Optimal Location and Sizing of Capacitors for Net saving Maximization in Radial Distribution System using ALO

N. Vijayalakshmi, K. Gayathri

Abstract: ***The key factor for voltage stability of a distribution system is one among the most interesting areas of industry and research sectors far and wide. It considered the steady load activity and permissible voltage limits all over the network nodes. Of this, the capacitor is equipped for providing reactive power in the network which effects of limiting the power misfortunes and improves the voltage profile and stability of the system. In this paper, net saving maximization is consider as a target and as speaking to an expense of energy loss, installation, purchase and operating costs of capacitors. It is solved by using an Ant Lion Optimizer (ALO) algorithm. The ALO is to actualize the issue in order to maximize the objective of problem formulation. The fixed and switched type capacitors have used in this approach. The prevalence of the presented method is veteran on 34-node and 69-node systems. The assessment results of this approach are compared with the existing report.***

Keywords: Radial distribution system, Voltage stability, Capacitors, net cost savings, power loss and Ant line optimizer.

I. INTRODUCTION

Many distribution grids suffer from a lot of problems while feeding consumers with inductive loads. Some of these problems related to low voltage regulation, and high power losses. Increasing reactive power consumption leads to higher line currents with un-allowed voltage drop. The lacking of reactive power supply can bring about voltage instability nature of the system. The network real and reactive power losses are numerically characterized by

$$P_{Loss} = \sum_{i=1}^{n} |I_i|^2 R_i \tag{1}$$

$$Q_{Loss} = \sum_{i=1}^{n} |I_i|^2 X_i \tag{2}$$

The voltage instability is a more important issue of system operation and planning. The proper arrangement of reactive power, possessions in the system which has diminish the power losses and improve the active power transfer capability and voltage profile of the system.

Capacitor banks, arrangement are probably the best strategy in the DG grids which used to complete the last destinations [1]. As capacitors having different sizes and different cost in the market, therefore its value and placement is variable in nature [2].

The researchers developed various approaches for improving the voltage stability and cost saving of RDS. In [3, 4], the author have been presented the reactive power planning problem for a system which is allocated and evaluate the ability of the reactive power resources. The authors have been proposed the comprehensive planning problem and which is solved by using tabu search (TS) algorithm with the effects of minimizing the cost of energy losses and total required reactive power during the planning period [5].

The different soft computing procedures have been archived by the researchers; it includes Genetic algorithm, Simulated annealing, Particle swarm optimization, Gravitational search algorithm, Cuckoo search algorithm and Differential evolution algorithm. Recently developed approaches such as Teaching-learning based optimization [6], ABC algorithm [7, 8], Fuzzy real coded-GA [9], Improved Harmony Algorithm [10], Bacterial Foraging algorithm [11] and OKH algorithm [12] also been used to solve the issues.

The ABC algorithm is applied to decide the voltage stability index and boost the absolute yearly saving of standard test systems with various loading conditions (50%, 75% and 100%) in [7, 8]. A hybrid approach of Fuzzy-Real Coded GA has utilized for voltage strength improvement and capacitor portion of the system in [9]. The authors built up a changed VSI formula for extra reactive power compensation. The fuzzy system decides the capacitor area and true coded GA utilized for estimating of capacitor for voltage profile improvement. The authors [10] prescribed the Improved Harmony Algorithm (IHA) principally. The most applicant buses for installing capacitors are identified using LSA and VSI. After, IHA is in work to infer the size of capacitors and their areas from the chosen buses. An IHA limit the complete expense and increment the net investment funds. Numerical case of 85-bus and 118-bus systems is considered.

Bacterial Foraging Algorithm [11] has been utilized to assess the size and ideal arrangement of capacitors. This technique figures the loss affectability factor and VSI of the framework. The authors present a procedure dependent on Oppositional Krill Herd based optimal position of capacitor thinking about reconfiguration in radial network. These

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* Correspondence Author
N.Vijayalakshmi, Assistant Professor, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India.
K.Gayathri, Associate Professor, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India

methodologies process the optimal location with reconfiguration of buses. This idea limits the complete power loss likewise improve the convergence of the solution. The authors moreover applied TLBO algorithm [12] for the similar issue. Appropriateness of the technique tried on standard 22, 69, 85 and 141 bus RDS. Conclusive outcomes are contrasted GA, PSO, DSA and MIP.

