Fundamentals of Power Systems

Presidential Climate Commission (PCC)

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Research interests

- Geomagnetically induced currents (GICs)
- Power system stability & SSR
- Power System Inertia
- Renewable energy integration (wind and PV)
  - Reliable operation of various energy mix *(ROCOF, etc)*
  - Considerations for non-renewable energy-based generation
  - Decentralised generation and OPT
- Power definitions/theory
- Grid frequency disturbance
- BESS
- R&D of power systems measurements
  - TEI
  - Power system monitoring
  - GIC (DMM & neutral)

Fundamental concepts

- Electrical voltage: Electromotive force between two points
- Electrical current: Flow of electrons
- Electrical Power: Rate at which electrical energy is consumed

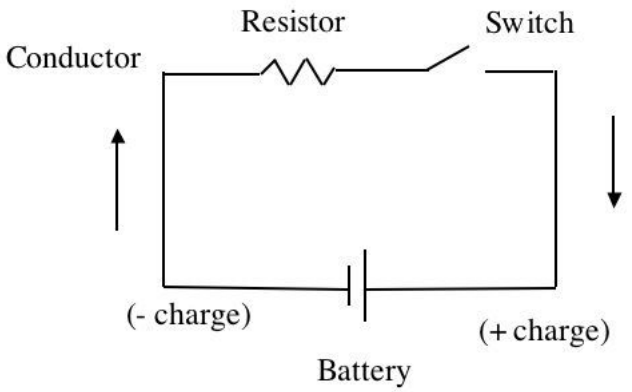


Fig. 1: Basic electrical circuit [1-a]

[1-a] https://za.pinterest.com/pin/413134965798848376/

Generalized perspective of complex systems

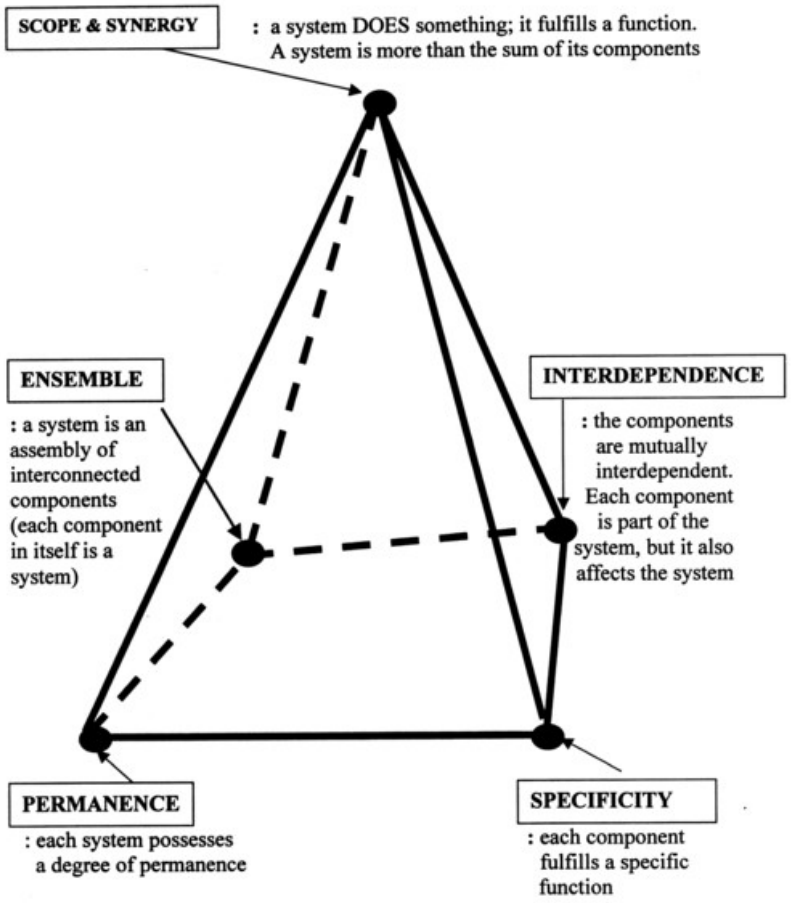


Fig. 1: Features of a power system. An example of a complex system [1]

