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The optimal design of earthing system based on genetic algorithm

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ABSTRACT

The earth resistance, earth potential increase, contact voltages, and step voltage are some of the basic design quantities for earthing meshes. Such quantities extremely depend on security of earthing system. This measure is purposed to minimize the aforesaid quantities when several safety constraints are deemed necessary based on standard rules and regulations. The innovative aspect of the suggested approach includes the effects of reflection coefficients of soil layer and thickness of the soil subgrade. The zone of irregular earthing network has been analyzed during taking this approach for optimal design of earthing mesh with the best economic attitude. Design of multi-purpose optimization of earthing meshes in substation, step voltage, mesh voltage, contact voltage, and the related cost were discussed by the designer. The computation may indicate that this technique is feasible and the suitable results can minimize the given quantities, which are not considered in soil hierarchical structure and the zone of irregular earthing mesh only depends on number of lightning arresters at horizontal and vertical axes, length of arresters, and depth of the buried mesh conductors.

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INTRODUCTION

The ground resistance, the ground potential rise, touches and step voltages are the basic design quantities of the grounding grids. Such quantities greatly depend on the safety of grounding system. The aim being pursued is to minimize these mentioned quantities, while the safety restrictions required by the standard regulations are met [1].

An effective earthing system has the following objectives [2]:

1) Ensure such a degree of human safety that a person working or walking in the vicinity of earthed facilities is not expressed to the danger of a critical electric shock. The touch and step voltage produced in a fault condition have to be at safe values. A safe value is one that will not produce enough current within a body to cause ventricular fibrillation.

2) Provide means to carry and dissipate electric currents into earth under normal and fault conditions without exceeding any operation and equipment limits or adversely affecting continuity of services.

3) Provide earthing for lightning impulses and the surges occurring from the switching of substation equipment, which reduces damage to equipment and cables.

4) Provide a low resistance for the protective relays to see and clear ground faults, which improves protective equipment performance, particularly at minimum fault.

Standard equations are used in the design of earthing system to get desired parameters such as touch and step voltage criteria for safety, earth resistance, grid resistance, maximum grid current, minimum conductor size and electrode size, maximum fault current level and resistivity of soil. By selection number of rod in horizontal and vertical, length of rods and the depth of buried grid conductors, the best choice of the project for safety is performed. This paper mentions the calculation of the desired parameters which are simulated by MATLAB program. Some simulated results are evaluated. The goal of this paper is to be a safe earthing system for substations [3].

The different calculation methods, the ground resistance, are based on the determination of the potential or capacitance of the grounding electrode. The calculation methods of grounding grids determine the ground resistance as well as the step and touch voltage, using different mathematical techniques, applying the hypotheses that allow us to model the real system in other theoretical of comparable results. These studies are

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There are two famous techniques to design eathing IEEE80-2000 and BS7430-1998. In this paper two method will be discussed and show how the genetic algorithm can achieved best resistance value with minimum cost.

Starting point is the calculation method of (IEEE80-2000 and BS7430-1998) and show with is the most efficiency parameter in the design (number of rod in horizontal and vertical, length of rods and the depth of buried grid conductors).

Genetic Algorithms [4]

Genetic algorithms (GAs) are search algorithms that reflect in a primitive way some of the processes of natural evolution. (As such, they are analogous to artificial neural) Networks' status as primitive approximations to biological neural processing). GAs often provides very effective search mechanisms that can be used in optimization or classification applications. Evolutionary computation (EC) paradigms work with a population of points, rather than a single point; each "point" is actually a vector in hyperspace representing one potential, or candidate, solution to the optimization problem. A population is thus just an ensemble, or set, of hyperspace vectors. Each vector is called an individual in the population; sometimes an individual in GA is referred to as a chromosome, because of the analogy to genetic evolution of organisms. Because real numbers are often encoded in GAs using binary numbers, the dimensionality of the problem vector might be different from the dimensionality of the bit string chromosome. The number of elements in each vector (individual) equals the number of real parameters in the optimization problem. A vector element generally corresponds to one parameter, or dimension, of the numeric vector. Each element can be encoded in any number of bits, depending on the representation of each parameter. The total number of bits defines the dimension of hyperspace being searched. If a GA is being used to find "optimum" weights for a neural network, for example, the number of vector elements equals the number of weights in the network. If there are w weights, and it is desired to calculate each weight to a precision of b bits, then each individual will consist of $b *w$ bits, and the dimension of binary hyperspace being searched is $2wb$. The series of operations carried out when implementing a "plain vanilla" GA paradigm is:

- 1. Initialize the population,
- 2. Calculate fitness for each individual in the population,
- 3. Reproduce selected individuals to form a new population,
- 4. Perform crossover and mutation on the population, and
- 5. Loop to step 2 until some condition is met.
- In some GA implementations, operations other than crossover and mutation are carried out in step four.