In this article, improved the voltage stability and maximize the annual savings for the best possible worth and location of capacitors. A creative algorithm of ALO is applied to deal with the issue. Numerical instance of 34-node and 69-node systems are considered to represent the prevalent exhibition of ALO. The test outcomes are compared with other writings.

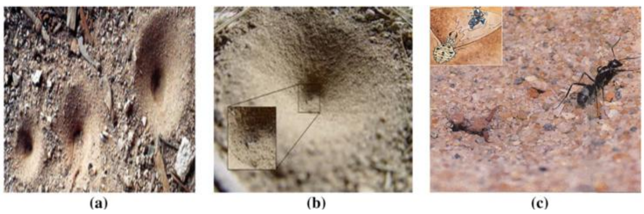
II. ANT LION OPTIMIZER AND ITS MATHEMATICAL FUNCTIONS

The ant line optimizer is a meta-heuristic populace based search optimization algorithm. This algorithm as of late created by Seedily Mirjalili [13] in 2014 and used to solve the several Engineering constrained and Non-constrained optimization problems. The ALO is a issue free control parameter algorithm and has various Ant Lions and most extreme number of iterations to tune and getting the global optimal solution. It is moved by the life cycle of Antlions (doodlebugs), which belong to the Myrmeleontidae family and Neuroptera order (net-winged insects).

The ALO algorithm impersonates the hunting technique of Ant lions (doodlebugs) and is depends on the accompanying steps of chasing the prey[14].

- Random strollof ants
- Building traps
- Entrapment of ants in snares
- Moving ants toward Antlion
- Catching preys and
- Re-building traps.

The steps for structuring traps and capture of ants intraps are appeared in Fig.1 (a–c).



The process of catching the prey and re-building traps are shown in Fig. 1 d–f.

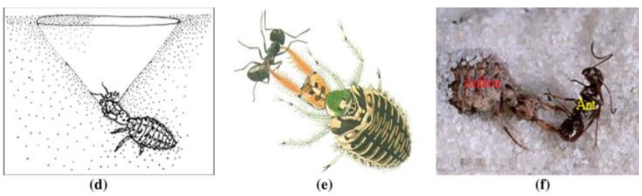


Fig. 1.a–c Building traps and entrapment of ants in traps; d–f catching the prey and Re-building traps

The numerical functions of proposed ALO approach has been formulated as pursues,

A. Random walks of ants

The ants move stochastically looking for nourishment in nature, the random/stochastic walks of ants can be mathematically demonstrated as

$$X(t) = [0, cumsum(2r(t_1), cumsum2r(t_2)-1), \ldots, cumsum(2r(t_n)-1)] \quad (3)$$

Where, cumsum calculates the cumulative sum, n is the most extreme numberof iteration, t shows the step of random walk (iteration in this study), and r(t) is a stochastic capacity spoken to as pursues:

$$r(t) = \begin{cases} 1 \; if \; rand > 0.5 \\ 0 \; if \; rand \leq 0.5 \end{cases} \quad (4)$$

So as to keep the arbitrary strolls of ants inside the inquiry space, the places of their strolls are standardized using the min–max normalization equation:

$$X_i^t = \frac{(X_i^t - a_i)\times(d_i - c_i^t)}{(d_i^t - a_i)} + c_i \quad (5)$$

B. Trapping in antlion's pits

The arbitrary strolls of ants are influencedby Antlions' traps; the numerical condition of catching of ants in Antlion's pits can be detailed as pursues:

$$c_i^t = Antlion_j^t + c^t \quad (6)$$

$$d_i^t = Antlion_j^t + d^t \quad (7)$$

C. Building Trap

So as to examine the chasing ability of Ant lion, the Roulette wheel is working. The ants are thought to be caught in just one chosenAntlion and shown in fig 2. During a streamlining, the ALO is important to utilize a roulette wheel operator for picking Ant lions dependent on their wellness. This process gives high probability to the fitter Ant lions for catching the ants.

