Loughborough University

INTEGRATION OF RENEWABLES

(22WSD532)

Semester 2 2023 In Person Examination

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL FIVE** questions.

Each question carries a total of 20 marks.

Any university-approved calculator is permitted.

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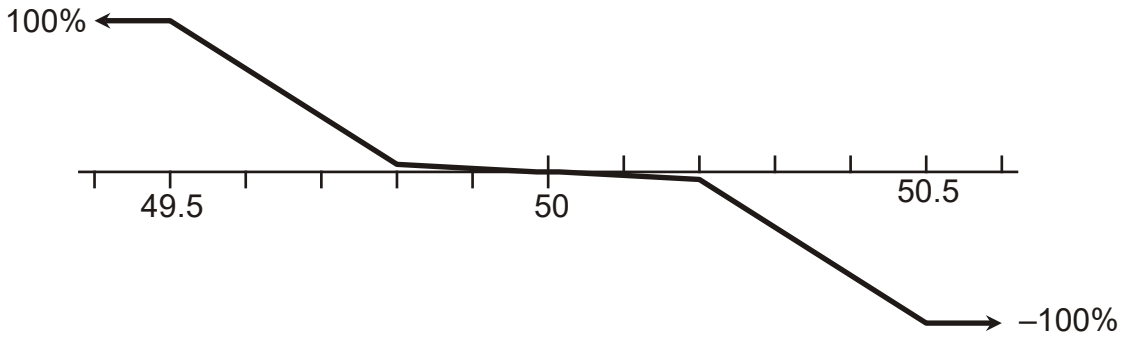
1. In 2020, the GB National Grid Electricity System Operator (NGESO) started to pay for a service called Dynamic Containment. Suppliers of this service have to provide an increase or decrease of power in response to frequency, as per the following graph. They have to respond within 1 second and sustain the response for up to 15 minutes.



The horizontal axis is frequency in hertz. The vertical axis is active power.

a) Why have NGESO found a need for this service? They didn't use to. [6 marks]

b) Explain how Dynamic Containment is useful. [6 marks]

c) Suggest types of equipment that could provide this service. Discuss their suitability and any limitations. [8 marks]

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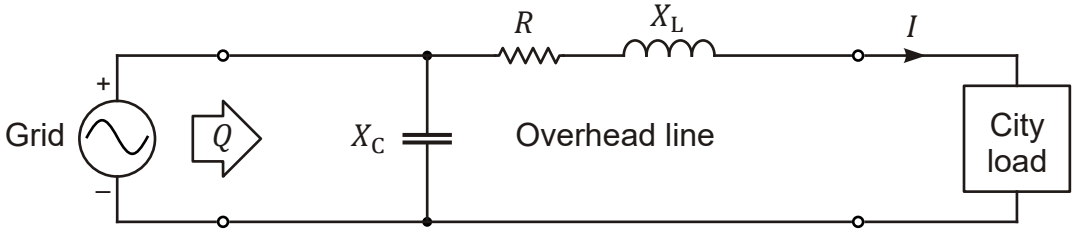
2. The diagram below is a per-phase equivalent circuit of a three-phase overhead line. In reality, the resistance, inductance and capacitance of the line are distributed along its length, but in the model they are lumped as shown.



The "Grid" indicated in the diagram is a large national grid. It has a line voltage of $400\ \mathrm{kV}$ at the point of connection to the overhead line.

