UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	INDUSTRIAL POWER SYSTEM
COURSE CODE	:	BNE 43203
PROGRAMME CODE	:	BNE
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWER ALL QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS ANSWER QUESTIONS PAPER CONSISTS OF **TWELVE (12)** PAGES

Q1 The following sub-questions are related to the basic theory and calculation exercises related to design of the distribution transformer.

(a) State the meaning terms ONAN and ONAF cooling circulation method of the distribution power transformer.

(3 marks)

(b) Illustrate (draw and label) a typical design of the shell type core and winding configuration of the distribution transformer.

(6 marks)

(c) **Figure Q1.1** provides the information electrical network of distribution transformer that supplies a large motor and other lumps loads on a mining industry in Pagoh, Johor.

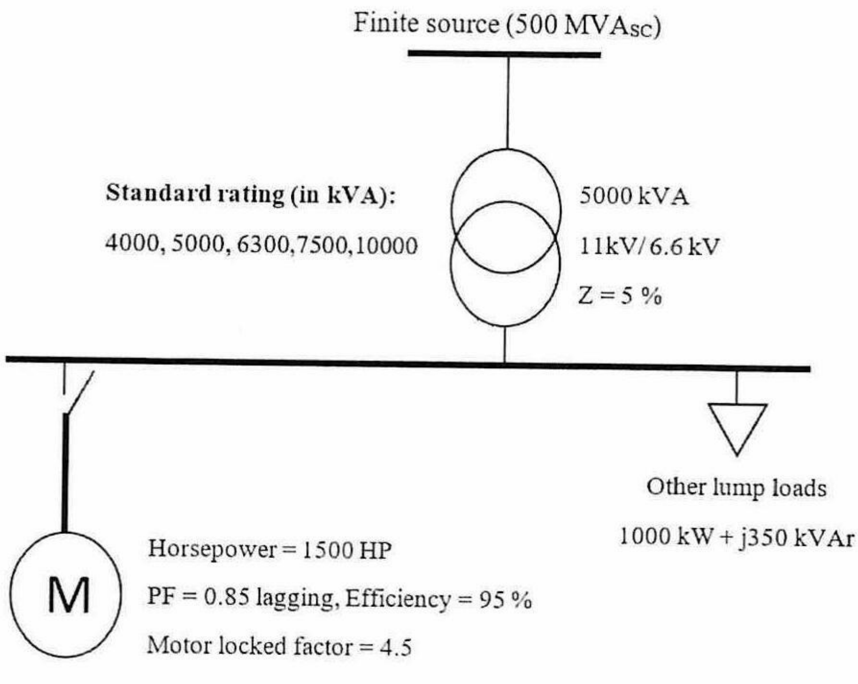

Figure Q1.1

(i) Determine the percentage maximum voltage variation 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 5 % only.

(8 marks)

Q2 The following sub-questions involve with the basic theory and calculation exercises related to power cable design in the industrial power system.

(a) Describe a common application of power cable and control cable used in industrial power system.

(4 marks)

(b) **Figure Q2.1** provides the information of the main components typically available inside the underground power cable. State the name of **A** until **F** components.

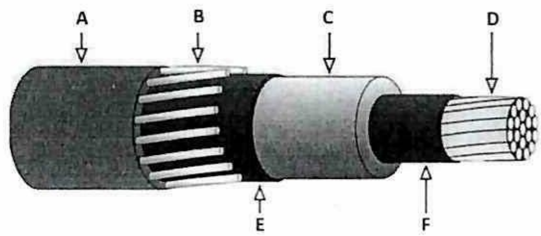

Figure Q2.1

(6 marks)

(c) Consider a feeder serving a large motor fed from 2.5 kV 50 Hz switchgear with a circuit breaker with a separate multifunction motor protection relay. The motor is rated at 200 kW with 0.85 power factor lagging and an efficiency of 95 %. Power cables laid between the feeder and the motor are 3-core aluminium, XLPE type. The cables are laid 150 cm underground in a horizontal formation with 60 cm spacing to each other. The number of cables in a group is 3 Nos. The ground ambient temperature is 35 °C and the thermal resistivity of soil is 150 °C cm/ Watt.

(i) If the fault clearing time for the circuit breaker is 5 cycles and the motor short circuit current is 150 times its rated value, propose the initial size of the cable based on the short circuit current withstand capacity criteria. Refer to **Appendix A** for information criterion.

(8 marks)

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

(7 marks)

Q3 The following sub-questions involve with the basic theory and calculation exercises related to the electrical supply, energy management and electrical quality in industrial power system.

(a) Describe the meaning of the technical and non-technical power losses in industrial power system.

(4 marks)

(b) **Table Q3.1** provides the load profiles of a small industrial plant. Decide a required system voltage to be supplied by Tenaga Nasional Berhad (TNB).

Table Q3.1

Load Profiles
Twenty (20), 100 HP motors (only half of them running at any given time), K = 0.78.
Eight (8), 80 HP motors (only 5 motors are in operational), K = 0.68.
1500 kW of heating and process loads.
Five (5), 25 kVA each lighting transformer, PF = 0.9, η = 95 %.
200 HP of collection small motors (mostly fraction HP, only 70 % are running at any given time), K = 0.85

(11 marks)

(c) **Table Q3.2** shows the voltages and currents data of the balance three-phase Y-connected network measured by a power analyser meter.