IEEE 80-2000 Calculation[5]

Prerequisites

The following information is required / desirable before starting the calculation:

- A layout of the site
- Maximum earth fault current into the earthing grid
- Maximum fault clearing time
- Ambient (or soil) temperature at the site
- Soil resistivity measurements at the site (for touch and step only)

- Resistivity of any surface layers intended to be laid (for touch and step only)

Earthing Grid Conductor Sizing

Determining the minimum size of the earthing grid conductors is necessary to ensure that the earthing grid will be able to withstand the maximum earth fault current. Like a normal power cable under fault, the earthing grid conductors experience an adiabatic short circuit temperature rise. However unlike a fault on a normal cable, where the limiting temperature is that which would cause permanent damage to the cable's insulation, the temperature limit for earthing grid conductors is the melting point of the conductor. In other words, during the worst case earth fault, we don't want the earthing grid conductors to start melting!

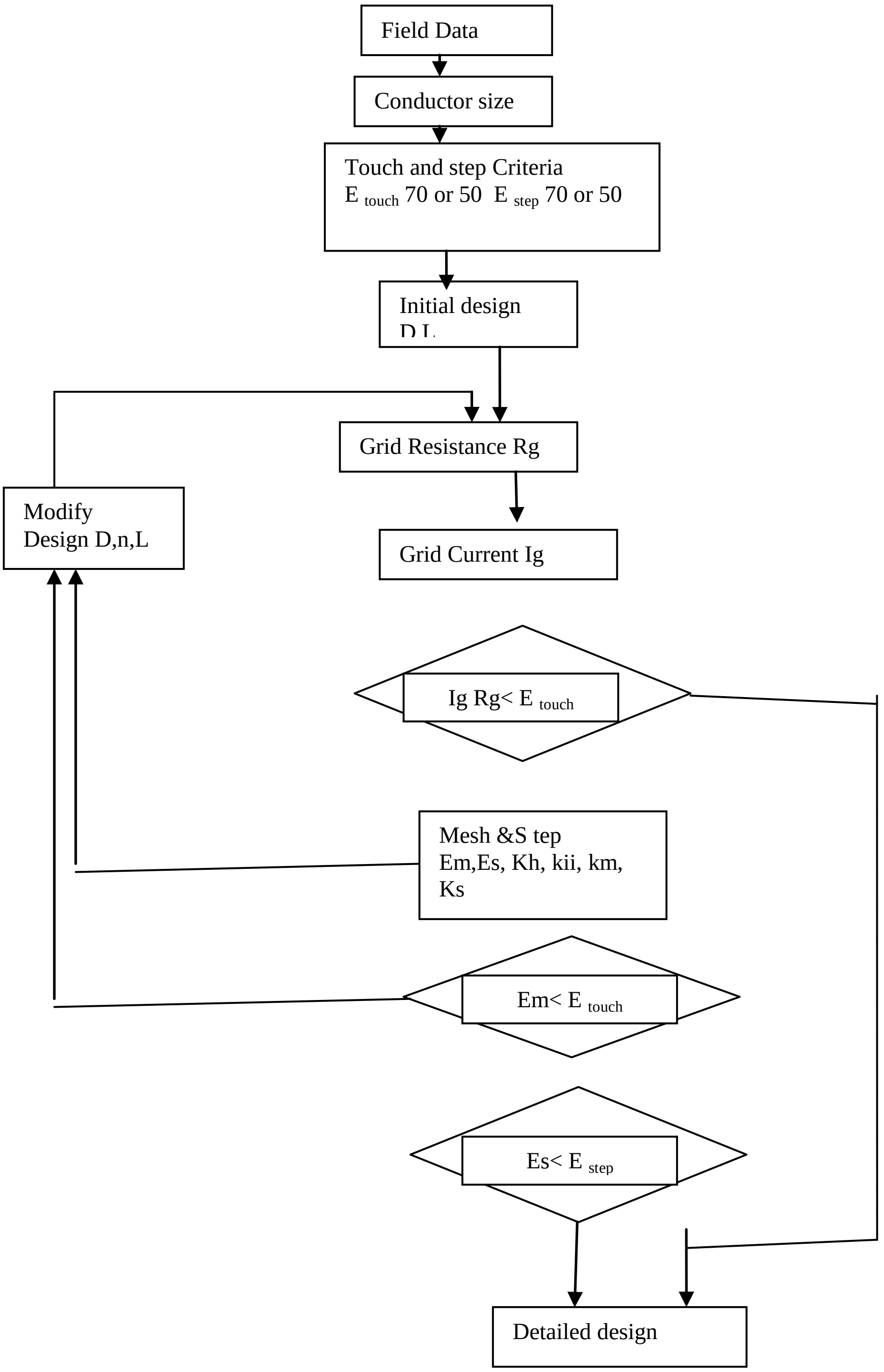


Fig. 1: Block Diagram of Design Procedure [3].

The minimum conductor size capable of withstanding the adiabatic temperature rise associated with an earth fault is given by re-arranging IEEE Std 80 Equation 37:

$$A= i^2\ t\blacklozenge[(\ \alpha\rho r\ 10\hat{}4/\ TACP)/(\ln(1+(\ T_m - T_a)/(\ K_{G+}\ T_a)$$

Where is the minimum cross-sectional area of the earthing grid conductor (mm2)
i^2 t is the energy of the maximum earth fault (A^2s)
T_m is the maximum allowable (fusing) temperature (ºC)
T_a is the ambient temperature (ºC)
αr is the thermal coefficient of resistivity (ºC - 1)
ρr is the resistivity of the earthing conductor (μΩ.cm)
K_G is (1/ α - 20 C)
TACP is the thermal capacity of the conductor per unit volume(Jcm - 3ºC - 1)
The material constants Tm, αr, ρr and TCAP for common conductor materials can be found in IEEE Std 80 Table 1. For example. commercial hard-drawn copper has material constants:
Tm = 1084 ºC
αr = 0.00381 ºC - 1
ρr = 1.78 μΩ.cm
TCAP = 3.42 Jcm - 3ºC - 1.

