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Optimal Capacitor Placement using Fruit Fly Optimization

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Abstract – Installation of capacitors in primary and secondary networks of distribution systems is one of the efficient methods for power loss reduction and voltage profile improvement. The loss of energy mainly incurred in the distribution network. The objective is to minimize the cost function along with power loss reduction and voltage profile improvement. Now a day this multi-objective problem creates a lot of concentration of the researcher. In this paper, a study based on two-stage procedure is presented. In the first stage, the optimum bus location is done by using a sensitivity index and voltage norm. In the second stage, Fruit Fly algorithm is used to optimize the size of the capacitor as well as bus location, a comparative study is made between Particle swarm optimization (PSO) and Fruit Fly optimization for solving the optimal capacitor problem. The Fruit Fly gives a better result in comparison with PSO for this optimization problem in terms of power loss and cost.

***Keywords*—** Backward sweep forward sweep, Radial distribution, Loss sensitivity Index, Voltage norm, Fruit Fly Optimization

I. INTRODUCTION

Electricity is modern society's most convenient and useful form of energy, without it the present social infrastructure would not at all feasible. The increasing per capita consumption of electricity throughout the world a growing standard of living of the people. Electrification in the early 20th century dramatically improved productivity and increased the well-being of the industrialized world. No longer has the luxury, now- necessity electricity powered the machinery, the computers, the health-care systems, and the entertainment of modern society. The optimum utilization by the society of this form of energy can be ensured by an effective distribution system. Many significant research works have been performed in the optimization of radial distribution network loss as well as reduction of cost and voltage profile improvement. Some of the prominent works have been discussed below.

In [1] a novel sensitivity based optimal location and sizing of the capacitor were presented. Prakash et al. [2] presented capacitor placement by using vector based Distribution Load Flow method (VDLF), sensitivity analysis and PSO. In [3] a sensitivity and Genetic Algorithm (GA) based optimal capacitor placement was presented. K.R. Devabalaji *et al.* [4] has proposed a method based on the use of integrated LSI and VSI for bus selection, and Bacterial Foraging is used to determine the size of the capacitor. In [5] Reddy and Veera presented a two-stage methodology based on the fuzzy approach and GA to find the optimal locations and sizing of capacitors, respectively. Attia A. El-Fergany *et al.* [6] was presented optimal capacitor allocation by using cuckoo search algorithm. In [7] a method based on Loss sensitivity factor and Flower Pollination Algorithm was presented. V.V.K. Reddy et al [8] presented index and genetic algorithm based optimal capacitor allocation. The potential formulation is done in section IV, where the formulation of the optimization problem is presented mathematically into a minimization problem with some acceptable range of parameters. Discussions about the optimization algorithms are done in section V. Results and location for capacitor placement is found by index, and size of the capacitor is by GA. Ahmed Elsheikh et al [9] presented loss sensitivity factor and PSO (Binary coded) based technique for capacitor placement.

In aforementioned papers, the selection of probable bus location is done by only one sensitivity index but in this paper, the probable bus location is performed by loss sensitivity index (LSI1 and LSI2) along with voltage norm. The process is further refined using the Fruit Fly optimization technique. The rest of the paper is organized as follows. In section II, the problem formulation is done, while block representation of the problem is presented in section III. The methodology used is presented in section IV and the optimization process is discussed in section V. In section VI, results and discussions are presented and finally, the paper is concluded in section VII.

II. PROBLEM FORMULATION

Optimal capacitor allocation is a multi-objective nonlinear problem. In this section design of objective function along with constraint is discussed. It is a discrete value problem because the capacitor is available in either step size of 50 or 150. The allocation problem is normally two dimensional along with the specified value. The objective function can be formulated as:

$$Min\ F = Kp * PlossT + Kcap * Q + Penalty \qquad (1)$$

where F is the cost in a \$/year, Kp is the annual cost of per unit loss of power 186 \$/kW-year .$K\ cap$ annual cost of installation of capacitor \$/ Kvar. Table 1 gives the cost of a specified size of the capacitor.