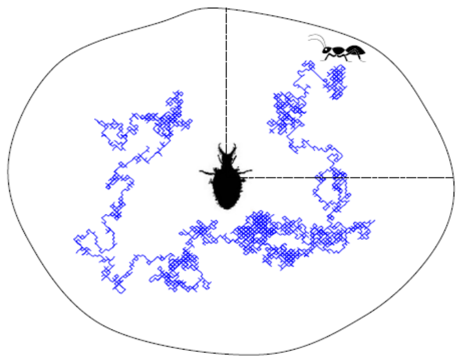


Fig. 2. Random walks of an ant inside an antlion's trap.

D. Sliding Ants toward Antlion

The sliding of ants toward Ant lions can be mathematically defined as

$$c^t = \frac{c^t}{I} \quad (8)$$

$$d^t = \frac{d^t}{I} \quad (9)$$

E. Catching Prey, Re-Building The Pit

Catching the ants by Antlion and re-arranging the pit can be formulated as follows

$$Antlion_i^t = Ant_i^t \;\; \text{if } f(Ant_i^t) > f(Antlion_i^t) \quad (10)$$

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F. Elitism

Elitism is a huge significant function of transformative algorithms for halting the program. It permits keeping up the best solution(s) getting at any phase of optimization technique. In this issue, the best Antlion obtained in every iterations is saved and considered as elite. The elitism movement can be done by utilizing the accompanying condition.

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$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (11)$$

III. VOLTAGE STABILITY INDEX

The VSI gives the data for voltage solidness of the radial distribution systems. The variety of this factor speaks the system voltage stability in case with or without capacitor condition. The VSI is given as [12],

$$VSI(m2) = |V(m1)|^4 - 4.0\{P(m2)\,x(jj) - Q(m2)\,r(jj)\}^2 - 4.0\{P(m2)\,r(jj) + Q(m2)\,x(jj)\}|V(m1)|^2 \quad (12)$$

IV. OBJECTIVE FUNCTION AND CONSTRAINTS

The net saving maximization is considered as a goal of optimal area and estimating of capacitors in RDS is to limit power loss and buy cost of capacitor with determined operating limitations. The ALO algorithm based net saving maximization is numerically detailed as,

$$\max f = C_E\left(P_{LB} - P_{LA}\right)T - \beta\left(C_I N_B + C_P \sum_{i=1}^{N_B} Q_{ci}\right) - C_o N_B \quad (13)$$

where,

- C_E = cost of energy is \$0.06/KWh
- C_I = cost of installation is \$1600/location
- C_P = cost of the capacitor purchase is \$25/KVAr
- C_o = capacitor operating cost is \$300/year/location
- β = Depreciation factor is 20%
- N_B = number of candidate location for capacitor placement
- P_{LA} = total active power loss after compensation
- P_{LB} = total active power loss before compensation
- Q_{ci} = size of the capacitor at node *i*
- T = time period 8760 hours/year.

The different appropriate constraints are considered into accountant which speaks as far as possible in the search is equipped for ant lions to move over the feasible region. These limitations are examined as pursues.

A. Real and Reactive Power - Conservation Limits

The arithmetical total of all receiving and sending powers in addition of line losses over the total circulation network and reactive power inject from capacitor unit ought to be equivalent to zero.

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$$P_{SS} = \sum_{i=2}^{NB} P_D(i) + \sum_{j=1}^{NL} P_{loss}(j) \quad (14)$$

$$Q_{SS} = \sum_{i=2}^{NB} Q_D(i) + \sum_{j=1}^{NL} Q_{loss}(j) - \sum_{k=1}^{NC} Q_C(k) \quad (15)$$

where,

- P_{SS} - Real power conservation of the system (MW)
- P_D - Total system real power demand (MW)
- P_{loss} - Total system real power loss (MW)
- Q_{SS} - Reactive power conservation of the system (MVAr)
- Q_D - Total system reactive power demand (MVAr)
- Q_{loss} - Total system reactive power loss (MVAr)
- Q_C - Total reactive power injects by capacitor (MVAr)
- NL - Number of lines
- NC - Number of capacitor.

