A Novel Smart Resilient Protective System Design

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ABSTRACT

Safe and resilient operation is essential for a Human/Machine or system. The dynamic behavior control and its protection play a vital role in sectors like power systems automation and sensitive electronic equipment. The main exposure of this work is to implement the safe economical protective system and the dynamic dependency of soil parameters on frequency, the effect of transient earthing design on cost. The related study focuses on the techno-economical solution to design a good transient earthing system, using optimal design parameters such as the number of electrodes, diameter, depth, length of the electrode etc., and safety parameters. Earthing system performance can assess during abnormal conditions and it's becoming a challenge. Under those conditions, the frequency-dependent soil parameters can decide the nature of a good earthing system. One of the electrode frequency-dependent dimensions (length of rod) is obtained under prescribed critical frequency range. To study the dependency of these soil parameters on cost, we proposed a mathematical model of cost function with eight decisive design parameters and six safety and security restrictions. The economical solution and the performance of the proposed model analyzed with the application of metaheuristic techniques.

Keywords: Critical Frequency, Critical Length, Cost Function, Metaheuristic Optimization, Safety Parameters, Safe Resilient Protection System (SRPS)

1. INTRODUCTION

The Importance of Earthing systems increases because of the necessity to protect Individual level to Industrial level. The role of these particular systems is to carry the current under normal and faulty conditions. The resilience of the system depends upon the ability to recover as fast as possible. Now, technologies make moving things to come near to us. In this perspective, the role of protection for every equipment is essential and becoming critical. Proper design of the particular protective system can reduce the negative impacts on the sensitive equipment. The optimum design of these parameters under constraints, if done manually, becomes tedious and sometimes inaccurate due to some human errors. To get guaranteed optimum economical design adopting the implementation of Metaheuristics to make things simpler and accurate. [1]- [5]

Several optimization problems solved by using Metaheuristic Techniques with ease.[1] Designing the cost function model, which is the objective function derived based on geometrical parameters [2], One should focus on the safety Parameters such as step and touch potentials to get rid of the shocks; those parameters should be in permissible levels[3][7]. Ghoneim and the team proposed an optimal grid design with Earth's surface potential characteristics and with a numerical example [7]. In-depth of the research area navvarina team proposed the grounding design with respective Boundary element method and Average potential method considering IEEE standards. [6][8][9]

Alik and Tegur, presented cost function modelling and applied Swarm Intelligence and genetic algorithm, and good agreement established.[5] The authors proposed the cost function includes material installation, Excavation. They have obtained good results and suggesting that Swarm Intelligence is superior to GA. Hybrid optimization Techniques such as Hybrid GA, PS studied in many papers to implement those in hard practical problems [4][5].

From the studies, it is important to mention the effect of transients during lightning that causes significant changes in impedance, effective radius, and soil resistivity. To avoid such things, we will take care of certain things like lowering mesh size, improving soil resistivity, proper maintenance of Earthing system, adequate design considerations like choosing the length of the Rod, which is less than the critical length. To get an effective, economical solution for transient earthing, it will be beneficial to all types of earthing design models [10]. A dynamic model for low-frequency resistance for single driven rod and the effect of lightning on the grounding system elaborated and explained using experimental data [11]. Experimental Evolutions and results given in the paper demonstrate the impact of transient impedance on the Earthing System.

In this study, we proposed a new mathematical model to find the cost-effective solution range of length of rod calculation and the minimization of the objective function can be elaborated from Teacher-Leaner Based Algorithm TLBO, ABCO. The corresponding Algorithms initiate under the same search space. From the depth of studies involved in the formulation of the cost function, we have taken the design parameters such as the number of conductors in x and y direction (n_x, n_y), the number of rods (n_r), depth, length of the rod (l_r), area of excavation and the safety/security aspects has taken from ANSI/IEEE Standard 80-2000, IEC 62305-2.[6]Apart from the mentioned restrictions, the length of the rod should be less than the critical length, is taken as another restriction in this work. The dependency of the restriction on Cost explained in Brief.

2. EXPRESSIONS IN COST FUNCTION

In this Section, We extend the cost function model implemented in the literature with the proposed method under critical safety constraints and dynamic soil parameters that depends on frequency. With proper Maintenance, the humidity level and soil resistivity can manage. But, the dynamic nature can adverse abnormal behavior under transients. In this study, we considered the electrode dimensions range by the critical length and critical frequency different notations used in this work, as tabulated in Table I.

