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A Double Stage Method for Optimal Distribution Network Planning and Loss Allocation using Radial Particle Swarm Optmization

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Abstract: Power losses in distribution network are more predominant and mitigating losses leads to reduction of generation and green house gases, saving in fuel reserves and improvement in voltage profile. Sizing and optimal placement of capacitors are the predominant factors for optimization of power loss and increase of bus voltages in radial distribution networks. Moreover, in order to reduce the power losses, optimal conductor sizing is also adaptable and after grading of feeder conductors, placing capacitors at the low voltage buses is more effective. Suitable size and allocation of capacitor at their optimal conditions in conjunction with optimal feeder conductor selection comprise of Double stage approach to minimize the objective function by considering economical and practical considerations. The proposed algorithm improves the performance of a distribution network by reducing losses in Double stages. This proposed approach includes particle swarm optimization algorithm where to optimize objective function consisting of both cost and power loss. Case studies have been conducted using IEEE 34 as well as 69 system and EPDCL, 28 bus system to validate the efficacy of proposed approach.
Keywords Conductor sizing, Loss minimization, Optimal planning, Particle Swarm optimization technique

I. INTRODUCTION

Indian power sector is continuously suffering to bridge the gap between supply and demand keeping in view environmental perspective, though increasing generation is one of the alternatives to meet the present demand which leads to produce green house gases and require more investment. Reducing the line losses can slow down_the impact on tangible generation against demand. Distribution is integral part of Power system and due to high R/X ratio in distribution system, more losses are occurred. In every sector energy is consumed and losses being occurred among these sectors, distribution system losses are more prominent because of their high R/X ratio and low voltage transmission. Reduction of losses in distribution system saves the fuel to be burnt out thus reducing the greenhouse gases produced from them and it also improves the voltage profile of the network. Optimal capacitor placement and sizing of conductors have been solved by various techniques. Earlier these techniques are based on analytical and numerical methods. But these techniques are complex, difficult to compute and needs high computing time to overcome these drawbacks. Heuristic techniques have been employed to solve this problem. Prakash et. al. [1] have been presented the sensitivity analysis and particle swarm optimization to maximize the reduction in power loss by allocating capacitors and optimize the size without considering cost of capacitors. Direct search algorithm for sizing of capacitors and its allocation is presented [9]. This is similar to analytical method having more computing time. Bat and Cuckoo search algorithm for capacitor allocation and their sizing are presented [6]**.** They compared the efficiency of these algorithms to some bio-inspired algorithms with maximizing saving as an objective. Energy loss cost is minimized with discrete Particle Swarm Optimization technique by optimal graded conductors [12]. Grading of conductors in radial distribution network is presented [11] based on PSO and DV differential evolution a hybrid algorithm (PSO-DV). Proper selection of location and its size is presented by Genetic Algorithm (GA) approach for finding location of capacitor and their suitable rating with a mechanism of natural selection is shown in [3]. Loss profile improvement and maintaining good voltage by identifying location and appropriate capacitor rating, Plant Growth Simulation Algorithm (PGSA) is used in [7]. Simultaneous action of capacitor optimal placing and its size have been presented in [10] using Harmony Search (HS) method. Evolutionary strategies like mutation and recombination has been used [15] for solving reconductoring problem. Discrete PSO has been proposed [16] for conductor selection to minimize the cost of investment and energy loss in the radial distribution system. Power loss is minimized [17] by conductor sizing and optimal capacitor placement under the technical constraints of the network by PSO. Conductor sizing uses the mixed integer linear model to obtain the Paleto front of conductor sizing [18] of the n for a network. A combine method of current density method and index directed method has been developed to solve the conductor selection problem considering its practical aspects of the network [19]

The most significant contribution of this approach to minimize both distribution system planning cost as well as overall losses of the system through Double stages for optimization of conductor sizing and capacitor placement.