B. Reactive Power Compensation Limits

The reactive power conveyed by every capacitor is limited by its lower and upper limits as,

Q_C = 600 KVAr (Fixed type capacitor)

$0 \le Q_{Ci} \le Q_{Ci}^{max}$ (Switched type capacitor) (16)

Permissible capacitor range 0 to 1500 KVAr with step of 50 KVAr.

C. Voltage Profile Limits

The voltage magnitude of each node is strictly maintained as,

$$V_i^{min} \le V_i \le V_i^{max} \quad (17)$$

$0.95 \le V_i \le V_i^{max}$ (34 - NODE SYSTEM)

$0.90 \le V_i \le 1.00$ (69 - NODE SYSTEM)

D. Line capacity Limits

The distribution of power is done through the feeder and in this feeder should not go beyond the thermal capacity of the line.

$$S_{(i,j)} \le S_{(i,j)}^{max} \quad (18)$$

E. Maximum Total Compensation

It is a practical constraint, the most extreme compensation by utilizing a capacitor bank share not exactly or equivalent to the all the total load reactive power demand:

$$\sum_{i=1}^{N_B} Q_c(i) \le \sum_{j=1}^{N_l} Q_D(j) \quad (19)$$

V. IMPLEMENTATION OF ALO ALGORITHM

The following steps are used to getting the optimal solution for Voltage stability improvement and maximize the cost savings problem as follows,

1. Read the line data, bus data and cost factor of given test systems.
2. Set the lower and upper limits of constraints and set the values control parameters of ALO technique and most extreme number of iterations.

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3. Initialize the first populace of ants, Ant lions arbitrarily. Run load stream and compute the wellness of ants and Ant Lions.

4. Estimate the best Ant lions and envision it as Elite.
5. Set Iteration = 1.
6. For every ant, choose an Antlion utilizing Roulette wheel Make a random walk and standardize it to keep it inside the search space by using the condition,

$$M_{Ant} = \begin{bmatrix} A_{1,1} A_{1,2} & \cdots & A_{1,d} \\ A_{2,1} A_{2,2} & \cdots & A_{2,d} \\ \vdots & \cdots & \vdots \\ A_{n,1} A_{n,2} & \cdots & A_{n,d} \end{bmatrix} \quad (20)$$

Update the estimations of c and d using equation (8) and (9).

7. Run load stream and figure the fitness of all ants,

$$M_{OA} = \begin{bmatrix} f([A_{1,1}, A_{1,2}, & \cdots & A_{1,d}]) \\ f([A_{2,1}, A_{2,2}, & \cdots & A_{2,d}]) \\ \vdots \quad \vdots & \vdots & \vdots \\ f([A_{n,1}, A_{n,2}, & \cdots & A_{n,d,}]) \end{bmatrix} \quad (21)$$

8. Take the place of an Antlion with its corresponding ant on the off chance that becomes fitter, and to refresh elite if an Ant lion ends up fitter than the elite.
9. Memorize the best solution accomplished up until this point.
10. Set Iteration = Iteration + 1
11. Check whether iteration is more prominent than or equivalent to Maximum Number of iterations, go to step 12, otherwise go to step 6.
12. Print the results and STOP.

VI. NUMERICAL RESULTS

To test the legitimacy of anticipated method, the 34-node and 69-node RDS have been taken as test systems. In these test system, the base values utilized are 100 MVA for both test systems and 11 KV for 34-node and 12.66 KV for 69-node. The one line structure of 34-node and 69-node RDS is shown in fig.3 and fig.5.The control parameters are chosen as, number of search agents or no. of Ant lions = 40, Most extreme no. of iterations = 100, Number of variables = 5. The proposed methodology introduces a result, which is contrasted with GA, PSO and ABC algorithms.

