Electrical, Electronic and
Computer Engineering
ENEL4HB - High Voltage 2

Main Examination

October 2016

Instructions

- Answer all questions, show all working and include all necessary comments (it is your reasoning that is being assessed, not the numerical answer)
- Time allowed = 2 hours
- Full marks = 100

Question 1

Consider the insulator shown, the insulator consists of a fibreglass rod and a silicon rubber coating. The ends of the insulator have metal end fittings one of which is connected to a high voltage and the other connected to a tower.

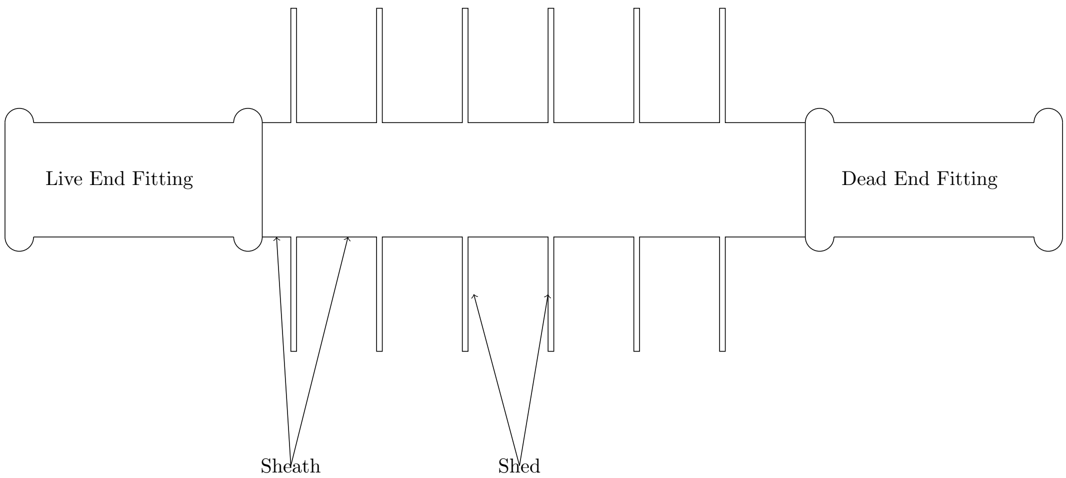

Figure 1: Polymeric Insulator

- What are the advantages of polymeric insulators over ceramic insulators? [5 Marks]
- Where would one expect the highest electric field to be and why? [4 Marks]
- What are the issues with a high electric field? [*Hint: Consider short term problems and long term problems in your answer*] [8 Marks]
- How would one measure if there are any problems? [4 Marks]
- What can one do to lower the electric field? [*Hint: Consider Gauss' law*] [4 Marks]

[Total Marks: 25]

Question 2

Describe the 6 phases of the pollution flashover mechanism for ceramic insulators. [12 Marks]

Describe two cases (different types of insulators, different types of pollution) where this mechanism is not applicable and why. [3 Marks]

[Total Marks: 15]

Question 3

An overvoltage travels on a 132 kV overhead line with a propagation velocity of $v = 0.8c$ and steepness of $S = 1500\ \mathrm{kV}/\mu\mathrm{s}$. A metal oxide surge arrester is to be installed in front of a transformer with a $U_{BIL} = 550$ kV. The distance between the arrester and transformer is 25 m.

- Describe the operation and use of a metal oxide surge arrester for protection. [5 Marks]
- Determine the voltage at the transformer if the surge arrester has a residual voltage of 330 kV. [2 Marks]
- Comment on why there is an increase in voltage across the terminals of the transformer and whether the transformer is protected or not. [4 Marks]
- Given that there is one incoming line with a single conductor and a span of 300 m, determine the protection distance that should be used and whether the transformer is currently protected or not. [4 Marks]

Table 1: Performance factor for incoming overhead line

Line Type	Factor A (kV)
Transmission lines (1ϕ to earth flashover)	
Single conductor	4500
Double conductor bundle	7000
Four conductor bundle	11000
Six and eight conductor bundle	17000

[Total Marks: 15]

Question 4

A 275 kV transmission tower with a height of 32 m has a surge impedance of 240 Ω connected to a single shield wire of 480 Ω and an earth resistance of 60 Ω. The phase conductor is connected to the tower by a 2 m long insulator. The transmission tower is struck by lightning with a peak current of 30 kA. The coupling coefficient is 0.1.

- Determine the peak voltage across the insulator string and if flashover occurs. (You may assume that the duration of the overvoltage is 2.5 μs) [9 Marks]
- Determine the number of insulator discs required if each has an expected flashover voltage of 125 kV in dry weather based on U_{50}. [2 Marks]
- Determine the number of strikes of 30 kA to the a 100 km line if the ground flash density is 6 strikes per $km^2/year$ and comment on what this means. [5 Marks]
- Determine the peak voltage across the insulator if the earth resistance is decreased to 20 Ω. [4 Marks]

[Total Marks: 20]

Question 5

A transmission line is situated in an area with ground flash density of 3 strikes/km^2/year and has 2 shielding wires at a height of 35 m spaced 7.5 m apart and phase conductors at a height of 25 m. The phase conductor has an insulator flashover voltage (U_{50}) of 820 kV and a surge impedance of 240 Ω.