II. METHODOLOGY FOR OPTIMAL CONDUCTOR SIZING USING PARTICLE SWARM OPTIMIZATION

Grading of line conductors have been done based on allowable conductor current rating and its network kVA rating considering planned load growth

A. Objective Function

The objective function is defined to reduce line losses and conductor cost without violating its current and voltage limits in the proposed method

$$Min\ Cost = \sum_{m=1}^{n} (Ct1_{(m,r)} + Ct2_{(m,r)}) \quad (1)$$

where $Ct1_{(m,r)} = \alpha * Cc * Len_{(m)} * A_{(r)}$

$Ct2_{(m,r)} = Cp * Ploss_{(m,r)} + Ploss_{(m,r)} * Ce * T * lsf$

Cc = Variable cost of feeder installation, $/mm2/km.

Ce = Energy cost, $/kWh.

Cp = Cost of generation, $/kW.

α = Carrying charge rate of feeder

T = number of hours in one year.

$Ploss_{(m,r)}$ = feeder power loss segment m for r type of conductor.

lsf = Loss factor

$Len_{(m)}$ = Length of branch in km.

B. Voltage Constraint

Voltage on each bus V_i should be within the following limits.

$$V_{min} \leq V_i \leq V_{max} \quad (2)$$

C. Load Growth

$$p_{il} = p_{il}(1+R)^n$$
$$Q_{il} = Q_{il}(1+R)^n$$

p_{il} = Active power injected on ith bus (kW)

Q_{il} = Reactive power injected on ith bus(kVAR)

R = Rate of load growth per year

D. Current Constraint

Current on each conductor should not exceed highest allowable current through it.

$$I_{(m,r)} < Im_{(r)}$$

$I_{(m,r)}$ = current flowing in r type conductor for M^{th} branch.

$I_{m(r)}$ = highest allowable current for r type conductor.

E. Particle Swarm Optimization (PSO)

PSO is a heuristic search algorithm for optimal solution. This algorithm imitates the swarm_behavior and their interaction for finding their food to search the solution of nonlinear problems.

This algorithm executes in finding optimal values from swarm of particles through two essential reasoning capabilities like local best and global best.

Each particle of swarm flies in search space or changes its position with a velocity and remembers its best position which gives minimum of objective function termed as pbest particle (local best or individual best) and the gbest (global best particle) which gives minimum of objective function among all pbest particles. Each particle decides its velocity according to its distance from personal best particle, global best particle and its previous velocity.

III. OPTIMAL LOCATION OF CAPACITOR AND ITS SUITABLE RATING

The optimal placement of capacitor is being carried out according to the loss sensitivity factors of the distribution network buses. The loss sensitivity factor of each bus gives the measure of change in active power loss subjected to injecting reactive power on the same bus. The loss sensitivity factors are computed as follows [1]. The single line diagram of distribution line as shown in Fig. 1.

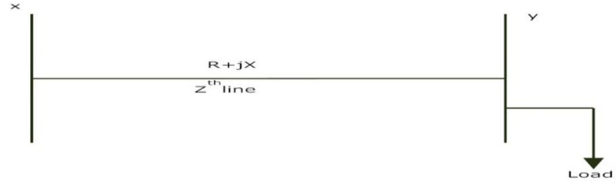

Fig. 1 Single line diagram of a distribution line

$$Ploss[z] = \frac{(P_{inj}^2[y] + Q_{inj}^2[y]) * R[z]}{(V[y])^2} \quad (3)$$

$$\frac{\partial p_{loss}}{\partial Qinj} = \frac{(2Q_{inj}[v] * R[z])}{(V[y])^2} \quad (4)$$