Table I: Cost Function Expressions

n	Number of unilateral mesh
$d_x, (d_y)$	Spacing between Conductors in x, (y) directions
$n_x, (n_y)$	Number of mesh (Unilateral) in x, y directions
$d_c, (d_r)$	Earthing grid conductor (rod) Diameter (in m)
$l_x, (l_y)$	length of the grid system in x, (y) directions (in m)
n_r	Number of vertical rods
h_s	Surface layer thickness (in m)
h	Depth of Earthing system (in m)
l_r	Length of the rod (in m)
l_c	Critical length (in m)
n_w	Number of bonding/ welding points
K	Bonding and welding cost coefficient
e_{trch}	Excavation trench Width (in m)
$R_g, (R_{gs})$	Earthing grid Resistance, Earthing grid resistance (tolerable)
E_{step70},($E_{touch70}$)	step voltage, (touch voltage) for 70 kg human weight (tolerable)
EPR, (EPR_s)	Earth potential Rise, Earth potential Rise (Tolerable)

c_{cm}	Material Cost Coefficient
c_{ci}	Material installation cost Coefficient
c_{cri}	Conductor (rod) installation cost Coefficient
c_{ce}	Excavation Cost Coefficient
c_{crm}	Coefficient of rod material cost
c_{cgm}	Coefficient of gravel cost
c_{cgi}	Gravel installation cost Coefficient
c_{cms}	Coefficient of maintenance services cost
c_{cins}	Coefficient of installations cost during Maintenance

2.1 Modeling Cost Function and its Parameters:

The Economic design of the Earthing system under consideration of safety issues obtained by the minimization of the proper objective function. Based on the survey performed on the methods and models regarding problem formulation, several mathematical cost functions have derived based on geometrical and safety parameters as at most criteria. [5]130

Most cited cost function expressions in the previous studies are as follows

Chou proposed cost function under IEEE std 8000 security restrictions taking design parameters like the diameter of the conductor, number of bonding/Welding points and depth of the grounding[16]. Security restrictions as per ANSI/IEEE STD 8000 taken are:

$$R_g \leq R_{gs} \quad (1)$$

$$E_s \leq E_{step70} \quad (2)$$

$$E_m \leq E_{touch70} \quad (3)$$

$$EPR \leq EPR_s \quad (4)$$

Table II: Literature Work And Cost Function Expressions

Proposed Team	Cost function Expression
Chou and team[16]	$f(d_c, h, n_w) = (c_{cm} d_c L_t + c_{ce} h L_t + k d_c n_w)$
Lee and chen [17]	$f(n, d_c, h) = \left[\left(c_{cm}\left(\frac{\pi d_c^2}{4}\right)\frac{L}{2}\right)[n+1]\right] + \left[c_{ce} h \left(\frac{L}{2}\right)[n+1]\right] + [\lambda(\left(\frac{\pi d_c^2}{4}\right)[n+1]^2]$ restrictions have taken: (1) –(4)
Vyas and Jamnani [18]	$f(n_x, n_y, n_r, l_r) = (c_{cm} + c_{ci})[(n_x+1)l_y + (n_y+1)l_x] + c_{crm}[n_r] + c_{cri}[n_r l_r]$ restrictions apart from (1)-(4) also considered as $0.95 d_x \leq d_y \leq 1.05 d_x$ (5)
Benamrane Alik , Madjid Teguar and Mekhaldi [5]	$f(n_x, n_y, d_c, h, n_r, l_r, d_r, h_s) = \left[c_{cm}\left(\frac{\pi d_c^2}{4}\right) + c_{ci} + c_{ce} h e_{trch}\right][(n_x+1)l_y + (n_y+1)l_x] + \left[c_{crm}\left(\frac{\pi d_r^2}{4}\right) + c_{cri}\right][n_r l_r] + \left[(c_{cgm} + c_{cgi})[l_x l_y h_s]\right]$ Restrictions taken : (1)-(4) and introduced penalty term as 10^6
Proposed Method(PM)	$f(n_x, n_y, d_c, h, n_r, l_r, d_r, h_s) = \left[c_{cm}\left(\frac{\pi d_c^2}{4}\right) + c_{ci} + c_{ce} h e_{trch}\right][(n_x+1)l_y + (n_y+1)l_x] + \left[c_{crm}\left(\frac{\pi d_r^2}{4}\right) + c_{cri}\right][n_r l_r] + \left[(c_{cgm} + c_{cgi})[l_x l_y h_s]\right] + [c_{cms} + c_{cins}]$ Restrictions taken : (1)-(4) and introduced penalty term as 10^6 and taken additional restriction as $l_r < l_c$ (6)

2.2 Critical Length Significance:

Several works have done on the dependency of soil parameters on high frequency and the respective computational models well explained.[23]-[25]In most of the cases, the soil resistivity, and permittivity assumed as constant. Soil treatment analysis indirectly affects transient behavior. Soil permittivity depends on the humidity level. So, improvement in the lifetime of Earthing System is possible with proper maintenance. Several field tests performed to analyze the frequency-dependent parameters. [25]

Current density can result in soil ionization; multiple tests performed to analyze the impulse resistance value in the case of single/Multiple Vertical rods. Results reveal that multiple rods are effective in the reduction of impulse resistance during the transient condition, and current rise time is independent of it. [26][27]

Broug and team experimented with a vertical rod length of less than 4m and performed under high resistivity soil.

