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# UNIVERSITI TUN HUSSEIN ONN MALAYSIA

## FINAL EXAMINATION
## SEMESTER I
## SESSION 2015/2016

| | | |
|---|---|---|
| COURSE NAME | : | INDUSTRIAL POWER SYSTEMS |
| COURSE CODE | : | BEF 44903 |
| PROGRAMME | : | BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS |
| EXAMINATION DATE | : | DECEMBER 2015/ JANUARY 2016 |
| DURATION | : | 3 HOURS |
| INSTRUCTION | : | ANSWER **ALL** QUESTIONS |

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

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**Q1** (a) Discuss a general overview of main components in industrial power systems

(5 marks)

(b) A 3-phase dry-type transformer is installed in a small industrial plant shown in **Figure Q1(b).** The characteristics of Motor 1 (*M1*) and Motor 2 (*M2*), are given in **Table Q1(b)(i)**. The fault clearing time for *Q1* and *Q2* are assumed to be 12 cycles based on 50Hz system. The types of conductor and insulator of *C1* and *C2,* and the final and initial temperatures of insulations are given in **Table Q1(b)(ii)** and **Appendix A**, respectively.

(i) Calculate the percentages of voltage variation ($\Delta$V) during the motor starting of *M1* and *M2* if the short circuit capacity of the transformer is 20MVA.

(8 marks)

(ii) Analyse the temperature rise constant (*k*) for *C1* and *C2*.

(2 marks)

(iii) Examine the minimum size (in mm$^2$) of *C1* and *C2* due to the short-circuit temperature rise. The standard rating for *Q1* and *Q2* to be chosen is 45 kA.

(4 marks)

(iv) Conclude the relationship between cable sizing and insulation material above

(1 mark)

**Q2** (a) Discuss **two (2)** ideas to enhance energy efficiency in motor.

(4 marks)

(b) An inverter based UPS is installed in a factory to power critical loads for a minimum of 30 minutes following a loss of normal power. The user believes that the UPS will be almost fully loaded for the entire discharge duration. Assume the UPS specifications applicable to the battery are as follows:

- Size: 7.5 kVA @ 0.8 power factor (6.0 kW)
- Inverter efficiency: 0.92 at full load
- Maximum/ minimum input dc voltage: 140 V / 105 V
- Aging: 1.25 (corresponding to 80 percent capacity)
- Temperature: 1.11 (assume lowest expected temperature is 15.6 °C or 60 °F)

(i) Examine the total battery load in kW.

(1 mark)

(ii) Establish the corrected battery load (kW) related with aging and temperature.

(1 mark)

(iii) Inspect the maximum number of cells required to power a minimum of 30 minutes (assume a maximum battery equalize voltage of 2.33 volts per cell).

(2 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.

(12 marks)

**Q3** (a) One of the advantages of doing the power factor correction is increasing the equipment life span. Interpret this statement with an appropriate example.

(4 marks)

(b) The single line diagram of a factory installation is shown in **Figure Q3(b)**.

(i) Find the average power factor for this factory

(6 marks)

(ii) Examine the minimum compensation reactive power ($Q_S$) to be injected into the system, if the overall power factor is to be corrected to at least 0.95 lagging.

(1 mark)

(c) A 6 steps power factor corrector is to be installed in the system as shown in **Figure Q3(c).** The voltage rating of the capacitors used in the power factor corrector is 525V. The power factor corrector has the arrangement as follows (total 12 units):

| Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 2 | 3 | 3 |

(i) Evaluate the effective reactive power ($Q_{Ceff}$) to be supplied by the capacitor bank.

(1 mark)

(ii) Determine the steps that the power factor corrector to be switched ON for 1 unit capacitor having 5 kVAr,

(2 marks)

(iii) Estimate the actual compensation reactive power ($Q_S$) injected into the system as to fulfil the case in Q3(c)(ii).

(2 marks)

(iv) With the actual compensation reactive power obtained in Q3(c)(ii), evaluate the actual average power factor for the system.

