ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

Optimal Capacitor Placement in 69-Bus RDS Using Shuffled Frog Leaping Algorithm

Shangavi S M[1], Ajin S[2],Kirthana K[3]

PG Student [PSE], Dept. of EEE, Anna University Regional Campus, Coimbatore, Tamilnadu, India[1]

PG Student [PSE], Dept. of EEE, Anna University Regional Campus, Coimbatore, Tamilnadu, India[2]

PG Student [PSE], Dept. of EEE, Anna University Regional Campus, Coimbatore, Tamilnadu, India[3]

ABSTRACT: This paper presents a method for the Capacitor Placement in Distribution Systems with theobjective of improving the voltage profile and reduction in power losses by applying shuffled frog leaping algorithm(SFLA).The solution methodology consist of two parts: in part I, the loss sensitivity factors are used to select the candidate locations for the placement of capacitor and un part II, SFLA is used to estimate the optimal size of capacitors at the optimal buses determined from the part I. The other advantage of the algorithm is the global search ability which is implemented by introducing neighborhood source production mechanism which is similar to mutation process. To demonstrate this, computer simulations are carried out on a 69-bus system and compared the results with the other approaches. The proposed method has outperformed the other methods in terms of the quality of solution and computational efficiency.

KEYWORDS: Capacitor placement, Sensitivity analysis, SFLA,

I. INTRODUCTION

Energy is always transferred from source to distribution via transmission and consuming active and reactive power losses. By Proper reactive power management, the losses due to the reactive power losses can be controlled. In order to avoid such reactive power loss, local reactive power compensation can be made by placing appropriate shunt capacitor. This is the most powerful method employed for this problem.

Shunt capacitors are of great use in enhancing the performance of distribution system and it may be unbalanced due to several reasons. This includes single and three phase loads, phases of transmission lines are unequally loaded and the overhead lines in distribution systems are not transposed.

Due to the extensive use of harmonic producing equipment, harmonics are propagated throughout the distribution systems. By excessive losses and potential malfunctioning of electrical equipment, harmonics may become undesirable and cause over heating in the equipment. This inclusion of shunt capacitor without the consideration of harmonics may leads to an increase in harmonic distortion levels.

Benefits of capacitor placement are minimizing active and reactive power losses, improving power factor, maintaining appropriate voltage profile and releasing capacity of feeders and transformers. If the capacitors are not selected with appropriate size and not placed in appropriate place then system may become vulnerable. It behaves in abnormal way and voltage may increase beyond limits, unacceptable power factor and series and parallel resonance issues.

Several methods was proposed and developed for the optimal capacitor placement and sizing by using various method such as dynamic programming method [1-2], a nonlinear programming based method [3], fuzzy based approach [4] in radial distribution networks in the presence of voltage and current harmonics.

However, most of the analytical, numerical Programming or heuristic based methods are unable to work well. In recent years, AI-based methods such as genetic algorithm (GA) [5-7] have been applied to the capacitor placement problem with promising results. Moreover, due to premature convergence of GA, its performance degrades and its search capability reduces.

Another Optimization technique used to solve the Optimal Capacitor Placement and Sizing is Particle Swarm Optimization (PSO) [8-9]. In PSO, there are only a few parameters to adjust, which make PSO more attractive. Hence,

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the shuffle frog leaping algorithm (SFLA) [10-13] is based on the combining concept of the shuffled complex evolution (SCE) and PSO .SFL algorithm similar to the SCE uses from portioning and shuffling members of population and to improve member of subsets has been used from a process similar to the PSO algorithm.