The tests reveal that there is a significant reduction in impedance upto 10MHz after that the impedance rises. [28] So, that in our study the critical frequency range taken as [0.1 1]MHz

Lolvera and the team experimented on mesh type of electrode system and analyzed the dynamic behavior of the impedance at MHz range frequency. [29]

The dynamic behavior of the soil at abnormal conditions during high impulse currents depends on two things. One is the soil property, and the other is the propagation of electromagnetic waves around the ground electrode. Inductive and capacitive behavior depends on the frequency variations. Based on that, two zones have been derived: low-frequency zone (LF) and HF Zone (High Frequency), the impedance varies with frequency represented in two zones to understand the behavior of the system. Here the critical frequency (F_c) the limiting frequency, and that is in range of [0.1-1] MHz depending on the soil resistivity. It is crucial to get HF impedance should be larger than the LF impedance. Based on the criteria for every F_c, there exists l_c (critical length). Using the length of electrodes less than critical length is advantageous with respective cost and safety.

Compare X/R ratio with frequency, by lowering the size of electrodes the (F_c) (Critical Frequency) increases. Though capacitive behavior is advantageous, it is typical to get this in a high soil resistivity environment, so most of the cases grounding electrodes have inductive behavior. Better Transient response obtained with characteristic dimensions of the electrode. Using short electrodes with capacitive nature or else the length of the rod should be less than critical length can give effective results [13]-[15]. The expression for the critical length was taken from the technical data of paper [14]

$$l_c = (0.6)\left(\frac{\rho}{F_c}\right)^{0.43} \quad (7)$$

From fig1, it is clear that for soil resistivity mentioned in Section V, the variation of critical length w.r.t the critical frequency shown. From the data the electrode length is small enough to get the good response under transients. For the particular analysis the range taken as [3 6] m.

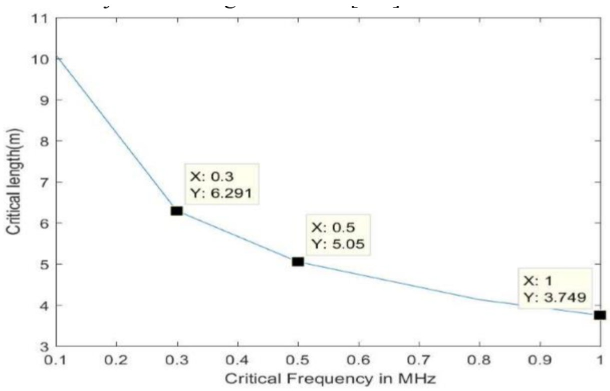

Fig 1: Critical frequency vs. Critical length

2.3 Nature of Impulse Impedance [31]:

Wave form of lightening for first and subsequent stroke taken from [49][50] as follows

$$i(t) = \frac{I_o}{\eta} \frac{(t/\tau_1)^n}{1+\left(\frac{t}{\tau_1}\right)^n} e^{-t/\tau_2} \quad (8)$$

Where $\eta = e^{\frac{-\tau_1}{\tau_2}} (n(\frac{\tau_2}{\tau_1}))^{1/n}$

I_o= Current pulse amplitude (KA)

τ_1= Front time Constant

τ_2= Decay Time Constant

n=Exponent Value [2 10]

η=Amplitude Correction Factor

- Larger Rate of Rise of Front has higher frequency content
- For 6.5KA range the $\tau_1 = 2\mu s$ and $\tau_2 = 230$ and exponent value is 2
- For 11KA range the $\tau_1 = 0.25\mu s$ and $\tau_2 = 2.5\mu s$ and exponent value is 2
- For 30 KA range the $\tau_1 = 1.8\mu s$ and $\tau_2 = 95\mu s$ and exponent value is 2

The Nature of impulse Impedance in region wise explained as follows:

- In LF region (upto 0.1MHz) = Independent of frequency and the value of impedance is equal to low-frequency resistance
- In the HF region (0.1- 1MHz) = It exhibits Inductive behavior, and the impedance value is more than low-frequency resistance.

Dynamic characteristics related to the fast transient period only after that due to capacitive nature it will exhibit the low-frequency resistance value so that the T1=8.38µs (first stroke) and T2= 0.835µs (subsequent stroke) decides the impulse coefficient and the critical length of the rod.

- For $l_r < l_c$ then A=1, Z=R
- For $l_r > l_c$, then $A = \alpha l_r + \beta$ (l is in m)
- For low-frequency resistance [31]

$$l_c = \frac{1-\beta}{\alpha}; A = e^{0.333(\frac{l_r}{l_c})^{2.3}} \quad (9)$$

Table 2 Critical Length Of Single Vertical Electrode

	Lightning Stroke		α	β
	subsequent	first		
Soil Resistivity(Ω m)	10	10	0.27	0.67
	100	100	0.105	0.25
	1000	1000	0.0355	0.17
	ρ	**ρ**	$0.025 + e^{-0.82(\rho T_1)^{0.257}}$	$0.17 + e^{-0.22(\rho T_1)^{0.555}}$

From Table 2, the calculated critical length is 7 m. From equations (7)-(9), it is clear that for soil resistivity (**ρ**= 150 Ω-m) the length of rod must be in the range [3 6].