(4 marks)

**Q4** (a) State **two (2)** objectives of a safe grounding design for an industrial AC substation.

(2 marks)

(b) Summarize the method used for the measurement of an industrial sub-station ground system resistance using fall-of-potential principle.

(3 marks)

(c) The measurement of the average resistivity of soil of an industrial sub-station premise can be done using 4-point or Wenner's method. The average resistivity of soil is given as

$$\rho = \frac{4\pi a R_g}{1 + \frac{2a}{\sqrt{(a^2 + 4b^2)}} - \frac{a}{\sqrt{(a^2 + b^2)}}}$$

where

$a$ = inter-probe distance in m,u

$b$ = depth of the probe in the ground layer in m,

$R_g$ = the soil resistance in ohm,

Analyze the condition for $\rho = 2\pi a R_g$ and $\rho = 4\pi a R_g$

(1 mark)

(d) UTHM Commercial Sdn Bhd is to establish a Technology Park in order to help UTHM's spin-off companies to operate their business with UTHM's assistances. The energy system of the park requiring an AC substation of 11 kV incoming from TNB 132/33 kV main in-take substation. The design is based on the followings:

- Soil resistivity is 70 Ωm,
- Surface resistivity for gravel of thickness hs = 150 mm, is 2500 Ωm,
- Duration of fault(maximum clearing time of the interrupting device) is 1.0s,
- Average weight of a personnel in the substation premise is 70 kg,
- Fault current is 21.46 kA,
- The schematic diagram of the substation grounding is shown in **Figure Q4(d)(i)** which is buried 0.25 m below the ground surface where the inter conductor interval is the same forming equal size mesh grid. The grid is made of copper bar of cross-sectional dimension of 8 mm x 25 mm and
- The performance of reduction factor $C_s$ as a function of reflection factor k and thickness of crushed rock(gravel) $h_s$ is shown in **Figure Q4(d)(ii)**
- The related constants to determine actual step and touch potential is given in **Table Q4(d).**

(i) Predict whether the proposed design is a safe industrial AC substation grounding system or not.

(13 marks)

(ii) Conclude the safety of the system if the gravel is not included in the design

(1 mark)

**Q5** (a) Centred within a 60 x 60 m station as shown in **Figure Q5(a)(i)** is a group of equipment having a height of 12 meters. The equipment area is 12 x 12 m. Using Young's equations with a design current of 10 kA;

(i) Point out the height of 2 masts located along the borders of the station marked by MT.

(9 marks)

(ii) Estimate the maximum probability for the equipment to be struck by lightning ground flashes, based on **Figure Q5(a)(ii).**

(2 marks)

(b) The cross-sectional view of a mast protecting a group of equipment in a substation covering 60 x 60 m of land area as shown in **Figure Q5(b)(i)**. Using Young's Equations with a design current of 10 kA;

(i) Simplify whether the mast standing by the equipment provides shielding from a direct lightning strike to the substation equipment.

(4 marks)

(ii) Recommend by sketching a design to provide shielding to maintain the design current of 10 kA, if additional equipment are to be installed in future as shown in **Figure Q5(b)(ii)**. State any assumptions made.

(3 marks)

(c) The current practice of shielding industrial substation equipment is by means of elevated Franklin rod replacing the traditional use of shielding wire which are installed above the substation equipment using steel towers. Justify **two (2)** possible reasons for the current practice.

(2 marks)

