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A New Meta Heuristic Algorithm Based Shunt Capacitive Compensation for Power Loss Reduction on Radial Distribution System

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Abstract: **This paper describes an efficient and novel approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of enhancing the voltage profile and reduction of power loss. The solution method has got two parts: in first part the loss sensitivity factors are used to select the potential buses for the capacitor placement . These loss sensitivity factors are determined by single base case power flow study .and in second part a new algorithm that employs Flower pollination Algorithm (FPA) is used to estimate the optimal size of capacitors at the optimal buses determined in part one.For the first time flower pollination algorithm is applied for capacitor placement and sizing. The main advantage of the proposed method is that it does require a very few control parameters. The proposed method is tested on 10, 15, 69 and 85-bus radial distribution systems. The results obtained by the proposed method are compared with other methods. The proposed method has given quite promising results over the other methods in terms of the quality of solution.**

Index Terms: **Capacitor Placement, Radial Distribution Systems, Loss Sensitivity Factors and Flower pollination algorithm.**

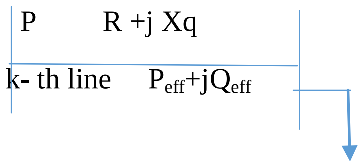
I. INTRODUCTION

Distribution Systems are growing large day by day in india and most of them are radial in nature being stretched too far ends give rise to increased system losses and poor voltage regulation. Studies have shown that as much as 13% of total power generated is wasted in the form of losses at the distribution level [5]. So the need for an efficient distribution system has therefore become an important issue. In this concern, Capacitor banks are installed on Radial Distribution system for Power Factor Correction, Reduction of Loss and Voltage profile enhancement.
As the optimal capacitor placement is a complicated combinatorial optimization problem, This problem has been investigated over decades. In the 1980's, more rigorous analysis were done as given by Grainger [3],[4] and Baran Wu [1],[6] proposed the Capacitor Placement as a mixed integer non-linear program.In the 90's combinatorial algorithms wereintroduced as a means of solving the Capacitor Placement Problem and neural network technique based papers [7] and[8] were investigated. Ng and Salama [9] have proposed a solutionapproach to the capacitor placementproblembased on fuzzy sets theory. Sundharajan and Pahwa [13] proposed the genetic algorithm approach to determine the optimal placement of capacitors based on the mechanism of natural selection.

Flower pollination algorithm is developed by Xin-She-Yang in 2012, inspired by the flower pollination process of flowering plants. Based on the successfully characteristics of biological systems, many nature-inspired algorithms have been developed over the last few decades .
From the biological evolution point of view , the objective of the flower pollination algorithm is the survival of fittest and the optimal reproduction of plants in terms of number as well as most fittest. In this paper, Capacitor Placement and Sizing of it is done by Loss Sensitivity Factors and Flower Pollination Algorithm (FPA) respectively.In this paper, simple and efficient Distribution Load Flow method [12] is used.

II.SENSITIVITYANALYSIS AND LOSS SENSITIVITY FACTORS

The potential buses for the placement of capacitors are determined using the loss sensitivity factors[14]. The determination of these potential buses or candidate nodes basically helps in reduction of the search space for the remaining optimization procedure.
Consider a radial distribution line connected between 'p' and 'q' buses.



R[k],X[k] –resistance and reactance of k-line respectively , p,q are sending ,receiving end nodes and I_k –current through k-th line

Active power loss in the k^{th}line is given by [I_k^2]*R[k],which can be expressed as,

$$P_{lineloss}=\frac{(P_{eff}^2[q]+Q_{eff}^2[q])*R[k]}{V[q]^2}$$

Similarly the reactive power loss in the kth line is given by

$$Q_{lineloss}=\frac{(P_{eff}^2[q]+Q_{eff}^2[q])*X[k]}{V[q]^2}$$

Where, Peff[q]=Total effective active powersupplied beyond the node ‘q’.

Qeff [q] = Total effective reactive powersupplied beyond the node ‘q’.

Now, both the Loss Sensitivity Factors can be obtained asshown below:

$$\frac{\partial p_{lineloss}}{\partial Q_{eff}}=\frac{(2*Q_{eff}^1[q])*R[k]}{V[q]^2}$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}}=\frac{(2*Q_{eff}^1[q])*X[k]}{V[q]^2}$$

Candidate Node Selection using Loss Sensitivity Factors:

The Loss Sensitivity Factors $\frac{\partial p_{lineloss}}{\partial Q_{eff}}$ are determinedfrom the base case power flows and the values are arranged in descending order for all the lines of the given system.A vector bus position ‘bus_pos [j]’ is used to store the respective ‘end’ buses of the lines arranged in descending order of the Values. The descending order of elements of “bus_pos[j]’ vector will decide the order in which the buses are to be choosen for compensation. At these buses of ‘bus_pos[j]’ vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given by (norm[j]= V[j]/0.95).Here 0.95 is taken because it is the minimum voltage that should maintained at any bus in radial distribution system . Now for the buses whose norm[j] value is less than 1.01 are considered as the candidate buses requiring the Capacitor Placement. These candidate buses are stored in ‘rank bus’ vector. The ‘norm[j]’decides whether the buses needs Q-Compensation or not. If the voltage at a bus in the sequence list is healthy (i.e.,norm[j]>1.01) such bus needs no compensation and that bus will not be listed in the ‘rank bus’ vector. The ‘rb_bus’vector (rank bus vector) gives the information regarding the possible candidate buses for capacitor placement. Now sizing of Capacitors at buses given in the ‘rb_ bus’ vector is done by using Flower pollination algorithm.