2.4 Mathematical Model of Proposed Method:

The cost function model based on the literature represented in table 2. The Eight Decisive Parameters $(n_x, n_y, d_c, h, n_r, l_r, d_r, h_s)$ and five Safety Restrictions are considered as inequality constraints in the proposed method and also include the maintenance cost. The proposed cost function is derived as follows:

Cost function: $f(n_x, n_y, d_c, h, n_r, l_r, d_r, h_s)$

$$=\left[c_{cm}\left(\frac{\pi d_c^2}{4}\right) + c_{ci} + c_{ce} h e_{trch}\right]\left[(n_x+1)l_y + (n_y+1)l_x\right] + \left[c_{crm}\left(\frac{\pi d_r^2}{4}\right) + c_{cri}\right][n_r l_r] + \left[(c_{cgm} + c_{cgi})[l_x l_y h_s]\right] + [c_{cms} + c_{cins}]$$

The following Cost coefficient values used for the study itabulated in table 3 and the expressions for the parameters used in the cost expression explained in Table 1.

3. TRANSIENT EARTHING DESIGN USING TLBO METAHEURISTIC OPTIMIZATION TECHNIQUE

Teaching and Learning Based algorithm (TLBO) first introduced by Rao in 2011. This algorithm behavior based on the traditional learning process. It has two phases one is the teacher phase, where the learner can extract the knowledge from the teacher and another one is the learner phase, in which each learner can share knowledge among themselves. The best learner selected as the best teacher with a particular objective function in each iteration. The performance of the teacher assessed based on the distribution of marks obtained by the student. It improves the other teachers' knowledge in the teacher phase with the average knowledge of all students in the learner phase. Based on the position of the student in the search space decides the knowledge level. The rapid Interaction between teacher phase and learner phase gives rise to the best solution. [20][21]

3.1 Cost Function and Variable Selection:

Using a set of input variables / Decisive Parameters ($n_x, n_y, d_c, h, n_r, l_r, d_r, h_s$) generates an initial set of random solutions, where n_L represents the number of learners, and max NFEs as stopping criteria. The initial population considered as learners of class. The teacher and learner phase will be performed sequentially in each iteration and gives the best solution. Replacement strategy used to update the new learners by the old ones.

3.2 Teacher Phase:

In this phase, the global search intensity of the algorithm identified. Initial learners are generated based on the teacher phase. After that, the generation of new L based on the teacher phase, where the normal mean value distribution can evaluate the merit of the learner. The performance of the class improved by shifting the mean position of class among all learners which considered as a teacher.

$$Step\ Size_i = T - TF_i X Mean\ _L \quad (8)$$

$$new\ L = L + rand_{i,j} X\ Step\ size$$

Where, i=1,2,….n_L and j= 1,2,…. n_V ; $rand_{i,j}$ = Random numbers taken from a uniform distribution in the interval [0 1]; TF is the teaching factor that decides the dynamic change in the mean knowledge of the class.

3.3 Learner Phase:

Local best Searching is done in this phase by the effective interaction and knowledge sharing among the learners. Comparison performed by using the following mathematical expressions

$$StepSize_i = \begin{cases} L_i - L_{rp} & P_{costi} < P_{costrp} \\ L_{rp} - L_i & P_{costi} \geq P_{costrp} \end{cases}$$

$$new\ L = L + rand_{i,j} X\ Step\ size \quad (9)$$

Where, i=1,2,….n_L and j= 1,2,…. n_V; $rand_{i,j}$ = random numbers taken from a uniform distribution in the interval [0 1];

Evaluate the new learner and apply the replacement strategy. Update the values and monitor the best results.

4. TRANSIENT EARTHING DESIGN USING ABCO METAHEURISTIC OPTIMIZATION TECHNIQUE

Artificial Bee Colony optimization, The Basic motivation behind the optimization technique is the behavior of a group of honey bees (HB). This swarm-based intelligence was first introduced by karaboga in 2005. ABC represents food sources as a candidate solution and the quality of the nectar is the objective function; the food sources repeatedly modified to get quality of nectar by the three categorized bees named as Employed Bees, Onlooker Bees, Scout Bees.

4.1 Cost Function and Variable Selection:

ABCO randomly generates an initial set of honey bees. The number of honey bees represent n_{HB} the number of food sources around and the candidate solution Using a set of input variables Parameters ($n_x, n_y, d_c, h, n_r, l_r, d_r, h_s$) generates an initial set of random solutions. In this cyclic process, three phases would perform by all categories of Bees. After completion of the search Process, old food Sources replaced by the new ones using Replacement Strategy. In the following, we assumed a greedy strategy as a replacement strategy, i.e., Smallest Penalized cost preferred to the old one.