**– END OF QUESTIONS –**

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

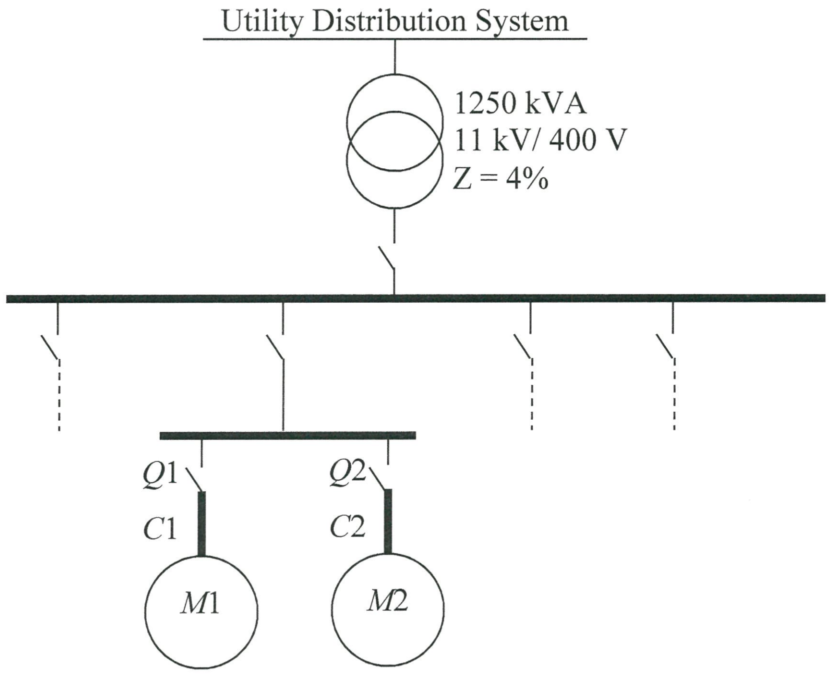


**FIGURE Q1(b)**

**TABLE Q1(b)(i)**

| **Characteristics** | **Motor 1 (*M*1)** | **Motor 2 (*M*2)** |
|---|---|---|
| Max. output power (kW) | 200 | 200 |
| Percentage Efficiency (%) | 85 | 90 |
| Power factor (PF) | 0.91 lagging | 0.93 lagging |
| Multiplication of starting inrush current as compared to its rated current | 5 | 5 |

**TABLE Q1(b)(ii)**

| **Item** | ***C*1** | ***C*2** |
|---|---|---|
| Conductor Material | Copper | Copper |
| Insulation Material | XLPE | PVC |

