Electrical Systems: Buildings and Renewable Energy
23CVP300

Semester 2 2024 | In-Person Exam Paper

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 **2 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.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **THREE** questions.

All questions carry equal marks.

Supplementary Tables (taken from the IET Wiring Regs) are provided at the end of the paper.

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1. a) State the definition and units of the following Solar Resource concepts:

   i) Air Mass
   ii) Beam Solar Radiation
   iii) Diffuse Solar Irradiation
   iv) Total Solar Irradiance

[8 marks; 2 marks each]

b) Give two reasons why the solar time differs from the local time.

[2 marks]

c) State the definition of the following concepts relating to sun position calculations. This should include the conditions under which an angle is either positive or negative.

   i) Latitude angle
   ii) Declination angle
   iii) Slope angle
   iv) Surface azimuth angle
   v) Hour angle
   vi) Angle of Incidence
   vii) Zenith angle
   viii) Solar altitude angle
   ix) Solar azimuth angle

[9 marks; 1 mark each]

d) Calculate the angle of incidence of beam radiation on a surface located at Madison, Wisconsin (at a latitude of 43°N), at 11:30 (solar time) on February 2nd if the surface is tilted at 40° from the horizontal and pointed 15° east of south. The equations for Declination Angle and Angle of Incidence are provided below where symbols have their usual meaning.

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right)$$

$$\begin{aligned}\cos\theta = {} & \sin\delta \sin\phi \cos\beta - \sin\delta \cos\phi \sin\beta \cos\gamma \\ & + \cos\delta \cos\phi \cos\beta \cos\omega + \cos\delta \sin\phi \sin\beta \cos\gamma \cos\omega \\ & + \cos\delta \sin\beta \sin\gamma \sin\omega\end{aligned}$$

[8 marks]

e) Draw a typical wind turbine power curve and label three important parts of the curve on the diagram.

[6 marks]

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…/continued

2. a) Plot the I-V curve for a PV module which has the following electrical characteristics. Each of the characteristics below should be labelled on the figure.

- Open circuit voltage: 37.8 V
- Short circuit current: 8.89 A
- Maximum power voltage: 31.2 V
- Maximum power current: 8.18 A

[2 marks]

b) A PV module has an area of 1.5 m^2, a module efficiency of 16.2% at Standard Test Conditions and a temperature coefficient of power of -0.5%/°C. Calculate:

i) The power output of the module under Standard Test Conditions.

[2 marks]

ii) The power output of the module under Standard Test Condition but with a cell temperature of 60°C.

[2 marks]

c) A 3 kWp PV array is installed on a 30° south-facing roof of building in the UK. Using the 'rule of thumb', what is the annual energy generated by this system over a year?

[2 marks]

d) A PV system includes a PV array and the 'Balance of System' components. State four Balance of System components and describe their function.

[4 marks; 1 mark each]

e) The standard equation for calculating PV cell temperatures based on the Nominal Operating Cell Temperature is given below where symbols have their usual meaning.

$$\frac{T_c - T_a}{T_{NOCT} - T_{a,NOCT}} = \frac{G_T}{G_{NOCT}} \frac{9.5}{(5.7 + 3.8V)} \left[1 - \frac{\eta_c}{\tau\alpha}\right]$$

Calculate the cell temperature and PV module efficiency of the PV module described in Table Q2(e) in a location with ambient temperature of 30°C, solar radiation of 1000 W/m^2 and wind speed of 1.4 m/s. Make the standard assumptions about any unknown variables as necessary and carry out at least 3 iterations.

Table Q2(e): PV module characteristics

Maximum power at STC	150 W
Temperature co-efficient of power	-0.45 %/°C
Module area	1.2 m^2
NOCT	49 °C

[8 marks]

Question 2 continues/…

f) You are a consultant working for a building consultancy firm. One of your clients is interested in using a heap pump system in their building as part of an overall aim for a net-zero energy building design. The building in question is a medium-sized office building located in an out-of-town industrial park.

Write a technical note for this client which:

i) Provides a concise explanation of heat pump technology suitable for a technical non-specialist reader.

[3 marks]

ii) Compares and contrasts heat pumps with other forms of renewable heating.

[3 marks]

iii) Compares and contrasts ground source heat pumps and air source heat pumps.

[3 marks]

iv) Makes a final recommendation to the client.

[4 marks]

3. a) A balanced star-connected three-phase load with a resistance of 8 Ω per phase is supplied from a 415 V, 50 Hz main supply at a 0.95 power factor.

Calculate.

i) The phase voltage.

[4 marks]

ii) The line current.

[4 marks]

iii) The total power consumed.

[4 marks]

b) A 240 kVA transformer has a primary winding resistance of 0.4 Ω and a secondary winding resistance of 0.001 Ω. The iron loss is 2.5 kW and the primary and secondary voltages are 5 kV and 330 V respectively.

If the power factor of the load is 0.85, calculate the efficiency of the transformer on full load.

[10 marks]

Question 3 continues/…

c) A 5 A lighting circuit is wired in 1.5 mm^2 PVC cable. The circuit length is 40 m and the cable resistance is 20.40 mΩ/m. The earthing arrangement is TN-S, which gives an earth fault loop impedance of the supply as 0.8 Ω. The multiplying factor under fault conditions is 1.20.