[1] Lecture slides. EEE 4126F – Energy System & Grids II

Ensemble of interconnected components








Power system model- Without RE

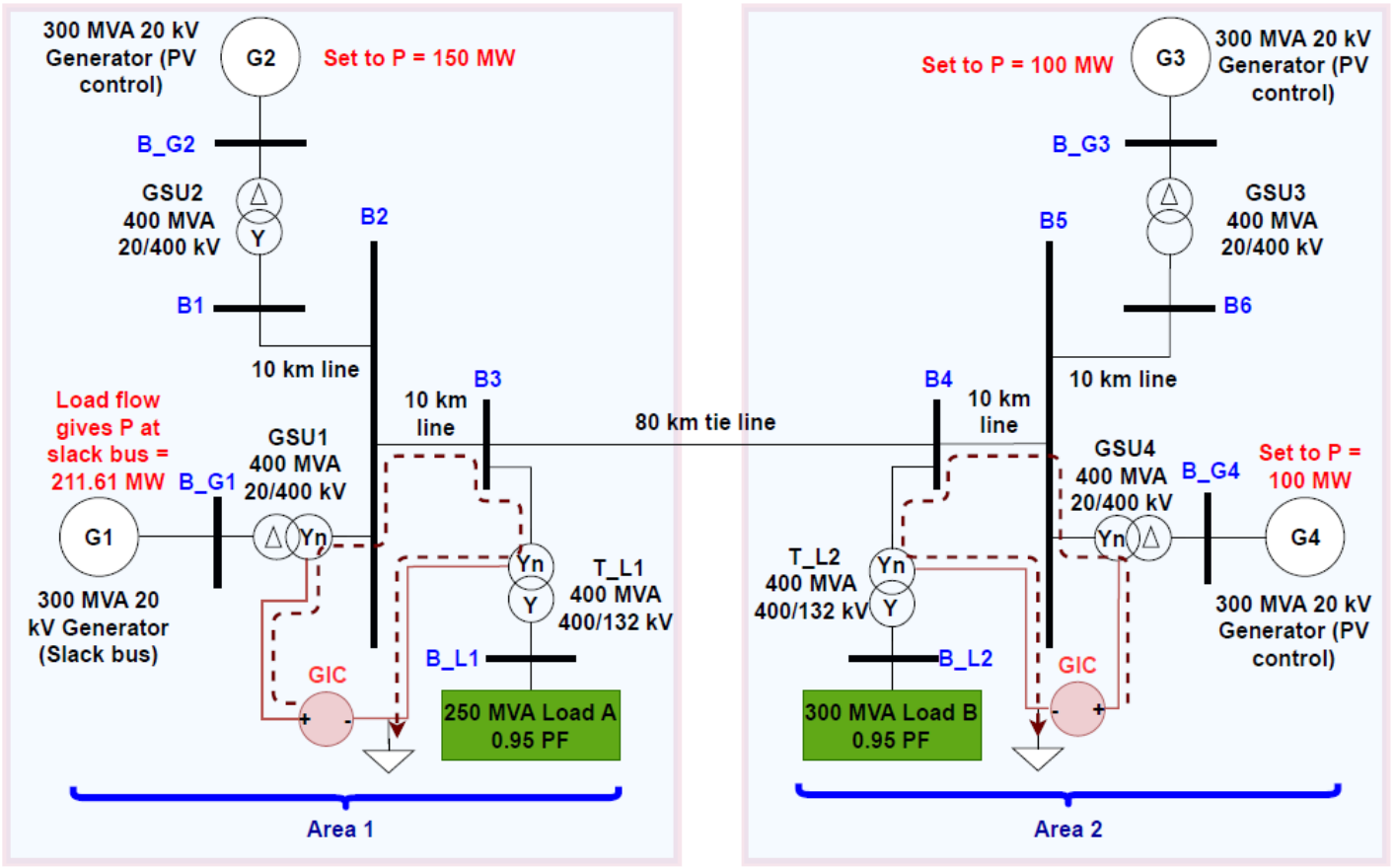


Fig. 2. Multi-generation power system model [2]

[2] P. Jankee, D. T. O. Oyedokun and H. K. Chisepo, "Dynamic Response of Power Systems With Real GICs: Impact on Generator Excitation Control," in *IEEE Transactions on Power Delivery*, vol. 37, no. 6, pp. 4911-4922, Dec. 2022, doi: 10.1109/TPWRD.2022.3162881