As described in IEEE Std 80 Section 11.3.1.1, there are alternative methods to formulate this equation, all of which can also be derived from first principles). There are also additional factors that should be considered (e.g. taking into account future growth in fault levels), as discussed in IEEE Std 80 Section 11.3.3.

Touch and Step Potential Calculations

When electricity is generated remotely and there are no return paths for earth faults other than the earth itself, then there is a risk that earth faults can cause dangerous voltage gradients in the earth around the site of the fault (called ground potential rises). This means that someone standing near the fault can receive a dangerous electrical shock due to Figure 1.

Touch voltages - there is a dangerous potential difference between the earth and a metallic object that a person is touching

Step voltages - there is a dangerous voltage gradient between the feet of a person standing on earth The earthing grid can be used to dissipate fault currents to remote earth and reduce the voltage gradients in the earth. The touch and step potential calculations are performed in order to assess whether the earthing grid can dissipate the fault currents so that dangerous touch and step voltages cannot exist

Step 1: Soil Resistivity

The resistivity properties of the soil where the earthing grid will be laid is an important factor in determining the earthing grid's resistance with respect to remote earth. Soils with lower resistivity lead to lower overall grid resistances and potentially smaller earthing grid configurations can be designed (i.e. that comply with safe step and touch potentials). It is good practice to perform soil resistivity tests on the site. There are a few standard methods for measuring soil resistivity (e.g. Wenner four-pin method). A good discussion on the interpretation of soil resistivity test measurements is found in IEEE Std 80 Section 13.4. Sometimes it isn't possible to conduct soil resistivity tests and an estimate must suffice. When estimating soil resistivity, it goes without saying that one should err on the side of caution and select a higher resistivity. IEEE Std 80 Table 8 gives some guidance on range of soil resistivities based on the general characteristics of the soil (i.e. wet organic soil = 10 Ω.m, moist soil = 100 Ω.m, dry soil = 1,000 Ω.m and bedrock = 10,000 Ω.m).

Step 2: Surface Layer Materials

Applying a thin layer (0.08m - 0.15m) of high resistivity material (such as gravel, blue metal, crushed rock, etc) over the surface of the ground is commonly used to help protect against dangerous touch and step voltages. This is because the surface layer material increases the contact resistance between the soil (i.e. earth) and the feet of a person standing on it, thereby lowering the current flowing through the person in the event of a fault. IEEE Std 80 Table 7 gives typical values for surface layer material resistivity in dry and wet conditions (e.g. 40mm crushed granite = 4,000 Ω.m (dry) and 1,200 Ω.m (wet)). The effective resistance of a person's feet (with respect to earth) when standing on a surface layer is not the same as the surface layer resistance because the layer is not thick enough to have uniform resistivity in all directions. A surface layer de rating factor needs to be applied in order to compute the effective foot resistance (with respect to earth) in the presence of a finite thickness of surface layer material. This de rating factor can be approximated by an empirical formula as per IEEE Std 80Equation 27:

$$C_s = 1 - 0.09(1 - \rho/\rho_s)/(2h_s + 0.09)$$

C_s Where is the surface layer derating factor
ρ is the soil resistivity (Ω.m)
ρ_s is the resistivity of the surface layer material (Ω.m)
h_s is the thickness of the surface layer (m)

This de rating factor will be used later in Step 5 when calculating the maximum allowable touch and step voltages.

Step 3: Earthing Grid Resistance

A good earthing grid has low resistance (with respect to remote earth) to minimize ground potential rise (GPR) and consequently avoid dangerous touch and step voltages. Calculating the earthing grid resistance usually goes hand in hand with earthing grid design - that is, you design the earthing grid to minimize grid resistance. The earthing grid resistance mainly depends on the area taken up by the earthing grid, the total length of buried earthing conductors and the number of earthing rods / electrodes. IEEE Std 80 offers two alternative options for calculating the earthing grid resistance (with respect to remote earth) - 1) the simplified method (Section 14.2) and 2) the Schwarz equations (Section 14.3), both of which are outlined briefly below. IEEE Std 80 also includes methods for reducing soil resistivity (in Section 14.5) and a treatment for concrete-encased earthing electrodes (in Section 14.6).

