THE UNIVERSITY of EDINBURGH

SCHOOL OF ENGINEERING

POWER ENGINEERING 2

SCEE08008

Exam Diet: December 2020 **Duration:** 24 hours **Expected workload:** 1 hour 30 minutes plus upload
Exam starts: 13:00 on 12/12/2020 **Exam ends:** 13:00 on 13/12/2020 ***All times are GMT (UTC+0)***

Before commencing work, please read the academic, formatting, scanning and uploading guidance.

Examination information

- This exam paper consists of THREE questions.
- Candidates should attempt ALL THREE questions.
- Analysis and Calculation: Candidates should ensure that all variables are defined and that solutions contain sufficient annotation/diagrams to demonstrate understanding.

Specific instructions

- Students should assume reasonable values for any data not given in a question, or not available on a datasheet, and should make any such assumption clear on their answer sheets.
- Students in any doubt as to the interpretation of the wording of a question, should make their own decision, and should state it clearly on their answer sheet.
- Write concise, complete answers. If a length limit is given, stay within it. Produce equations and diagrams to a good hand-drawn standard.
- This is an open book exam. This means you can freely access any printed or online materials to aid you in your answers. Online materials can include text, images, videos and data. You may NOT engage in interactions or discussions relating to the exam questions or examined subject matter in any form. Sharing the answers to this exam in any way, by any means and in any form is STRICTLY NOT allowed.
- Use only a standard calculator. Do not use computer-based spreadsheets, mathematical solvers, simulation tools, graphing calculators or any other tool which is interactive in nature, such as online mathematical equation solvers.

Technical instructions (For full details see the formatting guidance and how to upload your exam to learn)

- Write in dark blue or black ink on white or light-coloured A4 paper, or the nearest equivalent size; unlined, lined, and graph paper are all acceptable, as are pages with holes for binding.
- Write on one side of the paper only. Start every question on a new page. Use portrait orientation.
- On every page clearly write the QUESTION NUMBER (left side) and your EXAMINATION NUMBER (right side).
- Arrange your pages so that your answers are given in the same order as the question paper.
- Take clear individual pictures of each page and combine in a single PDF document according to the scanning instructions.
- Name your file with the course code and your examination number, e.g. ENGI00000-B123456.pdf
- Check your file carefully then upload it in the ONLINE EXAM area for *this* course on LEARN.
- If you require technical support, contact Exams.Eng@ed.ac.uk

Special Items

- Formula sheets (1 page)

Convenor of Board of Examiners: **Professor R Cheung**
External Examiner: **Professor J Morrow and Dr T Tjahjadi**

SECTION A

Question A1 **Note that the solution to this question is not to exceed 7 sides of A4 (Including diagrams and equations)**

a) In a large power system a lightning strike on a transmission line causes a large city to be disconnected from the rest of the grid. Sketch the frequency event on the grid that you would expect such an event to cause, label the main features of the frequency event and write **1-2 sentences** describing what is happening for each of the labels you have added. **(6)**

b) If a load has a unity power factor of one in a 50 Hz power system, will it necessarily have a power factor of one in a 60 Hz power system? Explain your answer, giving examples as appropriate. **(Solution not to exceed 1 side of A4)** **(4)**

c) Consider any 3-phase induction motor. When is the iron core of the motor closer to saturation, at starting or at steady state? Explain your answer in detail using the per-phase equivalent circuit. **(3)**

d) Consider a separately excited DC motor with the following nominal characteristics: P_N = 80 kW, V_s = 1500 V, n = 1500 rpm, efficiency η = 90% and for the field winding: V_f = 220 V, P_f = 1 kW. The mechanical losses are neglected and the machine is unsaturated.

(i) Calculate the armature resistance. **(3)**

(ii) By mistake, the field winding is connected in series with the armature. Can the motor start with the shaft coupled to the nominal load? Explain your answer. **(3)**

(iii) Is the operation described in (ii) safe? Explain your answer. **(1)**

SECTION B

Question B1 **Note that answers to some parts of this question are subject to page restrictions.**

a) Discuss what reactive power is and why it is important in ac power systems. You may support your answer with sketched diagrams. **(Solution not to exceed 2 sides of A4)** **(6)**

b) A capacitance of 3 mF, an inductance of 3 mH, and a resistance of 5 Ω are connected in parallel. This parallel combination is then placed in series with a 2 Ω resistor, as shown in Figure B1. Draw phasor diagrams for the above circuit showing the voltages across each component and the currents through each component when a voltage of 120 volts at 60 Hz is applied across the circuit input. Use the voltage across the 2 Ω resistor as the reference aligned with the real axis and show your workings. **(7)**

c) A delta connected industrial three-phase load, designed for use with a 415 V, 50 Hz supply, has a 200 kW power rating and a lagging power factor of 0.85. What star-connected shunt capacitance will be required to raise the power factor of the load to 0.95 leading when it is connected to a 380 V, 60 Hz supply? Assume the load can be modelled using series impedances and that the voltages given are line voltages. Show your workings. **(7)**