III. FLOWER POLLINATION ALGORITHM

Characteristics of Flower Pollination:

The main purpose of a flower is ultimately reproduction via pollination [2]. Flower pollination typically associated with the transfer of pollen,and such transfer is often linked with pollinators such as insects..etc.

Pollination can take in following forms:

Aboitic:This pollination does not require any pollinators.This pollination takes place only 10%.

Biotic:about 90% of flowering plants belong to this kind of pollination, pollen transferred by insects .

Self-pollination: It is fertilization of one flower ,from the pollen of the same flower.

Cross-pollination:means pollination can occur from pollen of a flower of a different plant.

Flower constancy: It maximizes transfer of flower pollen to the same or conspecific plants, and thus maximizing the reproduction of the same flower species.

Flower Pollination algorithm:

Now we can idealize above characteristics of pollination process, flower constancy and pollinator behavior as following rules[2].

1.Biotic and Cross-pollination considered as global pollination.

2. Abiotic and self –pollination considered as local pollination.

3.Flower constancy can be regarded as reproduction probability.
4..Local pollination and Global pollination is controlled by a switch probability 'p'∈[0,1].

From the above discussions in this algorithm two key steps are there. i.e.,global and local pollination.

In global pollination step, flower pollens are carried by pollinators and pollen can travel long distance because insects can often fly and move longer range.This ensures the pollination and reproduction of the most fittest , and thus we represent the most fittest as $\mathbf{g}_*$. The first rule plus flower constancy can be mathematically represented by

$$X[i]^{t+1}=X[i]^{t}+L(X[i]^{t}-\mathbf{g}_*)$$

where$X[i]^t$ is the pollen i or solution vector X[i] at iteration **t**, and $\mathbf{g}_*$ is current best. The parameter L is strength of pollination , which is essentially is a step size. That is , we draw L>0 from a Levy distribution.

L=step size drawn from levy's distribution [] *and it's value is given by*

$$L=\frac{\lambda\,\Gamma(\lambda)\,\sin(\pi\lambda/2)}{\pi S^{1+\lambda}}$$

Hereλ=1.5 andS_0= 0.1 $S>>S_0>0$

The local pollination (Rule 2) and flower constancy can be represented by

$$X[i]^{t+1}=X[i]^{t}+rand*(X[j]^{t}-X[k]^{t})$$

Where $X[j]^t$and$X[k]^t$are pollens from thedifferent flowers of the same plant species.

Pseudo code for flower pollination algorithm:

Objective :min or max f(x), x = (x1, x2, ..., xd)
Initialize a population of n flowers with random solutions. Find the best solution g∗ in the initial population

Define a switch probability p ∈[0, 1]
While(*t < max generation)*
For *i=1:n(for all flowers)*
If*rand < p*
Draw a step vector L from Levy distribution
Global pollination
$X[i]^{t+1}=X[i]^{t}+L*(X[i]^{t}-\mathbf{g}_*)$
Else
Randomly choose j and k solutions.
Local pollination
$X[i]^{t+1}=X[i]^{t}+\epsilon*(X[j]^{t}-X[k]^{t})$
End if loop
Evaluate new solutions

IV ALGORITHM FOR CAPACITOR PLACEMNT AND SIZING USING LOSS SENSITIVITY AND FLOWER POLLINATION ALGORITHM

Step1: Run the base case Distribution load flow and determine the active power loss.
Step2: Identify the Candidate buses for placement of capacitors using Loss Sensitivity Factors as foresaid.
Step3: Generate randomly 'n' number of flowers, where each flower is represented as X[i]={Qc 1,Qc2,….,Qcj} Where 'j' represents number of candidate buses or potential buses and find best solution g* in the initial population by running load flow for each X[i].
Step4: Define switching probability p ∈[0, 1]
Step5: Set the Iteration count, iter=1.
Step6: choose random number between [0,1]. If rand< p , go to step7 other wise go to step 8
Step7: draw a step vector L from Levys distribution and update flower solution by
$X[i]^{t+1}=X[i]^{t}+L(X[i]^{t}-\mathbf{g}_*)$
where $X[i]^t$ *= previous iteration value*
L=step size drawn from levy's distribution[] *and it's value is given by*

$$L=\frac{\lambda\,\Gamma(\lambda)\,\sin(\pi\lambda/2)}{\pi S^{1+\lambda}}$$

Hereλ=1.5 andS_0= 0.1 $S>>S_0>0$
g=current best flower (solution)*
Step8: Randomly choose j and k solutions from existing solutions and update solution by
$X[i]^{t+1}=X[i]^{t}+\epsilon*(X[j]^{t}-X[k]^{t})$

where $X[j]^t$ *= j th random solution(flower)*
$X[k]^t$ *=k th random solution(flower)*
∈= random number between [0,1]

Step9: Run the power flow with updated Xvalues. If power loss is less than previos iteration , update flower (Qc values) . if not keep old values as solutions

Step10: if all flowers not considered go to step 6. Other wise go to step 11.

