UNIVERSITY OF KWAZULU-NATAL
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Electrical, Electronic and Computer Engineering
ENEL4HB - High Voltage 2

Main Examination

10 Oct 2013

Instructions

- Answer all questions and show all working.
- Time allowed = 3 hours
- Full marks = 100

Question 1

A 600 kV bipolar high voltage direct current transmission line has pole conductors arranged linearly at a height of 30 m and separation distance of 20 m, each pole has a 4 conductor bundle with a conductor radius of 1.8 cm and a geometrical radius $R = 28$ cm.

Determine:

- The equivalent radius of the conductor bundle.
- The potential coefficients, the total charge on the conductor bundle and the average and average maximum bundle gradient on the pole conductor.
- If corona occurs on the pole conductor through the use of Peek's empirical expressions with the pressure at an altitude of 1000 m is 670 torr, the temperature is 30^oC and the conductor surface roughness is $m = 0.7$.

[25 Marks]

Question 2

Describe the phases of the pollution flashover mechanism of a ceramic insulator include any sketches that would aid in the description.

Describe two cases (ceramic or non-ceramic) where this mechanism is not applicable and why.

[15 Marks]

Question 3

A transmission line is situated in an area with ground flash density of 9 strikes/km^2/year and has 2 shielding wires at a height of 35 m spaced 10 m apart and phase conductors at a height of 30 m. The phase conductor has an insulator flashover voltage (U_{50}) of 880 kV and a surge impedance of 260 Ω.

- Determine the number of strikes per 100 km per year to the line.
- Determine I_{crit}.
- Describe the concept of 'perfect shielding'.
- Determine the optimal separation distance for 'perfect shielding'.
- Determine the probability of a lightning strike causing a shielding failure.

[15 Marks]

Question 4

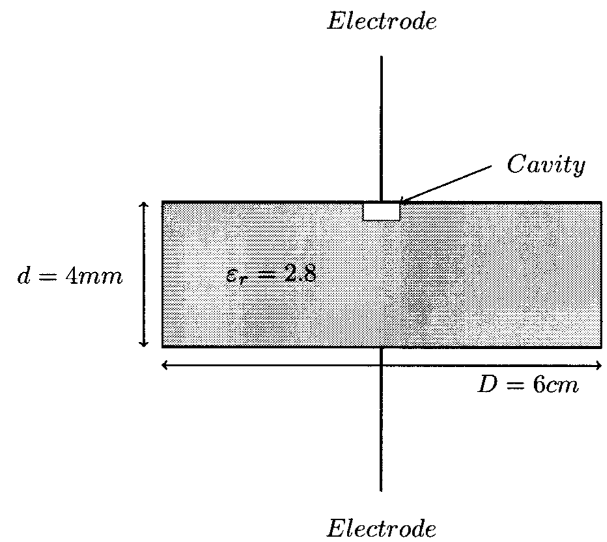
A metal oxide surge arrester has resistive elements with non-linear characteristics described by $R = 2400I^{-0.65}$. The arresters are to be installed at the end of an 33 kV distribution line. Considering the characteristics of the surge arrester:

- Determine the rms current that will flow through through each arrester under normal operating conditions.
- Determine the dissipated power.
- Comment on the calculated values. Is there a problem?
- Compare the MOA to a gapped arrester.

[15 Marks]

Question 5

Sketch a circuit representation of the dielectric and the cavity and explain what each component represents. Derive from first principles an expression to determine the inception voltage of a partial discharge. If the cavity has a depth of 0.2 mm and pressure of 1 bar, determine the inception voltage.



[15 Marks]

Question 6

Sketch a partial discharge measurement system (including the device under test) and discuss each component in the circuit.

[15 Marks]

Useful Formulae

Constants

Standard temperature: $t_0 = 20^o$C
Standard pressure: $P_0 = 760$ torr
Permittivity of free space: $\varepsilon_0 = 8.85 \times 10^{-12}$F/m

Formulae

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:

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

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 stength 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:

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