CONFIDENTIAL

UTM
UNIVERSITI TEKNOLOGI MALAYSIA

FINAL EXAMINATION SEMESTER I
SESSION 2020/2021

COURSE CODE	:	**MKEP 1543**
COURSE NAME	:	**ADVANCED HIGH VOLTAGE TECHNOLOGY**
LECTURER	:	**PROF. DR. ZULKURNAIN ABDUL MALEK**
PROGRAMME	:	**MKEP / MEP**
SECTION	:	**01**
TIME	:	**2 HOURS 30 MINUTES**
DATE	:	

INSTRUCTIONS TO CANDIDATE :

ANSWER ALL QUESTIONS

THIS EXAMINATION BOOKLET CONSISTS OF **8** PAGES INCLUDING THE FRONT COVER

Q.1 a) Briefly explain how to determine a suitable peak lightning current rating of an arrester. Also, explain how the peak current rating is related to the energy class of an arrester.

(7 marks)

b) A 300 kV substation transformer in a solidly grounded neutral system needs to be protected by a surge arrester with a nominal discharge current of 20 kA and energy class 4 (corresponding to Specific energy of 12.0 kJ/kV (U_{res}), Short-circuit/Pressure relief capability of 65 kA_{sym}, Specified long-term load of 2500 Nm, Specified short-term load of 4000 Nm, Maximum $U_{res\ 20kA,\ 8/20}/U_r = 2.50$, Maximum $U_{res\ 1kA,\ 30/60}/U_r = 1.98$). The transformer basic lightning impulse withstand level is 1050 kV peak. The following information is available:

ZnO residual voltage/length = 290 V/mm, Level II Creepage length/voltage = 28.7 mm/kV, minimum switching $\text{impulse}_{250/2500\ \mu s,\ wet}$ withstand voltage = 1.25 $U_{res\ 1kA,\ 30/60}$ (peak), fault level = 1.5 p.u., $k_{TOV,\ 10s} = 1.075$.

Design a suitable arrester for this transformer. Your design should include a suitable rated voltage of the arrester, corresponding protection level and margin of protection, length of the ZnO blocks required, minimum lightning impulse withstand of the housing, minimum phase-to-earth switching impulse withstand of the housing, creepage length, number of housing unit required, and the requirement of a grading ring.

(10 marks)

c) Table Q.1c shows the information of an MO arrester in a solidly earthed neutral 50 Hz system.

i. Draw the equivalent circuit of the surge arrester
ii. Accurately sketch the applied voltage and currents (resistive, capacitive, and total) versus time (for 1 cycle)
iii. Determine the 3-phase system rated voltage
iv. Determine the equivalent capacitance of the ZnO surge arrester

Neglect all harmonic components.

Table Q.1c

Parameter	Value
$I_{peak\ capacitive}$ (mA)	1.7
$I_{peak\ resistive}$ (mA)	0.13
Frequency (Hz)	50
V_{peak} (kV)	350

(8 marks)

Q.2 a) The insulation coordination standard divides the voltage systems into two different categories, namely **range I** (Um < 245 kV) and **range II** (Um > 245 kV). Explain the **differences** between the two ranges and the **effects** on the final values of withstand voltages.

(6 marks)

b) Briefly explain the differences between deterministic and statistical determination of the coordination factor, K_c, as defined in the standard insulation co-ordination procedure.

(4 marks)

c) A 24 kV substation is to be designed. Design the insulation withstand voltages for the substation. The following information is available:

Neutral earthing:	isolated
Altitude, H:	1000 m
Maximum TOV level (p-p) =	1.15 p.u. rms
U_{et} =	3.0 p.u. peak
U_{pt} =	4.4 p.u. peak
K_c =	1.0
U_{pl} =	80 kV peak
n =	4
A =	2700
L_{sp} =	100m
L_a =	42 m
L =	5 m for external and 3 m for internal
$U_{cw\ FFO}$ =	$U_{pl} + (A.L)/(n.(L_{sp}+L_a))$
$K_{s\ internal}$ =	1.15
$K_{s\ external}$ =	1.05
$K_{a\ phase\text{-}earth} = K_{a\ phase\text{-}phase}$	1.13
$SDW_{internal}$ =	U_{rw} x 0.5
$SDW_{external}$ =	U_{rw} x 0.6
$LIW_{internal}$ =	U_{rw} x 1.1

$LIW_{external}$ = U_{rw} x 1.06

(15 marks)

Q.3 a) Accurately sketch the electric field lines for the configuration shown in Fig. Q.3a.

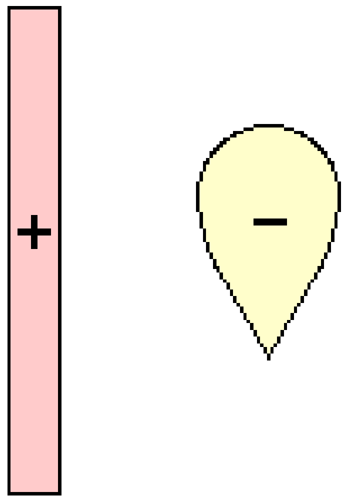

Fig. Q.3a

(5 marks)

b) With the help of the diagram in Fig. Q.3b, and if F_i is the energy for element i and $\emptyset_i$ is the potential at node i, for example, when i=1, F_1 is simplified to

$$F_1 = \frac{\varepsilon}{4}\left[\left(\frac{\emptyset_1 - \emptyset_2}{\Delta x}\right)^2 + \left(\frac{\emptyset_2 - \emptyset_3}{\Delta y}\right)^2\right] \Delta x \, \Delta y \, ,$$

show that the equation for minimisation of energy in the FEM is given by

$$\frac{\partial F}{\partial \emptyset_1} = \frac{1}{2}\varepsilon \left(8\emptyset_1 - 2(\emptyset_2 + \emptyset_4 + \emptyset_5 + \emptyset_7)\right)$$

where F is the total energy of all six elements.