Typical Power system model with RE

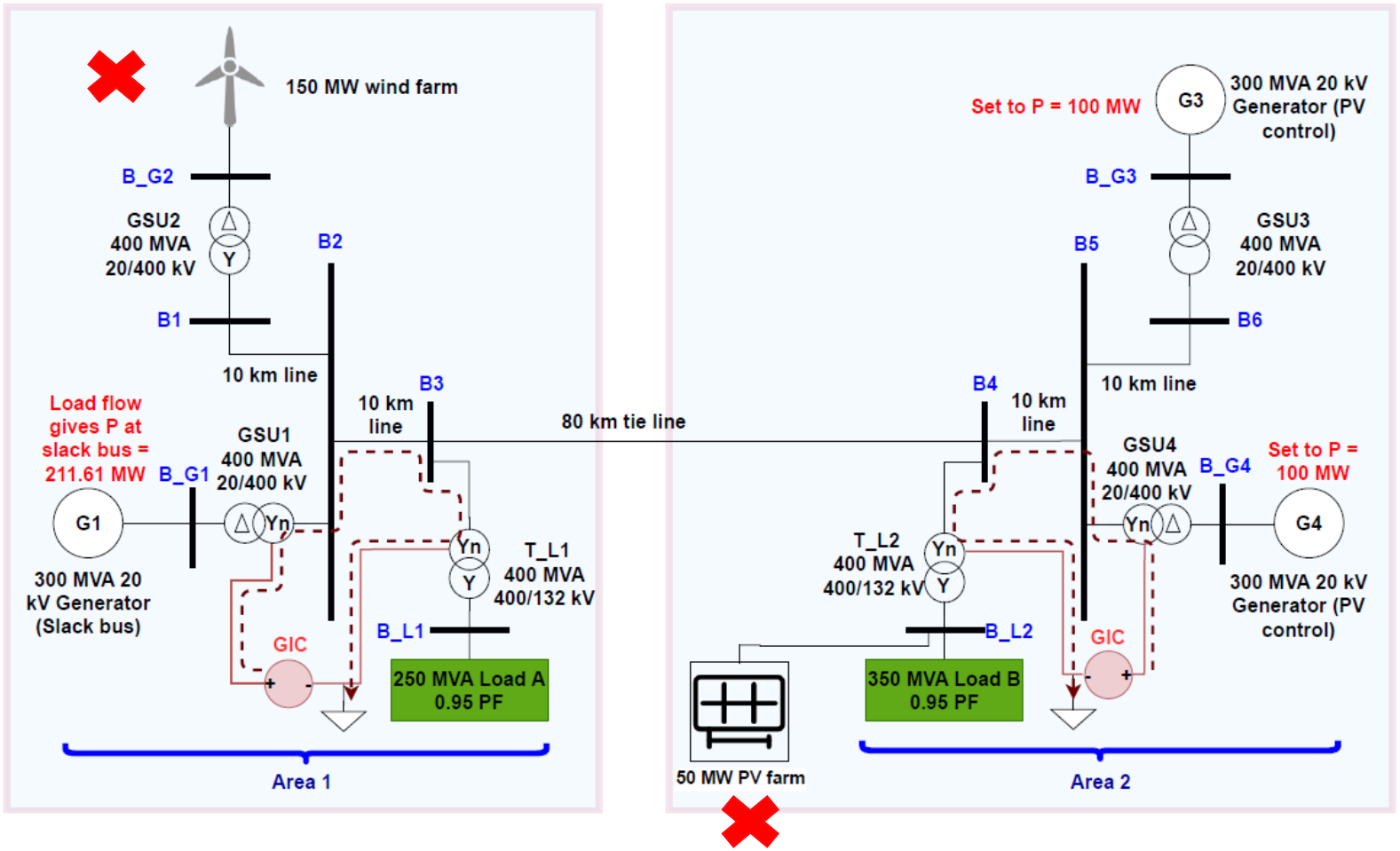
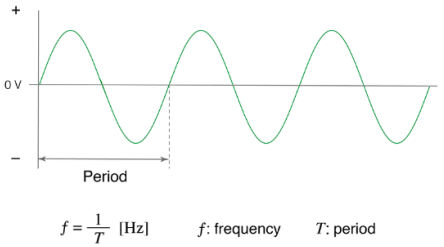


Fig. 3. Multi-generation power system model. Adapted from [2]

[2] P. Jankee, D. T. O. Oyedokun and H. K. Chisepo, "Dynamic Response of Power Systems With Real GICs: Impact on Generator Excitation Control," in *IEEE Transactions on Power Delivery*, vol. 37, no. 6, pp. 4911-4922, Dec. 2022, doi: 10.1109/TPWRD.2022.3162881

Power System Frequency

- A parameter that has no physical existence [3]
- It is a property of a signal
- Measure of oscillation [4]
- Number cycles in one second (unit Hz)
- Representative of something physical such as a machine speed [3]



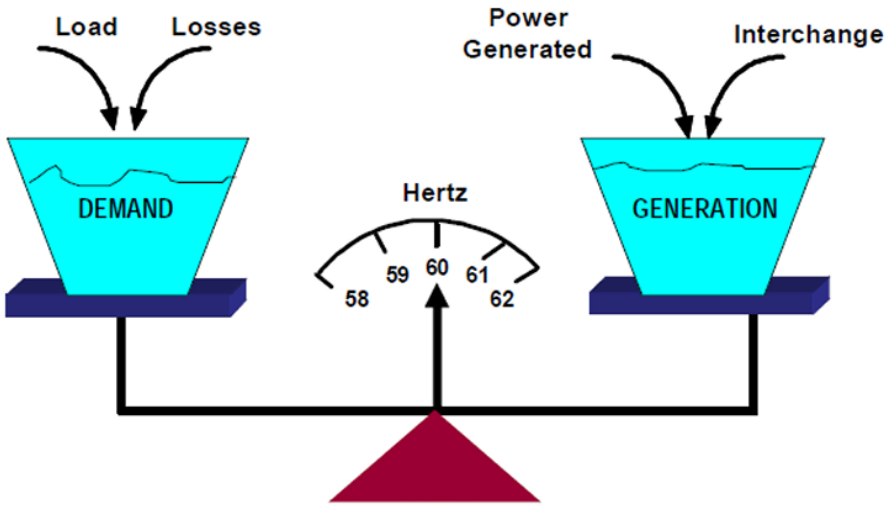


Fig. 4: Illustration of balance between demand and generation Frequency [5]

[3] H. Kirkham, W. Dickerson and A. Phadke, "Defining Power System Frequency," *2018 IEEE Power & Energy Society General Meeting (PESGM)*, Portland, OR, USA, 2018, pp. 1-5, doi: 10.1109/PESGM.2018.8586583.

