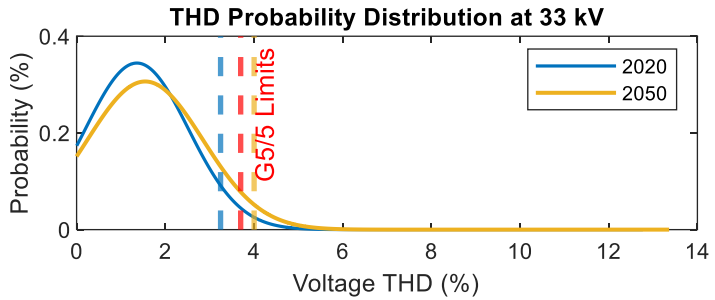


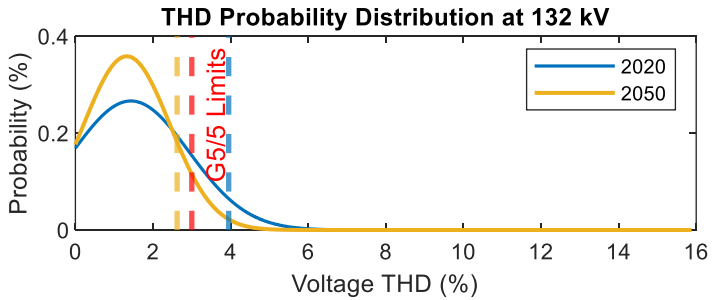
95th percentile voltage THDs at measurement busbars[1]

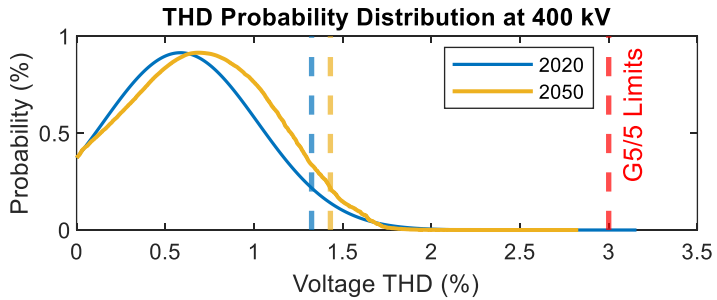
Voltage THD Probability Distributions

- The voltage THD probability distributions of 2020 and 2050 scenario obtained from 100 0.415 kV busbars, 116 33 kV busbars, 235 132 kV busbars and 92 400 kV busbars are shown below.



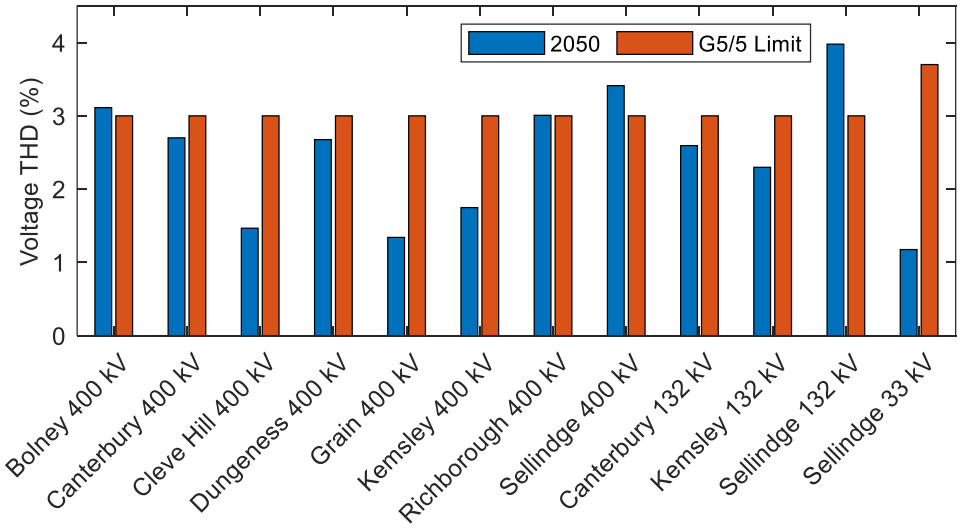






Worst Case

- By setting harmonic injection magnitudes to the average collected data, and harmonic injection phase angles in-phase, a worst case was studied by performing deterministic harmonic load flow.



Conclusions

- Under the assumptions made in this work, a general overview of harmonic levels in the future UK power grid is provided.

- The harmonic levels at the transmission side will be increased proportionally according to the power flow changes.

- Overall, the harmonic levels at transmission side are manageable and complied with standard. More attentions should be paid to the distribution network.

Acknowledgement

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Thank you so much for your attention!

https://nms.kcl.ac.uk/future-power-grid/

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