Table:1 Cost of capacitor size

Capacitor size	150	300	450	600	750	900	1050	1200
Annual cost($/kvar)	.500	.350	.253	.220	.220	.183	.228	.170
Capacitor size	1350	1500	1650	1800	1950	2100	2250	2400
Annual cost($/kvar)	.207	.201	.193	.187	.211	.176	.197	.170

Constraints are used in order to maintain the analyzed value of the problem within a specified zone. Violation of constraint results added penalty value to the objective function (cost function).

Mainly two constrain deal in this optimization problem:

- The voltage of each node within a specified range. $|Vimin\ / \leqslant / Vi\ / \leqslant / Vimax\ /$ where Vimin and Vimax are .9 p.u and 1.1 p.u
- Total reactive power compensates by capacitor always less than total reactive power demand. $QcTotal \leqslant QcL$, where $QcTotal$, total reactive power compensates by the capacitor and QcL is total reactive power of the system.

A. Load flow analysis (Backward sweep forward sweep Algorithm)

Step 1: Initialization

- The distribution system line and load data.
- The base power and base voltage.
- Calculate the base impedance.
- Calculate the per unit values of line and load data.
- Take the voltage for all buses at a voltage (1 p.u.).

Set convergence tolerance = 0.0001 and v = 0.

Step 2: Numbering of the radial distribution system

Numbering system contains lateral and sublateral. The lateral is the main root buses connected in series, sublateral are the branching buses connected to the bus of the main root. First numbering the main root buses and then numbering the sublateral. The branch of buses (sublateral) that is close to node 1 numbering first then gradually proceeds to the end.

Step 3: Nodal current calculation

Since load is constantly active and reactive power node. At iteration `r' current injected at node `i' is calculated as;

$$I_i^{\,r} = S_i / (V^{r-1}) \qquad (2)$$

Step 4: Backward Sweep

Effective complex power flow in each branch is calculated using backward sweep propagation

$$I^r_L = -I^r_j - \sum_{m}^{M} (S_m^* / V_j^{\,r}) \qquad (3)$$

$$S^r_L = (V^{\,r}_j + Z^r_L \times I^r_L) \times I^r_L \qquad (4)$$

S_m is the complex power at the sending end of branch $m, V^{\,r}_j$ is the voltage at bus j, S^r_L is the power flow in branch L and Z_L is the impedance of branch L.

Step 5: Forward Sweep

Nodal voltage is updated forward direction from the first section to those ends by using KVL. At any iteration, `r' branch section L connected sending end p and receiving end q. Then voltage at receiving end at any iteration is given by

$$V_q^{\,L} = V^{\,r}_p - Z_L \times I^r_L \qquad (5)$$

Step 6: Check the voltage mismatch

The voltage mismatch at any iteration `r' can be calculated as

$$\delta V = V^{\,r}_i - V_i^{\,r-1} \qquad (6)$$

$\delta V^{\,r}_i$ is greater than $\delta V\ max$.Then $V^{\,r}_i = \delta V_{max}$. δV_{max} is less than Є go to step 8 otherwise increment the iteration and go to step 3

Step 7: Checking the stopping condition When either maximum iteration reached or convergence criteria, the program is terminated.

Step 8: Power loss is calculated.

B: Power flow calculation

Reactive power flow through a branch between two specific nodes is given by the mathematical formula.

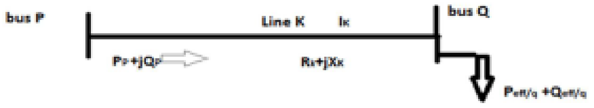

Fig. 1 Reactive power flow

$$P_p = P_{eff/q} + P_{Lossk} \quad (7)$$

$$Q_p = Q_{eff/q} + Q_{Lossk} \quad (8)$$

where P_p and Q_p, active and reactive power flow in branch k. $P_{eff\ /q}$ and $Q_{eff/q}$, effective active and reactive power node beyond node q . $P_{\ Lossk}$ and $Q_{\ Lossk}$ active and reactive power loss in the branch k.

