UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION (ONLINE) SEMESTER II SESSION 2019/2020

COURSE NAME	:	INDUSTRIAL POWER SYSTEMS
COURSE CODE	:	BEF 44903
PROGRAMME CODE	:	BEV
EXAMINATION DATE	:	JULY 2020
DURATION	:	4 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS **OPEN BOOK EXAMINATION**

THIS QUESTION PAPER CONSISTS OF **ELEVEN (11)** PAGES

Q1 (a) Explain **TWO (2)** advantages of installing Delta-Grounded Star configuration of distribution transformer in industrial power system

(4 marks)

(b) State **THREE (3)** different types of dry distribution transformer for industry use.

(3 marks)

(c) **Table Q1(c)** depicts the loading of Motor Control Centre (MCC) in an electronic based factory. Prepare a proper table to calculate the total loading of the MCC by indicating the three-phase and single-phase loads.

(8 marks)

(d) The MCC in **Q1(c)** is served by a three-phase cable installed from the 415 V main switchgear feeder. The insulation type and the conductor type of the cable are PVC and copper, respectively. The short circuit current capacity is to be assumed as 100 times of the MCC load current and the fault clearing time is taken as 0.5 second.

(i) Analyse the minimum size of the cable required based on the short circuit withstand capacity criteria (Refer to **Appendix A**).

(5 marks)

(ii) Evaluate again the cable size obtained in **Q1(d)(i)** for continuous current carrying capacity criteria based on **Table Q1(d)(1)** to **Table Q1(d)(3)**. The cable is directly clipped on the wall with the ambient temperature of 45°C. The cable is laid on 3 Nos of cable rack with number of cables per rack to be 3. Recommend the new cable size if necessary.

(5 marks)

Q2 (a) Propose **THREE (3)** ideas to enhance energy efficiency of industrial motor loads.

(6 marks)

(b) An inverter based UPS is installed in a factory to run 10 Nos of 250 W luminaires for at least 5 hours during the blackout period. The battery bank output voltage is 48 V and the inverter efficiency is assumed as 85%. Decide a proper battery size (in AH) if maximum depth of discharge is to be considered during the operation.

(5 marks)

(c) An industrial power system having three outgoing feeders that taps from the main utility supply and UPS system as depicted in **Figure Q2(c)**. Assume all the loads are operating at 415 V. The UPS is designed to power up the critical loads during power outage for at least 3 hours as follows:

- 30% of feeder 1
- 10% of feeder 2
- 15% of feeder 3

Design the UPS system by indicating its appropriate capacity (in kVA) and the proper battery rating for the UPS.

(14 marks)

Q3 (a) The flow of harmonics reduces power quality and consequently causes a number of problems. List **THREE (3)** possible consequences of harmonics in industrial power systems.

(3 marks)

(b) A large industrial plant receives 3-phase electric power from the local utility. The following loads are being fed in the plant at 11 kV:

- 1.2 + j 1.2 MVA
- 2.0 MW at 0.8 (lag) power factor
- 800 kW of pure heating and lighting (negligible reactive power) load
- A number of induction motors: total power output of 3,000 HP, with a composite efficiency of 0.85 and power factor of 0.88 (lag)

(i) Analyse the total active power, reactive power and apparent power.

(6 marks)

(ii) Compute the overall (composite) load power factor and the full load current.

(4 marks)

(iii) Plan the capacitive VAR requirements for the capacitor bank if the overall plant power factor is to be improved to 0.95 lag.

(2 marks)

(iv) Draw the simplified one-line diagram and the phasor diagram (power triangle).

(4 marks)

(c) **Figure Q3(c)** shows a feeder overcurrent protection scheme in which *A* represents the incoming feeder and *D* represents the outgoing feeders.

(i) If the minimum short circuit current at the busbar is 80 kA during the occurrence of *Fault 1*, propose the minimum current threshold settings for I_A and I_{D1}.

(4 marks)

(ii) Give the minimum short circuit current value at D_1 during the incidence of *Fault 2* as specified by the current threshold setting, I_{D1} in **Q3(c)(i)**.

(2 marks)

Q4 (a) Illustrate the voltage changes (ΔV_R and jΔV_X) of Load Voltage Monitoring Control (LVMC) using a phasor diagram when a motor load is switching on. The total impedance of the motor is given as $R_M + jX_M$ with power factor angle of θ and the load current is I_L.