4.2 Employed Bees Phase:

Each employee bee tried to change the food source and the particular information given to onlooker bees with random permutation-based step size as shown

$$Step\ Size = rand_{(i)(j)}.(HB - HB[permute(i)(j)] \quad (10)$$

New HB = HB +Step size (11)

Where, i=1,2,….nL and j= 1,2,….nV ; $rand_{i,j}$ = random numbers taken from a uniform distribution in the interval [0 1]; Permute is different rows permutation functions, Here mr=0.8.

4.3 Onlooker Bees phase:

From the information given by the employee bees, onlooker bees select the food source assuming each employed bee attracts an onlooker bee with a probability of P_i. Roulette wheel selection scheme used as the selection of probability.

$$P_i = P_{costi} \Big/ \textstyle\sum_{i=1}^{nHB} P_{costi} \quad (12)$$

$$Step\ Size = rand\_(i)(j).(HB_{rws} - HB[permute(i)(j)]$$

$$new\ HB = \begin{cases} HB_{rws} + Step\ size & if\ rand < mr \\ HB_{rws} & otherwise \end{cases} \quad (13)$$

4.4 Scout Bees Phase:

Employed Bees who are not capable of modifying their food sources after a Specified number of trails become Scouts.

5. NUMERICAL RESULTS AND VALIDATION

According to the specifications of the future PV plant, the following values had taken from internal studies. Some Assumptions are taken in this study as, C_1 is considered as the old method of modeling with (1)-(4) restrictions, is considered as the Proposed method of modeling with (1)-(6) restrictions

5.1 Parameter Values used for the Study:

The decisive parameters of the grounding system for the future plant took as follows:

- The total area of 300 x 430 m to be installed, and the soil resistivity is uniform in nature having a resistivity of 150 Ω.m, and top layer resistivity is 2000 Ω.resistivity calculations measured by Wenner Method under three conditions (rainy, sunny, winter) and the resistivity after treatment becomes 40 Ω.m

- The total area of 300 x 430 m to be installed, and the soil resistivity is uniform in nature having a resistivity of 150 Ω.m, and top layer resistivity is 2000 Ω.resistivity calculations measured by Wenner Method under three conditions (rainy, sunny, winter) and the resistivity after treatment becomes 40 Ω.m
- Fault duration time (t_f) = 0.5 s;
- Grid current(maximum) (I_G) =15 kA
- The boundaries of the cost function parameters (eight) are chosen for study as follows:

$n_x, n_y \in$ [4, 20]; $d_c, d_r \in$ [0.0015, 0.015]; $h \in$ [0.2 2.5]; $n_r \in$ [5, 30]; $h_s \in$ [0.01 0.5]

5.2 Transient Earthing Design Economical-Cost using TLBO and ABCO:

To express the effectiveness of optimization Techniques, three population sizes (30, 40, 50) considered and performed in three different iterations (200, 500, 1000). The results gave economic results for the proposed method fifth constraint, i.e., equation (6) explained above.

Table V Cost Of Cost Coefficient Parameters

Coefficient	Cost of Parameters	
c_{cm}	2/0	8($/m)
	4/0	12($/m)
c_{ci}	2/0	85($/m)
	4/0	85($/m)
c_{crm}	3m	24($)
	6m	48($)
c_{cri}	3m	48($)
	6m	78($)
c_{cgi}	Gravel 15/25	$8/m^3$
c_{cgm}	Gravel	$19/m^3$
c_{ce}	ρ< 500 (Ω.m)	25 ($\$/m^3$)
c_{cms}, c_{cins}	Under critical maintenance	100($)

Table VI Safety Parameters

N pop	Method						
30	TLBO	0.0525	0.0525	787	787	834	834
	ABCO	0.0525	0.0525	787	787	834	834
	TLBO	0.052	0.0525	787	787	823	834
90	ABCO	0.0525	0.0523	779	785	819	812
	TLBO	0.0523	0.0521	783	786	743	830
900	ABCO	0.0527	0.054	829	817	664	662

Table VII Safety Parameters

N pop	Method						
30	TLBO	1562	1562	2670	2670	1380	1380
	ABCO	1562	1562	2670	2670	1380	1380
	TLBO	1606	1562	2626	2670	1419	1380
90	ABCO	1646	1625	2611	2585	1454	1436
	TLBO	1658	1680	2707	2670	1465	1484
900	ABCO	1703	1689	1993	1990	2804	1909

From Table VI, VII, the safety parameters in TLBO and ABCO obtained for 30, 90,900 Population size respectively, and the objective function satisfies the permissible level limits. Clearly, Population size has no significant effect on these safety parameters. E touch and E step values started from initial value towards the corresponding minimum value.