$$P_{lossk} = I_k^2 \times R_k \quad (9)$$

$$Q_{Lossk} = I_k^2 \times X_k \quad (10)$$

$$I_k = ((P_{2eff/q} + Q_{2eff/q})/ \, / V_{\ q}^{\ \ 2} \, /) \quad (11)$$

C. Loss sensitivity

Loss sensitivity index *(LSI1)* can be calculated by the first derivative of $P_{\ lossk}$ with respect to V_q, *LSI2* derivative of P_{lossk} with respect to $Q_{2\ eff/q}$ [1]

$$LSI1 = (-2 \times R_k) \times ((P_{2eff/q} + Q_{2eff/q})/ V^3) \quad (12)$$

$$LSI2 = (2 \times R_k)\,(Q_{eff/q} / V_q^{\ 2}\ ) \quad (13)$$

LSI1 gives negative value and they have arranged the highest negative value to the lowest negative value. The buses with the highest negative value indexed at top of the *LSI1* table and lowest value indexed at the bottom. The buses that have the top rank of *LSI1* are candidate bus. *LSI2* give positive value and they are arranged high to low. The buses that have top of the table indicate candidate bus. The candidate buses are selected from combining 50% to 55% of both tables.

$$Norm = (V\,pu\ /.95) \quad (14)$$

The final list of candidate bus is again refined by using voltage norm. The buses that have Norm is less than 1.00 add to the list and those have Norm is greater than 1.00 discard from the list. This list gives the candidate bus for capacitor placement

III. BLOCK REPRESENTATION OF THE PROBLEM

Step by step approach to obtain the goal in the block diagram of the project is shown below.

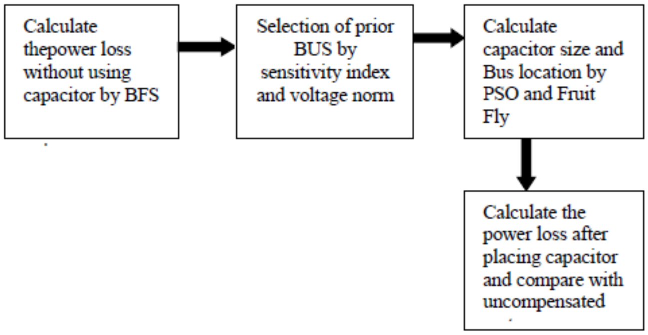

Fig. 2 Stepwise block representation to approach the problem

IV. METHODOLOGY USED

The IEEE33 bus system is a radial distribution network. The node 1 is a slack bus i.e. its voltage and angle are known. Its magnitude is 1p.u and angle is 0^0. The rest of the bus is PQ bus. Power flow solution is done by Backward Forward Sweep [1],[10]. The power loss without a compensated system is calculated. The next step is to find the domain of candidate buses.LSI $_1$ and LSI$_2$ is used to find the desired buses which are farther refine by using the norm of voltage. After selection of candidate buses, optimization algorithms like PSO [11] and Fruit fly are used to determine the capacitor size and its bus location, which reduce the power loss as well as cost and also improve voltage profile.

V. OPTIMIZATION ALGORITHMS

A: Fruit Fly optimization

The Fruit Fly optimization algorithm is introduced by Prof Pan, a scholar of Taiwan. The sensory perception of Fruit Fly is better than that of the other species. The Fruit fly uses a sense of smell for searching the food. The Fruit Fly can smell a food source, at a distance 40 km away. The Fruit Fly is a good optimization technique [12]

The Fruit Fly food searching characteristics are described below

- The population size and maximum iteration are fixed. The initial position of group X$_{axis}$ and Y $_{axis}$ randomly generate.

- Random direction and distance of searching food are done by using the sense of smell of each individual fruity.
  $$X_i = X_{axis} + Randomvalue \quad (15)$$
  $$Y_{\ i} = Y_{axis} + Randomvalue \quad (16)$$
- As the food location is unknown, the distance to the origin is estimated. The decision value of smell concentration S_i is calculated as the reciprocal of the distance.
  $$D_{isti} = (X_i^2 + Y_{\ i}^{\ 2})^{1/2} \quad (17)$$
  $$S_i = 1/D_{isti} \quad (18)$$
- The smell concentration value is substituted in smell concentration decision function.
  $$Smell_i = Function\ (S_i) \quad (19)$$
- Determine the Fruit Fly with maximum smell concentration among the Fruit Fly group.

  $$[Best\ smell,\ Bestindex] = Max\ (Smell) \quad (20)$$
- Store the best smell concentration value in *X*, *Y* coordinate, and Fruit Fly swarm moves towards the food.
  $$X_{axis} = X\ (best\ index) \quad (21)$$
  $$Y_{axis} = Y\ (best\ index) \quad (22)$$
- Repeat the step starting again, random position generates until the maximum iteration is reached. Store the best solution as compared with previous iterative smell concentration.

