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ABC Algorithm Based Voltage Stability Enhancement Strategy For Distribution System

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Abstract

The voltage stability of power distribution systems is a significant design consideration because of the potential to restrict the increase of load served by distribution companies. It is proposed to enhance the voltage profile in a radial distribution system by improving the voltage stability indices of weaker nodes. The voltage magnitude at each node obtained from the improved forward /backward sweep load flow method is used for the computation of voltage stability index (VSI) of each node. The weaker nodes operating near the stability limits are identified from the VSI values and compensated with reactive power support. The amount of reactive compensation/ optimal size of the capacitor are obtained using ABC optimization technique. The proposed methodology is applied to IEEE 69 node standard test system and the results show the rigidness of the method.

Keywords: Improved radial load flow,voltage stabilty enhancement,optimal capacitor placement,ABC algorithm

Introduction

The distribution system forms part of the final stage of the power system and assuages the delivery of electric power. It includes the essential components to comply the service requirements of the individual consumers. The power flow in a distribution network tends to be unidirectional where no little redundancy is found. The resistance in the distribution line accounts for significant proportion of voltage drop and line losses. Voltage instability in a power system may be manifested in many different ways depending on the system configuration and operating mode. These conditions can have a serious impact on the operation and integrity of the electric power system as well as cause damaging conditions to equipment. Voltage instability in power distribution systems could lead to voltage collapse and thus power blackouts. Voltage instability due to voltage collapse is therefore a dynamic phenomenon in distribution system operation that can restrict the reliability of supplying power to consumers. The problem of voltage instability has become a matter of great concern to the utilities in view of its prediction, prevention and necessary corrections to ensure stable operation of the system. It is required to know the strength of the buses to improve the stability of the system. Load flow analysis includes the determination of steady state voltages at all buses in the system along with real and reactive power flows in the power system.

The backward forward sweep based load flow takes into consideration, the changes in real and reactive power being consumed by loads [1]. An alternative method uses KVL and KCL to obtain voltage at each upstream bus in the backward sweep and linear proportional principle to update the voltage at each bus in forward sweep [2]. A simple approach for load flow analysis of a radial distribution network with embedded generation is used in [3][4]. Among these approaches, the improved forward /backward sweep based load flow method holds efficient by avoiding network identification schemes and requiring less computational time.

The weak nodes of the systems that are most sensitive to voltage collapse can be identified by these load flow equations. Capacitors are used in distribution systems to minimise line losses and improve the voltage profile. The amount of reactive compensation provided is very much related to the placement of capacitors in distribution feeders. The determination of the location, size, number and type of capacitors to be placed is of great significance, as it reduces power and energy losses, increases the available capacity of the feeders and improves the feeder voltage profile. Near-global optimization techniques have been suggested as a means for improving the quality of solution of the problem. These techniques include simulated annealing [5], the Tabu search [6], PSO [7] [8] and genetic algorithms (GA’s) [9] [10]. The bacterial foraging with a PSO algorithm used to determine the optimal placement of capacitors has been introduced in [11], and PGSA has been used for capacitor placement in [12]. More recently, an immune based optimization technique [13], the integration of DE and PS [14], and Big Bang-Big Crunch optimization [15] to obtain the optimum values of shunt capacitors in radial distribution networks have been utilized and employed. While these methods can easily handle discrete variables, they have several drawbacks. A major drawback of these methods is speed and the fact that they use certain control parameters that may be system dependent and difficult to determine.

Despite the fact that a number of intelligent optimization algorithm do exist, still the characteristics of the bees engage the process of search for the size of the capacitor more effectively than similar other approaches. The paper presents a novel discrete optimization approach to optimally solve the sizing problem of capacitor for the voltage stability enhancement in radial distribution networks using Artificial Bee Colony (ABC) algorithm. Optimal sizing and placement of shunt capacitors on distribution feeders can provide reduction in losses, increase the feeder capacity and improve the voltage profile.

Problem Formulation

Load Flow Solution

The forward backward sweep based method presents an efficient way for radial load flow solution. It uses a novel matrix transformation technique that makes the method more effective and fast. This matrix transformation technique exploits the radial feature of distribution networks. This method does not require any separate identification of up/down stream nodes and branches at any stage of load flow calculations.