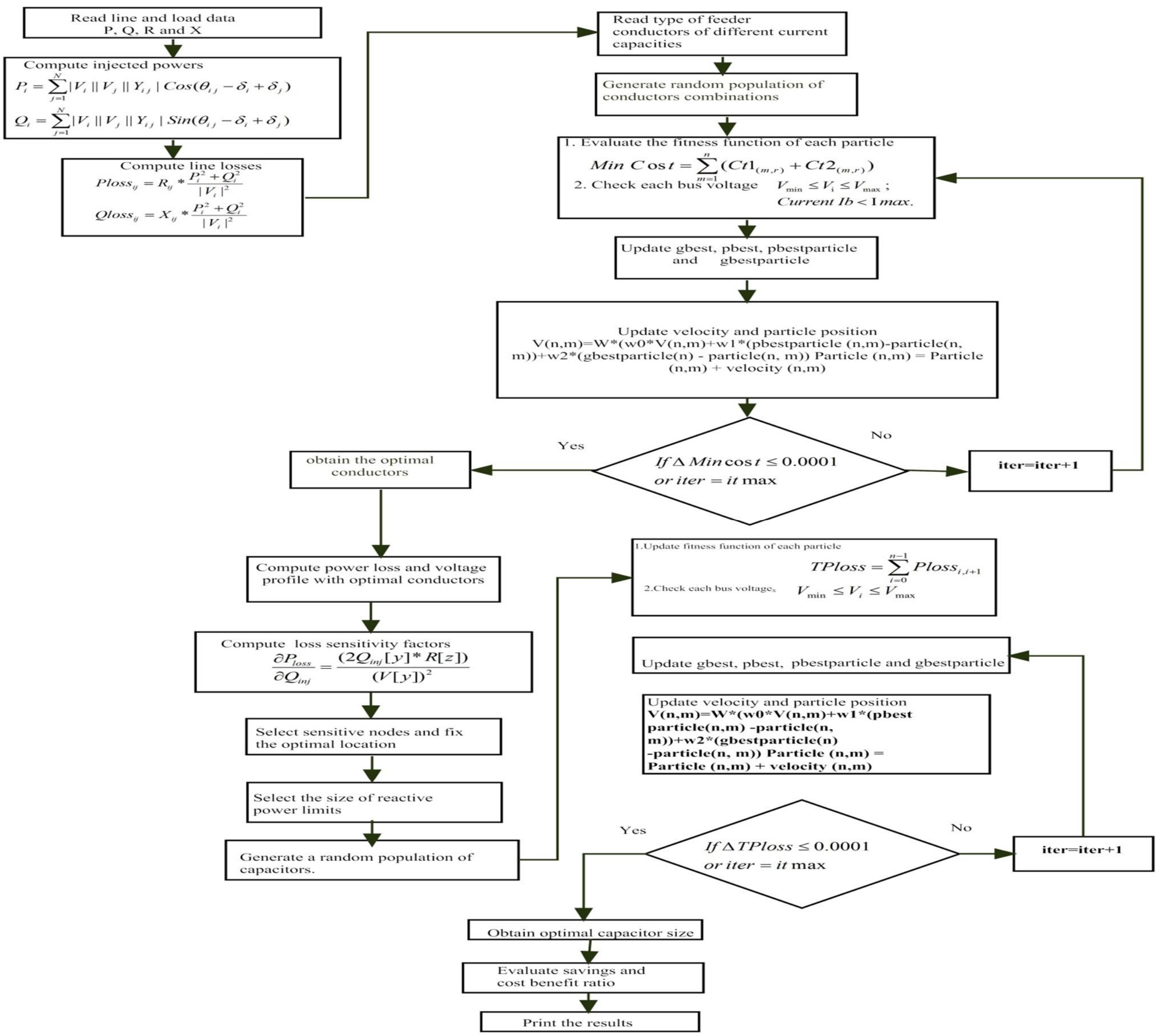

Fig. 2 Flow chart for proposed Double stage method

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Where

$P_{inj}[y]$ = Total injected kW powers supplied beyond node x.

$Q_{inj}[y]$ = Total injected kVAR power supplied beyond node x .

$V[y]$ = Bus voktage at node x

p_{loss} = Active power loss in kth branch

The net saving of the network is computed from the below equation.

$$\text{Net saving} = \text{Total cost} - \text{benefit}$$

$$\text{Total cost} = Kp * Tq + Kp * Tq * df + Ki * nl$$

$$\text{Benefit} = Ke * Pl * 8760$$

Kp = cost of purchase per kVAR

Tq = Total kVAR installed

df = depreciation factor

Ki = cost of installation per location

nl = number of location for capacitor installation

The proposed methodology is presented in the flow chart with the help of aforementioned equations as per Fig. 2. Particle swarm optimization have been applied for optimization to mitigate the losses of given radial network using proposed Double stage method. This method is described in the flow chart and demonstrated by considering various case studies as presented in section IV and obtained results are compared with several optimization methods.