Fig 6-8 explains the variation concerning the number of iterations and the convergence towards the optimal values.

Table VIII Design Parameters

	Parameter	TLBO		ABCO	
30		10	17	16	7
		6	10	7	18
		0.0073	0.013	0.0092	0.003
		1.09	2.43	2.4	1.46
		29	23	21	14
		5.9	3.54	5.12	3.9
		0.0057	0.012	0.0092	0.006
		0.466	0.12	0.471	0.431
	Cost ($)	2410000	2360000	2610000	2370000
90		7	10	8	5
		12	9	7	15
		0.007	0.012	0.005	0.011
		0.52	0.65	2.49	1.49
		17	28	27	14
		4.43	4	4.7	3.7
		0.0021	0.012	0.008	0.003
		0.54	0.166	0.47	0.45
	Cost ($)	2350000	2340000	2380000	2020000
900		8	16	7	14
		15	15	17	7
		0.006	0.011	0.0015	0.012
		0.538	0.58	0.73	0.71
		20	24	14	22
		4.2	3.8	3.8	3.2
		0.003	0.014	0.007	0.0056
		0.328	0.25	0.104	0.12
	Cost ($)	2570000	2500000	2030000	2010000

The cost variation is concerning population size in method 1, with four safety restrictions, and proposed method with six safety restrictions, tabulated in Table VII. The values obtained are economical and safe in the proposed method comparing with method 1 for both optimization Techniques.

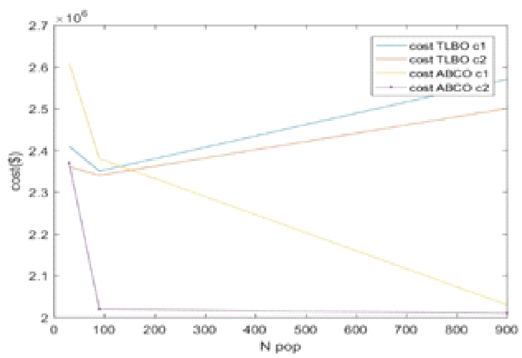

Fig 3: Population Size versus Cost ($)

From the above fig 3, it is clear that the proposed method gives the least cost value than c1 in both metaheuristic Techniques (TLBO, ABCO). The proposed method is economical and safe considering all the security/Safety Parameters mentioned above.

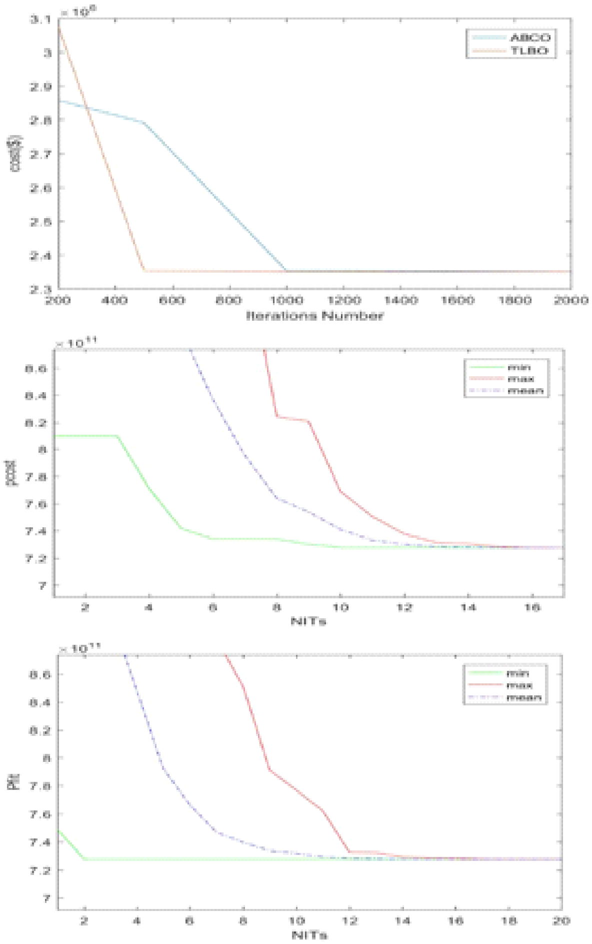

Fig 4: a) Number of Iterations versus Cost b) Number of Iterations versus P Cost in ABCO c)Number of Iterations versus P Cost in TLBO

Getting safe and minimum cost can be obtained by considering penalty if any constraint is violated its limits. The variation of number of iterations with cost and penalized cost in both TLBO and ABCO for 2000 iterations 50 population size is shown in the above fig 4. For analyzing the data regarding the effect of cost on the decisive parameters , it is clear that cost obtained in both optimizations are low and the comparison with method 1 and 2 also presents the effect of frequency dependent soil parameters on safety restrictions and overall cost including maintenance.

Fig 5 shows the variation in the safety parameter values with Maximum number of iterations using ABCO and TLBO. Both the Metaheuristic Techniques give good results with safe economical design.