[4] Bevrani, Hassan, Hêmin Golpîra, Arturo Román Messina, Nikos Hatziargyriou, Federico Milano, and Toshifumi Ise. "Power system frequency control: An updated review of current solutions and new challenges." *Electric Power Systems Research* 194 (2021): 107114.

[5] http://www.ee.unlv.edu/~eebag/4.pdf

Power System Stability

- Keep the lights on
- Keep them bright enough
- Keep them steady
- Reliably ride through contingencies

Fig. 5: Illustration load requirement Vs available power to keep lights on [6]

Definition:

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. [7]

[6] https://fineartamerica.com/featured/5-leadership-hanging-lightbulb-allan-swart.html?product=poster

[7] N. Hatziargyriou et al., "Definition and Classification of Power System Stability – Revisited & Extended," in IEEE Transactions on Power Systems, vol. 36, no. 4, pp. 3271-3281, July 2021, doi: 10.1109/TPWRS.2020.3041774.

Classification of Power System Stability

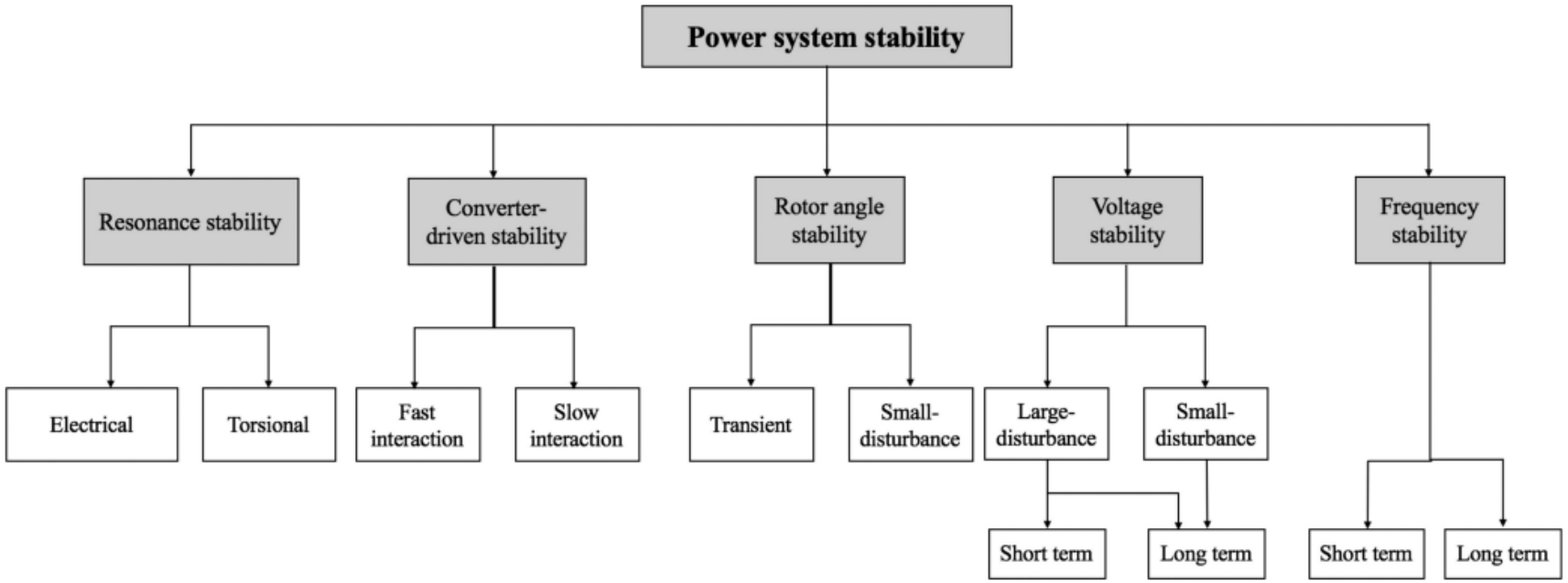


Fig. 6: Classification of Power System Stability [7]