34-node system

The system has one principle feeder and three laterals. The active power losing the system is 221.72 KW while the receptive power loss is at 65.11 KVAR. The results for real power loss, least voltage stability index, least voltage, optimal location and estimating of the fixed and switched capacitors and net saving/year of the 34-node system are gotten by various strategies are portrayed in table 1 and 2. These outcomes show that the ALO approach to obtain the minimum real power loss is 164.36 KW comparing with other methods. Resultant the loss of the system is diminished to 25.87% when compared to base case. The reduction power loss has incredible effects of voltage profile and voltage stability of the system.

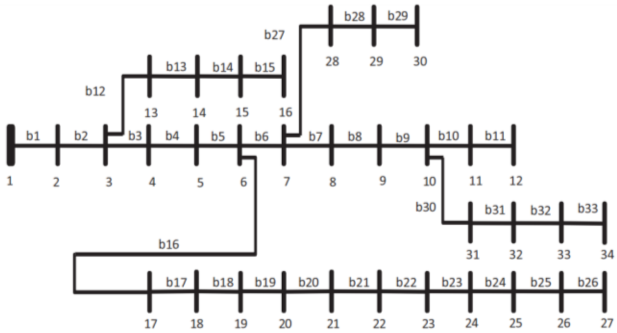

Fig. 3. Single line diagram of 34-node radial distribution system

Table- I: The performance analysis of 34-node system with switched capacitor

Method	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size (KVAr)	Net saving/year
Base case	221.72	0.7864	0.9416	-	-	-
GA	164.96	0.8071	0.9478	5 9 12 22 26	300 300 300 600 300	$15093.00
PSO	169.36	0.8097	0.9486	19 22 20	781 803 479	$15570.00
ABC	167.77	0.8129	0.9496	19 24	1050 800	$17871.00
ALO (Proposed)	**164.36**	**0.8146**	**0.9500**	**9 23**	**750 1400**	**$18161.00**

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Table- II: The performance analysis of 34-node system with fixed and switched capacitor

Method	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitorsize (KVAr)	Net saving/year
ABC	167.77	0.8129	0.9496	24(Fixed) 19 24	600 1050 200	$17246.00
ALO (Proposed)	**160.95**	**0.8146**	**0.95001**	**25(Fixed) 9 21**	**600 800 800**	**$19083.00**

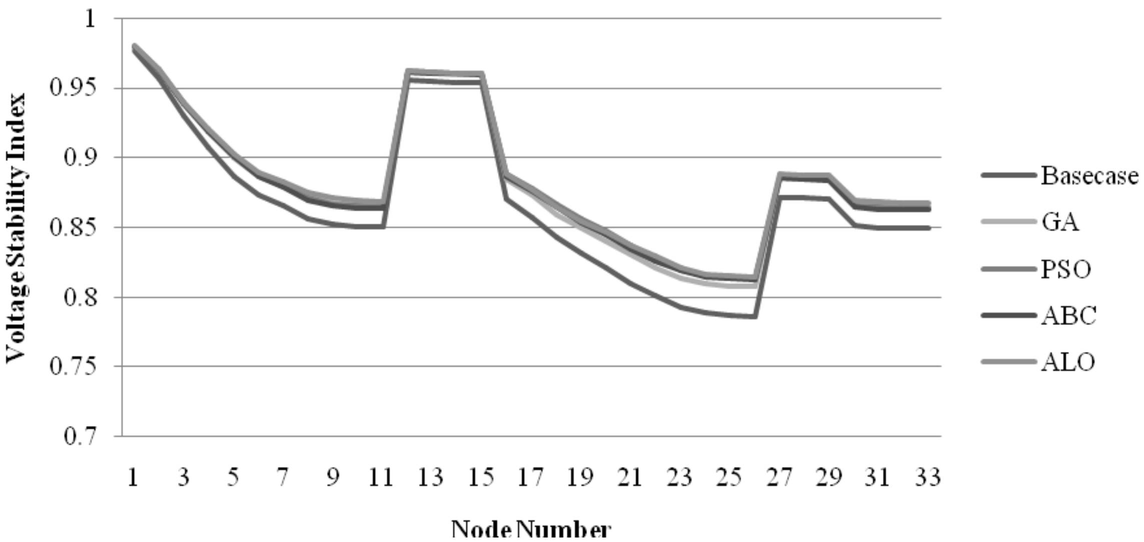

Fig. 4. Comparison of VSI curve for ALO with various method of 34-node in switched capacitor