Simplified Method

IEEE Std 80 Equation 52 gives the simplified method as modified by Sverak to include the effect of earthing grid depth:

$R_g = \rho\,[(1/L_t)+(1/\blacklozenge(20A))\,(1+(1/(1+h\blacklozenge(20/A))]$

Where R_g is the earthing grid resistance with respect to remote earth (Ω)
ρ is the soil resistivitiy (Ω.m)
L_t is the total length of buried conductors (m)
A is the total area occupied by the earthing grid (m2)

Schwarz Equations

The Schwarz equations are a series of equations that are more accurate in modeling the effect of earthing rods / electrodes. The equations are found in IEEE Std 80 Equations 53, 54, 55 and 56, as follows:
Where is the earthing grid resistance with respect to remote earth (Ω)
$R_1$is the earth resistance of the grid conductors (Ω)
$R_2$is the earth resistance of the earthing electrodes (Ω)
R_m is the mutual earth resistance between the grid conductors and earthing electrodes
(Ω) And the grid, earthing electrode and mutual earth resistances are:

$R_1 = (\rho/\pi\, Lc)[Ln\,(2\,Lc/\alpha\,')+(K_1\,Lc/\blacklozenge A) - K_2]$

$R_2 = (\rho/\pi\, n_r\, Lr)[Ln\,(4L_r/b)-1+(2\,K_1\,L_r/\blacklozenge A)(\blacklozenge n_r-1)^2]$

$R_m = (\rho/\pi\, Lc)[Ln\,(2\,L_r/\alpha\,')+(K_1\,Lc/\blacklozenge A) - K_{2+1}]$

Where is the soil resistivity (Ω.m)
Lc is the total length of buried grid conductors (m)
α ' is √(r*2h) for conductors buried at depth h meters and with cross-sectional radius r meters, or simply r for grid conductors on the surface
A is the total area covered by the grid conductors (m2)
L_r is the length of each earthing electrode (m)
n_r is number of earthing electrodes in area
b is the cross-sectional radius of an earthing electrode (m)
K_1andK_2 are constant coefficients depending on the geometry of the grid
The coefficient K_1 can be approximated by the following:
(1) For depth h=0: K_1 = -0.04 L/R +1.41
(2) For depth h=(1/10)*♦A: K_1 = -0.05 L/R +1.20
(3) For depth h=(1/6)*♦A: K_1 = -0.05 L/R +1.13
The coefficient K_2 can be approximated by the following
(1) For depth h=0: K_2 = 0.15 L/R +5.5
(2) For depth h=(1/10)*♦A: K_2 = 0.10 L/R +4.68
(3) For depth h=(1/6)*♦A: K_2 = 0.05 L/R +4.40
Where in both cases, L/R is the length-to-width ratio of the earthing grid.

Step 4: Maximum Grid Current

The maximum grid current is the worst case earth fault current that would flow via the earthing grid back to remote earth. To calculate the maximum grid current, you firstly need to calculate the worst case symmetrical earth fault current at the facility that would have a return path through remote earth (call this I_{kis}). This can be found from the power systems studies or from manual calculation. Generally speaking, the highest relevant earth fault level will be on the primary side of the largest distribution transformer (i.e. either the terminals or the delta windings).

Current Division Factor

Not all of the earth fault current will flow back through remote earth. A portion of the earth fault current may have local return paths (e.g. local generation) or there could be alternative return paths other than remote earth (e.g. overhead earth return cables, buried pipes and cables, etc). Therefore a current division factor S_f must be applied to account for the proportion of the fault current flowing back through remote earth. Computing the current division factor is a task that is specific to each project and the fault location and it may incorporate some subjectivity (i.e. "engineering judgment"). In any case, IEEE Std 80 Section 15.9 has a good discussion on calculating the current division factor. In the most conservative case, a current division factor of can be applied $S_f = 1$, meaning that 100% of earth fault current flows back through remote earth. The symmetrical grid current I_g is calculated by:

$I_g = I_{kis} * S_f$

Decrement Factor

The symmetrical grid current is not the maximum grid current because of asymmetry in short circuits, namely a dc current offset. This is captured by the decrement factor, which can be calculated from IEEE Std 80 Equation 79:

$D_f = \blacklozenge[1+ (T_A\ / t_f)(1-e^{(-2\ tf\ /\ TA)})]$

D_f Where is the decrement factor

t_f is the duration of the fault (s)

T_A is the dc time offset constant (see below)

The dc time offset constant is derived from IEEE Std 80 Equation 74:

$T_A = X/(R*2*\pi*f)$

X/R Where is the X/R ratio at the fault location

f is the system frequency (Hz)

The maximum grid current IG is lastly calculated by:

$I_G = I_g * D_f$

Step 5: Touch and Step Potential Criteria

One of the goals of a safe earthing grid is to protect people against lethal electric shocks in the event of an earth fault. The magnitude of ac electric current (at 50Hz or 60Hz) that a human body can withstand is typically in the range of 60 to 100mA, when ventricular fibrillation and heart stoppage can occur. The duration of an electric shock also contributes to the risk of mortality, so the speed at which faults are cleared is also vital. Given this, we need to prescribe maximum tolerable limits for touch and step voltages that do not lead to lethal shocks. The maximum tolerable voltages for step and touch scenarios can be calculated empirically from IEEE Std Section 8.3 for body weights of 50kg and 70kg: Touch voltage limit - the maximum potential difference between the surface potential and the potential of an earthed conducting structure during a fault (due to ground potential rise):

50kgperson:

$E_{touch,50} = (1000+1.5\ \mathbf{C_s}\ \rho s\ )0.116/\blacklozenge t_s$

70kg person:

$E_{touch,70} = (1000+1.5\ \mathbf{C_s}\ \rho s\ )0.157/\blacklozenge t_s$

Step voltage limit - is the maximum difference in surface potential experience by a person bridging a distance of 1m with the feet without contact to any earthed object:

50kg person:

$E_{step,50} = (1000+6\ \mathbf{C_s}\ \rho s\ )0.116/\blacklozenge t_s$

70kg person:

$E_{step,70} = (1000+6\ \mathbf{C_s}\ \rho s\ )0.157/\blacklozenge t_s$

E_{touch} Where is the touch voltage limit (V)

E_{step} is the step voltage limit (V)

C_s is the surface layer derating factor (as calculated in Step 2)

ρ_s is the soil resistivity (Ω.m)

t_s is the maximum fault clearing time (s)

The choice of body weight (50kg or 70kg) depends on the expected weight of the personnel at the site. Typically, where women are expected to be on site, the conservative option is to choose 50kg.

Step 6: Ground Potential Rise (GPR)

Normally, the potential difference between the local earth around the site and remote earth is considered to be zero (i.e. they are at the same potential). However an earth faults (where the fault current flows back through remote earth), the flow of current through the earth causes local potential gradients in and around the site. The maximum potential difference between the site and remote earth is known as the ground potential rise (GPR). It

is important to note that this is a maximum potential difference and that earth potentials around the site will vary relative to the point of fault. The maximum GPR is calculated by:
GPR= $I_G * R_g$
Where GPR is the maximum ground potential rise (V)
I_G is the maximum grid current found earlier in Step 4 (A)
R_g is the earthing grid resistance found earlier in Step 3 (Ω)

Step 7: Earthing Grid Design Verification

Now we just need to verify that the earthing grid design is safe for touch and step potential. If the maximum GPR calculated above does not exceed either of the touch and step voltage limits (from Step 5), then the grid design is safe. However if it does exceed the touch and step voltage limits, then some further analysis is required to verify the design, namely the calculation of the maximum mesh and step voltages as per IEEE Std 80 Section 16.5.

Mesh Voltage Calculation

The mesh voltage is the maximum touch voltage within a mesh of an earthing grid and is derived from IEEE Std 80 Equation 80:
$E_m = \rho_s * K_m * K_i * I_G / L_M$
Where ρ_s is the soil resistivity (Ω.m)
I_G is the maximum grid current found earlier in Step 4 (A)
K_m is the geometric spacing factor (see below)
K_i is the irregularity factor (see below)
L_M is the effective buried length of the grid (see below)

Geometric Spacing Factor Km

The geometric spacing factor k_m is calculated from IEEE Std 80 Equation 81:
$K_m = (1/2\pi)[\ln(D^2/16h\times d)+(D+2h)^2/8D\times d - (h/4d)] + (Kii/K(h))\ln[8/\pi(2n-1)]$
Where D is the spacing between parallel grid conductors (m)
h is the depth of buried grid conductors (m)
d is the cross-sectional diameter of a grid conductor (m)
Kh is a weighting factor for depth of burial =
Kii is a weighting factor for earth electrodes /rods on the corner mesh
Kii =1 for grids with earth electrodes along the grid perimeter or corners
Kii $=1/(2n^{n/2})$ for grids with no earth electrodes on the corners or on the perimeter
n is a geometric factor (see below)

Geometric Factor n

The geometric factor n is calculated from IEEE Std 80 Equation 85:
n =na*nb*nc*nd
with na = 2Lc/Lp
nb =1 for square grids, or otherwise nb= ♦(Lp/4♦A)
nc =1 for square grids, or otherwise nc= $[L_x L_y / A]^{0.7A/ Lx\ Ly}$
nd =1 for square grids, or otherwise nd= D_m /(♦ $L_x^2 + L_y^2$)
Where
Lc is the total length of horizontal grid conductors (m)
Lp is the length of grid conductors on the perimeter (m)
A is the total area of the grid (m2)
L_x and L_y are the maximum length of the grids in the x and y directions (m)
D_m is the maximum distance between any two points on the grid (m)

Irregularity Factor Ki

The irregularity factor Ki is calculated from IEEE Std 80 Equation 89:
Ki=0.664+0.148 n
Where n is the geometric factor derived above

Effective Buried Length

The effective buried length **LM** is found as follows:
For grids with few or no earthing electrodes (and none on corners or along the perimeter):
$\mathbf{L_M} = L_c + L_R$
Where L_c is the total length of horizontal grid conductors (m)

L_R is the total length of earthing electrodes / rods (m)
For grids with earthing electrodes on the corners and along the perimeter:
$\mathbf{L_M} = L_c + [1.55+1.22\ (Lr/\blacklozenge\ L_x^2 + L_y^2)]\ L_R$
Where L_c is the total length of horizontal grid conductors (m)
L_R is the total length of earthing electrodes / rods (m)
L_r is the length of each earthing electrode / rod (m)
L_x and L_y are the maximum length of the grids in the x and y directions (m)

Step Voltage Calculation

The maximum allowable step voltage is calculated from IEEE Std 80 Equation 92:
$E_s = \rho_s * K_s * K_i * I_G/L_s$
Where ρ_s is the soil resistivity (Ω.m)
I_G is the maximum grid current found earlier in Step 4 (A)
K_s is the geometric spacing factor (see below)
K_i is the irregularity factor (as derived above in the mesh voltage calculation)
Ls is the effective buried length of the grid (see below)