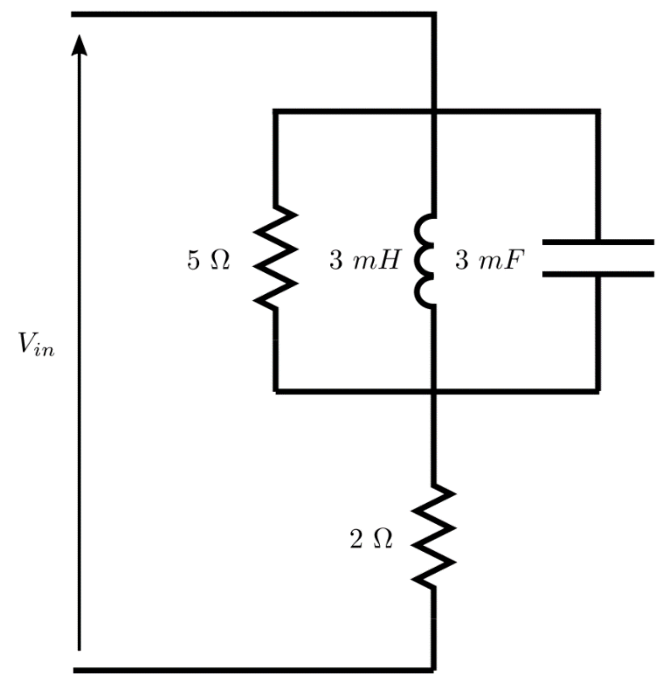

Figure B1

Question B2

a) A 3-phase, 30 kW, 600 V, 4-pole, 50 Hz Y-connected wound rotor induction motor is subjected to a series of tests giving the following results:

- No-load test:
  $f = 50$ Hz, $V_s = 600$ V, $I_s = 3.5$ A, $P = 900$ W.
- Locked rotor test:
  $V_s = 200$ V, $I_s = 20$ A, $P = 4.5$ kW
- The average resistance of the stator phase windings is 2.1 Ω

The mechanical losses are neglected.

(i) Draw the per-phase equivalent circuit (referring to the stator) and estimate the parameters from the above test results. Assume that the rotor and stator leakage reactances of the circuit are equal. **(6)**

(ii) Calculate the iron and Joule losses of the motor for operation under slip 4% and nominal voltage. **(4)**

(iii) Calculate the motor's electromagnetic power and electromagnetic torque for operation under slip 4% and nominal voltage. **(2)**

(iv) Calculate the efficiency of the motor for operation under slip 4% and nominal voltage. **(2)**

b) An ideal (efficiency 100%) salient pole synchronous motor is serving a load at steady state, when suddenly the field winding is open circuited. What do we expect to happen? **(3)**

c) You are working as an engineer and have been asked to provide a solution in an electromechanical application that requires frequent start-ups under full load. Which motors suit this sort of application? Discuss their advantages and disadvantages that will guide you to select the most appropriate type depending on the various application requirements. **(3)**

END OF PAPER

Formula Sheet

Trigonometric Identities

Fundamental Identities

$\cos^2\theta + \sin^2\theta = 1$
$1 + \tan^2\theta = \sec^2\theta$
$1 + \cot^2\theta = \csc^2\theta$

$\sin\theta = -\sin(-\theta)$
$\cos\theta = \cos(-\theta)$
$\tan\theta = -\tan(-\theta)$

$\csc\theta = -\csc(-\theta)$
$\sec\theta = \sec(-\theta)$
$\cot\theta = -\cot(-\theta)$

Addition formulas

$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$
$\sin(\alpha-\beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$

$\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$
$\cos(\alpha-\beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$

Double-angle formulas

$\sin 2\alpha = 2\sin\alpha\cos\alpha$
$\cos 2\alpha = \cos^2\alpha - \sin^2\alpha = 2\cos^2\alpha - 1 = 1 - 2\sin^2\alpha$

Half-angle formulas

$\sin^2\alpha = (1 - \cos 2\alpha)/2$
$\cos^2\alpha = (1 + \cos 2\alpha)/2$

*Exponential forms**

$$\sin\alpha = \frac{e^{i\alpha} - e^{-i\alpha}}{2i} \qquad \cos\alpha = \frac{e^{i\alpha} + e^{-i\alpha}}{2}$$

Fourier Series

$$f(x) = a_o + \sum_{n=1}^{\infty} (a_n\cos(nx) + b_n\sin(nx))$$

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos(mx)dx = \frac{1}{\pi}\int_{0}^{2\pi} f(x)\cos(mx)dx$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin(mx)dx = \frac{1}{\pi}\int_{0}^{2\pi} f(x)\sin(mx)dx$$