Calculate the total earth fault loop impedance.

[8 marks]

d) The minimum required illuminance on a desk in an office is 350 lux. A luminaire is suspended from the ceiling at a height of 1.8 m above the desk.

Calculate the minimum luminous intensity of the lamp.

[3 marks]

4. a) A 230 V to 12 V bell transformer is constructed with 450 turns on the primary winding.

When the transformer supplies an 8 W alarm bell, calculate:

i) The number of turns on the secondary winding.

[2 marks]

ii) The secondary current.

[2 marks]

iii) The primary current.

[2 marks]

b) A 230 V ring main circuit of socket outlets is wired in 2.5 mm^2 single PVC copper cables in a plastic conduit with a separate 1.5 mm^2 CPC. An earth fault loop impedance test identifies (Zs) as 0.95 Ω.

Verify that the 1.5 mm^2 CPC meets the requirements of IET Wiring Regulations when the protective device is a 30 A semi-enclosed fuse.

NOTE: From the IET Wiring Regulations, the maximum operating time of the protective device for a circuit not exceeding 32 A is 0.4 s, k=115 from Table 54.3 of BS 7671

[8 marks]

Question 4 continues/…

c) With the aid of a graph, explain how the voltage and current vary throughout time for a purely inductive AC circuit, and the effect this has on the available power.

[5 marks]

d) A household three-phase electrical appliance has a load of 3 kW and is located 30 m from the mains consumer unit. The appliance is fed by a 70 °C thermosetting plastic insulated cable at 230 V, and is clipped directly to the side of the ceiling joists over much of its length in an uninsulated roof space which is anticipated to reach 35 °C. The circuit is protected by a Type-B MCB to BS EN 60898.

Determine the minimum size of the cable and the appropriate MCB rating, if the voltage drop across the circuit is limited to 5%. *You should make use of the supplementary tables at the end of this exam paper.*

[10 marks]

e) Briefly state the advantages of three-phase systems over single-phase supplies.

[4 marks]

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Supplementary Tables (taken from the IET Wiring Regs):

Table 4D5 - 70°C thermosetting plastic insulated and sheathed flat cable with protective conductor (copper conductors).

CURRENT-CARRYING CAPACITY (amperes) and VOLTAGE DROP (per ampere per metre):

Conductor Cross-sectional area	Method 100# (above a plasterboard ceiling covered by thermal insulation not exceeding 100mm in thickness)	Method 101# (above a plasterboard ceiling covered by thermal insulation exceeding 100mm in thickness)	Method 102# (in a stud wall with thermal insulation with a cable touching the inner wall surface)	Method 103# (in a stud wall with thermal insulation with a cable not touching the inner wall surface)	Reference method C* (clipped direct)	Reference Method A* (enclosed in conduit in an insulated wall)	Voltage drop (per ampere per metre)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
(mm²)	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(mV/A/m)**
1	13	10.5	13	8	16	11.5	44
1.5	16	13	16	10	20	14.5	29
2.5	17	21	13.5	13.5	27	20	18
4	22	27	18.5	18.5	37	26	11
6	27	35	23.5	23.5	47	32	7.3
10	36	47	32	32	64	44	4.4
16	46	63	42.5	42.5	85	57	2.8

Table 4B1 – Rating factors (C_a) for ambient air temperatures other than 30°C.

Ambient temperature °C	Insulation				
	60°C Thermosetting	70°C thermoplastic	90°C thermoplastic	Mineral*	
				Thermoplastic covered or bare and exposed to touch 70°C	Bare and not exposed to touch 105°C
25	1.04	1.03	1.02	1.07	1.04
30	1.00	1.00	1.00	1.00	1.00
35	0.91	0.94	0.96	0.93	0.96
40	0.82	0.87	0.91	0.85	0.92
45	0.71	0.79	0.87	0.78	0.88
50	0.58	0.71	0.82	0.67	0.84
55	0.41	0.61	0.76	0.57	0.80
60	-	0.50	0.71	0.45	0.75
65	-	-	0.65	-	0.70
70	-	-	0.58	-	0.65
75	-	-	0.50	-	0.60
80	-	-	0.41	-	0.54
85	-	-	-	-	0.47
90	-	-	-	-	0.40
95	-	-	-	-	0.32

Table 52.2 – Cable surrounded by thermal insulation (C_i)

Length in insulation (mm)	Derating factor
50	0.88
100	0.78
200	0.63
400	0.51

Table 4C1 – Rating factors for one circuit or one multicore cable or for a group of circuits, or a group of multicore cables, to be used with current-carrying capacities of Tables 4D1A to 4J4A, (C_g)

Item	Arrangement (Cables touching)	Number of circuits or multicore cables												To be used with current-carrying capacities, Reference Method
		1	2	3	4	5	6	7	8	9	12	16	20	
1.	Bunched in air, on a surface, embedded or enclosed	1.00	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.45	0.41	0.38	A to F
2.	Single layer on wall or floor	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	0.70	0.70	0.70	C
3.	Single layer multicore on a perforated horizontal or vertical cable tray system	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72	0.72	0.72	0.72	E
4.	Single layer multicore on cable ladder system or cleats etc.	1.00	0.87	0.82	0.80	0.80	0.79	0.79	0.78	0.78	0.78	0.78	0.78	