IV. CASE STUDIES AND RESULTS

The proposed Double stage method is carried out on IEEE 34 bus, IEEE 69 bus and practical 28 bus networks to show the ability of the proposed approach. For each of the networks, computations are presented as voltage profile, power losses, loss sensitivity index, capacitor location and its sizes and optimal grading of conductors of the network. The results are found to be very encouraging and economically viable. Technical, economic data and cost parameters are presented in the appendix. The detailed computation process and results obtained for various networks are presented below. Firstly, IEEE 34 bus radial distribution network with lateral branches is having 34 nodes and 33 branches and 4 laterals as shown in Fig. 3.

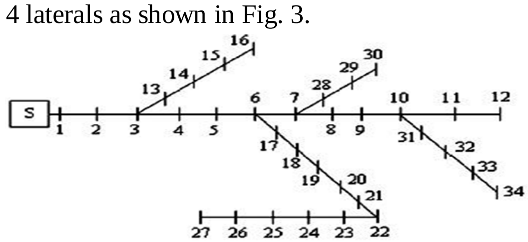

Fig.3 Single line diagram of IEEE 34 bus network.

After performing load flow analysis on IEEE 34 bus, the kW and kVAR losses on the existing network are 221.69 kW and 65.12 kVAR against a total peak load of 4636.5 kW and 2731 kVAR respectively. The minimum and maximum voltages of this network are 0.9417p.u. (bus no 27), 0.9940p.u. (bus no 2) respectively. Hence, the obtained results of proposed load flow are validated with the existing network results [2].

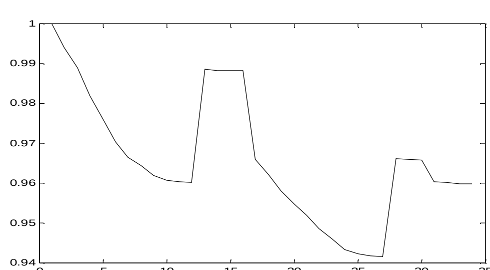

Fig. 4 Voltage profile of IEEE 34 bus network.

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Table 1 with other optimization methods

IEEE 34 bus	HS [13]	ABC [14]	EA [2]	GA [3]	Proposed Method
Node number	4,11,17,16	8,18,25	8,18,25	5,9,12,22,26	8,18,25
Capacitor kVAR	250,750,300’1400	900,900,800	1050,750,750	300,300,300,600,300	847,904,761
Total kVAR	2700	2600	2550	1800	2512
Active power loss(kW)	168.48	161.06	161.26	164.95	160.99
Loss reduced (%)	24.02	27.34	27.26	25.61	27.42
Vmin (p.u)	0.9522	0.9496	0.9501	0.9478	0.9504
Vmax (p.u)	0.9953	0.9949	0.9952	0.9949	0.9941
Net saving($)	11,991	17,018	17,165	17,740	18,283

The Double stage method is implemented on IEEE 34 bus to find the optimal capacitor locations and sizing. This method obtains Power loss, Voltage profile and Net savings. The results are incorporated in the Table.1. Volage profile is shown in Fig. 4.
The results of proposed method on IEEE 34 bus compared with published results from Harmony Search (HS), Ant Bee Colony (ABC), Evolution Algorithm (EA) and Genetic Algorithm (GA) in Table 1.
Computation of proposed method on IEEE 34 bus as shown in the Table 2-3 with base network optimal Conductor grading, placement of capacitors on the identified sensitive buses.

Table 2 Conductor grading of IEEE 34 bus network

IEEE 34 bus branch number	Conductor type
1 to 5,8,10,16to26,29,32	4 (Lion)
6,9,15,27,30,31	1(Ferret)
7,14,33	3(Mink)
11to13,28	2(Rabbit)