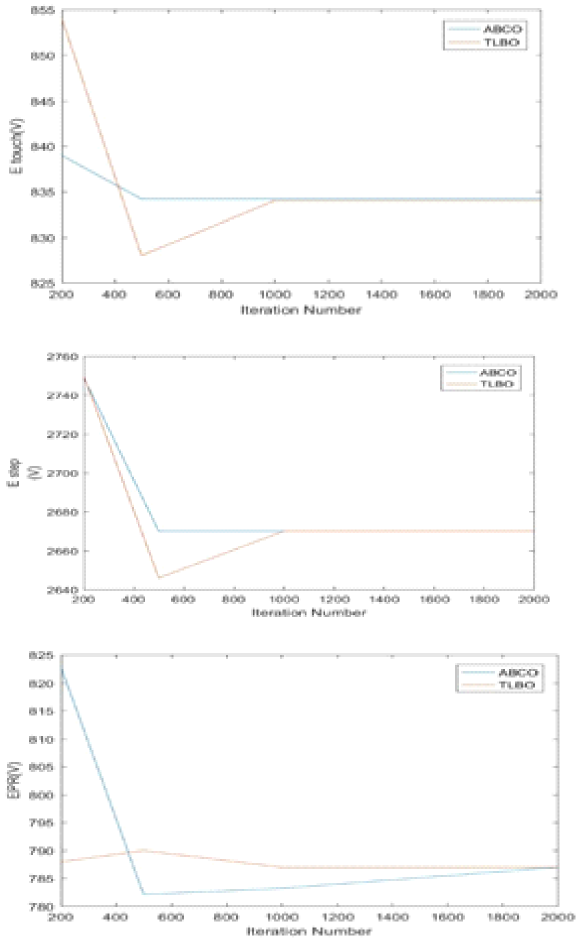

Fig 5: a) Number of iterations versus touch Voltage (50 populations) b) Number of iterations versus step Voltage (50 populations c) Number of iterations versus EPR (50 populations)

6. CONCLUSION

The primary exposure of this work is to design a cost effective, safe design model of earthing under transients and to study the dynamic dependency of soil parameters on frequency.Several authors recommended their computational and numerical simulations on effective grounding design. In this paper, we presented the effectiveness of the proposed model with six safety restrictions for transient Earthing, which is universal for all types of Earthing systems maintaining less resistance value below the prescribed. The following are the significant findings in this work:

1. Exposing the soil parameters dependency on frequency. Transient behavior controlled by proper design of the frequency dependent parameters such as soil resistivity, permittivity, electrode dimensions.

2. Proper maintenance can result in uniform and adequate static values in the first two aspects. Electrode dimensions, such as critical length obtained under the critical frequency range.

3. Optimal Range of Rod/Electrode length decided based on the geographical data at the site.

4. Mathematical Modelling of the cost function for proper transient Earthing System using Eight design parameters and five, four safety /Security restrictions proposed by IEEE STD 8000 and critical length as inequality Constraints.

5. Cost Minimization had done using Metaheuristic Optimization Techniques (TLBO, ABCO).

6. The dependency of frequency and the critical length on safety parameters and decisive parameters elaborated.

7. With proper maintenance, the overall performance of the system improves, so that cost of maintenance also considered in this study.

7. REFERENCES

[1] K. Y. Lee and M. A. El-Sharkawi, "Modern heuristic optimization techniques with applications to power systems, "in IEEE Power Engineering Society. Hoboken, NJ, USA: Wiley/IEEE, 2008, pp.25–42.

[2] Q. Zhang and X. Wu, "Software development of optimal substation ground grid design based on genetic algorithm and pattern search, "in Proc.IEEE Conf. Pub., NorthAmer. PowerSymp., Pullman, WA, USA, Sep. 7–9, 2014, pp. 1–6.

[3] He, Y.Gao, R.Zeng, W.Sun, J.Zou, and Z. Guan, "OptimaldesignofgroundingsystemConsidering the influence of seasonal frozen soil layer," vol.20,no.1,pp.107–115, Jan.2005

[4] S. Yavari, M. J. V. Zoej, A. Mohammadzadeh, and M. Mokhtarzade, "Particle swarm optimization of RFM for geo referencingofsatelliteimages," IEEE.Geosci.Eng.RemoteSens.,vol.10,no.1,pp.705–714, Jan. 2013.

[5] Benamrane Alik, Madjid Teguar, and Abdelouahab Mekhaldi, "Minimization of Grounding System Cost Using PSO,GAO,HPSGAOTechnique"IEEETrans. PowerDel.,,vol.30,no.6,december2015

[6] IEEE Guide for safety in AC substation grounding, IEEE Std.80-2000.

[7] S. Ghoneim, H. Hirsch, A. Elmorshedy, and R. Amer, "Optimum grounding grid design by using an evolutionary algorithm,"inProc. IEEEPowerEng.Soc.Gen.Meeting,Jun.24–28, 2007,pp.1–7.