Then, show that the solution of finite element method is similar to that for finite difference technique.

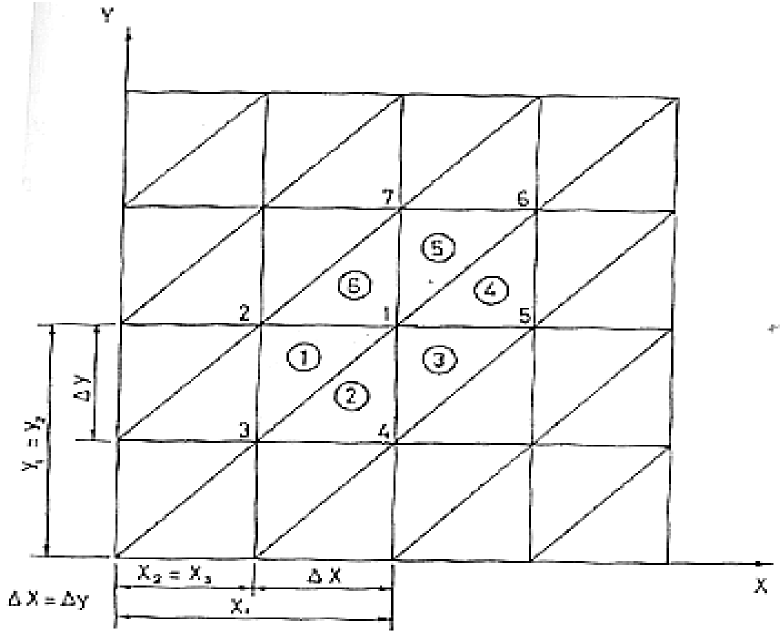

Fig Q.3b. Triangular elements associated with node 1

(10 marks)

c) A hollow building in the shape of a cube is made of metal sheets for all its walls and roof. The floor of the building is however isolated from the rest of the building using special insulation. The floor is grounded to the grounding system. The dimension of the cube is given as 4 m x 4 m x 4 m. If a lightning with a peak voltage of 2 MV strikes the roof of the building, determine the peak voltage at the central point (exactly at the centre of the cube) and estimate the peak vertical electrical field just 0.05 m above the central point. You should use a minimum of 16 square meshes and two iterations to solve this problem.

(10 marks)

Q.4 a) Using suitably labelled diagrams, briefly explain the working principles of a transient earth voltage sensor when used to measure a partial discharge signal. Describe its advantages and name a typical application of this sensor.

(8 marks)

b) Briefly explain the followings:

i. Advantages and disadvantages of a PD measuring system using a coupling capacitor.

ii. The working principle of an optical technique for PD detection, and its typical applications.

(10 marks)

c) A partial discharge underground cable mapping measurement using a very low frequency (VLF) supply was carried out on a 0.55-km long cable. If the time difference between the two pulses measured is 4.9 μs, determine the location of discharge from the injection point. Assume wave travels at 0.31×10^8 m/s in the cable and discharges occur only at one point.

(7 marks)

Appendix I (extracted from IEC 60071-1)

Table 2 – Standard insulation levels for range I (1kV < U_m ≤ 245 kV)

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated short-duration power-frequency withstand voltage kV (r.m.s. value)	Standard rated lightning impulse withstand voltage kV (peak value)
3,6	10	20 40
7,2	20	40 60
12	28	60 75 95
17,5 [a]	38	75 95
24	50	95 125 145
36	70	145 170
52 [a]	95	250
72,5	140	325
100 [b]	(150)	(380)
	185	450
123	(185)	(450)
	230	550
145	(185)	(450)
	230	550
	275	650
170 [a]	(230)	(550)
	275	650
	325	750
245	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1050

NOTE If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand voltage tests are needed.

[a] These U_m are non preferred values in IEC 60038 and thus no most frequently combinations standardized in apparatus standards are given.

[b] This U_m value is not mentioned in IEC 60038 but it has been introduced in range I in some apparatus standards.

Table 3 – Standard insulation levels for range II (U_m > 245 kV)

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated switching impulse withstand voltage: Longitudinal insulation [a] kV (peak value)	Standard rated switching impulse withstand voltage: Phase-to-earth kV (peak value)	Standard rated switching impulse withstand voltage: Phase-to-phase (ratio to the phase-to-earth peak value)	Standard rated lightning impulse withstand voltage [b] kV (peak value)
300 [c]	750	750	1,50	850
				950
	750	850	1,50	950
				1050
362	850	850	1,50	950
				1050
	850	950	1,50	1050
				1175
420	850	850	1,60	1050
				1175
	950	950	1.50	1175
				1300
	950	1050	1,50	1300
				1425
550	950	950	1,70	1175
				1300
	950	1050	1,60	1300
				1425
	950 1050	1175	1,50	1425
				1550
800	1175	1300	1,70	1675
				1800
	1175	1425	1,70	1800
				1950
	1175 1300	1550	1,60	1950
				2100

NOTE The introduction of U_m above 800 kV is under consideration, and 1050 kV, 1100 kV and 1200 kV are listed as U_m in IEC 60038 Amendment 2, 1997.

[a] Value of the impulse component of the relevant combined test while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2} / \sqrt{3}$.

[b] These values apply as for phase-to-earth and phase-to-phase insulation as well; for longitudinal insulation they apply as the standard rated lightning impulse component of the combined standard rated withstand voltage, while the peak value of the power-frequency component of opposite polarity is $0{,}7 \times U_m \times \sqrt{2} / \sqrt{3}$.

[c] This U_m is a non preferred value in IEC 60038.