Geometric Spacing Factor Ks

The geometric spacing factor **Ks** based on IEEE Std 80 Equation 81 is applicable for burial depths between 0.25m and 2.5m:
$K_s = (1/\pi)\ [1/2h+1/(D+h)+(1/D)(1-0.5^{n-2})]$
Where D is the spacing between parallel grid conductors (m)
h is the depth of buried grid conductors (m)
n is a geometric factor (as derived above in the mesh voltage calculation)

Effective Buried Length Ls

The effective buried length Ls for all cases can be calculated by IEEE Std 80 Equation 93:
Where Lc is the total length of horizontal grid conductors (m)
L_R is the total length of earthing electrodes / rods (m)
Now that the mesh and step voltages are calculated, compare them to the maximum tolerable touch and step voltages respectively. If:
$E_m < E_{touch}$ and
$E_s < E_{step}$
then the earthing grid design is safe. If not, however, then further work needs to be done. Some of the things that can be done to make the earthing grid design safe:

- Redesign the earthing grid to lower the grid resistance (e.g. more grid conductors, more earthing electrodes, increasing cross-sectional area of conductors, etc). Once this is done, re-compute the earthing grid resistance (see Step 3) and re-do the touch and step potential calculations. Limit the total earth fault current or create alternative earth fault return paths
- Consider soil treatments to lower the resistivity of the soil
- Greater use of high resistivity surface layer materials

In this paper genetic algorithm has been tuned these parameter and the fineness function the

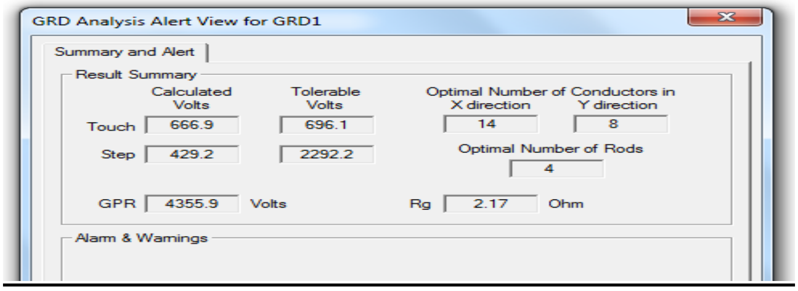
- Earthing resistance
- Earthing resistance +Es + Em
- Earthing resistance +Es+ Em – Estep-Etouch
- Earthing resistance +Es +Em – Estep-Etouch +cost

By using optimum tool in ETAP we can see the benefits for genetic algorithm
Case study 1-a
In this example calculation has been done be Etap (using optimum tool in ETAP) after that
A rectangular earthing grid with the following parameters is proposed:

```
 length=90;
 width = 50;
 %step1% Soil_Resistvity
 %Soil_Resistvity=300;
 p=300;
 %resistivity of surface layer material (?.m) =3000;
 ps=3000;
 %thickness of surface layer materials (m)=0.1;
 hs=0.1;
 %step2 surface layer materials
```

```
  %derating factor=cs
  cs=1-((0.09*(1-p/ps))/((2*hs)+0.09));
%step 3earthing grid resistance
%Lt=total length of buried conductors (m)
Lt=length*kb1(i)+width*kb2(i);
%A=total area occupied by the earthing grid (m2)
A=4500;
%H=burried depth kb3
%Rg=earthing grid resistance
Rg = p*((1/Lt)+(1/(20*A)^0.5)*(1+((1)/(1+kb3(i)*(20/A)^0.5))));
%step 4 maximum grid current
%Df=decrement factor
%Ta=DC time offset
%ig=single phase to earth fault
ig=2000;
%X/R=ratio at the fault
XR=1;
%tf=fault time
tf=0.5;
Ta=(XR)*(1/(2*3.14*50));
Df=(1+(Ta/tf)*(1-exp(-2*tf/Ta)))^0.5;
Ig=Df*ig;
%Step 5 touch and step potential criteria
%Etouch50=step voltage limit (V);
%ts=max fault clearing time (s);
ts=0.5;
Etouch50=(1000+1.5*cs*ps)*(0.157/(ts)^0.5)*50/70;
Estep50=(1000+6*cs*ps)*(0.157/(ts^0.5))*50/70;
%Step6 ground potential rise (GPR)
%GPR=Ig *Rg
GPR=Ig *Rg;
%Step 7 earthing grid design verification
%Mesh voltage calculation
%km=geometric spacing factor
%Ki=irregularity factor
%Lm=effective buried length of the grid
%Kh=weightining factor for depth of burial
%kii=weightining factor for earth electrodes/rods on the corner mesh
%n=geometric factor
%na=(2*Lc ) /Lp
%D maximum distance between rods
D=0.5*(width/(kb1(i)-1)+length/((kb2(i)-1)));
%d diameter of conductor
d=.0124;
na=(2*Lt/(2*(length+width)));
nb= ((2*(length+width)/(4*(A)^0.5))) ^0.5;                % nb=1 ; for square
nc=1;
nd=1;
n=na*nb*nc*nd;
Ki=0.644+0.148*n;
%Rl=rod _lenght;
 %Nr=total number of rods
%Nr=2*(kb1(i)+kb2(i))-4;
%R rod kb4
Lm =Lt+(1.55+1.22*(kb4(i)/(length^2+width^2)^0.5))*kb5(i)*kb4(i);
x1=(D^2/(16*d*kb3(i)));
x2=(D+2*kb3(i))^2/(8*D*d);
x3=-kb3(i)/(4*d);
x=log(x1+x2+x3);
kii=1;
```

```
kh=(1+kb3(i))^0.5;
y=(kii/kh)*(log(8/((pi)*(2*n-1))));
Km=(1/(2*(pi)))*(x+y);
%Em= Mesh voltage
Em=p*Km*Ki*Ig/Lm;
Ks=(1/(pi))*((1/(2*kb3(i)))+1/(D+kb3(i))+(1/D)*(1-0.5^(n-2)));
Ls=0.75*Lt+0.85*(kb4(i)*kb5(i));
%Es= maximum limit step
Es=p*Ks*Ig*Ki/Ls;
fitness Function =min(Rg);
```