Current Flow Based Forward/Backward Sweep Method

In this method, branch current flows are used to estimate voltage values. The branch current (I_k) in any kth branch and node voltage (V_{k+1}) at (k + 1)th node can be expressed by following equations (1) and (2) respectively.

$$I_k = \sum_{i \in NB_k} I_{Li} \tag{1}$$

$$V_{k+1} = V_k - I_k Z_k \tag{2}$$

where NB_k is the set of all downstream nodes beyond kth node and I_{Li} is the load current at any downstream ith node. I_{Li} can be calculated by following relation,

$$I_{Li} = (S_i / V_i)^* \tag{3}$$

Node voltage can be calculated in forward sweep. If we neglect the charging currents of all the branches then branch current through any kth branch is equal to the sum of the load currents of all the nodes beyond k th branch. Thus starting from last branch, the upstream branch current can be calculated by employing KCL at every junction point. Therefore the branch current calculation requires backward sweep. To perform backward sweep, nodes and branches beyond each node are needed to be stored for determining branch currents.

To determine the branch currents, first we form a matrix to store load currents of different nodes. In radial networks each node is fed by only one source node but a source node may feed more than one nodes. Therefore if we form a matrix to store value of load currents in which sending end node number of a branch represents the row number and receiving end node number of same branch represents columns number in the matrix then there is one non-zero element in each column. But there may be more than one nonzero element in each row. The algorithm for forming the load current matrix and transforming the matrix containing load currents to another matrix containing branch currents are given below.

Formation of Load Current Matrix

Determine the load currents at each node 'j' and save it to $I_{LM}(i,j)$ position in a matrix I_{LM}, where 'i' is the upstream node just previous to jth node. After storing all load current values the load current matrix I_{LM} of N*N order will be formed with some zero rows showing the extreme end nodes, which have no node ahead to feed. The column position of non zero values in any ith row shows the node numbers fed by ith node, while row number in any jth column shows feeding node of jth node.

Transformation To Branch Current Matrix

Based on backward sweep we need to start from terminal node. Therefore moving from bottom row to top row of the load current matrix I_{LM} find the sum of all elements of jth row and store it in to a temporary variable 'tv', which gives the total current injected by jth node in the branches ahead. If ith node is the source node of jth node then branch current in the branch (i, j), can be determined by adding the value stored in 'tv' to the nonzero element of jth column, which represents the magnitude of load current (I_{LM}(i, j)) at jth node. Therefore,

$$\mathrm{tv}_j = \sum_{k=1}^{n} I_{LM}(i, j) \tag{4}$$

$$\mathrm{I}'_{LM}(\mathrm{i, j}) = I_{LM}(i, j) + \mathrm{tv}_j \tag{5}$$

where j = n, n – 1, . . . ,2 and i = k. $I'_{LM}(i,j)$ is the new value of corresponding element of I_{LM} (i, j) during transformation.

The process is repeated for all rows except for first row, because first row represents the substation node, which has no source node behind it. Finally we get matrix I'_{LM} containing branch currents.

Voltage Stability Index

To identify the optimal location of shunt capacitors to be placed in order to enhance the voltage stability, the computation of voltage stability index of all nodes of the RDS is necessary. As the loads in the distribution systems are increasing, the system is operating at the verge of its stability limits. The enhancement of voltage profile can be achieved by placing shunt capacitors at the nodes which are operating close to the stability limit. By calculating the voltage stability index for all the nodes, the weak nodes which are prone to voltage instability can be identified. The voltage stability index of each node of the test system is calculated using equation (6)

$$VSI(r)=(V_S)^4 - 4(PX-QR)^2 - 4(V_S)^2(PR+QX) \tag{6}$$

where "r" indicates the succeeding node, Vs is the magnitude of the bus voltage of the preceding node "s". P and Q are the real and reactive power loads which are lumped at the succeeding node, R and X are the effective resistance and reactance of the bus section. The nodes with the lowest value of stability index are taken as the candidate nodes for the placement of shunt capacitors.

ABC Optimization Technique

In ABC optimization technique, the intelligent foraging food search behavioral pattern of honey bee approach is used to get a solution for constrained optimization problems. The ABC approach includes of three steps namely employee, onlookers and scout bee phase. In the employee bee phase, employee bees start exploring randomly within the search space to discover the food sources. The employee bees intimate the nectar amount (quality of solution) by dancing. The employee bees dancing duration indicates the quality of the food source that it has found. Based on the probabilistic selection, the onlooker bee exploits the food source positions in the neighborhood of the best solution provided by the employed bee phase. In scout bee phase, the solutions that are not having any improvement during search process are abandoned and a scout bee is allowed to explore randomly within the search space to get entirely new food source.