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV

COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

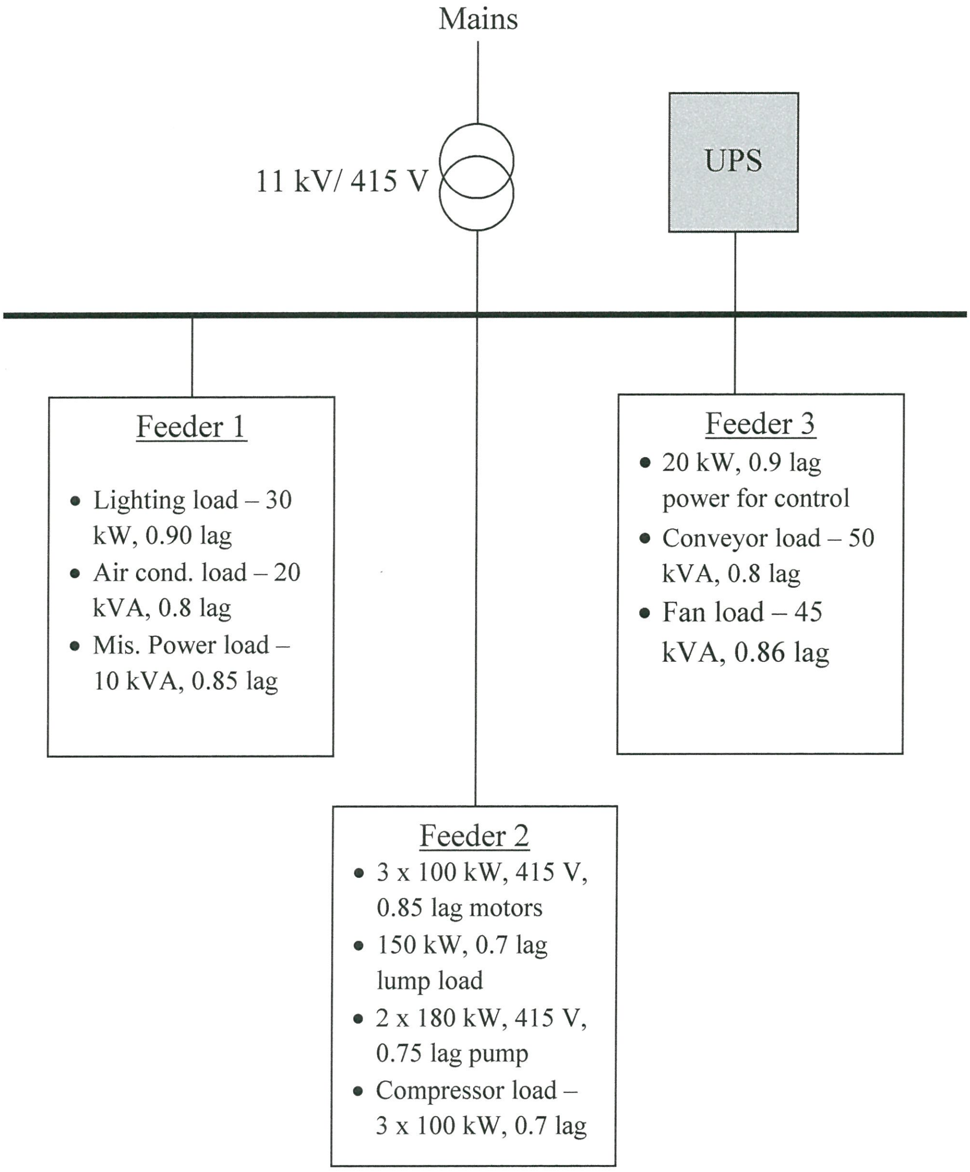


**FIGURE Q2(c)**

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| SEMESTER/SESSION : SEM I/ 2015/ 2016 | PROGRAMME : 4 BEV |
| COURSE NAME : INDUSTRIAL POWER SYSTEMS | COURSE CODE : BEF 44903 |