	Calculated Volts	Tolerable Volts
Touch	666.9	696.1
Step	429.2	2292.2

Optimal Number of Conductors in X direction: 14
Optimal Number of Conductors in Y direction: 8
Optimal Number of Rods: 4
GPR 4355.9 Volts
Rg 2.17 Ohm

Fig. 1: ETAP Optimization tool result.

Our result from our program
Rg = 2.1421; Em = 606.9674; Es = 245.4886; Etouch50 = 672.9305; Estep50 = 2215.9

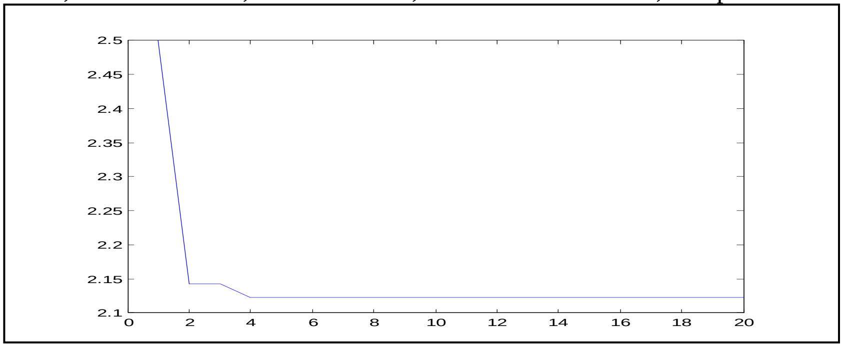


Fig. 2: Rg value versus generation number.

Number of row	number of column	Burial _depth	Length of rod	Number Of rods
10	10	1.50	6.0000	9.3333

From comparison, genetic algorithm has been achieved minimum resistance, Em, and Es by using fitness function minimum Rg

Case study 1-b

In this example we use fitness function Rg+ Em + Es:

Number of row	number of column	Burial _depth	Length of rod	Number Of rods
10	10	1.50	6.0000	20

Our result from our program
Rg = 2.1421; Em =650.7319; Es = 257.9649; Etouch50 = 672.9305; Estep50 = 2215.9
From comparison, genetic algorithm has been achieved minimum resistance, Em, and Es by using fitness function minimum Rg and Em

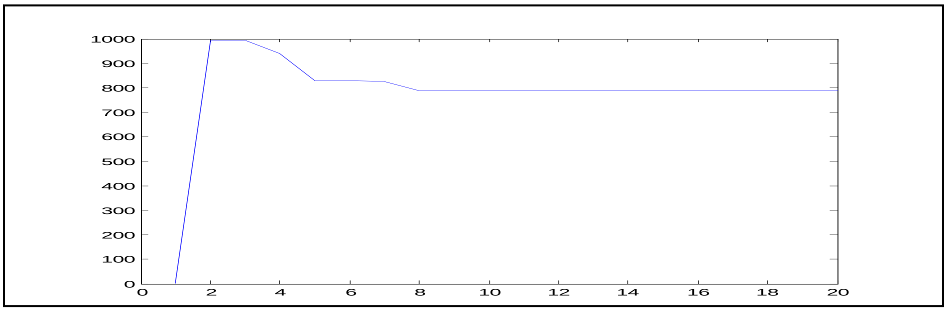


Fig. 3: Rg+Em+Es Versus generation Number.

In this example we use fitness function Rg+ Em + Es-Etouch50-Estep50:
Rg = 2.12; Em =621; Es = 213.9649; Etouch50 = 672.9305; Estep50 = 2215.9
From comparison, genetic algorithm has been achieved minimum resistance, Em, and Es by using fitness function minimum Rg,Es, and Em

Number of row	number of column	Burial _depth	Length of rod	Number Of rods
10	10	1.50	6.0000	20

