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Optimal Design of Unequal Conductor Spacing in Grounding Grid by Modern Computational Intelligent Techniques

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Abstract*: *With uniform grid spacing current distribution among grid conductors is non-uniform; conductors towards the periphery carry more current and conductors towards the centre carry less current. Non- uniform grid spacing increases leakage current in the centre conductors while decreases in the fringe conductors bringing about uniform distribution of leakage current. This paper presents optimal design of unequal grid spacing in grounding grid design by two modern computational intelligent techniques: Particle Swarm Optimization technique and Bat Algorithm technique. Compression ratio is the method adapted in creating unequal grid conductor spacing, in which compression ratio C is varied from 0.1 to 1 to result in numerous unequal grid configurations. Modern intelligent techniques such as PSO and BAT algorithm are implemented to find the optimal value of compression ratio C so as to achieve one best unequal grid configuration among numerous feasible unequal grid configurations. Mat Lab software is developed for both PSO and BAT algorithm which are extremely adaptable to examine the unequal grid spacing. Optimal value of compression ratio C is obtained for different number of grid conductors along the x-axis and y-axis and unequal grid spacing is analysed through distinct graphs.

Index Terms*: *Touch Voltage, Step Voltage, Unequal grid distance, Compression ratio.

I. INTRODUCTION

Studying the impact of voltage distribution on the grounding grid surface is an important parameter to design the grounding grid system of substation to make sure the safety of people above the substation ground. This can be achieved by equalizing the potential distribution of the ground surface and reducing the step and touch voltages [2]. Grounding grid spacing must be so arranged that calculated touch voltages and step voltages must be with in tolerable touch voltages and step voltages for known two layer resistivity [1].

Apparent resistivity is a very important parameter in determining the maximum touch voltage and step voltage and can be obtained by Winner's four point method. Unequal grid conductor spacing should be progressively increased from periphery to the centre to achieve the best voltage gradient distribution in the grid. Percentage of potential difference between central and edge conductors, with any number of conductors are around 28%, 37% and 15% in case of evenly spaced grid spaced, unequal spaced having denser conductors at the middle and edges respectively [12]. Hence unequal grid conductor spacing

Having dense conductors at the edges provides the most efficient design. The mesh voltage may not be the worst case touch voltage if ground rods are located near the perimeter or if the mesh spacing near the perimeter is small [1]. In these cases, the touch voltage at the corner of the grid may exceed the corner mesh voltage [1].

When the value of compression ratio C is 1 grid conductor distance is more uniform or equal spacing and moving its value towards zero makes more conductors to be crowded at the periphery of the grid and sparse at the center of the grid. Therefore unequal grid spacing increases leakage current at the center conductors and decreases towards the edges of the grid. As the current density is more at the edge, it is better to have a grid with more conductors crowded at the periphery [4]. Generally, unequal grid distance technique does not guarantee the reduction in number of grid conductors hence the total length of the grid, yet rather assures their better utilization [3]. Resistance of the ground grid depends only on soil resistivity and area of grounding grid. Thus when soil resistivity and area of grounding grid specified, the impact of compression ratio C, grid conductor spacing has negligible impact on reduction in grid resistance.

The mathematical technique in finding various grid configurations by compression ratio is given by

$$d_i = d_{max} C^i, \; (i = 0 \text{ to } m) \tag{1}$$

d_i is the i[th] conductor spacing form center

d_{max} is maximum conductor spacing at the center.

m is the total number of conductor spacing from center to the left of the grid.

Maximum distance at the centre is given by

$$d_{max} = \frac{L(1-C)}{1+C-2C^{\left(\frac{N}{2}\right)}} \qquad \text{N is even number} \tag{2}$$

$$d_{max} = \frac{L(1-C)}{2\left(1-C^{\left(\frac{N-1}{2}\right)}\right)} \qquad \text{N is odd number} \tag{3}$$

Where

L is the length of the grid side

N is the total number along the x-axis or y– axis.

If N is an odd number then grid will have symmetrical arrangement throughout but if N is an even number grid will have symmetrical arrangements except the center space.

In this paper two modern intelligent techniques such as PSO and BAT logarithms are used in identifying optimal value of compression ratio C so as to achieve one best grid configuration which as well satisfies the grid design criteria. Results obtained from both the methods are compared and tabulated.

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Both the algorithm has been tested for grounding grid design input data shown in table 1. Square grid has been tested with length and breadth of the grid 80m. Rectangular and L-shaped grid can also be tested to achieve best grid configuration.