(2 marks)

(b) **Figure Q4(b)** depicts a simplified electrical installation schematic for a factory plant. Analyse the total symmetrical short circuit current for this installation using Per Unit (PU) method if the fault occurred at Motor Control Centre (MCC) as indicated at location *F1* in the figure. The cable impedance calculations should refer to **Table Q4(b)**. Take the disconnecting switch reactance (fuse) as 0.00008 Ω and the calculation base as 10,000 kVA.

(13 marks)

(c) Examine again the total symmetrical short circuit current for the installation shown in **Figure Q4(b)** using Ohmic method. Compare the error caused between the Per Unit method and the Ohmic method.

(10 marks)

– END OF QUESTIONS –

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TABLE Q1(c)

Load description	3ø/ 1ø	Duty N or S	Motor rating (kW)	Operating motor power (kW)	Power Factor	Efficiency (%)
Hoist system	3	N	50	42	0.80	88
Cooling tower fan	3	S	20	17	0.86	92
Heater	3	N	15	-	-	-
Fan coil	1	N	2	1.6	0.90	82
Water pump	3	N	18	15	0.82	70
Extract fan	1	N	1.5	1.2	0.87	90
Compressor	1	N	1.5	1.3	0.88	82
Future pump	3	N	10	8.8	0.90	80

TABLE Q1(d)(1)

Rating factors for variation in ambient air temperature:

Air Temp. (°C)	20	25	30	35	40	45	50	55
Rating Factor	1.81	1.41	1.10	1.05	1.00	0.95	0.89	0.84

TABLE Q1(d)(2)

Rating factors for multi-core cables laid on open racks in air:

No. of racks	No. of cables per rack				
	1	2	3	6	9
1	1.00	0.84	0.80	0.75	0.73
2	1.00	0.80	0.76	0.71	0.69
3	1.00	0.78	0.74	0.70	0.68
6	1.00	0.76	0.72	0.68	0.66

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TABLE Q1(d)(3)

TABLE 4D2A – Multicore 70 °C thermoplastic insulated and thermoplastic sheathed cables, Non-armoured (COPPER CONDUCTORS)

Ambient temperature: 30 °C

CURRENT-CARRYING CAPACITY (amperes): Conductor operating temperature: 70 °C

Conductor cross-sectonal area	Reference Method A (enclosed in conduit in thermally insulating wall etc.)		Reference Method B (enclosed in conduit on a wall or in trunking etc.)		Reference Method C (clipped directly)		Reference Method E (in free air or on a perforated cable tray etc, horizontal or vertical)	
	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.
1	2	3	4	5	6	7	8	9
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	11	10	13	11.5	15	13.5	17	14.5
1.5	14	13	16.5	15	19.5	17.5	22	18.5
2.5	18.5	17.5	23	20	27	24	30	25
4	25	23	30	27	36	32	40	34
6	32	29	38	34	46	41	51	43
10	43	39	52	46	63	57	70	60
16	57	52	69	62	85	76	94	80
25	75	68	90	80	112	96	119	101
35	92	83	111	99	138	119	148	126
50	110	99	133	118	168	144	180	153
70	139	125	168	149	213	184	232	196
95	167	150	201	179	258	223	282	238
120	192	172	232	206	299	259	328	276
150	219	196	258	225	344	299	379	319
185	248	223	294	255	392	341	434	364
240	291	261	344	297	461	403	514	430
300	334	298	394	339	530	464	593	497
400	-	-	470	402	634	557	715	597