The city consumes only active power. (All consumption of reactive power within the city is compensated for within the city.)
At some time after sunset, the load is such that $I = 1000\ \mathrm{A}$

The overhead line is $100\ \mathrm{km}$ long and its per-phase characteristics are:

$$R = 0.03\ \Omega/\mathrm{km}$$

$$X_L = 0.3\ \Omega/\mathrm{km}$$

$$X_C = 200{,}000\ \Omega\mathrm{km}$$

a) Show that 10 Mvar of reactive power flows from the grid into the overhead line. [6 marks]

b) At some time in the morning, solar PV systems throughout the city provide active power that exactly matches the demand of the city. Recalculate the flow of reactive power from the grid into the overhead line. [4 marks]

c) Describe how this change in reactive power flow could present a challenge to the grid and how the grid operator could manage this. [5 marks]

d) Discuss the possibility of using solar PV systems to help alleviate this challenge. You may like to use a phasor diagram or power triangle to illustrate the technical potential and any limitation. You should include discussion of any commercial / organisational challenges. [5 marks]

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3. Wind turbines currently offered by the major manufacturers fall mainly into two concepts:

- direct-drive permanent-magnet (DDPM)
- doubly fed induction generator (DFIG)

Explain the fundamental differences between these concepts and the pros and cons of each aspect. (Do not just describe the two concepts separately. The marks are for the comparison.) [20 marks]

4. Multi-megawatt-scale electrolysers for the production of hydrogen are being developed and demonstrated in various countries aiming to decarbonise their energy systems.

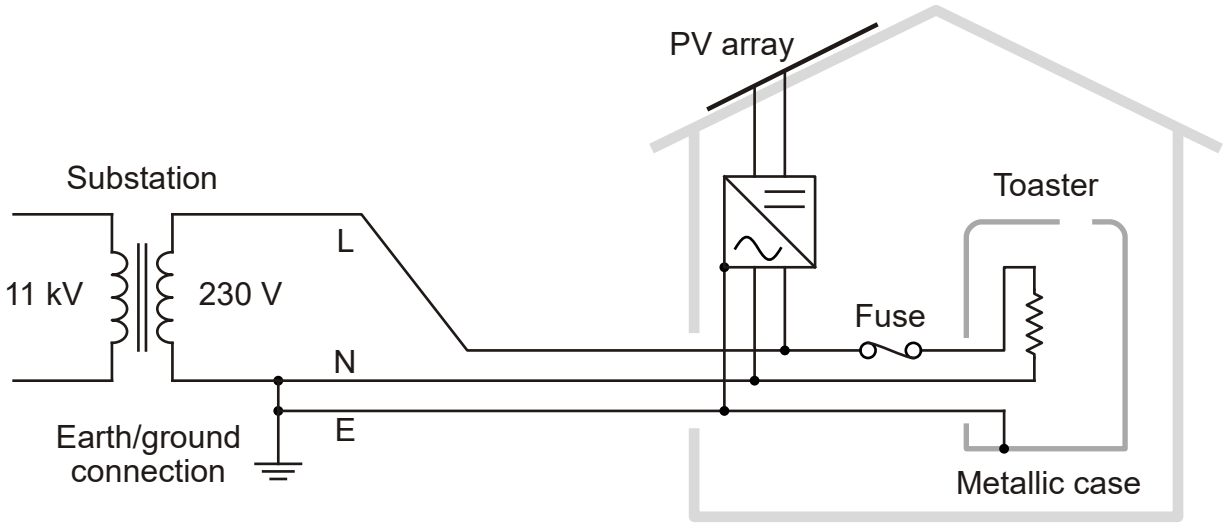
a) Discuss the rationale for running such electrolysers:

- continuously at full power, or
- intermittently at variable power.

Include consideration of capital and running costs. [8 marks]

b) Electrolysers need a controlled DC power supply operating from an AC grid. Outline ***two*** possible technologies to achieve this. Sketch or describe the circuits indicating the main components. Discuss the pros and cons of each design. [12 marks]

5. The diagram below shows a house with PV and an electric toaster, and how it is fed from a distribution transformer in a local substation. The wiring is simplified and only shows what is relevant to this question.



a) Explain how the fuse helps to keep people safe. [4 marks]

b) Explain ***two*** reasons why this safety mechanism may not work if the house were running off stand-alone PV. [5 marks]

c) Explain how a similar concern can affect a national grid and how synchronous condensers can help. [7 marks]

d) Suggest other ways that the above safety concerns can be managed in grids increasingly served by inverter-connected generation. [4 marks]

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