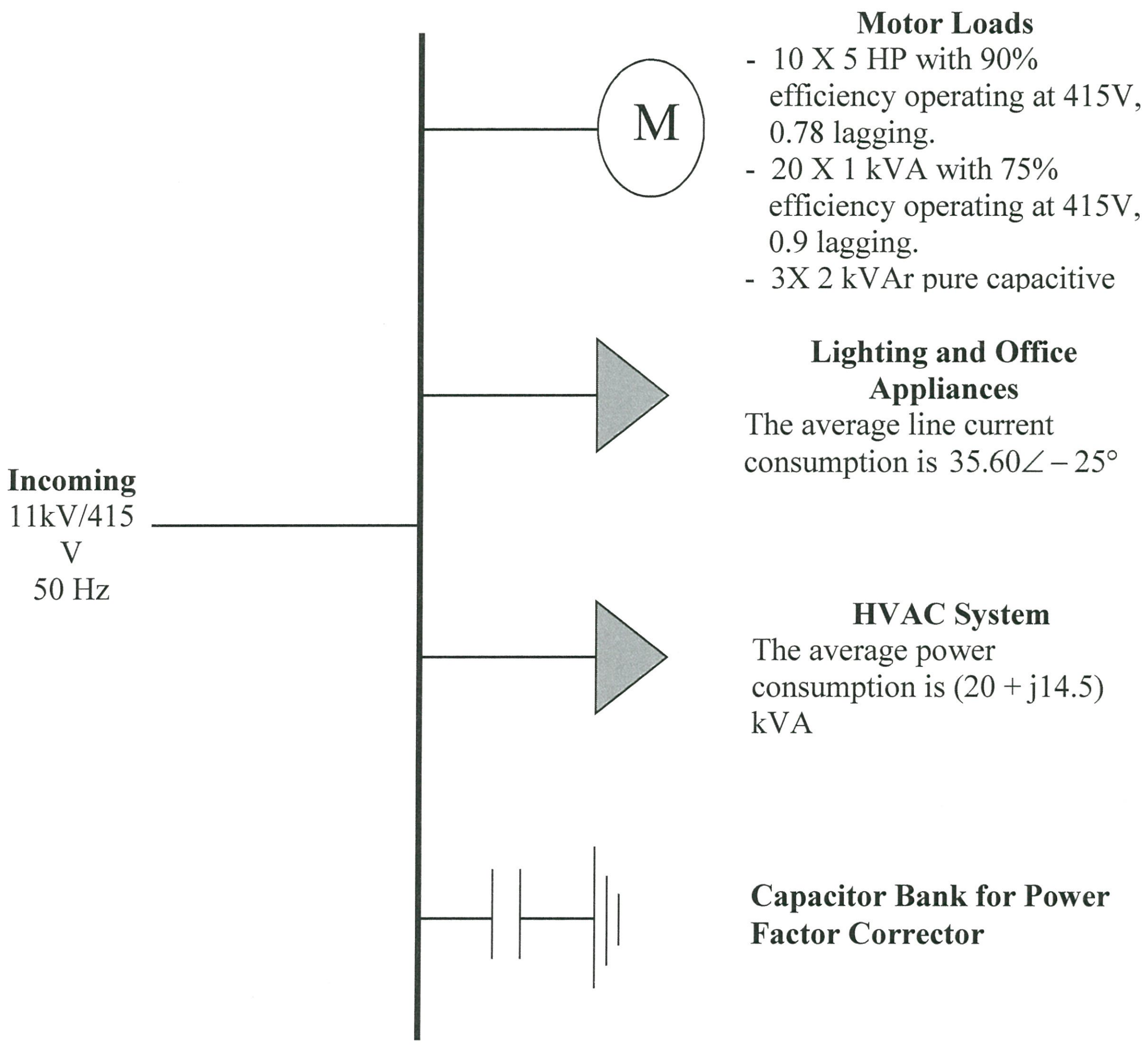



**FIGURE Q3(c)**

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

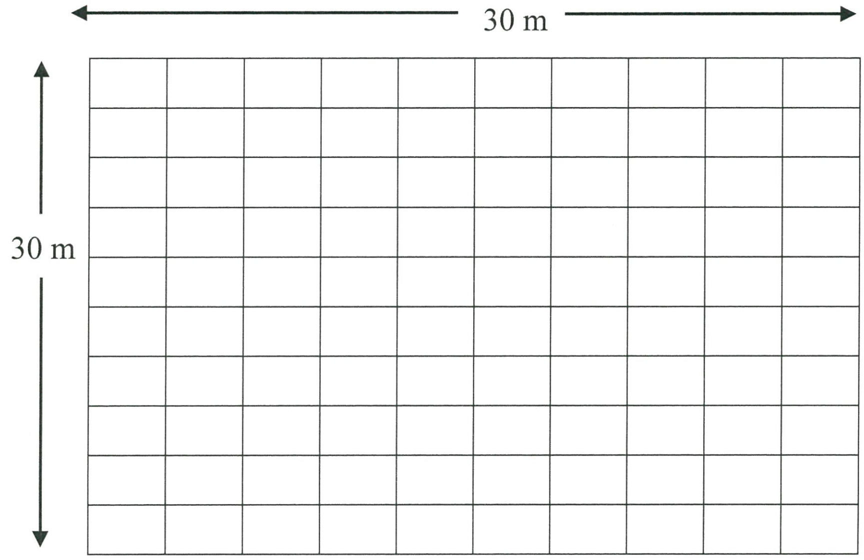



**FIGURE Q4(d)(i)**

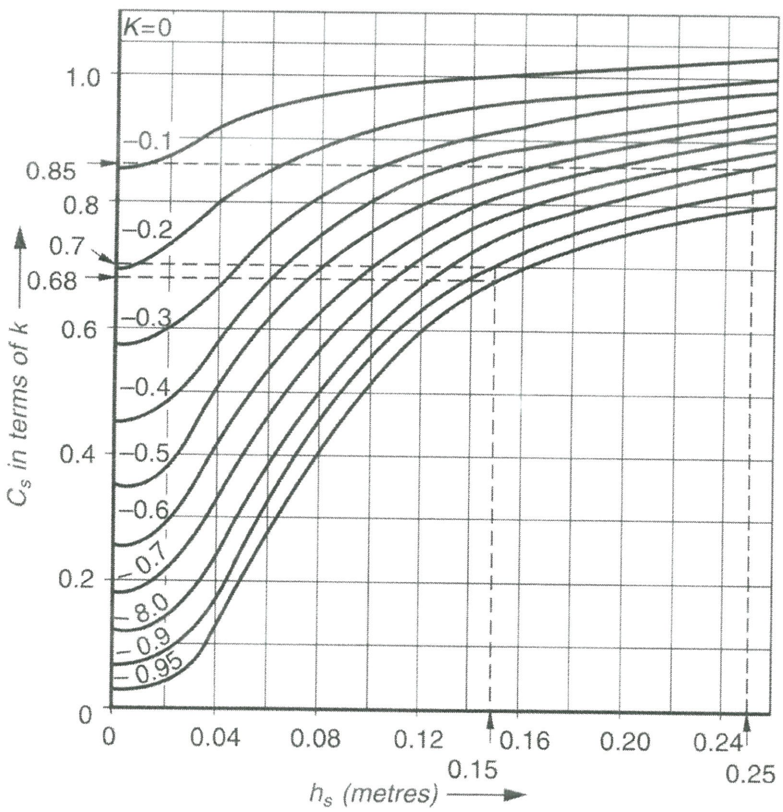



**FIGURE Q4(d)(ii)**

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

## TABLE Q4(d)

| Constant | The formulae based on IEEE Std 80 |
|---|---|
| $K_i$ | $0.656+0.172n$ |
| $K_m$ | $\frac{1}{2\pi}\left(log_e\left(\frac{D^2}{16hd}+\frac{(D+2h)^2}{8Dd}-\frac{h}{4d}\right)+\frac{K_{ii}}{K_h}log_e\left(\frac{8}{\pi(2n-1)}\right)\right)$ where $K_{ii}=\frac{1}{(2n)^{2/n}}$ , $K_h=\sqrt{1+\frac{h}{h_o}}$ |
| $K_s$ | $\frac{1}{\pi}\left(\frac{1}{2h}+\frac{1}{D+h}+\frac{1}{D}(1-0.5^{n-2})\right)$ |

n = the number of conductors on each side of a square grid
D =inter conductor spacing in m
h = grid depth height from the soil surface in m
$h_0$ = the reference depth of grid = 1 m
d = diameter of circular conductor in m

