UNIVERSITI TUN HUSSEIN ONN MALAYSIA
FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	INDUSTRIAL POWER SYSTEM
COURSE CODE	:	BNE 43203
PROGRAMME CODE	:	BNE
EXAMINATION DATE	:	JULY / AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS
	:	2. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.**
		3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

THIS QUESTIONS PAPER CONSISTS OF **FOURTEEN (14)** PAGES

Q1 (a) Describe **TWO (2)** main uses of electrical energy in industry.

(4 marks)

(b) **Table Q1(b)** provides the load profiles of a small industrial plant. Decide a required system voltage to be supplied by Tenaga Nasional Berhad (TNB).

(7 marks)

(c) A 4,000 kVA, 11 kV / 6.6 kV with a 7 % impedance distribution transformer is to be installed to serve an industrial motor pump as illustrated in **Figure Q1(c)**.

(i) Determine the percentage voltage drop at the power transformer secondary terminal during the starting of the large motor.

(8 marks)

(ii) Decide the proper size of the transformer from its standard ratings if the voltage variation during the motor starting is to be limited to a maximum value of 10 %

(6 marks)

Q2 (a) Name components A, B, C, and D of the power transformer shown in **Figure Q2(a)**.

(4 marks)

(b) A factory consumes 450,000 kVAh/year with an average power factor of 0.86. Let the maximum demand was 1200 kW,

(i) Calculate average load demand.

(2 marks)

(ii) Find the annual load factor.

(2 marks)

(iii) Determine maximum load demand if the factory decided to increase the electricity usage to 500,000 kWh and the load factor to 60 %.

(4 marks)

(c) Consider a feeder serving a large motor fed from 3.3 kV 50 Hz switchgear with a circuit breaker with a separate multifunction motor protection relay. The motor is rated at 150 kW with 0.85 power factor lagging and an efficiency of 92 %. Power cables laid between the feeder and the motor are 3-core copper, PVC type. The cables are laid 105 cm underground in a horizontal formation with 30 cm spacing to each other. The number of cables in a group is 2 Nos. The ground ambient temperature is 45 °C and the thermal resistivity of soil is 100 °C cm/ Watt.

(i) If the fault clearing time for the circuit breaker is 7 cycles and the motor short circuit current is 200 times its rated value, propose the initial size of the cable based on the short circuit current withstand capacity criteria. Refer to **Appendix A**.

(7 marks)

(ii) Analyse again the cable size as obtained in **Q2(c)(i)** by considering the continuous current carrying capacity criteria. Is the proposed cable size suitable to serve the large motor? Refer to **Appendix A** and **Appendix B**.

(6 marks)

Q3 (a) Summarise the main characteristic of the lead acid battery typically used in the industrial plant.

(3 marks)

(b) Design a flow chart that can show **FIVE (5)** proper steps in determining the sizing of battery for the telecommunication, voltage support or emergency control applications in an industrial plant.

(5 marks)

(c) A critical load operational for the household fabrication plant to be supplied by UPS during power failure is shown in **Table Q3(c)**. The design features of the UPS are given below.

Output voltage = 120V DC　　Depth of discharge = 85%
Battery ageing factor = 25%　　Capacity rating factor = 8%
Recharge efficiency factor = 1.1　　Minimum recharge time = 3 hours
Future growth contingency = 10%　　Design margin = 10%
Temperature correction factor for a vented cell at 30°C = 0.956

(i) Design a load duration graph that shows the load profile of volt-ampere (VA) versus the period in an hour for the UPS loading.

(4 marks)

(ii) Analyse the peak design load, total energy demand, design energy demand and minimum battery size (in AH).

(5 marks)

(iii) Infer a suitable minimum battery size (in AH) based on **Q3(c)(ii)**.

(2 marks)

(iv) Design a minimum DC rectifier and charging currents, and a minimum AC load current of 415 V output voltage.

(6 marks)

Q4 (a) Summarise **TWO (2)** non-technical benefits gained by the industry that practices a proper load monitoring system.

(2 marks)

(b) Determine the harmonic orders at which parallel resonance occurs on 1500 kVA, 415 V three-phase system that has a total inductance, X_T of 10.79 μH with the power factor corrector rated at 500 kVAr.