Power System Frequency Stability

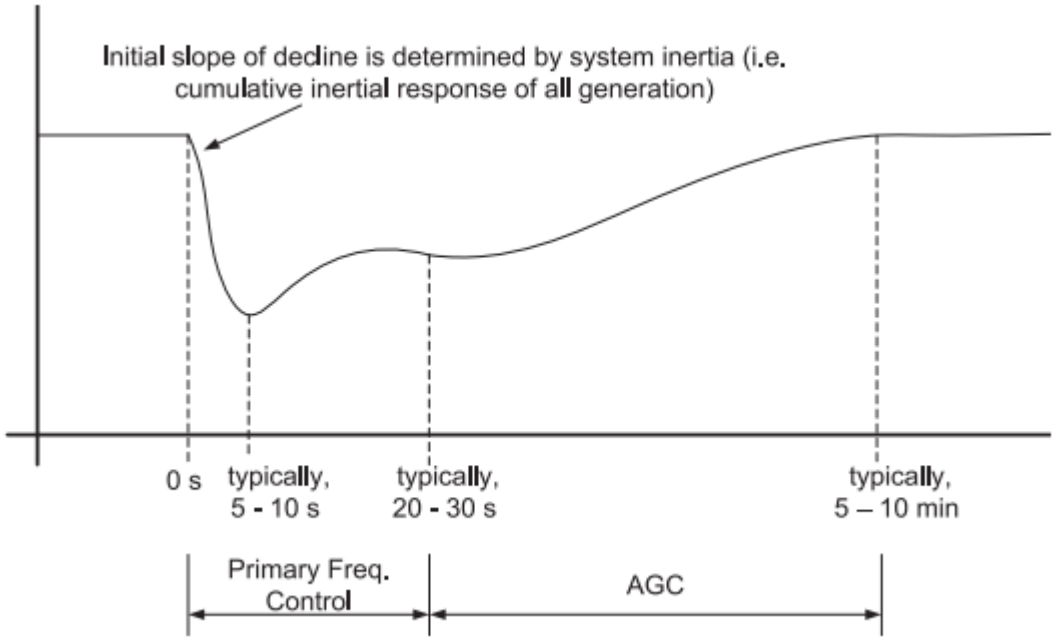


Fig.7: An illustration of power system frequency response to a major loss of generation. (IEEE © 2013)

Variability in RE availability

Case in point: 24 hrs solar PV vs load profile

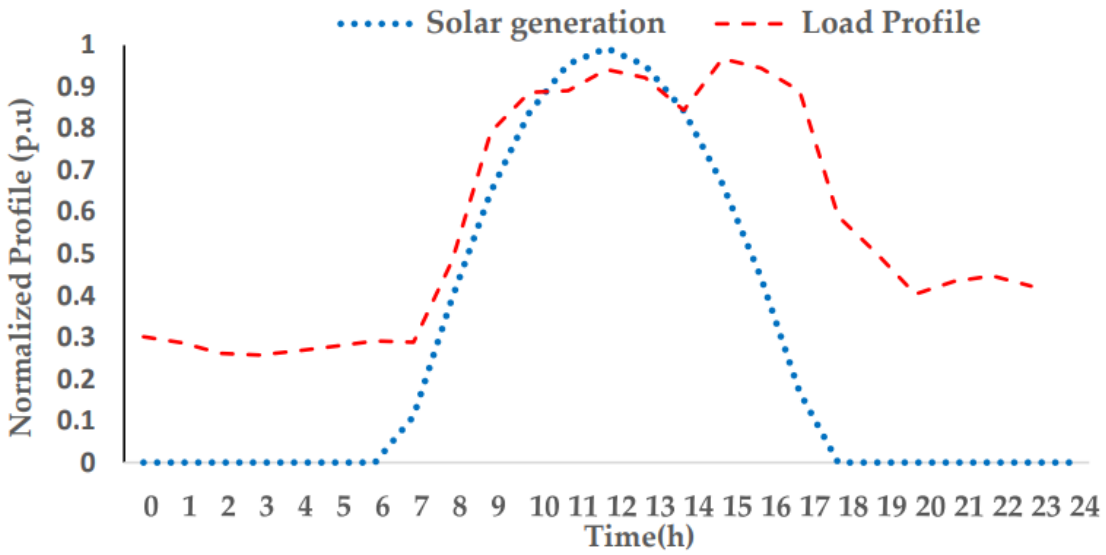


Fig. 8: Normalized load consumption and solar PV generation profile

[8] M. R. Maghami, J. Pasupuleti, and C. M. Ling, "A Static and Dynamic Analysis of Photovoltaic Penetration into MV Distribution Network," *Processes*, vol. 11, no. 4, p. 1172, Apr. 2023, doi: 10.3390/pr11041172.

Power Quality

- Measure of electrical current and voltage relative to ideal/expected conditions
  - Voltage level, voltage spikes, and variations, voltage dips/sags
  - Harmonic distortions

- Causes: Overloads, insufficient reactive power support, protection malfunction, harmonics, network inadequacy, etc

- Impact: Possible equipment (grid + consumer) damage

Power System Reliability

RELIABILITY = ADEQUACY + SECURITY

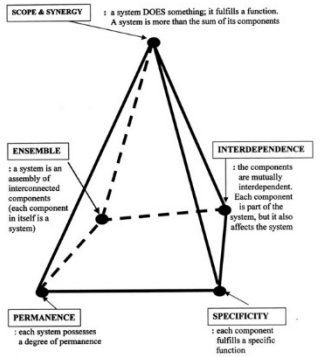
Power system reliability describes the ability of the system to perform its intended function.