- Determine the number of strikes per 100 km per year to the line. [3 Marks]
- Determine I_{crit} (ignore the effect of the tower impedance). [3 Marks]
- Using the equation for attractive radius, describe a shielding failure and the concept of 'perfect shielding'. [6 Marks]
- Determine the optimal separation distance for 'perfect shielding'. [3 Marks]
- Determine the probability of a lightning strike causing a shielding failure. [5 Marks]

[Total Marks: 20]

Question 6

Sketch the standard partial discharge measurement system (including the device under test and measurement instrument) and discuss each component in the circuit. Include in your answer typical measurement quantities.

[Total Marks: 10]

Useful Formulae

Constants

Standard temperature: $t_0 = 20^o$C
Standard pressure: $P_0 = 760$ torr
Permittivity of free space: $\varepsilon_0 = 8.85\times10^{-12}$F/m

Formulae

Electric field in layer k in a uniform dielectric with multiple layers and permittivities:

$$E_k = \frac{V}{\frac{\varepsilon_k}{\varepsilon_1}d_1 + \frac{\varepsilon_k}{\varepsilon_2}d_2 + \ldots}$$

Electric field in layer k in a coaxial system with multiple layers and permittivities:

$$E_k = \frac{V}{r_k\left[\frac{\varepsilon_k}{\varepsilon_1}\ln\frac{r_2}{r_1} + \frac{\varepsilon_k}{\varepsilon_2}\ln\frac{r_3}{r_2} + \ldots\right]}$$

Electric field in relation to a line charge q:

$$\vec{E} = \frac{q}{2\pi\varepsilon_0 r}\angle\theta$$

The equivalent bundle radius:

$$r_{eq} = \left(nrR^{n-1}\right)^{\frac{1}{n}}$$

Relationship between Q and V:

$$[P][Q] = [V]$$
$$[Q] = [P]^{-1}[V]$$

Resultant electric field:

$$\vec{E}_R = \frac{1}{2\pi\varepsilon_0}[P]^{-1}[V][\tfrac{1}{r}\angle\theta + \tfrac{1}{r'}\angle\theta']$$

Self potential coefficient:

$$P_{ii} = \frac{1}{2\pi\varepsilon_0}\ln\frac{2h_i}{r_i}$$

Mutual potential coefficient:

$$P_{ij} = \frac{1}{2\pi\varepsilon_0}\ln\frac{D_{ij}}{d_{ij}}$$

$$D_{ij} = \sqrt{((x_i - x_j)^2 + (y_i + y_j)^2}$$

$$d_{ij} = \sqrt{((x_i - x_j)^2 + (y_i - y_j)^2}$$

Average bundle gradient:

$$E_a = \frac{q}{n}\frac{1}{2\pi\epsilon_0 r}$$

Average maximum bundle gradient:

$$E_{am} = E_a\left[1 + (n-1)\frac{r}{R}\right]$$

Peek's empirical expressions:

$$|\vec{E}_{positive}| = 33.7m\delta(1 + \frac{0.24}{\sqrt{\delta r_c}}) \quad [kV/cm]$$

$$|\vec{E}_{negative}| = 31m\delta(1 + \frac{0.308}{\sqrt{\delta r_c}}) \quad [kV/cm]$$

$$|\vec{E}_{acpeak}| = 29.8m\delta(1 + \frac{0.301}{\sqrt{\delta r_c}}) \quad [kV/cm]$$

Relative air density:

$$\delta = \frac{P}{P_0}\frac{273 + t_0}{273 + t}$$

Voltage across cap and pin insulator string:

$$V_n = V\frac{\sinh\sqrt{\frac{C_p}{C_s}}n}{\sinh\sqrt{\frac{C_p}{C_s}}N}$$

Efficiency of cap and pin insulator:

$$\eta = \frac{V}{NV_N}$$

Method of determinants:

$$\Delta = det\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{21}a_{12}$$

$$\begin{aligned} \Delta &= det\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \\ &= a_{11}a_{22}a_{33} + a_{12}a_{23}a_{31} + a_{13}a_{21}a_{32} \\ &- a_{31}a_{22}a_{13} - a_{32}a_{23}a_{11} - a_{33}a_{21}a_{12} \end{aligned}$$

Probability of negative lightning stroke:

$$P = \frac{1}{1 + (\frac{I_p}{31})^{2.6}}$$

Average number of strikes to line:

$$N_s = N_g\left(\frac{28h^{0.6} + b}{10}\right)$$

Attractive radius:

$$R_a = 0.67h_t^{0.67}I^{0.74}$$

Flashover current:

$$I_{crit} = \frac{2U_{50}}{Z_0}$$

Shielding separation:

$$X_{sp} = R_s - \sqrt{R_p^2 - (Y_s - Y_p)^2}$$

Reflection co-efficient:

$$\rho_r = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

Insulator flashover volt-time curve:

$$U(t) = \left(400 + \frac{710}{t^{0.75}}\right) W$$

Switching impulse strength of airgaps:

$$U_{50} = k\frac{3400}{1 + \frac{8}{d}}$$

Voltage at protected equipment:

$$U_{equip} = U_a + \frac{2 \times (d + a) \times S}{v}$$

Protective zone:

$$L_p = \frac{N}{A}\left(\frac{U_{BIL}}{1.15} - U_a\right) \times L_{sp}$$

Paschen's eqn:

$$V_b = 6.72\sqrt{pd} + 24.36(pd)$$