* with or without a protective conductor

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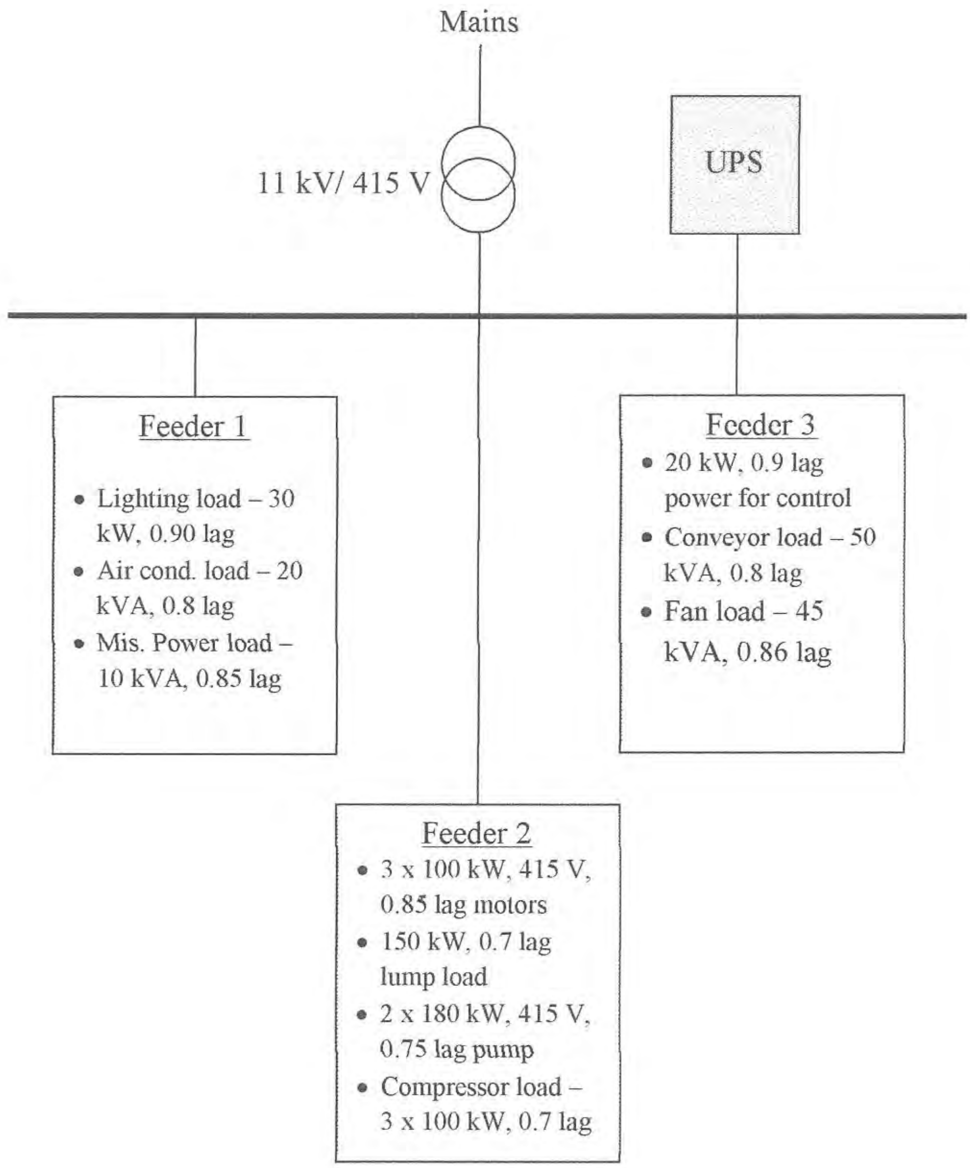

Figure Q2(c)

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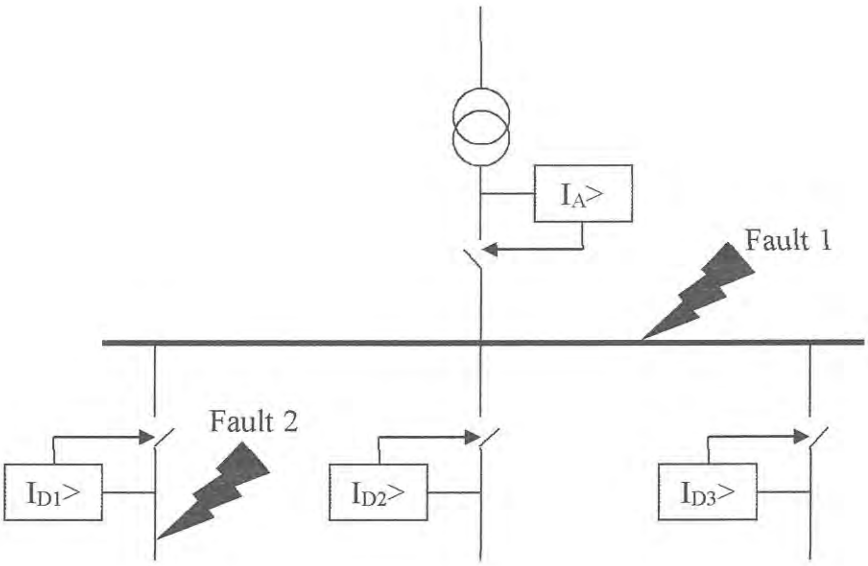