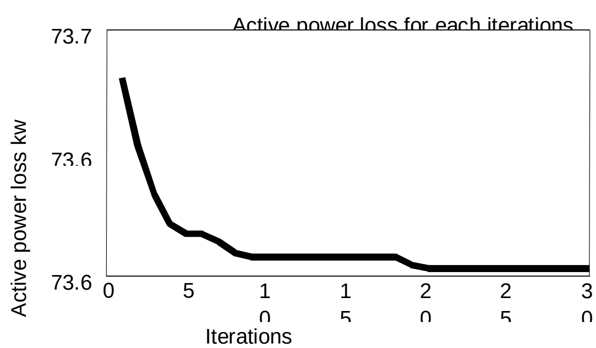

Fig. 5 Active power loss with iterations using PSO

Table 3 Proposed Double stage method on IEEE 34 bus

IEEE 34 bus	Base case	Capacitor placement	Conductor sizing	Conductor sizing and capacitor placement
Active power loss (kW)	221.69	168.7	104	73.60
Vmin (p. u)	0.9417	0.9495	0.9559	0.979
Node number		8,18,25	NA*	8,18,25
Capacitors (kVAR)		895,874,267		840,912,838
Total kVAR		2038		2590

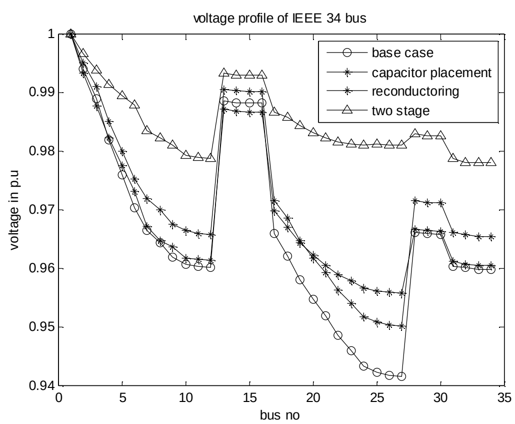

Fig. 6 Voltage profile of IEEE 34 bus network.

The application of proposed method is employed on IEEE 69 bus and practical 28 bus network to know the effectiveness. The results and voltage profile of the networks for proposed approach are shown in the below Tables and figures (4-8).

Table 4 Results of Optimal capacitor placement for base networks

Network	IEEE 69	EPDCL 28 bus
base case active power loss(kW)	225.008	66.6061
Active power loss(kW)	152.37	35.17
Loss reduced(kW)	72.638	31.4361
Node no	57,58,61	5,4,6
Capacitor(kVAR)	316,355,837	200,260,338
Total kVAR	1508	798
Vmin (p.u)	0.9307	0.9458
Vmax (p.u)	0.999	0.9925
Net saving ($)	36999	12500

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Table 5 Conductor grading for IEEE 69 bus

IEEE 69 bus branch number	Conductor type
1-7,10,11,13-18,20,21,23,28,33,37-41,43,44,48,54,56,60,63,64,65	4(Weasel)
8,9,25,27,30,31,32,45,46,51,53,58,61,66,67	3(Gopher)
12,19,22,24,29,34,35,42,47,49,50,52,55,57,59,62	2(Squirrel)
36	1(Mole)

Table 6 Proposed Double stage method results on IEEE 69 bus network

IEEE 69 bus	Base case	Capacitor placement	Conductor sizing	Conductor sizing and capacitor placement
Active power loss (kW)	225.008	152.37	143.77	97.72
Vmin (p.u)	0.9092	0.9307	0.9330	0.9605
Node number		57,58,61	NA*	57,58,61
Capacitor rating (kVAR)		316,355,837		258,341,11031
Total kVAR		1508		11630