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

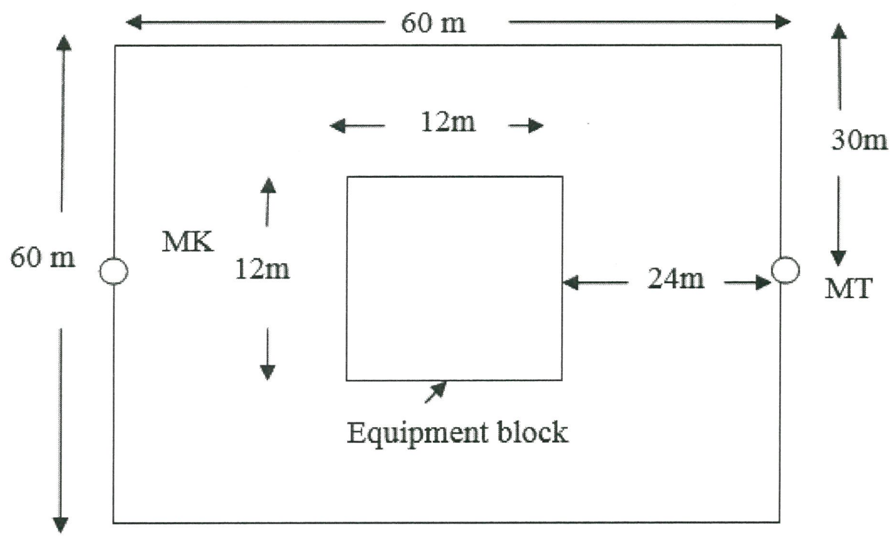



**FIGURE Q5(a)(i)**

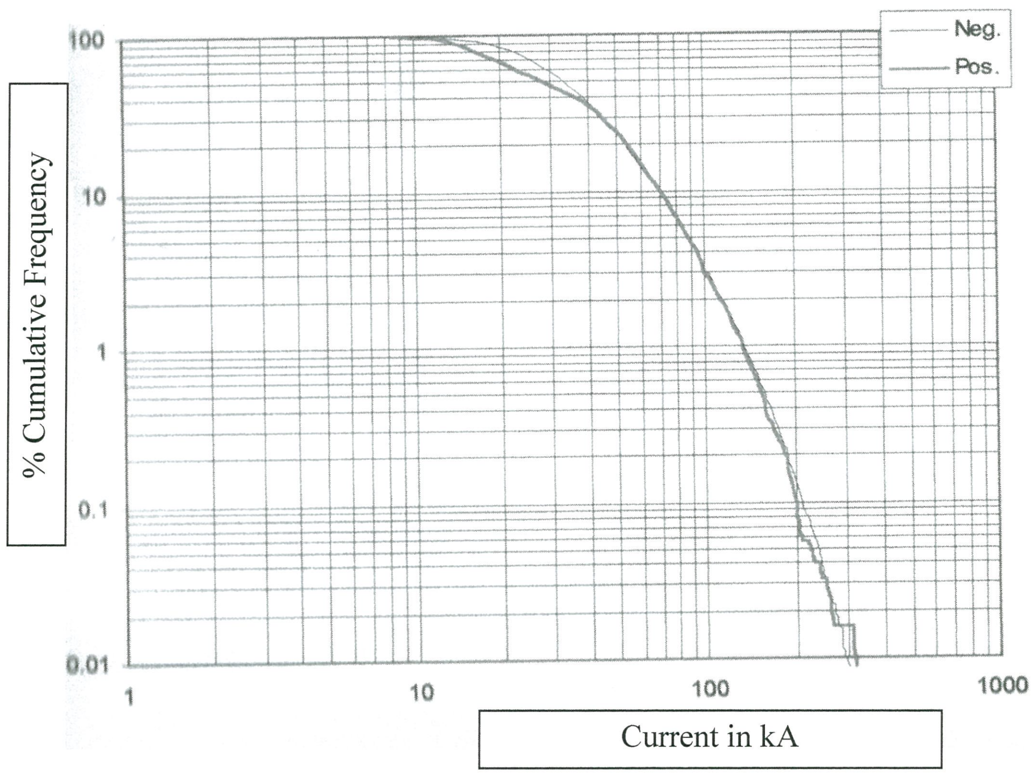
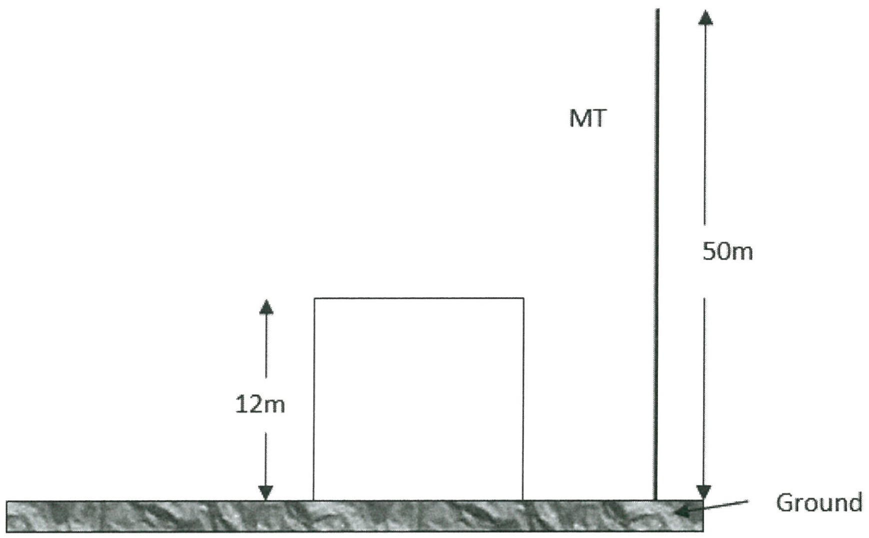