Figure Q3(c)

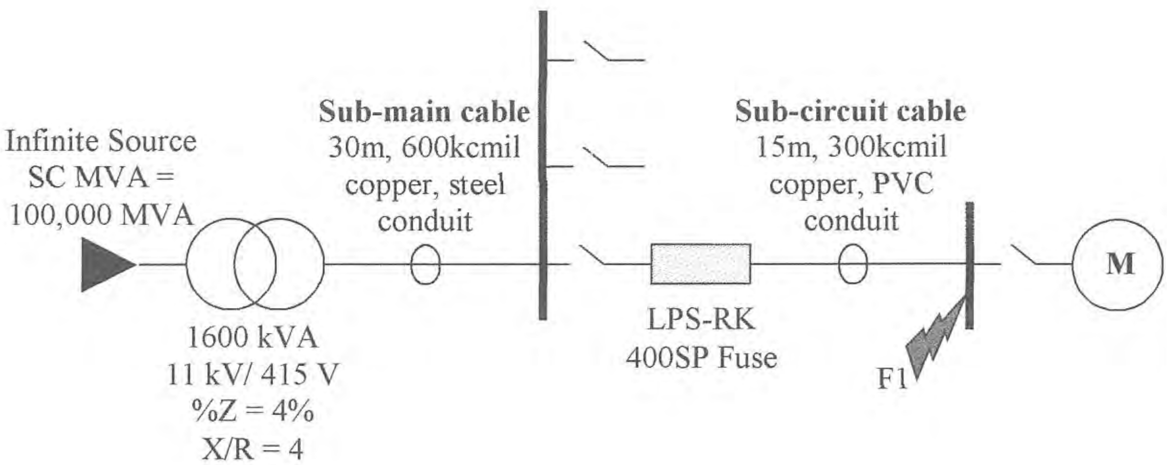

Figure Q4(b)

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Table Q4(b)

Size (AWG or kcmil)	Ohms to Neutral per Kilometer Ohms to Neutral per 1000 Feet										
	X_L (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 PF for Aluminum Wires		
	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit
14	0.190 0.058	0.240 0.073	10.2 3.1	10.2 3.1	10.2 3.1	- -	- -	- -	- -	- -	- -
12	0.177 0.054	0.223 0.068	6.6 2.0	6.6 2.0	6.6 2.0	10.5 3.2	10.5 3.2	10.5 3.2	9.2 2.8	9.2 2.8	9.2 2.8
10	0.164 0.050	0.207 0.063	3.9 1.2	3.9 1.2	3.9 1.2	6.6 2.0	6.6 2.0	6.6 2.0	5.9 1.8	5.9 1.8	5.9 1.8
8	0.171 0.052	0.213 0.065	2.56 0.78	2.56 0.78	2.56 0.78	4.3 1.3	4.3 1.3	4.3 1.3	3.6 1.1	3.6 1.1	3.6 1.1
6	0.167 0.051	0.210 0.064	1.61 0.49	1.61 0.49	1.61 0.49	2.66 0.81	2.66 0.81	2.66 0.81	2.33 0.71	2.36 0.72	2.36 0.72
4	0.157 0.048	0.197 0.060	1.02 0.31	1.02 0.31	1.02 0.31	1.67 0.51	1.67 0.51	1.67 0.51	1.51 0.46	1.51 0.46	1.51 0.46
3	0.154 0.047	0.194 0.059	0.82 0.25	0.82 0.25	0.82 0.25	1.31 0.40	1.35 0.41	1.31 0.40	1.21 0.37	1.21 0.37	1.21 0.37
2	0.148 0.045	0.187 0.057	0.62 0.19	0.66 0.20	0.66 0.20	1.05 0.32	1.05 0.32	1.05 0.32	0.98 0.30	0.98 0.30	0.98 0.30
1	0.151 0.046	0.187 0.057	0.49 0.15	0.52 0.16	0.52 0.16	0.82 0.25	0.85 0.26	0.82 0.25	0.79 0.24	0.79 0.24	0.82 0.25
1/0	0.144 0.044	0.180 0.055	0.39 0.12	0.43 0.13	0.39 0.12	0.66 0.20	0.69 0.21	0.66 0.20	0.62 0.19	0.66 0.20	0.66 0.20
2/0	0.141 0.043	0.177 0.054	0.33 0.10	0.33 0.10	0.33 0.10	0.52 0.16	0.52 0.16	0.52 0.16	0.52 0.16	0.52 0.16	0.52 0.16
3/0	0.138 0.042	0.171 0.052	0.253 0.077	0.269 0.082	0.259 0.079	0.43 0.13	0.43 0.13	0.43 0.13	0.43 0.13	0.43 0.13	0.46 0.14
4/0	0.135 0.041	0.167 0.051	0.203 0.062	0.220 0.067	0.207 0.063	0.33 0.10	0.36 0.11	0.33 0.10	0.36 0.11	0.36 0.11	0.36 0.11
250	0.135 0.041	0.171 0.052	0.171 0.052	0.187 0.057	0.177 0.054	0.279 0.085	0.295 0.090	0.282 0.086	0.308 0.094	0.322 0.098	0.33 0.10
300	0.135 0.041	0.167 0.051	0.144 0.044	0.161 0.049	0.148 0.045	0.233 0.071	0.249 0.076	0.236 0.072	0.269 0.082	0.282 0.086	0.289 0.088
350	0.131 0.040	0.164 0.050	0.125 0.038	0.141 0.043	0.128 0.039	0.200 0.061	0.217 0.066	0.207 0.063	0.240 0.073	0.253 0.077	0.262 0.080
400	0.131 0.040	0.161 0.049	0.108 0.033	0.125 0.038	0.115 0.035	0.177 0.054	0.194 0.059	0.180 0.055	0.217 0.066	0.233 0.071	0.240 0.073
500	0.128 0.039	0.157 0.048	0.089 0.027	0.105 0.032	0.095 0.029	0.141 0.043	0.157 0.048	0.148 0.045	0.187 0.057	0.200 0.061	0.210 0.064
600	0.128 0.039	0.157 0.048	0.075 0.023	0.092 0.028	0.082 0.025	0.118 0.036	0.135 0.041	0.125 0.038	0.167 0.051	0.180 0.055	0.190 0.058