B: Flow Chart of Fruit Fly optimization

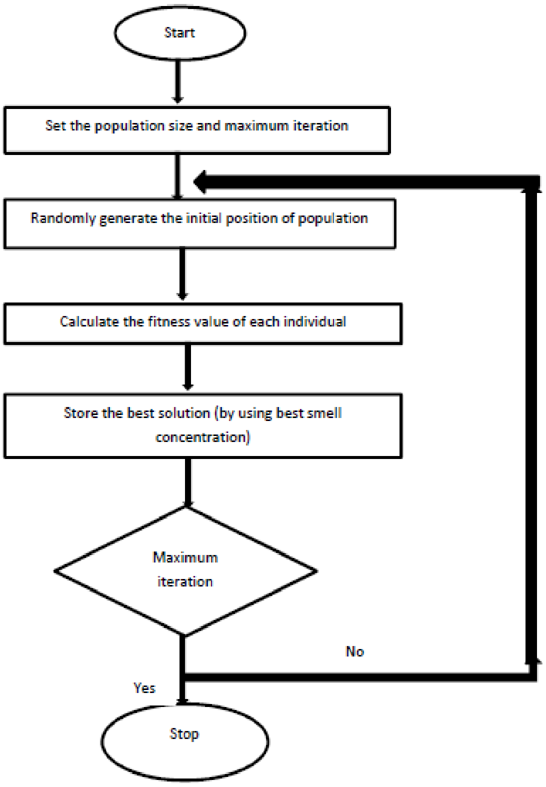

Fig.3 Flowchart of the optimization process [12]

VI. RESULTS AND DISCUSSIONS

A: Result from capacitor placement by PSO

Using PSO the power loss is reduced 281.587 kW to 193.74 kW after placing the first capacitor of size 1350 Kvar at bus location 30 and cost is reduced 52,375.182$/year to 36,315.811 $/year as shown in Fig. 4. This power loss gradually reduces to 183.74 kW after placing the second capacitor of size 450 of bus no 14. The total cost is reduced to 34,569.54$/year which is shown in Fig. 5. The placing of the third capacitor of size 300 placed bus 25 farther reduce to power loss 180.82 kW and the cost is 34131.9013 $/year as shown in Fig. 6. The voltage profile of the system is improved.