(4 marks)

(c) Consider a three-phase feeder supply a voltage, $\overline{E} = 6.6$ kV with X_S/R_S ratio of 5 and short circuit level, S_c = 180 MVA as depicted in **Figure Q4(c)**. The feeder is supplying a star connected inductive load of S_L = 10 kW + j 25 kVAr.

(i) Examine the suitable load bus voltage, $\overline{V}$.

(8 marks)

(ii) Conclude the result obtained in **Q4(c)(i)**.

(3 marks)

(iii) If the load bus voltage is to be maintained as at the supply bus voltage $\overline{E}$, decide a suitable amount of reactive power that should be supplied by the compensator (Comp.).

(8 marks)

- END OF QUESTIONS –

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Table Q1(b)

Load Profiles
Twenty-four (24), 150 HP motors (only half of them running at any given time), K = 0.75.
Eight (8), 100 HP motors (6 motors are running at the same time), K = 0.68.
1000 kW of heating and process loads.
Three (3), 50 kVA lighting transformer, PF = 0.92, n = 95 %.
50 HP of small motors (mostly fraction HP, only 85 % are running at any given time), K = 0.75

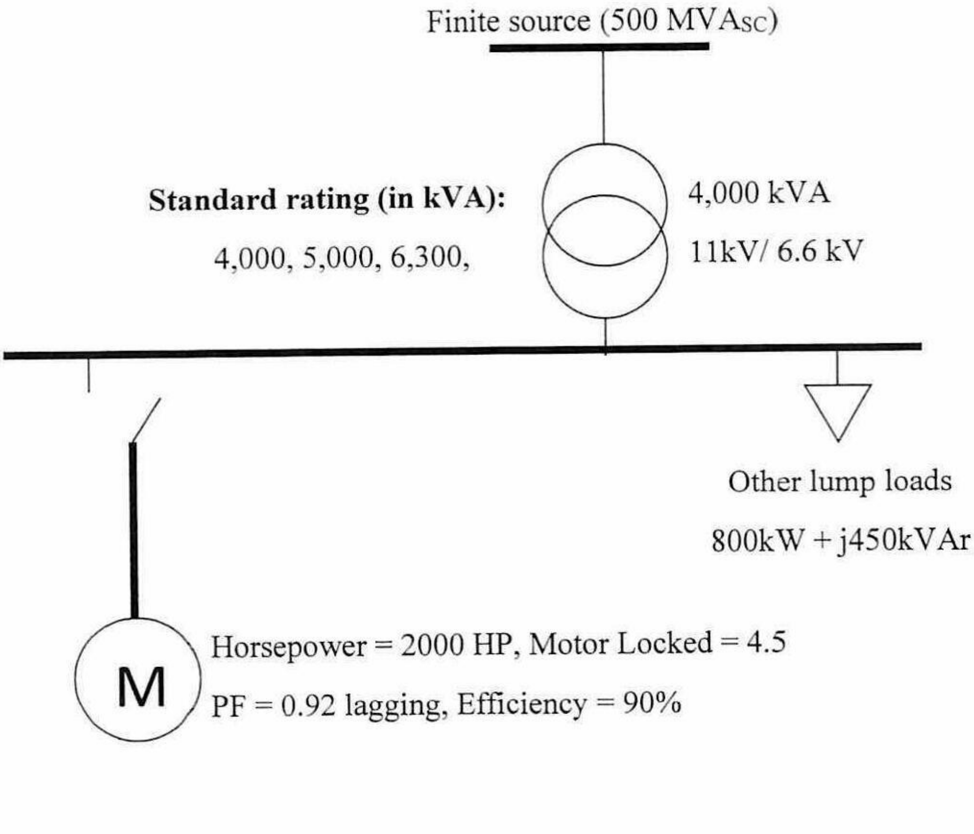

Figure Q1(c)