II. GROUNDIG GRID DESIGN

Table 1: Grounding grid design input data

Soil resistance of upper layer	1000 Ω-m
Soil resistance of lower layer	40 Ω-m
Thickness of upper layer soil	0.2 m
Duration of fault current	0.5 sec
Fault current	9 kA
Length of Grid	80 m
Breadth of Grid	80 m
Depth of Burial	0.6 m
Length of the Ground Rods	2.4 m
Ambient Temperature	40°C
Duration of Shock Current through body	0.5 s

Table 2 Simulated results at equal conductor spacing.

Tolerable Step Voltage (Person Weight 70 Kg)	1319.3204 V
Tolerable Touch Voltage (Person Weight 70 Kg)	496.3537 V
Calculated step voltage	211.3541 V
Calculated touch voltage	408.1987 V
Equal Conductor Spacing (d m)	6.666 m
Number of Conductor on X- axis and Y- axis.	13

Initially, software developed using MATLAB was tested with the data given in table 1 for equal grid conductor distance and simulated results for optimal grounding grid design are shown in table 2. Simulated results shows that for the data given in table 1, calculated touch voltage is 408.19V and calculated step voltage is 211.35V and equal grid conductor distance is 6.666 m with 13 number of conductor on X- axis and Y- axis as the grid is square. With 13 conductors on both the axis, conductor distance is now varied by compression ratio method such that more conductors are crowed towards periphery to make uniform distribution of leakage current.

III. PARTICLE SWARM OPTIMIZATION

PSO is a population based stochastic optimization intelligent technique inspired by social behaviour of bird flocking. In PSO each single solution is a bird in the search space called particle. All of particles have fitness function to be optimized and have velocities which direct the flying of the particle. PSO finds approximate solutions to extremely difficult or impossible numeric minimization and maximization problems. It is simple algorithm, easy to implement and few parameters to adjust mainly the velocity.

PSO is initialized with a group of random particle or solution and then search for optimal by updating generations. Particles move through the solution spaces and are evaluated according to some fitness criterion after each time step. In all the iterations each particle is updated by two best values. The first one is the best solution (fitness) it has achieved so far this value is called pbest. Another best value that is tracked particle swam optimization is the best value obtained so far by any particle in the population. Second best value is global best and called gbest.

Equation used for finding optimal value of compression ratio C is

$V= W*V +c1*rand1*(P_{Best}-C)+c2*rand2(g_{Best}-C)$

Chosen

$W=1$ and $c_1=c_2=1.5$

3.1 Flow Chart of the PSO Algorithm

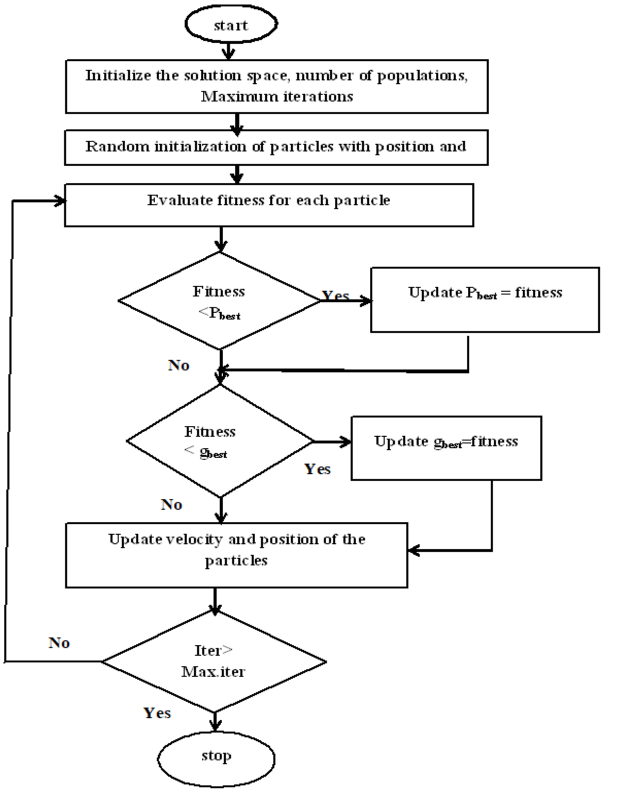

Fig.1. Flow chart of the PSO Algorithm

3.2 Simulated Results of PSO Algorithm

Software developed using PSO Algorithm is tested for different grid configuration by selecting the value of C as a random number between 0 and 1.