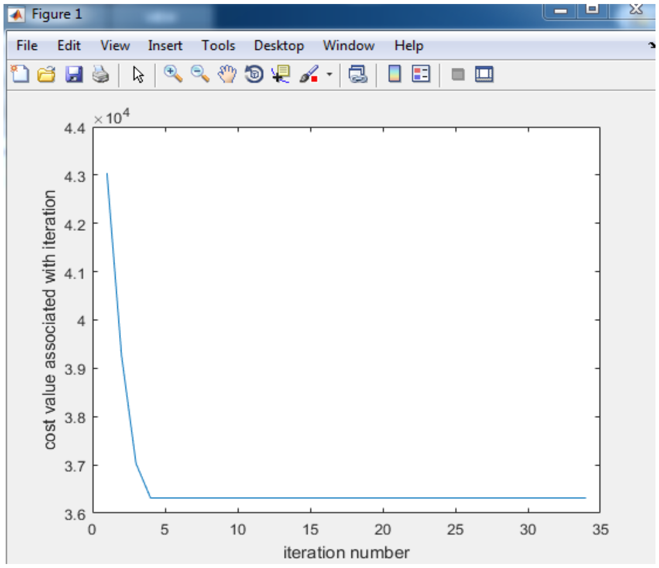

Fig. 4 Cost after first capacitor placement using PSO

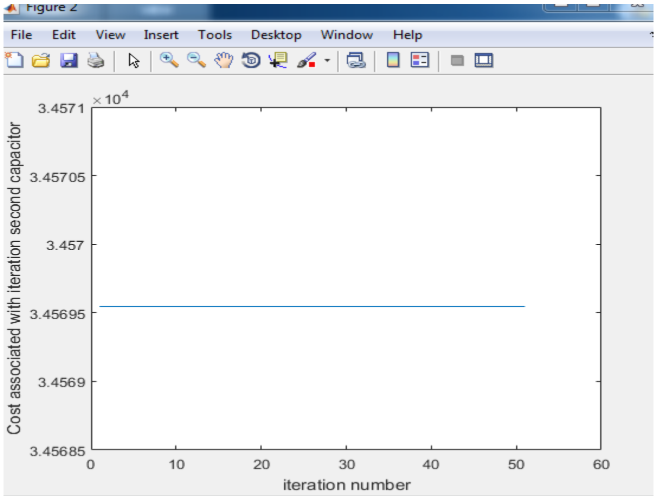

Fig.5 Cost after second capacitor placement

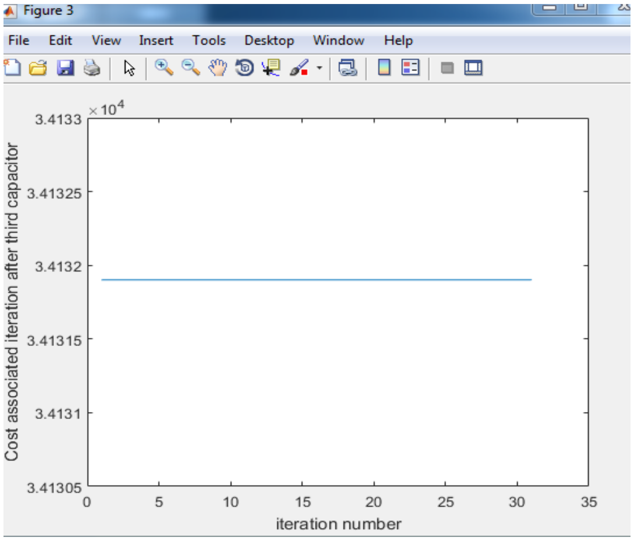

Fig. 6 Cost after third capacitor placement

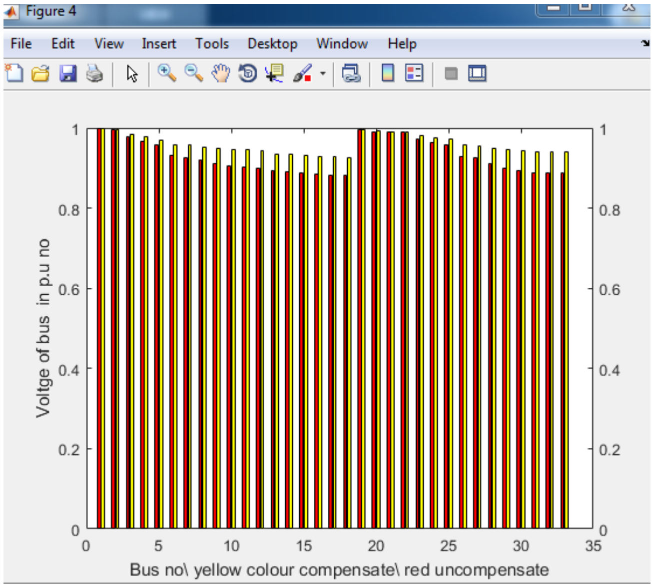

Fig. 7 Voltage profile improvement after capacitor Placement using PSO

In Fig. 7, a comparison is shown between uncompensated and compensated system as the yellow bar diagram represents the compensated system and red bar diagram represents the uncompensated system. It is revealed from Fig. 7 that the minimum value of voltage changes from .88202 p.u to .9346 p.u.