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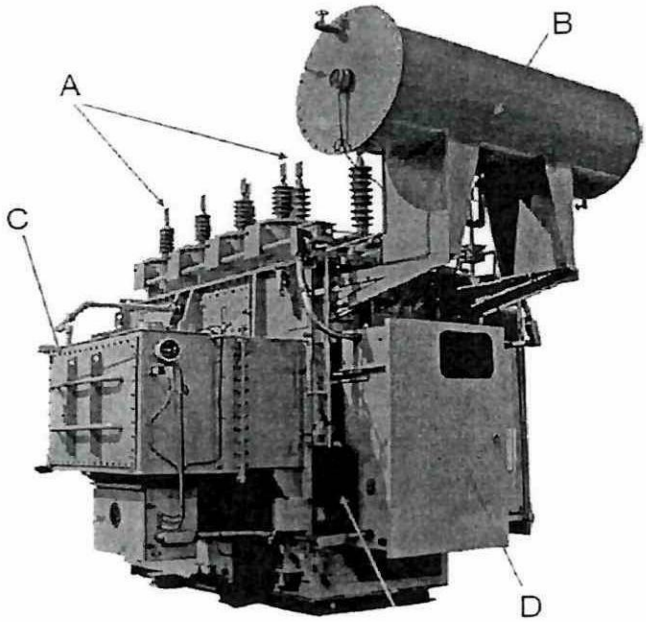

Figure Q2(a)

Table Q3(c)

Load Description	Rating (VA)	Nos (Unit)	Time (Hours)
MDF Unit	100	4	2
SMART TV Cabinet	150	6	4
Computer System	200	8	6
Distributed Regulator System	330	4	2
ESD Cabinet	410	6	4
HMI / Server Data Units	120	8	6

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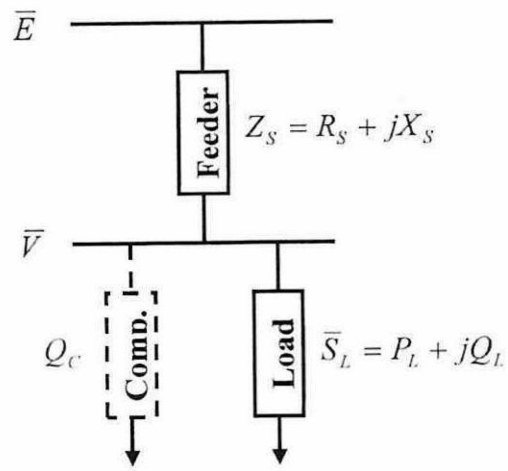

Figure Q4(c)

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Appendix A: Supported Information

$$K = 148\sqrt{In\left(1+\frac{T_2 - T_1}{228.1+T_1}\right)}\ ,\ K = 226\sqrt{In\left(1+\frac{T_2 - T_1}{234.5+T_1}\right)}\ ,\ A = \frac{\sqrt{I_{SC}^2 t}}{K}$$

Insulation material	Final temperature, T_2 (°C)	Initial temperature, T_1 (°C)
PVC	160	70
Butyl Rubber	220	85
XLPE/ EPR	250	90

TABLE 4D4A – Multicore 70 °C armoured thermoplastic insulated cables (COPPER CONDUCTORS)

Air ambient temperature: 30 °C
Ground ambient temperature: 20 °C
Conductor operating temperature: 70 °C

CURRENT-CARRYING CAPACITY (amperes):

Conductor cross-sectional area	Reference Method C (clipped direct)		Reference Method E (in free air or on a perforated cable tray etc, horizontal or vertical)		Reference Method D (direct in ground or in ducting in ground, in or around buildings)	
	1 two-core cable, single-phase a.c. or d.c.	1 three- or four-core cable, three-phase a.c.	1 two-core cable, single-phase a.c. or d.c.	1 three- or four-core cable, three-phase a.c.	1 two-core cable, single-phase a.c. or d.c.	1 three- or four-core cable, three-phase a.c.
1	2	3	4	5	6	7
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)
1.5	21	18	22	19	22	18
2.5	28	25	31	26	29	24
4	38	33	41	35	37	30
6	49	42	53	45	46	38
10	67	58	72	62	60	50
16	89	77	97	83	78	64
25	118	102	128	110	99	82
35	145	125	157	135	119	98
50	175	151	190	163	140	116
70	222	192	241	207	173	143
95	269	231	291	251	204	169
120	310	267	336	290	231	192
150	356	306	386	332	261	217
185	405	348	439	378	292	243
240	476	409	516	445	336	280
300	547	469	592	510	379	316
400	621	540	683	590	-	-

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Appendix B: Supported Information

Ground Temp. (°C)	20	25	30	35	40	45	50
Rating Factor	1.12	1.08	1.04	0.96	0.91	0.87	0.82