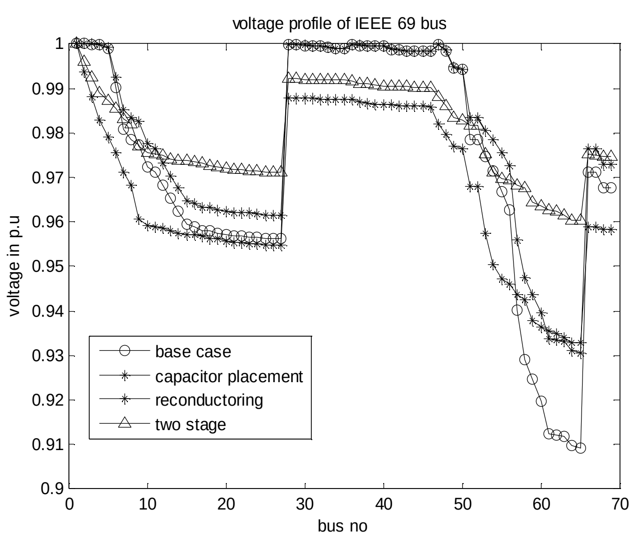

Fig. 7 Voltage profile of IEEE 69 bus for proposed Double stage approach

Table 7 Conductor grading for practical 28 bus network

EPDCL 28 bus conductor grading	Conductor type
1,2,9,10,11,13,14,16,17,19	4(Weasel)
3-5,7,12,22,24-26,	3(Gopher)
6,15,18,23	2(Squirrel)
8,21,27	1(Mole)

There are no sensitive buses in 28 bus system when proposed method is being used

Table 8 Results of proposed Double stage method on 28 bus network

EPDCL 28 bus	Base case	Capacitor placement	Conductor sizing
Active power loss(kW)	66.6061	35.17	22.022
Vmin (p.u)	0.9138	0.9458	0.97
Node number		5, 4, 6	NA*
Capacitor rating (kVAR)		200,260,338	
Total kVAR		798	

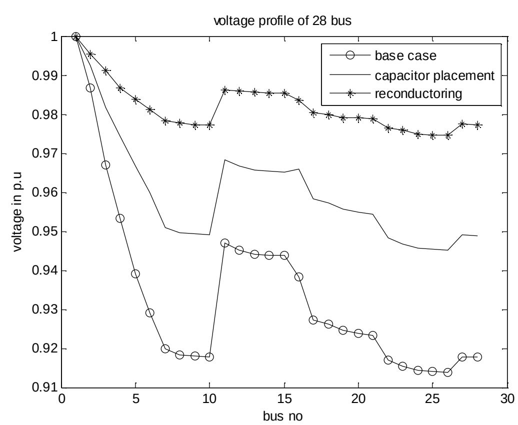

Fig. 8 Voltage profile of practical 28 bus for proposed Double stage approach

The case studies corroborate the applicability of the proposed approach for practical distribution systems. The proposed approach employs optimal conductor sizing and capacitor placement as Double stage approach by Particle Swarm Optimization technique for maximum loss reduction and decrease the investment cost for increasing savings in distribution systems. This method has been tested on standard networks like IEEE 34 bus, IEEE 69 bus and practical 28 bus network. The results from this method are compared with existing literature are found to be effective. In the proposed approach the loss reduced in IEEE 34bus, IEEE 69 bus and practical 28 bus is 66.8%, 56.48%, 66.69% respectively and the average loss reduction in the networks is **63.32%.** The net savings obtained by capacitor placement by PSO in the IEEE 34 bus, IEEE 69 and practical 28 bus network for a plan period of ten years is $18,283, $36999, $12500 respectively.

APPENDIX

Technical details of Conductors.				
Conductor type	Resistance/km	Reactance/km	Area (mm2)	Current carrying capacity
Mole	2.702	0.348	10.6	87
Squirrel	1.370	0.327	20.6	131
Gopher	1.093	0.320	26.2	151
Weasel	0.908	0.314	31.6	169
Ferret	0.6795	0.3760	42.4	180
Rabbit	0.5441	0.3673	32.26	208
Mink	0.4565	0.3660	63.2	252
Raccon	0.3657	0.3579	48.39	270
Panther	0.136	0.248	212	500
Lion	0.121	0.244	238	628

Cost Parameters [6]	
Description of the cost parameter.	Specification
Average kWh cost (Ke)	$0.06
factor of depreciation (df)	10%
Cost of capacitor per kVAR(Kp)	$25/kVAR
Cost of installation of capacitor per location (Kl)	1600/location
Hours per year(T)	8760
Maximum capacitor rating	1200kVAR
Minimum capacitor rating	200kVAR

Economical and technical data [11]	
variable installation cost of feeder(Cc)	$7.51/mm^2/km
Cost of energy(Ce)	$0.01/kWh
Cost of power(Cp)	$37.54/kW
Loss factor(lsf)	0.2
Carrying charge rate of feeder (α)	0.1

V. CONCLUSION

The results obtained from the proposed approach as compared with existing literature are more effective. The distribution system planning over Double stages seems to be more efficient to optimize both conductor size as well as capacitor placement to minimize losses as well as capital investment.