Maximum number of iteration chosen is 500, Population=30, W=1, c1=c2=1.5 and Wdamp = 0.99. Results are tabulated in table 3 and table 4.

Input Data:

Upper layer resistivity = 1000 sq.mm
Lower layer resistivity = 40 sq.mm
Tolerable touch voltage = 496.35 V
Tolerable step voltage = 1319.32 V
Calculated touch voltage = 408.1987V
Calculated step voltage= 211.3541V
Number of horizontal and vertical conductors =13
Number of horizontal and vertical meshes=12

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Table 3: Executed Results at Optimal Compression Ratio C= 0.5275

Unequal Spacing (Mesh Number)	Touch Voltage in Volts	Step Voltage in Volts
0.7891 (1,12)	240.6365	556.3900
1.4958 (2,11)	258.5943	390.4094
2.8355 (3,10)	311.1914	291.4056
5.3751 (4,9)	386.0401	234.1348
10.1893 (5,8)	471.4304	202.0658
19.3152 (6,7)	561.5601	184.5412

Software developed is tested for above input data which resulted in many combination of unequal grounding grid conductor spacing. Out of these combinations one best combination was found at optimal compression ratio shown in Table 3. From table 3 it can be observed that at the edge of the grounding grid touch voltage is less and step voltage is more. Touch voltage increases and step voltage decreases as we move towards center of the grid. According to IEEE Std.80 actual touch and step voltage of the grounding grid should be less than or equal to corresponding tolerable voltages. Keeping this in the mind software is developed to find the optimal value of compression ratio C. Optimal compression ratio obtained by PSO algorithm is 0.5275 for the data given in table 1.

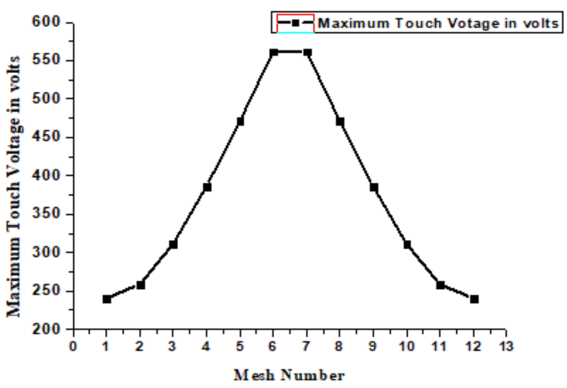

Fig.2 Maximum voltage profiles along all gird meshes in case of unequal spacing having denser conductor at the periphery.

The most important factor to determine the efficient design of the grounding system is the potential difference between center and the corner grid conductors. Fig. 2 illustrate that touch voltage is more at the center mesh and reduces towards the corner mesh in case of unequally spaced grid having denser conductors at the edges.

Table 4: Optimal compression ratio and Touch voltage at different number of parallel grid conductors

Number of Parallel conductor along x axis and y axis	Optimal Compression Ratio	P_{best} (Maximum Touch Voltage)
13	0.5275	240.6365
15	0.5293	262.6004
17	0.5826	284.1945
19	0.6067	305.4465
21	0.7115	326.3766

Software developed is also tested by varying number of parallel conductors along the x axis and y axis from 13 to 21 corresponding optimal compression ratio and touch voltage are recorded as shown in table 4.It is noted that optimal compression ratio and touch voltage is increasing with increase in number of conductors as shown in Fig.3 and Fig.4

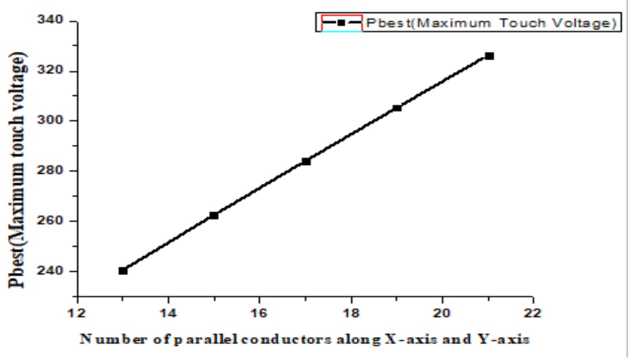

Fig.3 Impact of Touch Voltage with variation in number of parallel grid conductors