**FIGURE Q5(a)(ii)**

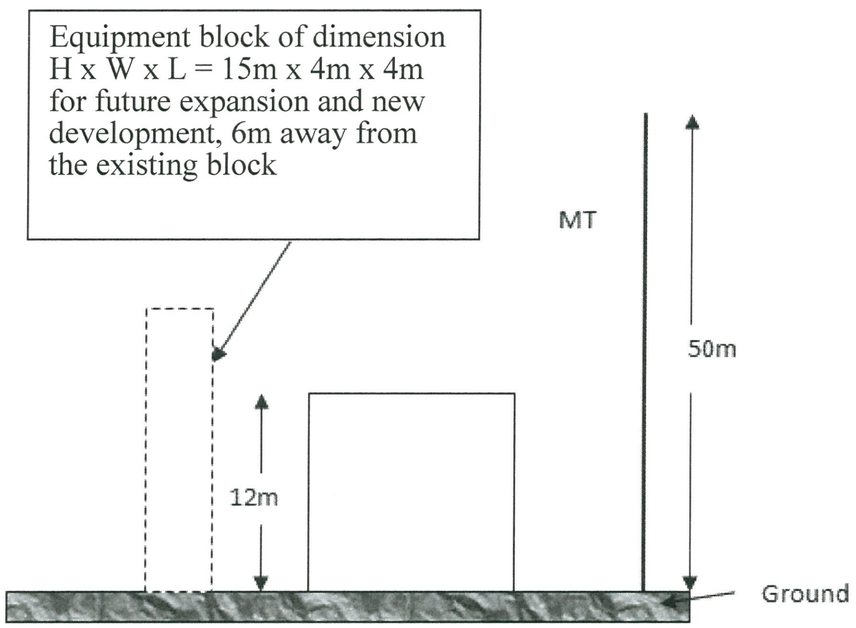
**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903




Front view of the industrial power system substation (not drawn to scale)

**FIGURE Q5(b)(i)**




Front view of the industrial power system substation (not drawn to scale)

**FIGURE Q5(b)(ii)**

**FINAL EXAMINATION**

SEMESTER/SESSION : SEM I/ 2015/ 2016 PROGRAMME : 4 BEV
COURSE NAME : INDUSTRIAL POWER SYSTEMS COURSE CODE : BEF 44903

## 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:

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

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

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.

**FINAL EXAMINATION**

| | | | |
|---|---|---|---|
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## APPENDIX B

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

$$I_{L,DC} = \frac{S}{V_{DC}}$$

$$I_C = \frac{C(k_l)}{t_C}$$

$$E_d = E_t(1+k_g)(1+k_C)$$

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

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

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

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

$$V^4 + \{2(R_S P_L + X_S Q_L) - E^2\}V^2 + (R_S^2 + X_S^2)(Q_L^2 + P_L^2) = 0$$

$$X = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$$

$$Q_N = Q_L + Q_C$$

$$(R_S^2 + X_S^2)Q_N^2 + 2V^2 X_S Q_N + (V^2 + R_S P_L)^2 + X_S^2 P_L^2 - E^2 V^2 = 0$$

$$C = \frac{Q_{CAP}}{(V_{LL})^2 \times 2\pi f}$$

$$L = \frac{(V_{LL})^2}{2\pi f \times S_{SC}}$$

$$\frac{I_{rush}}{I_{ncap}} = \sqrt{2}\left(\frac{1}{2\pi f \times \sqrt{C \times L}}\right)$$