Pseudo code of ABC algorithm

Step 1: Initialize the population of solutions $X_{i,j}$

Step 2: Evaluate the population

Step3: cycle=1

Step 4: repeat

Step 5: Produce new solutions (food source positions) $V_{i,j}$ in the neighborhood of $X_{i,j}$ for the employed bees using the formula

$$V_{ij} = X_{i,j} + u(X_{i,j} - X_{k,j}) \tag{7}$$

(k is a solution in the neighborhood of i, u is a random number in the range [-1,1]) and evaluate them

Step 6: Apply the greedy selection process between xi and υi

Step 7: Calculate the probability values Pi for the solutions xi by means of their fitness values using the equation

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \tag{8}$$

In order to calculate the fitness values of solutions we employed the following equation

$$fit_i = \left\{ \frac{\frac{1}{1+f_i}}{1+abs(f_i)} \frac{if}{if} \frac{f_i \geq 0}{f_i \prec 0} \right\} \tag{9}$$

Normalize Pi values into [0,1]

Step 8: Produce the new solutions (new positions) υi for the onlookers from the solutions xi, selected depending on Pi, and evaluate them

Step 9: Apply the greedy selection process for the onlookers between xi and υi.

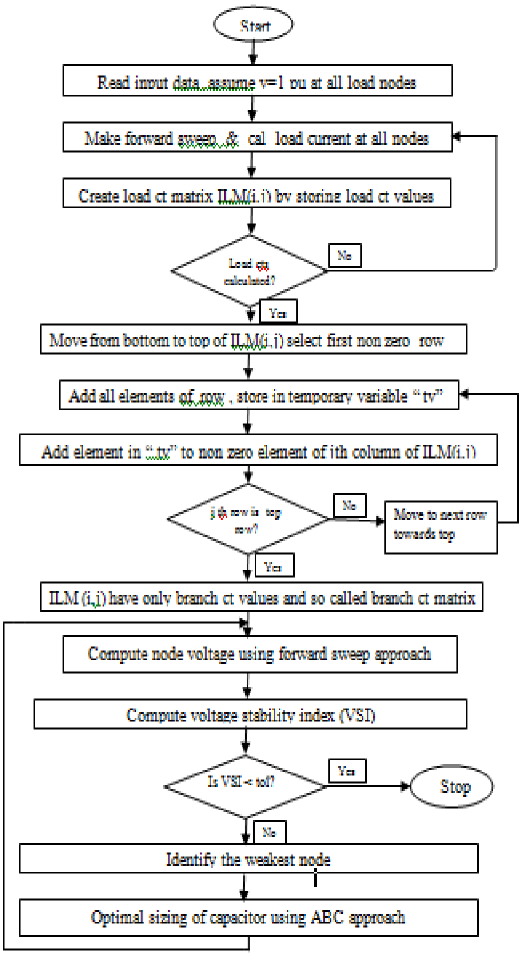

Figure 1: Flowchart of The Proposed Method

Results and Discussion

The data for the test system is taken from [16].The voltage magnitude at each bus obtained from forward backward sweep based load flow method is tabulated. The voltage stability index is calculated at all the nodes and added in the table 1.

Table 1: Voltage Magnitude and VSI At All Nodes

BUS NO	VOLTAGE (IN P.U)	VSI
1	1	0
2	0.99997	1.0001
3	0.99993	0.99992
4	0.99984	0.99988
5	0.99902	0.99879
6	0.99009	0.96934
7	0.9808	0.93396
8	0.97858	0.91899
9	0.97745	0.91379
10	0.97246	0.89422
11	0.97136	0.89022
12	0.9682	0.8786
13	0.96528	0.8679
14	0.9624	0.85752
15	0.95953	0.84744
16	0.9590	0.84577
17	0.95812	0.84263
18	0.95811	0.84269
19	0.95765	0.84107
20	0.95735	0.84001
21	0.95687	0.83833
22	0.95686	0.8383
23	0.95679	0.83805
24	0.95663	0.8375
25	0.95646	0.83691
26	0.9564	0.83666
27	0.95638	0.83659
28	0.99993	0.99974
29	0.99985	0.99983
30	0.99973	0.99894
31	0.99971	0.99885
32	0.99961	0.99842
33	0.99935	0.99741
34	0.99901	0.99606
35	0.99895	0.99578
36	0.99992	0.99976
37	0.99975	0.99996
38	0.99959	0.99888
39	0.99954	0.99832
40	0.99954	0.99817
41	0.99884	0.99764