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Appendix A

The minimum cable size due to short circuit temperature rise:

$$A = \frac{\sqrt{I_{SC}^2 t}}{K}$$

where,
A = Minimum required cross section area in mm^2
t = The duration of the short circuit in second
K = Short circuit temperature rise constant

The temperature rise constant (K) according to IEC 60364-5-54:

$$K = 226\sqrt{In\left(1 + \frac{T_2 - T_1}{234.5 + T_1}\right)} \text{ .....(for copper conductors)}$$

$$K = 148\sqrt{In\left(1 + \frac{T_2 - T_1}{228.1 + T_1}\right)} \text{ .....(for aluminium conductors)}$$

where,
T_1 = the initial conductor temperature in °C
T_2 = the final conductor temperature in °C

Table A1: Boundary conditions of initial (T_1) and final (T_2) temperature for different insulation:

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

Standard Cable Size (mm^2):

1, 1.5, 2.5, 4, 6, 10, 16, 25, 35, 50, 70, 95, 120, 150, 185, 240, 300, 400.

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Appendix B: Formulae

$$Z_S = \frac{E^2}{S_{SC}}$$

$$\tan\phi_{SC} = \frac{X_S}{R_S}$$

$$R_S = Z_S \cos\phi_{SC}$$

$$X_S = Z_S \sin\phi_{SC}$$

$$P_{3\phi} = \sqrt{3} \times V_L \times I_L \times \cos\theta$$

$$X_{utility(pu)} = \frac{S_{base}}{S_{SC(utility)}}$$

$$X_{TX(pu)} = \frac{(\%X)S_{base}}{(100\%)S_{TX}}$$

$$R_{TX(pu)} = \frac{(\%R)S_{base}}{(100\%)S_{TX}}$$

$$X_{\substack{component(cable, \\ switches, CT, bus)(pu)}} = \frac{(X_\Omega)S_{base}}{(V)^2}$$

$$R_{\substack{component(cable, \\ switches, CT, bus)(pu)}} = \frac{(R_\Omega)S_{base}}{(V)^2}$$

$$I_{SC,symRMS} = \frac{S_{base}}{\sqrt{3}V\left(Z_{total(pu)}\right)}$$

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