ADEQUACY –describes the ability of the power system to:

- Supply load demand
- Satisfy operational constraints (considering scheduled outages and unscheduled outages that could reasonably be expected).

SECURITY – describes the ability of the power system to withstand a pre-determined set of disturbances.

Fig. 9: Definition of Power system reliability [1]



Adequacy

System Adequacy

- Ability of the power system to convert primary fuels into electricity and transfer it to end-user in a sustainable manner

Generation Adequacy

- Availability of enough generating (and import) capacity to meet demand

Adequacy Cont'd

Network Adequacy

Implies adequacy of:

- Transmission network
- Distribution network
- Cross-border interconnections

Market Adequacy

- Ability of the market to establish and maintain an efficient link between producers and consumers of electricity.

Security

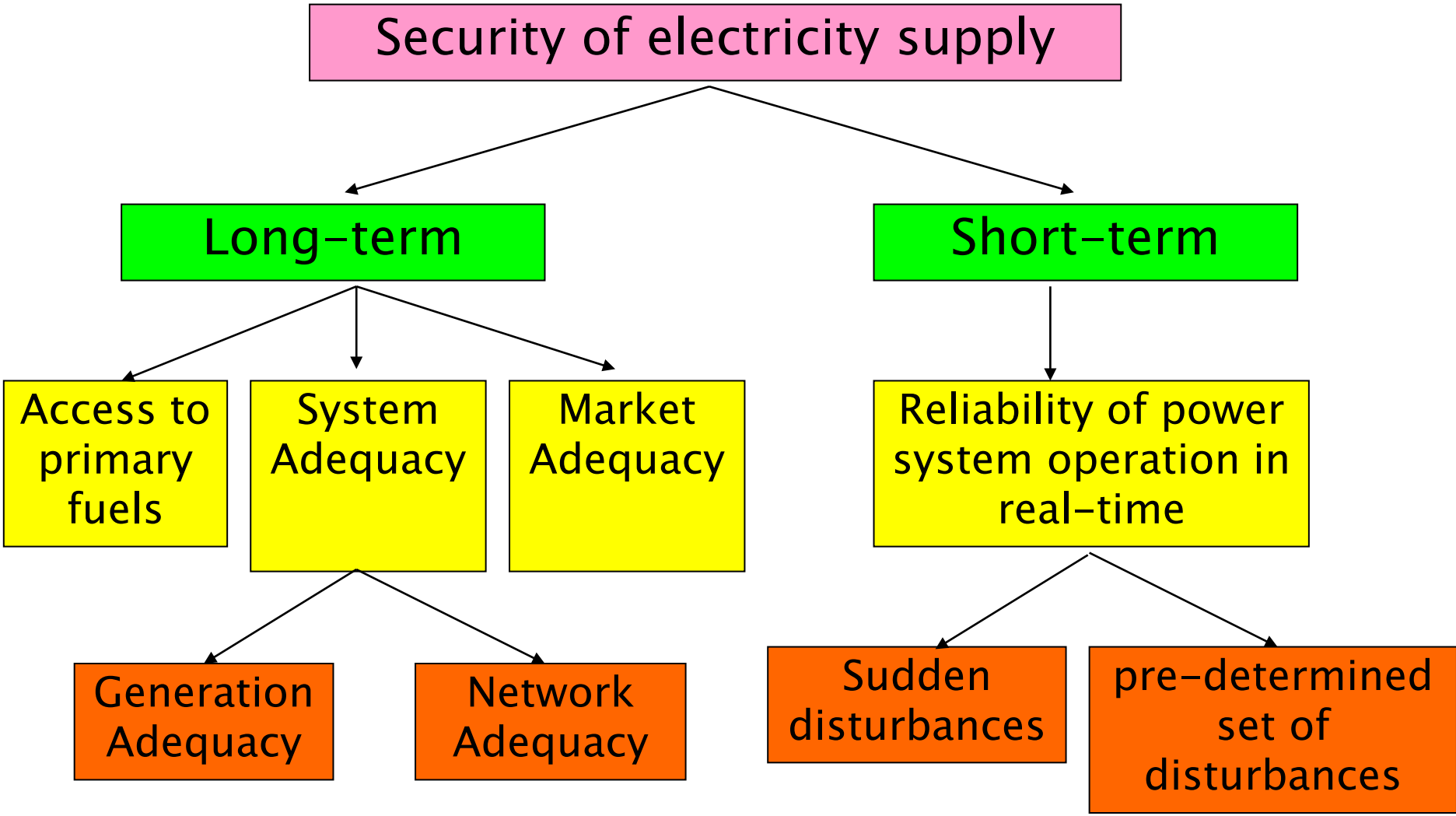
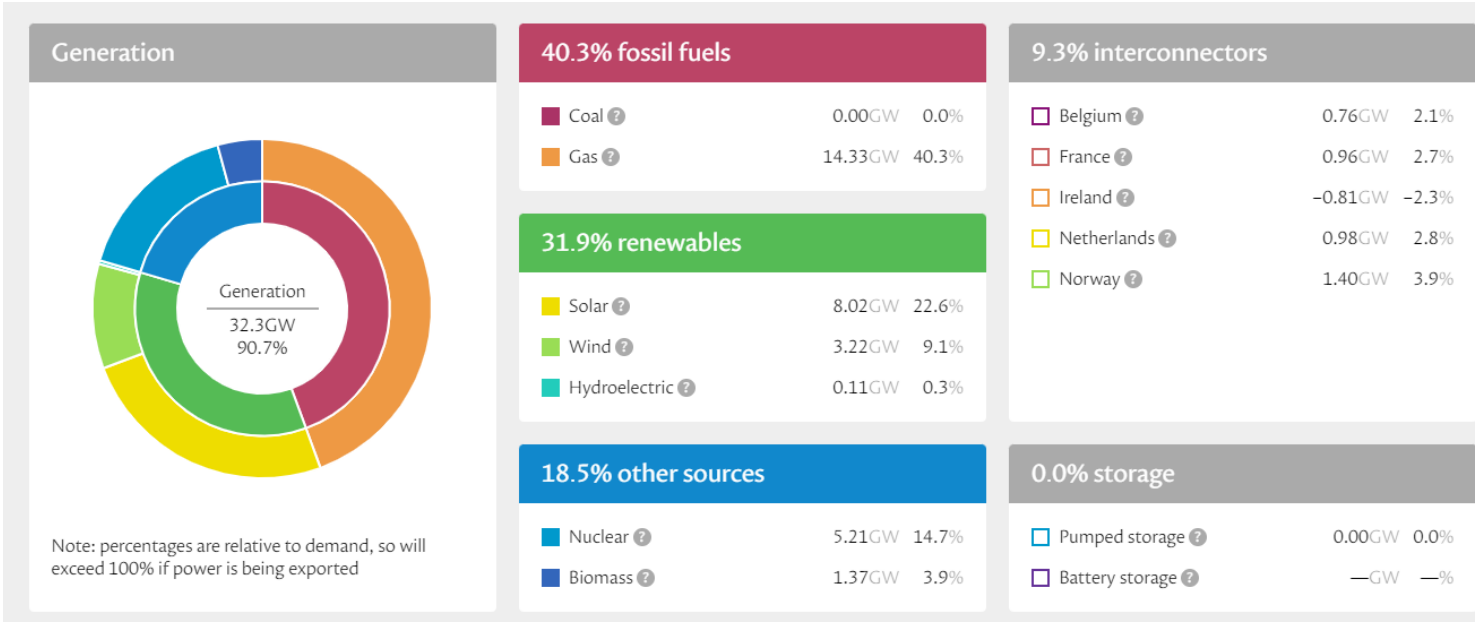