42	0.99855	0.99516
43	0.99851	0.99419
44	0.9985	0.99406
45	0.99841	0.99398
46	0.9984	0.99364
47	0.99979	0.99945
48	0.99854	1.0013
49	0.9947	1.0007
50	0.99415	0.97989
51	0.97855	0.91695
52	0.97854	0.91688
53	0.97467	0.90491
54	0.97142	0.89331
55	0.96695	0.87807
56	0.96258	0.86225
57	0.94011	0.78415
58	0.92905	0.74599
59	0.92477	0.73154
60	0.91975	0.71519
61	0.91235	0.69878
62	0.91206	0.6922
63	0.91167	0.69109
64	0.90977	0.68652
65	0.9092	0.68376
66	0.9713	0.89005
67	0.9713	0.89005
68	0.96787	0.87757
69	0.96787	0.87754

From the calculated values of voltage stability index, the candidate nodes for the placement of shunt capacitors are identified and tabulated. The optimal size of the capacitor is obtained using ABC algorithm and is given in the table 2.

Table 2: Optimal Placement and Size of Capacitor

Optimal Capacitor Placement Bus No	Optimal Capacitor Size
65	671.81
64	218.37
63	841.24

Apart from voltage stability enhancement, the real and reactive power losses are minimized by the compensation provided by the shunt capacitors. The real and reactive power losses calculated as the square of the product of the real and reactive component of the current along with the feeder resistance and reactance respectively are compared for cases before and after compensation through entries given in table 3.

Table 3: Reduction of Losses

Before Compensation	**After Compensation**
Real Power loss (KW)	Real Power loss (KW)
224.8949	154.25
Reactive Power loss (KVAR)	Reactive Power loss (KVAR)
102.1155	71.69

The methodology forges a definite improvement both in the voltage magnitude and VSI in accordance with the additional reactive power support offered at those nodes determined from the results of the load flow method.The graphical variation of both voltage magnitude and VSI seen in figure brings out the effectiveness of the algorithm in enhancing the voltage stability of the distribution system.It further elucidates the significance of VAR devices in shaping the system to suit the utility requirement and fostering them to serve with greater efficiency.

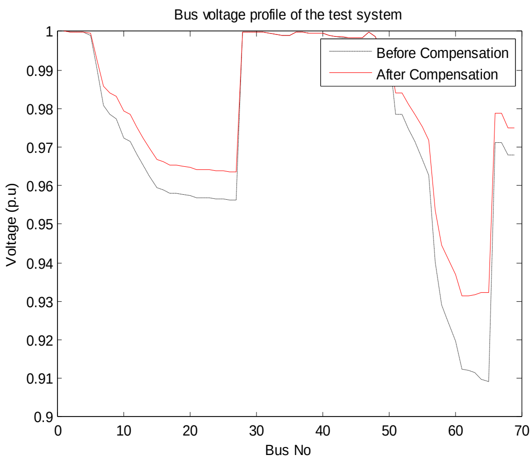

Figure 2: Bus Voltage Profile Before and After Compensation

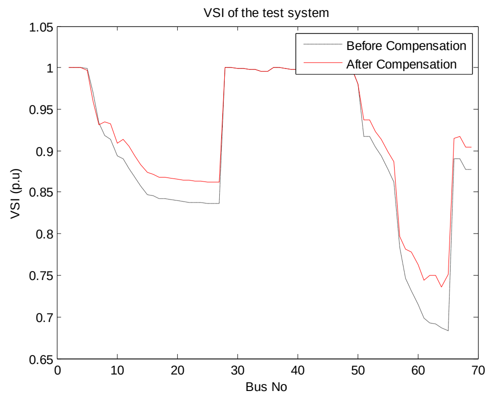

Figure 3: VSI of The Bus Before and After Compensation

The graph seen in Fig.4 highlights the merits of the convergence property associated with the ABC algorithm and establishes its supremacy over other meta-heuristic techniques in terms of the faster rate of convergence.

