Problem 5:

Design an earthing grid for a 220kV substation.

Use following data:
Soil resistivity = 55 ohm-m.
Area for substation = 47.50m x 31.5m
Maximum grid current = 5000A
Fault clearing time = 0.5s
Resistivity of soil at surface = 3000 ohm-m
Conductor type: Steel
Cable joints: Welded

$\rho := 55$ ohm-m
$\rho_s := 3000$ ohm-m
$A_{area} := 47.5\ \mathbf{m} \cdot 31.5\ \mathbf{m} = 1496.25\ \mathbf{m}^2$
$I_G := 5000$ A
$t_c := 0.5$ seconds

Solution:

a). Conductor size:

Ambient temperature: $\theta_a := 40$ deg C

$$A_{c\_initial} := 12.25 \cdot 10^{-3} \cdot I_G \cdot \sqrt{t_c}$$

$A_{c\_initial} = 43.31$ mm^2

Corrosion allowance: $Corr_{alw} := 15\%$

Conductor size with corrosion allowance:

$A_c := A_{c\_initial} \cdot (1 + Corr_{alw}) = 49.807$ mm^2

Conductor diameter d:

$$d_{mm} := \sqrt{\left(\frac{4 \cdot A_c}{\pi}\right)}$$ $d_{mm} = 7.963$ mm

$$d := \frac{d_{mm}}{1000}$$ $d = 0.00796$

$d := 0.00796$ m entered manually

b). Preliminary design:

Let th grid cover the entire substation.
No of parallel rows = (length/spacing)+1
5.25m spacing gives 10 rows for 47.5 m, and 7rows for 31.5m.
Conductor buried - 0.5m

Total length of conductors in grid, L:

$L_{length} := 10 \cdot 31.5\ \mathbf{m} = 315\ \mathbf{m}$
$L_{width} := 7 \cdot 47.5\ \mathbf{m} = 332.5\ \mathbf{m}$
$L_T := L_{length} + L_{width}$
$L_T = 647.5\ \mathbf{m}$

First layout of grid with no earthing electrode (ground rod):
Use equation 18.34 for h> 0.25m
Depth of conductor burial = 0.5m

$h := 0.5\ \mathbf{m}$ $\rho := 55\ \mathbf{ohm} \cdot \mathbf{m}$

$$R_g := \rho \cdot \left(\frac{1}{L_T} + \frac{1}{\sqrt{(20 \cdot A_{area})}} \cdot \left(1 + \left(\frac{1}{1 + h \cdot \sqrt{\left(\frac{20}{A_{area}} \right)}} \right) \right) \right)$$

$R_g = 0.703\ \Omega$ grid resistance

c). Conductor length for gradient control:

$n := 10$ No of parallel conductors in one direction n = 10
$K_i := 0.656 + 0.172 \cdot n$ Correction factor for grid geometry
$K_i = 2.376$

$$K_{ii} := \frac{1}{(2 \cdot n)^{\frac{2}{n}}}$$ For grids with no ground rods or few ground rods corrective weighting factor

$K_{ii} = 0.549$

$$K_h := \sqrt{1 + \frac{h}{\mathbf{m}}}$$ divided h/m tp remove unit m from h

$K_h = 1.225$ Corrective factor for grid depth, simplified method

$D := 5.25\ \mathbf{m}$ Spacing between parallel conductors

Entering the variables again to remove units so as to make the result work , this is possible due to the use of natual log (ln) does not accept unit

$D := 5.25$ $h := 0.5$ $d := 0.008$

$$K_m := \frac{1}{2\pi}\left(\left(\ln\left(\frac{D^2}{16\cdot h\cdot d}+\frac{(D+2\cdot h)^2}{8\cdot D\cdot d}-\frac{h}{4\cdot d}\right)\right)+\left(\left(\frac{K_{ii}}{K_h}\right)\cdot\ln\left(\frac{8}{\pi\cdot(2\cdot n-1)}\right)\right)\right)$$

$K_m = 0.855$ Spacing factor for mesh voltage

Conductor length for gradient control:
(ie the conductor length required to keep the mesh voltage within safe limits)

Equation 18.37 = 18.38, solve for L
Etouch = Em solve for L
Lcond below gives the required length for the mesh voltage.

$\rho := 55$ ohm-m, unit removed to avoid error in result

$$L_{cond} := \frac{\rho\cdot K_m\cdot K_i\cdot I_G\cdot\sqrt{t_c}}{(1000+1.5\cdot\rho_s)\cdot(0.116)}$$

$L_{cond} = 619.38$ m

Since the conductor length from the preliminary design calculation LT (647m) is greater than conductor length required to keep the mesh voltage Lcond (619m), the design is safe from from the consideration of mesh potential.

d) Step Potential:

Tolerable Estep 50kg weight:

$$E_{tol\_step} := (1000+6\cdot\rho_s)\cdot\left(\frac{0.116}{\sqrt{t_c}}\right)$$

$E_{tol\_step} = 3117\,V$

$$K_s := \frac{1}{\pi}\cdot\left(\frac{1}{2\cdot h}+\frac{1}{D+h}+\frac{1}{D}\cdot\left(1-0.5^{n-2}\right)\right)$$

$K_s = 0.434$ Spacing factor for step voltage

$L_T = 647.5$ **m** $L_T := 0$
$L_T := 647.5$ m unit removed to avoid unit error in result for Em

Step Voltage Es:

$E_s := \frac{\rho \cdot K_s \cdot K_i \cdot I_G}{L_T}$ Actual step voltage

$E_s = 438.017$ V

Since actual step voltage Es (439V) is much lower than the tolerable step voltage Etol_step (3117V), the grid is safe from the consideration of step potential.

e). Touch Potential:

Tolerable Ttouch for 50kg weight:

$$E_{tol\_touch} := (1000 + 1.5 \cdot \rho_s) \cdot \left(\frac{0.116}{\sqrt{t_c}}\right)$$

$E_{tol\_touch} = 902$ V

Ground Potential Rise:

$R_g = 0.703\ \Omega$ $R_g := 0.703$

$GPR := I_G \cdot R_g = 3515$ V

The GPR voltage 3515V is higher than the tolerable touch voltage of 902 volts, there is a danger of transferred potential. So it is necessary to safeguard personnel and equipment from transferred potential.
Section 18.6.3 Transferred Potential (textbook).

f). Final design:

Add some ground rods distributed over the grid area.
Then perform another calculation with ground rods included, the final GPR should be lowered, it may need to be made lower than the Etouch voltage. See next page.

This means an increase in cost.
The textbook does not suggest another calculation, however ground rod inclusion has its own specific equation, so another calculation with ground rods included is to be performed. IEEE 80 has the equations as indicated in textbook, end of section 18.5.6 Earthing Grid.

Suggested Grid shown below.