Step11: Find current best solution **g***

Step12: if iter<max_iter goto step5 other wise terminate.

V. TEST RESULTS

The proposed FPA method for loss reduction by capacitorplacement and sizing is tested on 10bus [10], 15bus [12], 69bus [1] and 85bus [12] radial distribution systems.The constant used in the proposed algorithm is only '*p*' (switching probability). In this algorithm '*p*'=0.8 is taken. The above process is implemented and coded in MATLAB.The test results are shown below in various tables. The 10 bus test system with the proposed FPA method is compared with the paper [10] and with the paper [14] in which the total kvar placed is 4950 kvar with a loss reduction of 10.06% And total kvar placed is 3186 kvar with loss reduction of 11.17% respectively where as the proposed FPA method for the identified locations with the paper [14] the total kvar placed is only 3115 kvar that too with a loss reduction of 11.62% as shown in Table I.When the proposed FPA method is tested on 15 bus system and compared with the paper [11] and with the paper [14], in which the total kvar placed is 1193 kvar with a loss reduction of 47.24% And total kvar placed is 1192 kvar with loss reduction of almost same as before respectively where as the proposed FPA method for the identified locations with the paper [14] the total kvar placed is only 964 kvar with a loss reduction of 48.03% as shown in Table II. Similarly Table III shows the test results of the proposed FPA method on 69bus system with a loss reduction of 32.64% and compared with results given in paper[syd] and Table IV shows the test results of the 85bus radial distribution system with a loss reduction of 51.43% and compared with results given in paper[syd] in which loss reduction is of 48.26%.

TABLE I

COMPARISION OF PREVIOUS METHODS[10]&[14] AND PROPOSED FPA METHOD FOR OF 10BUS RADIAL DISTRIBUTION SYSTEM.
BASE CASE ACTIVE POWER LOSS=783.77 KW

Fuzzy method[10]		PSO metod[14]		Proposed FPA metod	
Bus No.	Size (kvar)	Bus No.	Size (kvar)	Bus No.	Size (kvar)
4	1050	6	1174	6	1200
5	1050	5	1182	5	1200
6	1950	9	264	9	495
10	900	10	566	10	220
Total kvar	4950	Total kvar	3186	Total kvar	3115
Active power loss(kW)	704.88	Active power loss(kW)	696.21	Active power loss(kW)	692.72

TABLE II

COMPARISION OF PREVIOUS METHODS[11]&[14] AND PROPOSED FPA METHOD FOR OF 15BUS RADIAL DISTRIBUTION SYSTEM.
BASE CASE ACTIVE POWER LOSS=61.79 KW

Method given in [11]		PSO method[14]		Proposed FPA method	
Bus No.	Size (kvar)	Bus No.	Size (kvar)	Bus No.	Size (kvar)
3	805	3	871	6	356
6	388	6	321	3	608
Total kvar	1193	Total kvar	1192	Total kvar	964
Active power loss(kW)	32.6	Active power loss(kW)	32.7	Active power loss(kW)	32.11

TABLE III
COMPARISION OF PREVIOUS METHOD [14] AND PROPOSED METHOD FOR OF 69 BUS RADIAL DISTRIBUTION SYSTEM.
BASE CASE ACTIVE POWER LOSS=225 KW

PSO method[14]		Proposed FPA method	
Bus No.	Size (kvar)	Bus No.	Size (kvar)
46	241	57	213
47	365	58	200
50	1015	61	1066
Total kvar	1621	Total kvar	1479
Active power loss(kW)	152.48	Active power loss(kW)	151.55

TABLE IV
COMPARISION OF PREVIOUS METHODS[15]&[14] AND PROPOSED METHOD FOR OF 85 BUS RADIAL DISTRIBUTION SYSTEM.
BASE CASE ACTIVE POWER LOSS=315.71 KW

PSO method[14]		Proposed FPA method	
Bus No.	Size (kvar)	Bus No.	Size (kvar)
8	796	8	775
58	453	7	200
7	314	58	615
27	901	27	759
Total kvar	2464	Total kvar	2349
Active power loss(kW)	163.32	Active power loss(kW)	153.34

VI. CONCLUSION

In this paper, an algorithm that employs Flower pollination algorithm, a meta heuristic optimization technique fordetermination of required level of shunt capacitive compensationto improve the voltage profile of the system and reduce activepower loss. This algorithm (FPA) for the first time presented in this paper for active power loss reduction in radial distribution systems. Loss Sensitivity Factors are used to determine theoptimum locations required for compensation. The mainadvantage of this proposed method is that it systematicallydecides the locations and size of capacitors to realize theoptimum sizable reduction in active power loss and significantimprovement in voltage profile. Test results on 10, 15, 69and 85 bus systems are presented and compared with other methods as loss reduction in proposed method is more.

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