Table Q3.2

f (Hz)	$V_L \angle\delta$ (Volt)	$I_L \angle\theta = I_{Ph}\angle\theta$ (Amp)
50	$400\angle 0°$	$60\angle -25°$
150	$11.6\angle 15°$	$17\angle 67°$
250	$4.5\angle 50°$	$6\angle -22°$

(i) Estimate the total active power in the network.

(3 marks)

(ii) Analyse the total voltage harmonic distortions in the network.

(2 marks)

(iii) Analyse the total current harmonic distortions in the network.

(2 marks)

(iv) Determine the total true power factor in the network.

(3 marks)

Q4 The following sub-questions involve with the basic theory and calculation exercises related to the battery technology use in the uninterrupted power supply (UPS), the application of load monitoring system and the reactive power compensation concept use in the industrial power system application.

(a) Summarise **TWO (2)** general concepts of lead acid battery use in industrial power system UPS applications.

(4 marks)

(b) Explain in brief the technical benefits of having industrial load monitoring system with regards:

(i) To maintain good power quality of the network electrical parameters.

(3 marks)

(ii) To prolong lifespan of the equipment or devices.

(3 marks)

(c) A power meter in the main general distribution board (SMGDB) unit that supplying 400V, 3-phase, 50 Hz in the harmonic driven loads building is measuring the apparent power of the network, $S_L = 500\angle 43.11°$ kVA. A set of capacitor bank system with step arrangement of 1 : 2 : 2 : 2 : 3 auto-switching modes is available in the SMGDB unit to feed a compensative reactive power, Q_c into the network. Each capacitor unit is capable to produce about 90 kVar with 550 V voltage handling. With this system in place, the average power factor in the network is aimed to keep at minimum of 0.98 at most of the time.

(i) Analyse the existing the active power, reactive power average and average power factor as to be measured by the power meter.

(2 marks)

(ii) Analyse a required leading reactive power, Q_R feed in the network to improve the average power factor to a minimum value of 0.98.

(2 marks)

(iii) Analyse the compensative reactive power, Q_C supplies by capacitor bank system and recommend the number of steps needed in the operational.

(5 marks)

(iv) Evaluate a new actual average power factor feed into the system based on the unit step as recommended in **Q4(c)(iii)**.

(6 marks)

- END OF QUESTIONS -

APPENDIX A

Supporting Information

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

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	-	-

APPENDIX B

Supporting Information (Continue)

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

APPENDIX C

Supporting Information (Continue)

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

APPENDIX D

Supporting Formulae

Horsepower	:	$1HP = 746W$
Power factor	:	$\mathrm{PF} = \cos\theta$
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:	:	$S = \dfrac{P}{K\,factor}$
Average Demand	:	$Demand_{(Average)} = \dfrac{\sum Demand}{Period}$
Load Factor	:	$LF = \dfrac{Demand_{(Average)}}{Demand_{(Maximum)}}$
Load Loss Factor	:	$LLF = k \times LF + (1-k) \times LF^2$
Rated Current (Transformer)	:	$I_{rated(Tx)} = \dfrac{S_{3\emptyset}}{\sqrt{3} \times V_{3\emptyset}}$
Short Circuit Current (Transformer)	:	$I_{SC(Tx)} = \dfrac{I_{rated(Tx)}}{Z_{(Tx)}}$

APPENDIX E

Supporting Formulae (Continue)

Total Short Circuit Apparent Power	:	$S_{SC(Total)} = \frac{(S_{SC(Finite\ Source)} \times S_{SC(Tx)})}{(S_{SC(Finite\ Source)} + S_{SC(Tx)})}$
Starting Motor Current	:	$I_{starting(M)} = I_{rated(M)} \times Factor_{Locked(M)}$
Voltage Variation/Drop (%)	:	$\%V_{drop(starting)} = \frac{S_{starting(M)}}{S_{SC(Total)}} \times 100\%$
New Transformer Short Circuit Apparent Power	:	$S_{SC(Tx)new} = \frac{(S_{SC(Total)new} \times S_{SC(Finite\ Source)})}{(S_{SC(Finite\ Source)} - S_{SC(Total)new})}$
New Rated Current (Transformer)	:	$I_{rated(Tx)new} = I_{SC(Tx)new} \times Z_{(Tx)}$
Short Circuit Motor Current	:	$I_{SC(M)} = I_{rated(M)} \times SC_{(times)(M)}$
Clearing Time of Circuit Breaker	:	$t_{operating(CB)} = \frac{1}{f_{(sys)}} \times CB_{(cycle)}$
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)	:	$Cable_{(Area)} = \frac{\sqrt{I_{SC}^2 t}}{K_{Temp}}$
Total Three-phase Active Power	:	$P_{3\emptyset\_Total}\ (\text{W}) = \sqrt{3} \sum_{k=1}^{\infty} \lvert V_k \rvert \lvert I_k \rvert cos(\delta_k - \theta_k) + \lvert V_{k2} \rvert \lvert I_{k2} \rvert cos(\delta_{k2} - \theta_{k2}) + .. \lvert V_{kn} \rvert \lvert I_{kn} \rvert cos(\delta_{kn} - \theta_{kn})$

APPENDIX F

Supporting Formulae (Continue)

Total Harmonic Distortion (Voltage & Current)	:	$THD_V = \frac{\sqrt{\sum_{k=2}^{\infty} V_{krms}^2}}{V_{1rms}} \times 100\%$ $THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \times 100\%$
Required Leading Reactive Power	:	$Q_R = P[tan(\cos^{-1}\theta_{desired}) - tan(\cos^{-1}\theta_{existing})]$
Compensative Reactive Power		$Q_C = Q_R \left[\frac{V_C}{V_S}\right]^2$