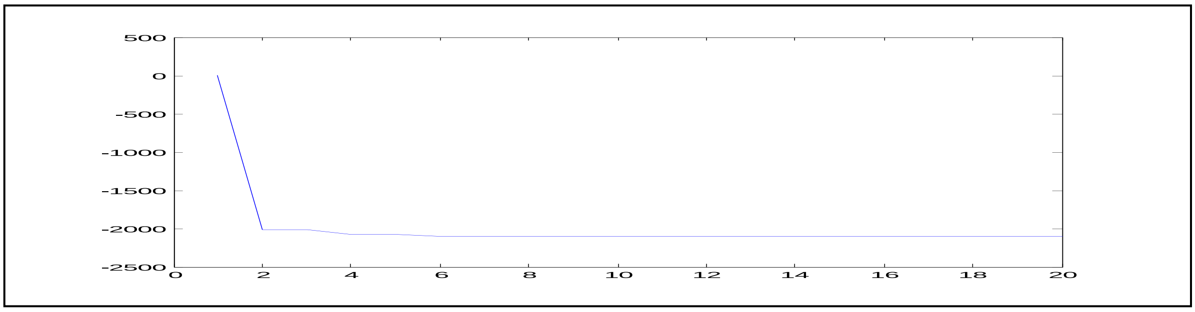


Fig. 4: Rg+Em+Es –Estep-Etouch Versus generation Number.

Case study 1-d
In this example we use fitness function Rg+ Em + Es-Etouch50-Estep50+ total_cost
Rg = 2.2091; Em = 1288.5; Es = 162.5; Etouch50 = 672.9305; Estep50 = 2215.9
From comparison, genetic algorithm has been achieved minimum resistance, Em, and Es by using fitness function minimum cost, Rg, and Es

Number of row	number of column	Burial _depth	Length of rod	Total cost	Number Of rods
2	2	1.50	6	147660	4

In this example we used Rg and cost without weight factor, if we want genetic to to concentrate on special parameter we can multiple it by factor (1-100)

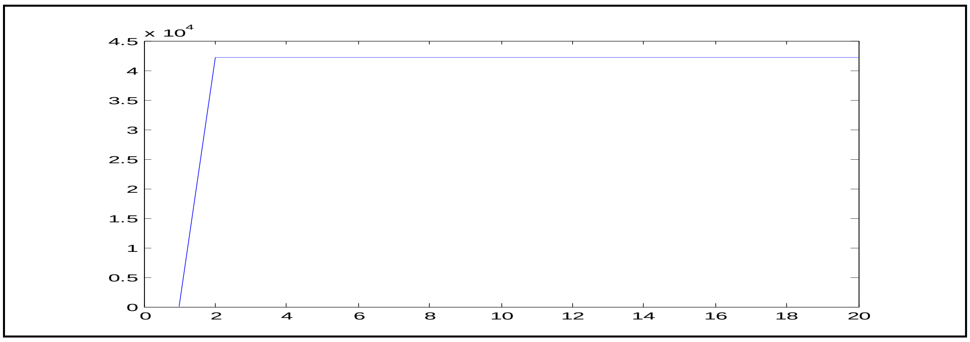


Fig. 5: Rg+Em+Es –Estep-Etouch+cost Versus generation Number.

Case study 1-e
In this example we use fitness function Rg+ Em + Es-Etouch50-Estep50+ total_cost
Rg = 2.6349; Em = 1871.2; Es = 235.6413; Etouch50 = 672.9305; Estep50 = 2215.9
From comparison, genetic algorithm has been achieved minimum resistance, Em, and Es by using fitness function minimum cost

Number of row	number of column	Burial _depth	Length of rod	Total cost	Number Of rods
2	2	1	6	61793	4

In this example weight factor, to Rg so fitness function = (10*Rg+Em+Es-Etouch50-Estep50+total_cost);

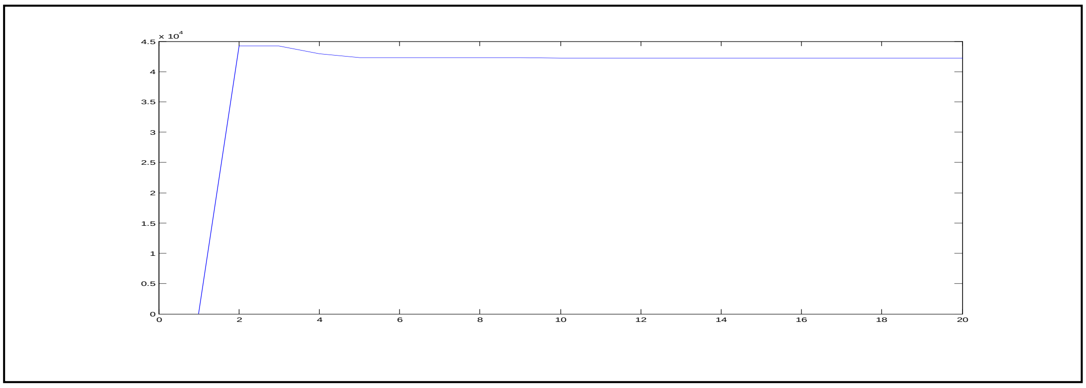


Fig. 6: 10*Rg+Em+Es –Estep-Etouch+cost Versus generation Number.

Conclusion:

There are many majors factors in design earthing (such as number of rod in horizontal and vertical, length of rods and the depth of buried grid conductors) best design has been achieved by tuning these parameter

Genetic algorithm can be used to optimization all these parameter in the same time to achieved the best design with economic approach.

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