B: Result from Fruit Fly Optimization

Using Fruit Fly the power loss is reduced from 281.587 kW to 202.93 kW after placing the first capacitor of size 900 Kvar at bus location 30 and cost is 37,911.145 $/year as shown in Fig. 8. This power loss gradually reduces to 183.79 kW after placing the second capacitor of size 600 Kvar of bus no 11. The total cost is reduced to 34482.04 a $/year as shown in Fig. 9. The third capacitor of size 450 placed bus 25 farther reduce to power loss 179.52 kW. The cost is 33802.35 $/year, which can be noticed from Fig. 10. The placement of the fourth capacitor of size 150 kvar at the bus no 32 reduce the power loss 178.46 kW, and the cost is 33679.47 $/year as shown in Fig. 11. Minimum voltage is improved from 0.88202 p.u to 0.9264 p.u, which is shown in Fig. 12.

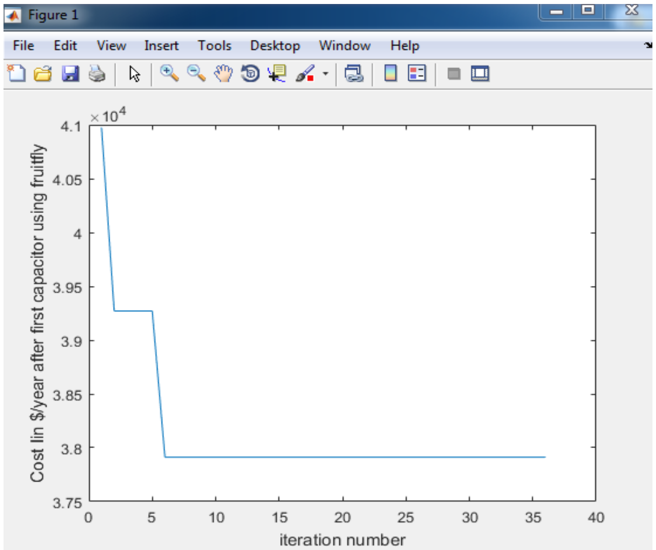

Fig.8 Cost after first capacitor placement using Fruit Fly

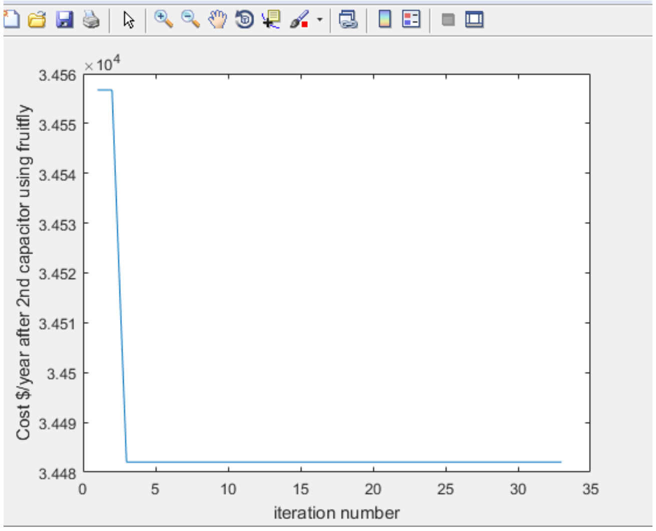

Fig. 9 Cost after placing the second capacitor using Fruit Fly

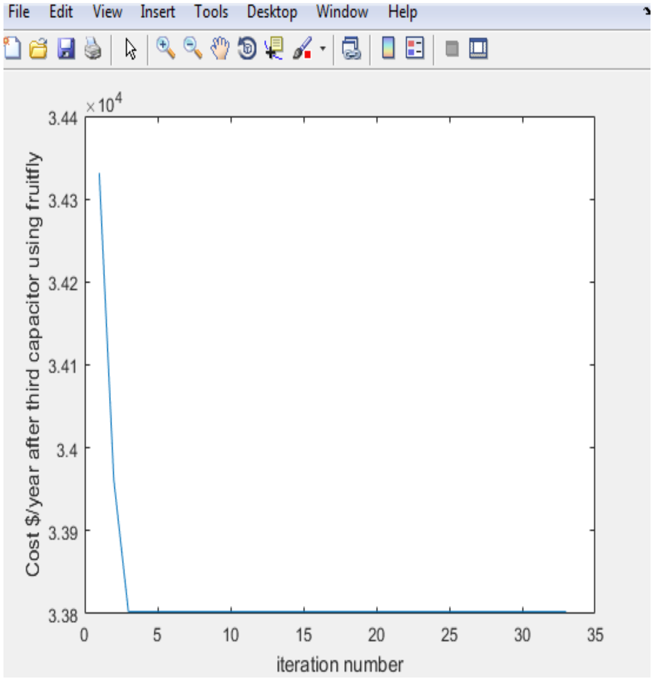

Fig.10 Cost after third capacitor Placement using Fruit Fly

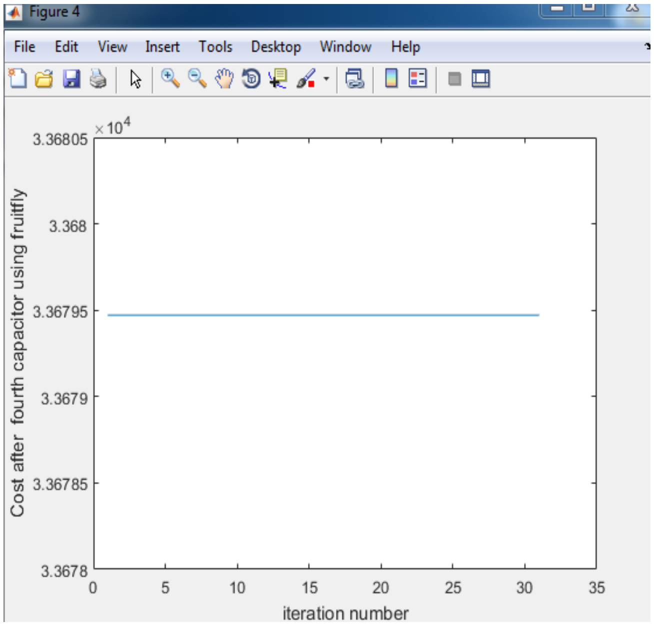