Spacing	No. of cables in group				
	2	3	4	6	8
Touching	0.79	0.69	0.62	0.54	0.50
15 cm	0.82	0.75	0.69	0.61	0.57
30 cm	0.87	0.79	0.74	0.69	0.66
45 cm	0.90	0.83	0.79	0.75	0.72
60 cm	0.91	0.86	0.82	0.78	0.76

Cable size	Depth of laying (cm)					
	75	90	105	120	150	180 ≥
up to 25 sq. mm.	1.00	0.99	0.98	0.97	0.96	0.95
25 to 300 sq. mm	1.00	0.98	0.97	0.96	0.94	0.93
above 300 sq. mm.	1.00	0.97	0.96	0.95	0.92	0.91

Nominal area of conductor in sq. mm	Rating factors for value of Thermal Resistivity of Soil in °C cm / Watt					
	100	120	150	200	250	300
25	1.24	1.08	1.00	0.91	0.84	0.78
35	1.15	1.08	1.00	0.91	0.84	0.77
50	1.15	1.08	1.00	0.91	0.84	0.77
70	1.15	1.08	1.00	0.90	0.83	0.76

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Appendix C: Supported Information

M.D ranges of individual consumer	Supply voltage	Minimum supply scheme
Up to 12 kVA	230 V	Single phase overhead or underground services from existing LV network
>12 kVA to 100 kVA	400 V	Three phase overhead or underground cable service from existing LV network subject to system availability study by TNB
>100 kVA to 350 kVA	400 V	Underground cable service from feeder pillar or a new/existing substation, subject to system availability study by TNB
>350 kVA to <500 kVA	400 V	Direct underground cable service from new substation
500 kVA up to 5000 kVA	11 kV	Directly fed through TNB 11 kV switching station or a PPU land is required subject to system availability study by TNB
500 kVA up to 10000 kVA	22 kV	Directly fed through TNB 22 kV switching station or a PPU land is required subject to system availability study by TNB
5000 kVA to 25000 kVA	33 kV	Directly fed through TNB 33 kV switching station or/and a PPU / PMU land is required subject to system availability study by TNB
Above 25000 kVA	132 kV, 275 kV	Directly fed through TNB 132 kV and 275 kV switching station respectively or a PMU land is required

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Appendix D: Formulae

Horsepower : $1HP = 746W$

Power factor : $\text{PF} = \cos\theta$

K factor : $PF \times \eta$

Apparent Power (three-phase): : $S_{3\emptyset} = P_{3\emptyset} + jQ_{3\emptyset} = \sqrt{\lfloor P_{3\emptyset}\rfloor + \lfloor Q_{3\emptyset}\rfloor}$

$S_{3\emptyset} = \sqrt{3}V_{3\emptyset}I_{3\emptyset}^*$

$S_{3\emptyset} = \sqrt{3}V_{3\emptyset}I_{1\emptyset}^*$

$S_{3\emptyset} = \sqrt{3}V_{1\emptyset}I_{3\emptyset}^*$

$S_{3\emptyset} = 3V_{1\emptyset}I_{1\emptyset}^*$

Active Power (three-phase):

$P_{3\emptyset} = \sqrt{3}V_{3\emptyset}I_{3\emptyset}^* \cos\theta$

$P_{3\emptyset} = \sqrt{3}V_{3\emptyset}I_{1\emptyset}^* \cos\theta$

$P_{3\emptyset} = \sqrt{3}V_{1\emptyset}I_{3\emptyset}^* \cos\theta$

$P_{3\emptyset} = \sqrt{3}V_{3\emptyset}I_{3\emptyset}^* \cos\theta$

$P_{3\emptyset} = 3V_{1\emptyset}I_{1\emptyset}^* \cos\theta$

Apparent Power (K factor): : $S = \frac{P}{K}$

Average Demand : $Demand_{(Average)} = \frac{\sum Demand}{Period}$

Load Factor : $LF = \frac{Demand_{(Average)}}{Demand_{(Maximum)}}$

Load Loss Factor : $LLF = k \times LF + (1 - k) \times LF^2$

Rated Current (Transformer) : $I_{rated(Tx)} = \frac{S_{3\emptyset}}{\sqrt{3} \times V_{3\emptyset}}$

Short Circuit Current (Transformer) : $I_{SC(Tx)} = \frac{I_{rated(Tx)}}{Z_{(Tx)}}$