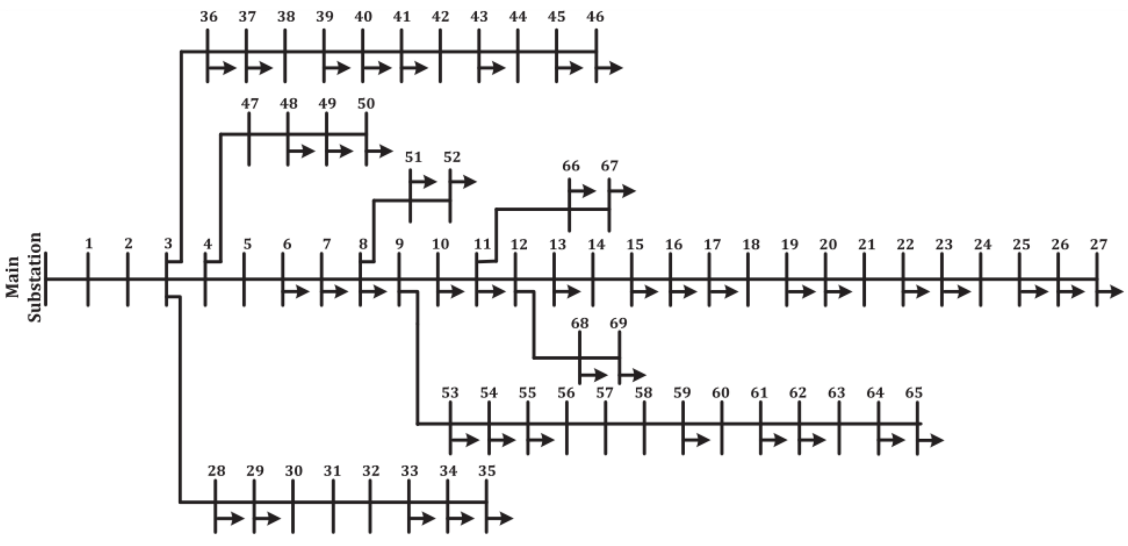

Fig. 5. Single line diagram of 69-node radial distribution system

The least value of VSI is 0.8146 and voltage is 0.95005 (p.u.) of this approach greatly improved when compared to different methods in the system. The proposed ALO algorithm based result of net saving/year is shown in table 1 and 2. From Table 2, the real power loss of test system is 160.95 KW which is greatly reduced when compare to ABC algorithm. The least value of VSI is 0.8146 and voltage is 0.95001 (p.u.) for fixed and switched capacitors condition in the ALO algorithm in table 2.

The value of net saving/year increases which altogether impacts the cost factor of capacitor. The expense of energy value is always higher than the remaining cost of capacitor. It is a conceivable way for Ant lions hunt to ant in the trap. The voltage constraint of the problem is strictly followed in proposed ALO algorithm which is proved that the minimum value of voltage is more prominent than or equivalent to 0.95 (p.u.). It is clear that the proposed ALO approach has better execution when compared to existing techniques.

Figure 4 demonstrates the graphical representation of VSI curve for proposed ALO approach compared with different strategies. Because of this, ALO is top most improvement when compared to remaining methods. It is apparent that the VSI for every node in the RDS were extremely poor in base case condition. From the results, stability indexes at the nodes for system were improved in the wake of introducing the capacitor.

69-node system

The system load request is 3.80 MW and 2.69 MVAR. In this system have one main principle feeder and seven laterals. Table 3 demonstrates the after-effects of real power loss, voltage stability index, voltage, optimal placement and value of the fixed and switched capacitors of the 69-node system acquired by using ALO.

The active power loss is 147.76 KW which is diminished to 34.32 % comparing with base case. The least value of VSI is 0.7445 and least voltage is 0.9289 p.u. switched capacitor condition of this approach and which is significantly improved when compared to base case. The presence of fixed and switched capacitor condition, the real power is decreased to 148.66 KW, minimum VSI is 0.7541 and voltage is 0.9319 p.u. The estimation of net saving/year is changes in condition depending upon the number of location placed in capacitors are recorded in table 3. When increasing the location of capacitor, the installation cost of capacitor is significantly expanded.