Fig. 10: Definition of Power system security [1]

National Grid: Live

The National Grid is the electric power transmission network for Great Britain

Time	Price	Emissions	Demand		Generation		Transfers
1:10pm	£61.86/MWh	172g/kWh	35.6GW	=	32.3GW	+	3.3GW



https://grid.iamkate.com/
https://www.gridwatch.templar.co.uk/download.php

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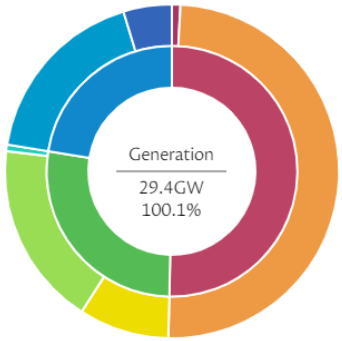
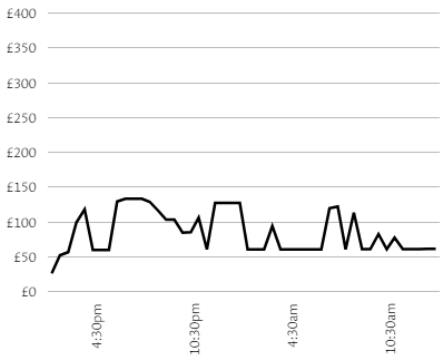
Past day | Past week | Past year | All time