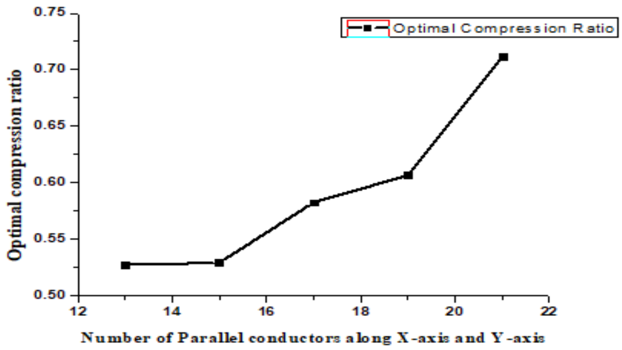

Fig. 4 Optimal Compression Ratio corresponding to number of parallel grid conductor.

IV. BAT ALGORITHM

BAT algorithm exploits the so called echolocation of the bat. Bat sends the waves in the form of frequencies, whenever frequency hits its target it reflects back. This refection tells the bat about its location. Pulse rate emission and loudness parameter are the two main features considered in BAT algorithm. If pray is far the loudness is more and as it reaches to the target loudness decreases, whereas the pulse rate emission increases. It is probability base algorithm technique. Probability lies between 0 and 1. Pulse rate emission is taken between 0 and 1.Bat sends signal with frequency f and the echo signal is used to calculate the distance.

Main things that make the BAT algorithm more useful and very efficient is the parameter it involves. In BAT algorithm three parameters are involved Position, Velocity and Loudness parameter and pulse rate emission.

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Frequency will tell about the distance of the pray. It is also more efficient due Frequency tuning, automatic zooming and parameter control.

Generating new solution is performed by moving virtual Bats according to the following equations

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (4)$$

$$V_i^{\,t} = V_i^{\,t-1} + (X_i^{\,t} - X^*)f_i \quad (5)$$

$$X_i^{\,t} = X_i^{\,t-1} + V_i^{\,t} \quad (6)$$

B € [0,1] is a random vector drawn from a uniform distribution.

X^* is the current global best location(solution) which is located after comparing all the solution among all the bats.

The current best solution according the equation

$$X_{new} = X_{old} + \partial A^t \quad (7)$$

Where

∂ €[-1,1] is a random number

A^t is the average loudness of all the best at this time step.

Loudness factor continually decrease once the optimal solution is found, as it cannot be zero it will be 0.1. Rate of pulse will increase very closed to value of 1 but around 0.9 is the estimated value experimentally found. X_{best} can take any value depending upon application.

4.1 Pseudo Code of the BAT Algorithm

1. et objective function : f(x), X= (X_1,X_2, ……,X_n)
2. nitialize the bat population X_i and velocity V_i, I = 1,2,….n
3. efine frequency f_i at X_i
4. nitialize the pulse rate(r_i) and Loudness(A_i)
5. Set Number of Iteration t=0, & Number of Solution S=0
6. hile (t< maximum number of iterations)
7. enerate new solution by adjusting updated velocity, frequency and solution.
8. heck new solution is better than the existing one if yes accept the solution as the best, increment iteration count t and solution S if no go to next step
9. enerate the random number
10. f(rand>r_i)
11. elect the solution among the best solution.
12. Develop a local solution around the selected best solution
13. End If
14. If(rans<A_i) and f(X_i<f(X*)
15. Accept the new solutions
16. Increase r_i reduce A_i
17. End If
18. Ranks the bats and find current best x*
19. End While
20. Display results.

4.2 Simulated Results of Bat Algorithm

Software developed is tested for different grounding grid configuration by selecting the value of C as a random number between 0 and 1. Selected population size is 100, number of generation 5, Loudness factor 0.5 and pulse rate 0.5.Simulated results are tabulated in table 5 and table 6.

Input Data:

Upper layer resistivity = 1000 sq.mm
Lower layer resistivity = 40 sq.mm
Tolerable touch voltage = 496.35 V
Tolerable step voltage = 1319.32 V
Calculated touch voltage = 408.1987V
Calculated step voltage= 211.9045 V
Number of horizontal and vertical conductors =8
Number of horizontal and vertical meshes=7

Table 5: Executed Results at Different Compression Ratio.