Table- III: The performance analysis of 69-node system with fixed and switched capacitor

Method	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size(KVAr)	Net saving/year
Base case	224.97	0.6833	0.9416	-	-	-
ALO (switched capacitor)	147.76	0.7445	0.9289	20 61	250 1150	$32341
ALO (fixed and Switched Capacitor)	**148.66**	**0.7541**	**0.9319**	**61 (fixed) 61 68**	**600 750 250**	**$30247**

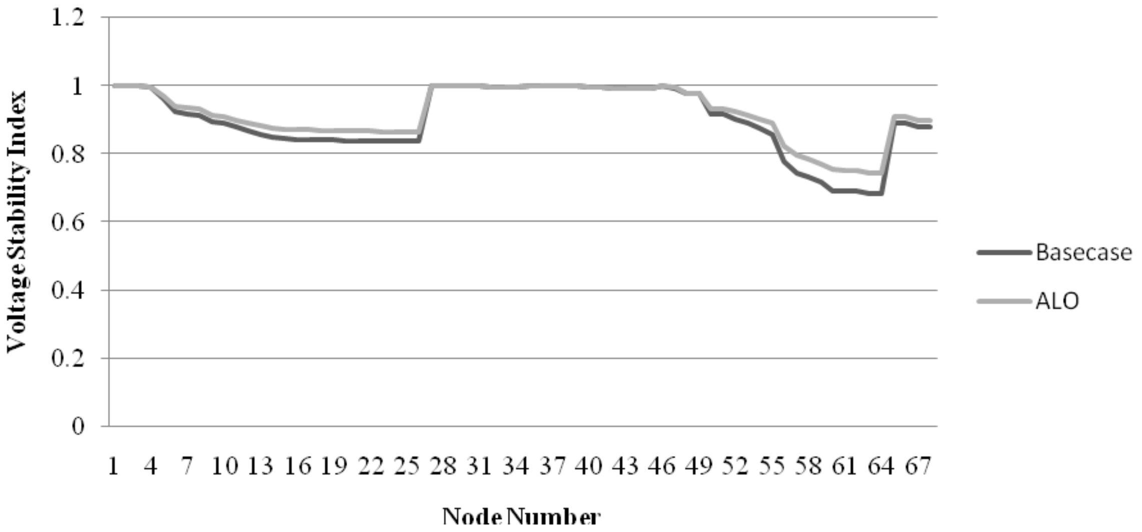

Fig. 6. Comparison of VSI curve for ALO with base case of 69-node in switched capacitor

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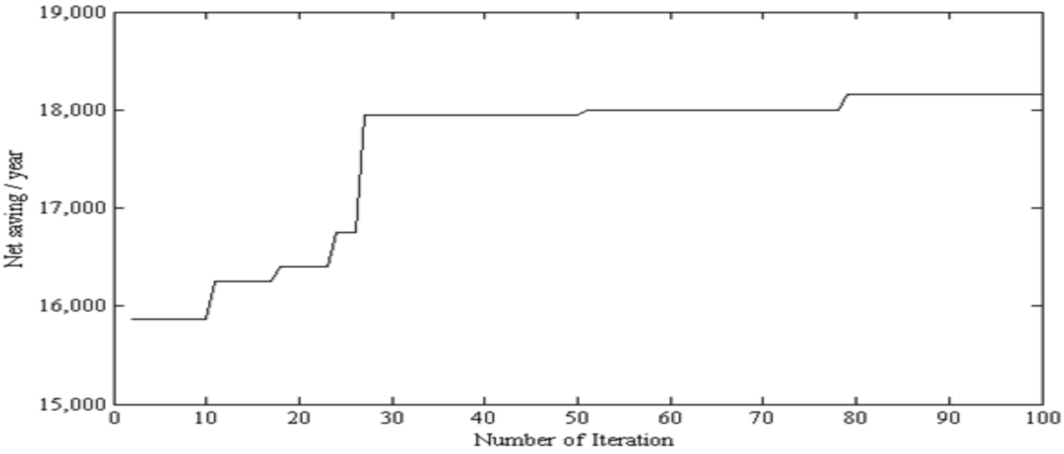