RE gen share:
~ 30%

Price per MWh



Time	Price	Emissions
Past day	£85.30/MWh	200g/kWh

Demand		Generation		Transfers
29.4GW	=	29.4GW	+	0.0GW

Generation by type

Fossil fuels	14.8GW	50.4%
Renewables	8.0GW	27.3%
Other sources	6.6GW	22.4%

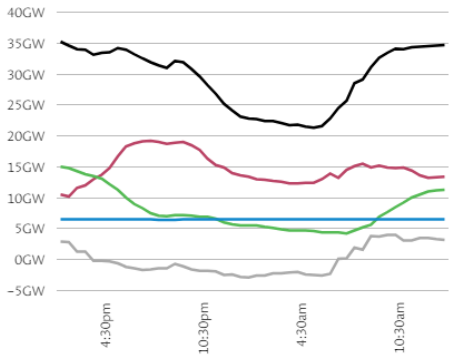
Generation by source

Coal	0.24GW	0.8%
Gas	14.55GW	49.5%
Solar	2.57GW	8.8%
Wind	5.24GW	17.9%
Hydroelectric	0.19GW	0.6%
Nuclear	5.21GW	17.8%
Biomass	1.38GW	4.7%

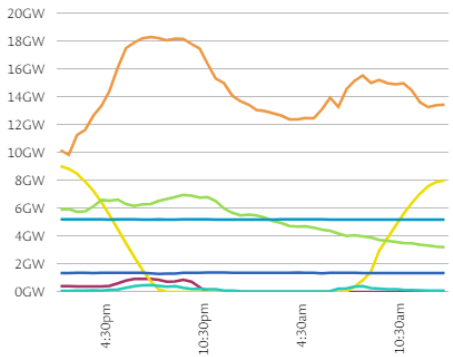
Interconnectors

Belgium	-0.48GW	-1.6%
France	0.20GW	0.7%

Demand



Generation



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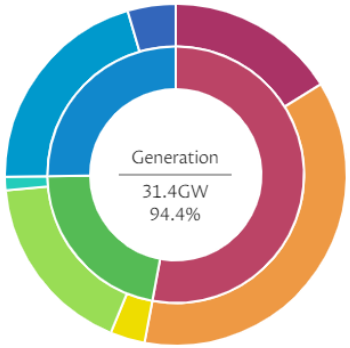
Past day | Past week | Past year | All time



Time	Price	Emissions
All time	£67.01/MWh	283g/kWh

Demand		Generation		Transfers
33.3GW	=	31.4GW	+	1.9GW

Generation by type

Fossil fuels	16.6GW	50.0%
Renewables	6.9GW	20.7%
Other sources	7.9GW	23.8%

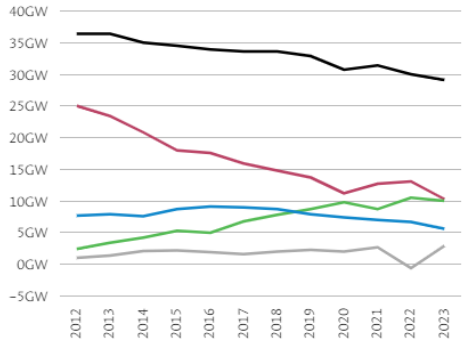
Generation by source

Coal	5.07GW	15.2%
Gas	11.58GW	34.8%
Solar	1.04GW	3.1%
Wind	5.45GW	16.4%
Hydroelectric	0.40GW	1.2%
Nuclear	6.49GW	19.5%
Biomass	1.43GW	4.3%

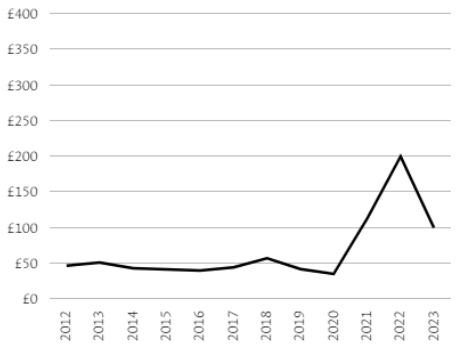
Interconnectors

Belgium	0.19GW	0.6%
France	1.07GW	3.2%

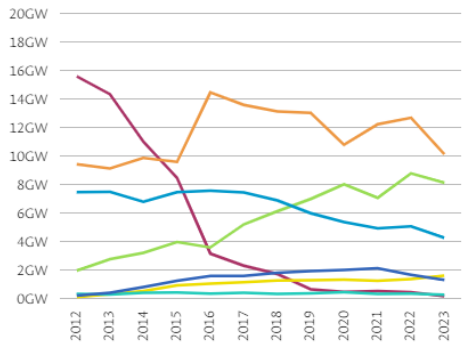
Demand



Price per MWh



Generation



RE gen share:
~ 23%

Challenges in modern power systems: Opportunities for R & D

- Increasing CIGs
- Increasing role of power electronics
- Unbalance and harmonics
- Transmission and distribution thermal limit management
- UCT patents and R&D projects

Acknowledgements

- Colleagues & PG students in the Power Systems Research Group-UCT
- EEE 4126: Energy Systems & Grids II
- Data from National Grid - UK

Thank you