Value of C	Grid Conductor Distance(Mesh Number)	Touch Voltage (V)	Fitness
0.9575	10.7974(1,7)	402.1366	402.1366
	11.2764(2,6)	406.9891	
	11.7767(3,5)	411.8564	
	12.2991(4)	416.7376	
0.6882	6.5584(1,7)	347.7559	347.7559
	9.5303(2,6)	388.2717	
	13.8490(3,5)	430.1496	
	20.1246(4)	472.8983	
0.4239	2.5821 (1,7)	259.2032	259.2032
	6.0918 (2,6)	339.9782	
	14.3722(3,5)	434.3585	
	33.9080(4)	**533.4776**	
0.4993	3.6264 (1,7)	288.4721	288.4721
	7.2627 (2,6)	358.6409	
	14.5454(3,5)	435.7203	
	29.1308(4)	**515.7633**	

Random variation of compression ratio C between 0.1 to 1 resulted in many different grid configruation. At each configration mesh voltage from corner mesh to center mesh and the fitness values are been calculated. Grid configurations in which calculated mesh voltage or touch voltage exceeds tolerable values are discorded as shown in table 5.

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At C= 0.4239 and C=0.4993 mesh voltage at mesh number 4 is 533.4776 and 515.7633 respectively which are exceeding the tolerable touch voltage value 496.35 V**.** Hence these two grid configurations will be discarded**.** Fitness corresponding to population graph is as shown in fig.5

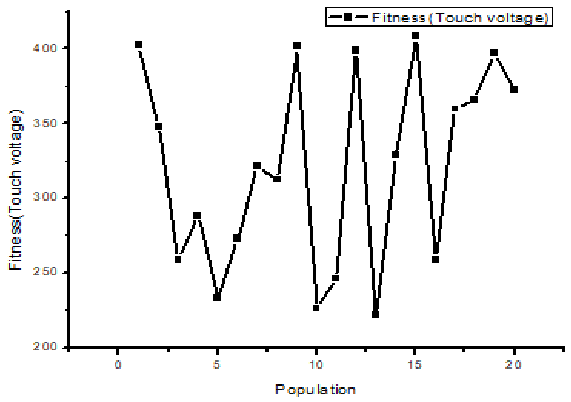

Fig.5 Touch Voltage Corresponding to Population

Table 6 Touch voltage at different Compression Ratio

Value of C	**Maximum Touch voltage in Volts**
0.9575	402.1366
0.6882	347.7559
0.4239	259.2032
0.4993	288.4721
0.4581	272.7475
0.5948	321.1094
0.5674	312.3415
0.9527	401.3800
0.1865	226.4048
0.3912	246.1958
0.2545	**210.0567**
0.9354	398.6342
0.7919	372.0897
0.1964	221.7753
0.9964	407.9705
0.4235	259.0709
0.7355	359.4664
0.7634	365.8832
0.9220	396.4346
0.6199	328.7883

Execution of Bat algorithm resulted in optimal value of the compression ratio C as 0.2545 and corresponding touch voltage as 210.0567 V

4.3 Comparison of PSO and BAT Algorithm

Mat Lab programme is developed for the analysis of unequal grounding grid spacing using two modern computational intelligent techniques such as Particle Swam Optimization and BAT algorithm techniques. Same input data is used in both the techniques. Number of parallel conductors along the X-axis and Y-axis is varied from 8 to 20 and corresponding simulated results are tabulated in table 7.

Table 7: Comparison of PSO and BAT Algorithm

Number of Parallel conductor	Optimal Compression Ratio C	Touch Voltage	Method
8	0.2343	211.1990	PSO
	0.2545	210.0563	BAT
10	0.2553	236.7043	PSO
	0.2551	236.7039	BAT
12	0.2639	262.9133	PSO
	0.2551	262.9074	BAT
14	0.4931	288.6842	PSO
	0.4915	288.6755	BAT
16	0.4945	314.0317	PSO
	0.4919	314.0315	BAT
18	0.6400	339.0025	PSO
	0.6399	339.0024	BAT
20	0.7307	363.6261	PSO
	0.7323	363.6145	BAT

V. CONCLUSION

In this paper optimal design of unequal grid spacing by modern computational intelligent techniques such as PSO and BAT algorithms are presented. These techniques are implemented to achieve one optimal unequal grid configuration among many feasible configurations. It has been found that depending on the grid mesh number grid has its own optimal compression ratio. Touch and step voltages are calculated for different compression ratio generated by the MATLAB program. Developed MATLAB software programs are extremely adoptable to find optimal compression ratio for given area of the grid and number of grid conductor.

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