Fig. 7. Convergence characteristics of 34-node system with switched capacitor

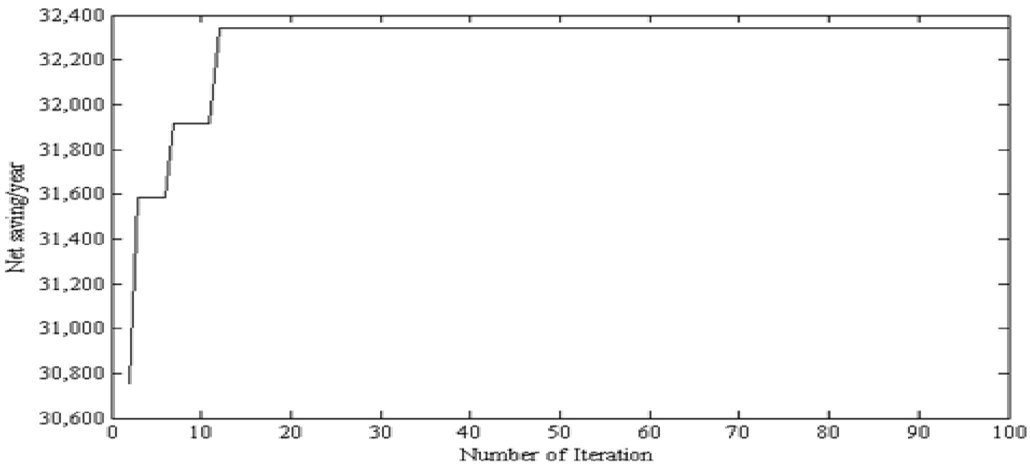

Fig. 8. Convergence characteristics of 69-node system with switched capacitor

The VSI curve of 69-node system is shown in figure 6. The VSI value of every nodes of the system is significantly improved when contrasted with base case and which is demonstrated in figure 6.

The convergence characteristics curves of the test systems are appeared in figure 7 and 8. It is the better convergence of the proposed ALO approach.

VII. CONCLUSION

The ALO has been recommended for the assessment of optimal allotment and measuring of fixed and switched capacitors in the test systems. It has been adequately executed in the test systems for voltage stability improvement and maximizes the cost of net saving/year. The ALO effectively choose the optimal place and sizing of switched and fixed capacitors. The capacitors are placed in the test systems which results are the effects of voltage profiles and power loss. The case investigation with 34-node and 69-node systems is considered to examine the exhibition of proposed algorithm. The implemented ALO method draws out the accompanying best after-effects of RDS, for example, Power loss

- Minimum voltage stability index and Minimum Voltage profile
- Capacitor placement Node and Sizing of the Capacitor
- Cost of net saving per year

The simulations results of proposed strategy are compared with earlier reported methods. The ALO have good convergence and increasingly resolute then the other existing techniques. From the comparison, the ALO approach is one the best optimization tool for solving engineering optimization issues

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AUTHORS PROFILE

N .Vijayalakshmi, received her B.E degree in Electrical And Electronics Engineering in 1996 from Annamalai University, India and M.E degree in Power Systems Engineering in 2008 in the same University. She worked as an Assistant Professor in Department of Electrical Engineering, Annamalai University from 2003 to 2016. Currently she is deputed and working as a Lecturer in Govt. Polytechnic college, Coimbatore.

K. Gayathri, (kasinathan Gayathri) was born on April 10, 1976.She completed her B.E. degree in Electrical and Electronics in 1999, M.E. degree in Power Systems in 2005 and also awarded her Ph.D in Electrical Engineering in September 2010 at Annamalai University. She is presently working as a Associate Professor at Annamalai University, India. She has 22 publications to her credit. Her research interests include power system operation and control, power system analysis, fault diagnosis and artificial intelligence techniques to power systems