VI. ACKNOWLEDGEMENTS

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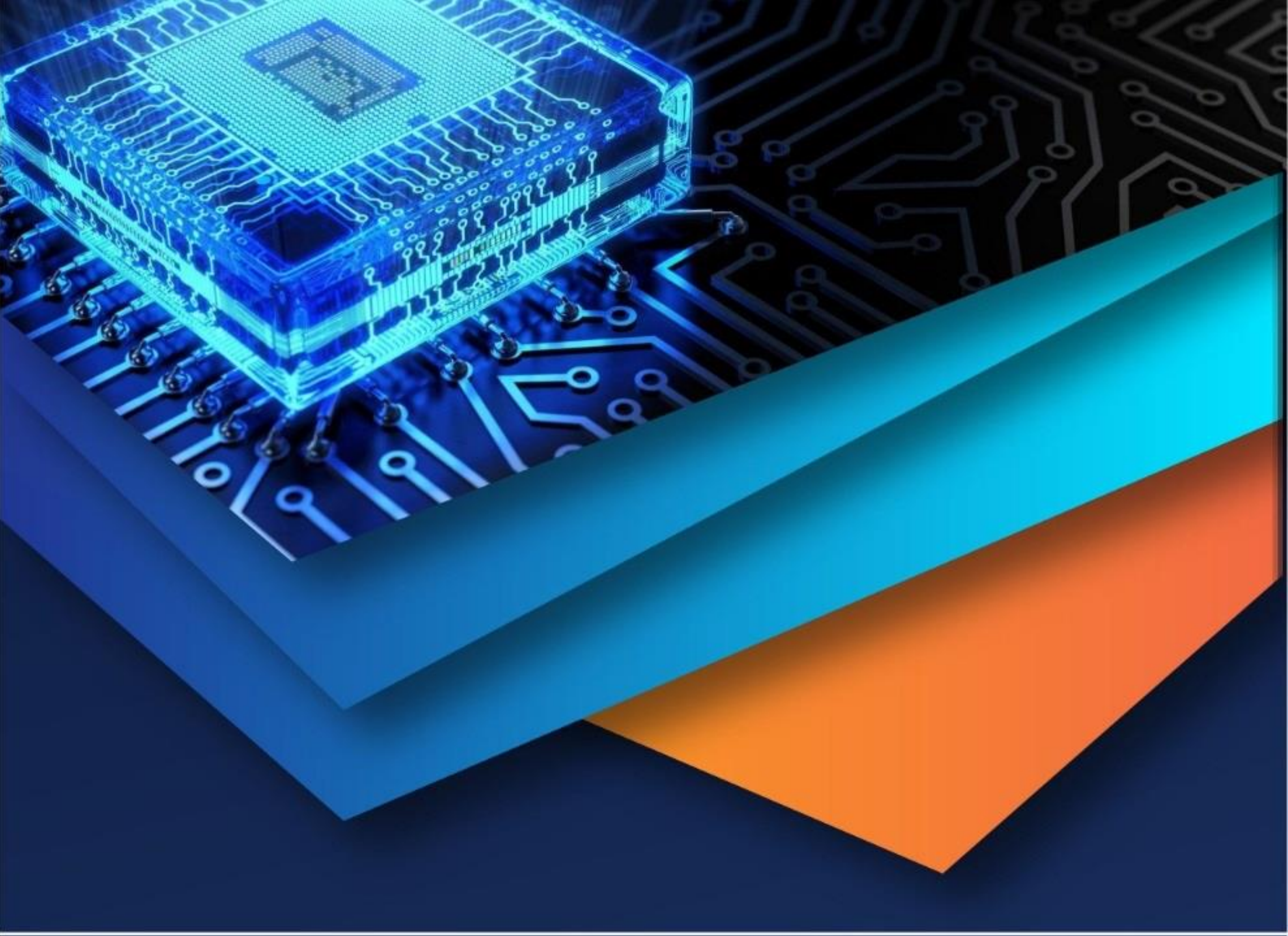

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