[8] F. Navarrina, I. Colominas, "Why Do Computer Methods for Grounding Analysis Produce Anomalous Results?," IEEE Transaction on power delivery, vol. 18, No. 4, October 2003, pp 1192-1201.

[9] I. Colominas, F. Navarrina, M. Casteleiro, "A Numerical Formulation for Grounding Analysis in Stratified Soils", IEEE Transactions on Power Delivery, vol. 17, April 2002, pp 587-595.

[10] I. F. Gonos, "Experimental study of transient behavior of grounding grids using scale model", Measurement Science and Technology. 17 (2006), pp. 2022-2026.

[11] A. C. Liew and M. Darveniza "Dynamic model
of impulse characteristics of concentrated earths" PROC.IEE, Vol. 121,No.2, FEBRUARY 1974

[12] R. Kosztaluk,M.loboda,D.Mukhudar, "Experimental study of transient ground impedances" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 11 November 1981

[13] L. Grcev, "Improved Earthing System Design Practices for Reduction of Transient Voltages", 1998 CIGRE Session – International Conference on Large High Voltage Electric Systems, (Paper 36-302), Paris, France, August 1998.

[14] Leonid Grcev, "improved design of power transmission line grounding arrangements for better protection against effects of lightning" Proceedings of the International Symposium on Electromagnetic Compatibility (EMC'98 ROMA), Roma, Italy, September 1998, Paper C1-7, pp. 100-103.

[15] P. Chowdhuri, "Electromagnetic Transients in Power Systems", John Wiley & Sons, Inc., New York, 1996.

[16] C.Chou,"Optimal design of large grounding grids based on simulatedannealingmethod, "ChungYuanJ.,vol.26,no.3,pp.77–85,1998.

[17] C.Y.LeeandY.X.Shen,"Optimalplanning of ground grid basedonparticleswamalgorithm,"Int.J.Eng.Sci.Technol.,vol.3, no.12,pp. 30–37, Dec. 2009

[18] A.VyasandJ.G.Jamnani,"Development of IEEE complaint software 'economical substation grounding system designer' using matlab gui development environment," Int. J.

Elect. Eng. Inf., vol. 4, no. 2, pp. 335–345, Jul. 2012

[19] IEC 62305-1, "Protection Against Lightning, Part 1: General Principles", 2010.

[20] Rao RV, Savsani VJ, Vakharia DP (2011) Teaching–learning-based optimization: a novel method for constrained mechanical design optimization problems. Computer Aided Des 43(3):303–315

[21] Books: A. Kaveh, T. Bakhshpoori, Metaheuristics: Outlines, MATLAB Codes and Examples, https://doi.org/10.1007/978-3-030-04067-3_5

[22] Karaboga D (2005) An idea based on honey bee swarm for numerical optimization. Technical Report, Erciyes University, Engineering Faculty Computer Engineering Department, Erciyes,Turkey.

[23] "IEEE Guide for Safety in AC Substation Grounding," ANS/IEEE, New York, USA, 2000.

[24] N. M. Nor, A. Haddad and H. Griffiths, "Performance of earthing systems of low resistivity soils" in IEEE Transactions on Power delivery,vol21,no.4,pp.2039-2047,oct.2006.

[25] S. Mousa, N. Harid, H. Griffiths, and A. Haddad, "Experimental investigation of high frequency and transient performance of earth rod systems,'Electric power systems Research,vol.113,ElsevierB.V.,pp.196-203,2014.

[26] A. Liew and M. Darveniza, "Dynamic model of impulse characteristics of concentrated earths", Proc. IEE, vol.121, no.2, p.122, February 1974

[27] S. Mousa, "Experimental investigation of enhanced earth electrode systems under high frequency and transient conditions," Ph.D. dissertation, Cardiff University, 2014

[28] S. Brourg and B. Sacepe, "Deep earth electrodes in highly resistive ground frequency behaviour", IEEE International Symposium on Electromagnetic Compatability,pp.584-589,1995.

[29] P. Llovera, J. Antonio, A. Quijano and V. Fuster, "High frequency measurements of grounding impedance on resistive soils," Proceedings on 28th International Conference on Lightning Protection (ICLP), Kanazawa, Japan, Sep. 2006

[30] Leonid Grcev, Senior Member, IEEE, Impulse Efficiency of Ground Electrodes, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 24, NO. 1, JANUARY 2009

[31] B. R. Gupta and B. Thapar, "Impulse impedance of grounding systems," in Proc. IEEE Power Eng. Soc. Summer Meeting, Paper A 78 563-9., 1978, pp. 1–6.

[32] Lightning Response of Grounding Grids: Simulated and Experimental Results SilverioVisacro,SeniorMember,IEEE,Rafael Alipio,CleverPereira,MiguelGuimar˜aes,and Marco A. O.Schroeder