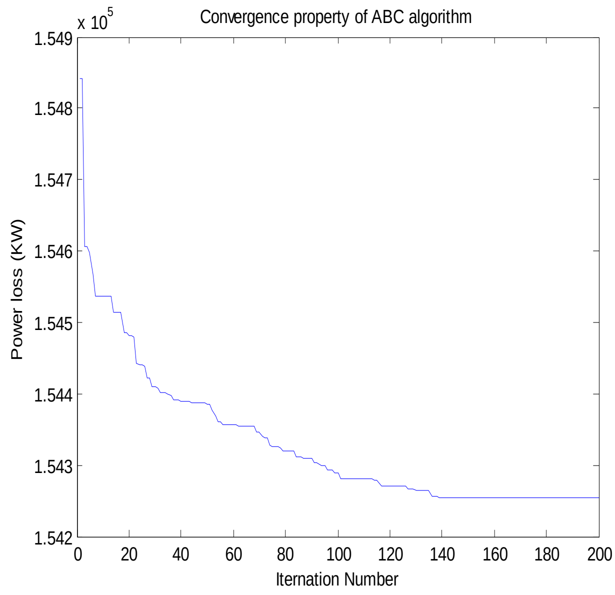

Figure 4: Convergence Property of ABC Algorithm

Conclusion

The matrix transformation technique in forward backward sweep method paves a way which cut downs the basic time required in load flow analysis. The nodes with lower voltage stability index values are treated to be the optimal nodes for the placement of shunt capacitors. The size of the shunt capacitors to be placed is optimized by using the ABC algorithm. The robustness of the proposed ABC approach has been tested on IEEE 69 bus radial distribution system. The effectiveness of the anticipated technique is realized in the enhancement of voltage profile of the system after shunt capacitor placement at the optimal nodes. The course of action of the algorithm is immediate and converges at a high speed which suits its relevance in rapid scheming of radial distribution systems.

References

[1] T Murali Krishna, Balasubrahamanyam, Dr. N. V. Ramana, Dr. S. Kamakshaiah, 2012, "Power Flow Algorithm for Radial Distribution System with Voltage Sensitive Loads", IEEE transactions on power systems.

[2] G. W. Chang, S.Y.Chu,H.L.Wang, 2007, "An improved backward/forward sweep load flow algorithm for radial distribution systems", IEEE transactions on power systems.

[3] W. H. Kersting and D. L. Mendive, 1976,"An application of ladder network theory to the solution of three phase radial power flow problems," in Proc. IEEE PES Winter Meeting.

[4] T.H. Chen, M.S. Chen, T. Inoue, P. Kotas, and E. A. Chebli, 1991,"Three-phase cogenerator and transformer models for distribution system analysis," IEEE Trans. Power Delivery.

[5] Chiang HD, Wang JC, Cockings O, Shin HD,1990, "Optimal capacitor placements in distribution systems: part 1: a new formulation and the overall problem", IEEE Trans Power Deliv.

[6] Gallego RA, Monticelli AJ, Romero R,2001, "Optimal capacitor placement in radial distribution networks using tabu search", IEEE Trans Power Syst .

[7] Prakash K, Sydulu M,2007, " Particle swarm optimization based capacitor placement on radial distribution systems", IEEE PES general meeting, Tampa, FL.

[8] Singh SP, Rao AR,2012, " Optimal allocation of capacitors in distribution systems using particle swarm optimization", Int J Electr Power Energy Syst.

[9] Swarup KS, June 16–18, 2005, " Genetic algorithm for optimal capacitor allocation in radial distribution systems", In: Proc the 6th WSEAS Int. Conf Evolut Comput, Lisbon, Portugal.

[10] Hsiao YT, Chen CH, Chien CC ,2004 , "Optimal capacitor placement in distribution systems using a combination fuzzy-GA method", Int J Electr Power Energy Syst.

[11] Tabatabaei SM, Vahidi B.,2011, " Bacterial foraging solution based fuzzy logic decision for optimal capacitor allocation in radial distribution system", Electr Power Syst Res.

[12] Rao RS, Narasimham SVL, Ramalingaraju M.,2011, " Optimal capacitor placement in a radial distribution system using plant growth simulation algorithm", Int J Electr Power Energy Syst.

[13] Huang S.,2000, “ An immune-based optimization method to capacitor placement in a radial distribution system”,IEEE Trans Power Deliv.

[14] Attia El-Fergany,2013, “ Optimal capacitor allocations using evolutionary algorithms”, IET Gener Transm Distrib.

[15] Sedighizadeh M, Arzaghi-haris D., 2011,“ Optimal allocation and sizing of capacitors to minimize the distribution line loss and to improve the voltage profile using big bang-big crunch optimization”, Int Rev Electr Eng (IREE) .

[16] Ghosh S, Das D., 1999, “Method for load-flow solution of radial distribution networks”, IEE Proc Gener Transm Distrib;146(6):641–8.