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Appendix D: Formulae

Total Short Circuit Current : $$S_{SC(Total)} = \frac{\left(S_{SC(Finite\ Source)} \times S_{SC(Tx)}\right)}{\left(S_{SC(Finite\ Source)} + S_{SC(Tx)}\right)}$$

Starting Motor Current : $$I_{starting(M)} = I_{rated(M)} \times Locked_{(M)}$$

Motor Starting Regulation (%) : $$Reg_{(M)} = \frac{S_{starting(M)}}{S_{SC(Tx)}} \times 100\%$$

Temperature Rise Constant : $$K_{Temp(Copper)} = 226\sqrt{ln\left(1 + \frac{T_2 - T_1}{234.5 + T_1}\right)}$$

$$K_{Temp(Aluminum)} = 148\sqrt{ln\left(1 + \frac{T_2 - T_1}{228.1 + T_1}\right)}$$

Cable Area Size (mm^2) : $$Cable_{(A)} = \frac{\sqrt{I_{SC}^2 t}}{K_{Temp}}$$

Design Load Demand (VA) : $$S_d = S_{peak}\left(1 + k_g\right)(1 + k_c)$$

Design Energy Demand (VAH) : $$E_d = E_t\left(1 + k_g\right)(1 + k_c)$$

Minimum Battery Size (AH) : $$C_{\min} = \frac{E_d \times (1 + k_a) \times (1 + k_c) \times k_t}{V_{DC} \times k_{dod}}$$

Number of Cells (Battery) : $$N_{\max} = \frac{V_{DC}\left(1 + V_{l,\max}\right)}{V_c}$$

$$N_{\min} = \frac{V_{DC}\left(1 - V_{l,\min}\right)}{V_{eod}}$$

DC Current (Battery Charger) : $$A = \left[\frac{1.1 \times AH}{T} + L\right] \times \frac{1}{C1} \times \frac{1}{C2}$$

Design DC Load Current (Rectifier & Charger) : $$I_{L,DC} = \frac{S}{V_{DC}}$$

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Appendix D: Formulae

Design Maximum Charging Current (Battery Charger)	:	$I_C = \frac{C(k_l)}{t_C}$
Total Minimum DC Current (Rectifier & Charger)	:	$I_{DC} = I_{L_{DC}} + I_C$
Sizing AC Current (Inverter & Static Switch)	:	$I_{L,AC} = \frac{S}{\sqrt{3} \times V_0}$
Feeder Supply Impedance	:	$Z_S = \frac{E^2}{S_{SC}}$
Short Circuit X/R Ratio	:	$\tan\phi_{SC} = \frac{X_S}{R_S}$
Feeder Supply (Resistor & Reactance)	:	$R_S = Z_S \cos\phi_{SC}$ $X_S = Z_S \sin\phi_{SC}$
Load Bus Profile (Without Compensator, E ≠ V)	:	$V^4 + \{2(R_S P_L + X_S Q_L) - E^2\}V^2 + (R_S^2 + X_S^2)(Q_L^2 + P_L^2) = 0$
Quadratic Formula	:	$X = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$
Net Reactive Power at Load Bus		$Q_N = Q_L + Q_C$
Load Bus Profile (With Compensator, E = V)	:	$(R_S^2 + X_S^2)Q_N^2 + 2V^2 X_S Q_N + (V^2 + R_S P_L)^2 + X_S^2 P_L^2 - E^2 V^2 = 0$
Harmonics (Voltage & Current)	:	$V_{rms} = \sqrt{\sum_{k=1}^{\infty} V_{krms}^2} = \sqrt{V_{1rms}^2 + \sum_{k=2}^{\infty} V_{krms}^2}$ $I_{rms} = \sqrt{\sum_{k=1}^{\infty} I_{krms}^2} = \sqrt{I_{1rms}^2 + \sum_{k=2}^{\infty} I_{krms}^2}$

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Appendix D: Formulae

Total Harmonic Distortion (Voltage & Current) :

$$THD_V = \frac{\sqrt{\sum_{k=2}^{\infty} V_{krms}^2}}{V_{1rms}} \times 100\%$$

$$THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \times 100\%$$

Capacitance (Ω) :

$$X_c = \frac{V_L^2}{Q}$$

Resonance Condition :

$$\omega L = \frac{1}{\omega C}$$

Load Shedding Frequency (Hz) :

$$f = \frac{1 + \frac{d-1}{d}\Delta P}{1 + \Delta P}$$