Fig.11 Cost after fourth capacitor Placement Fruit Fly

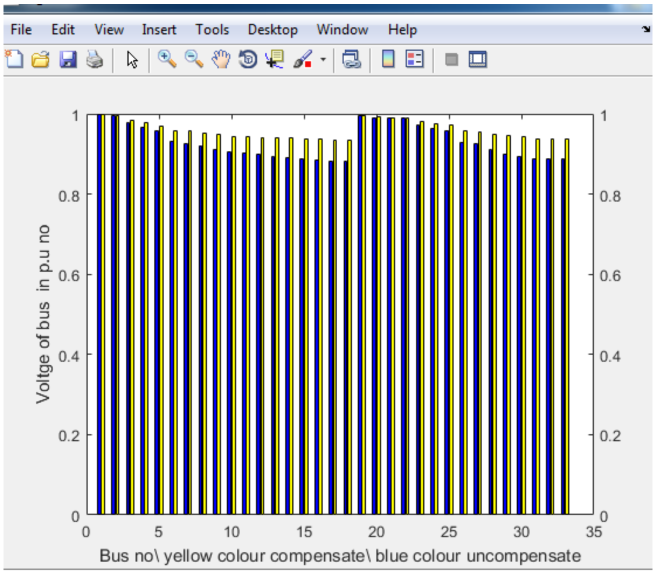

Fig.12 Voltage profile improvement after capacitors Placement using Fruit Fly

Table 2: Comparison Table

	Uncompensated	PSO	Fruit Fly
Cost in$/year	52,375.182	34,131.9013	33,679.47
Capacitor value	NA	1350,450,300	900,600,450,150
Bus location	NA	30,14,25	30,11,25,32
Minimum voltage in p.u	.88202	.9346	.9264
Power loss in Kw	281.82	180.82	178.46

From Table 2, it is revealed that fruit fly algorithm gives better results in terms of cost and power loss than that of the PSO algorithm. But, in terms of voltage in per unit PSO is more than the Fruit fly.

VII. CONCLUSION

In this paper, Fruit Fly has been successfully implemented along with two sensitivity index and voltage norm for optimal location and sizing of shunted capacitors in various distribution systems. The designed problem has been formulated as an optimization task with the computing cost of power losses, installation capacitor. The results have been compared with those obtained using other algorithms. The software used is Matlab 2016.

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