II. PROBLEM FORMULATION

The objective of the capacitor placement is to minimize the cost of the system by reducing the real power losses subjected to certain constraints and load pattern. Here, in this paper, for simplicity, the operation and maintenance cost of the capacitor is not taken in to consideration. The three- phase system is considered as balanced and loads are assumed as time invariant. The Objective function can be described as,

$$\min f = \min(\cos t) \text{ or } \min f = \min(P_{loss}) \qquad (1)$$

where *cost* is the objective function which includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within limits and is expressed as,

$$V_{\min} \le V_i \le V_{\max} \qquad (2)$$

where V_i is the voltage magnitude of bus *i*. The power flows are computed by the following equations derived from the single line diagram show in fig.1

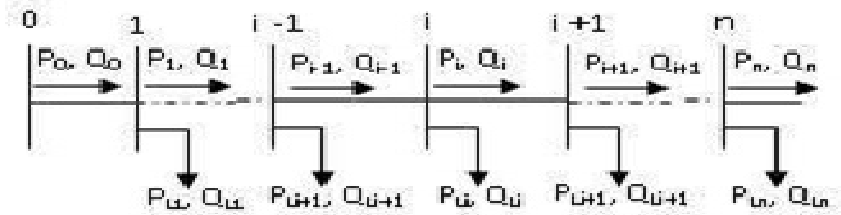

Fig.1. Single line diagram of main feeder

Real and reactive power equations,

$$P_{i+1} = P_i + P_{Li+1} - R_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (3)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (4)$$

$$\left|V_i^2\right| = |V_i|^2 - 2\left(R_{ij+1}P_i + X_{ij+1}Q_i\right) + \left(R_{ij+1}^2 + X_{ij+1}^2\right)\frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (5)$$

Where P_i and Q_i are the real and reactive power flowing out of bus *i*, PL_i and QL_i are the real and reactive power loads at bus *i*. The resistance and reactance of the line section between buses *i* and *i+1* are denoted by $R_{i,i+1}$ and $X_{i,i+1}$ respectively. The Power loss of the line section connecting buses *I* and *i+1* may be computed as,

$$P_{LOSS(i,i+1)} = R_{j+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (6)$$

The total power loss of the feeder, PT, Loss, may then be determined by Summing up the losses of all line sections of the feeder which is given as,

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$$P_{F,LOSS} = \sum_{i=0}^{N-1} P_{LOSS(i,i+1)} \quad (7)$$

Consider the practical capacitors, there exists a finite number of standard sizes which are integer multiples if smallest size Q_{0c}.Besides, the cost per kVAr varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_{\max}^{\ c} = LQ_0^{\ c} \quad (8)$$

whereL is an integer. Therefore, for each installation location, there are L capacitors sizes $Q_0, 2Q_{0,....} LQ_0^{\ L}$ available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and the change in power loss is written as,

$$COST = K_P P_{T,Loss} \sum_{i}^{c} \left(K_{Cf} + K_i^{\ c} Q_i^{\ c} \right) \quad (9)$$

where n is the number of candidate locations for capacitor placement, K_P is the equivalent annual cost per unit of power loss in *$/ (kW-year).* K_{Cf} is the fixed cost for the capacitor placement. The constant $K_c^{\ i}$ is the annual capacitor installation cost and *i=1,2,…n* are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_c^{\ i} \le \sum_{i=1}^{n} Q_{Li} \quad (10)$$

Where $Q_c^{\ i}$ and Q_{Li} are the reactive power compensated at bus *I* and the reactive load power at bus *I*, respectively.

III. SENSITIVITY ANALYSIS AND SENSITIVITY FACTORS

The candidate nodes for the placement of capacitors are determined by using loss sensitivity factors. The estimation of these candidate nodes helps in the reduction of the search space for the optimization process.

Consider the distribution line with an impedance $R + jX$ and a load of $P_{eff} + jQ_{eff}$ connected between p and q buses as shown in fig.2. Active power loss in the k_{th}line is given by, $I_k^{\ 2} * R[k]$ which can be expressed as,

$$P_{lineloss}[q] = \frac{\left(P_{eff}^{\ 2}[q] + Q_{eff}^{\ 2}[q]\right) R[k]}{(V[q])^2} \quad (11)$$

Similarly, reactive power loss in k_{th} line is given as,

$$Q_{lineloss}[q] = \frac{\left(P_{eff}^{\ 2}[q] + Q_{eff}^{\ 2}[q]\right) X[k]}{(V[q])^2} \quad (12)$$

Where $P_{eff}[q]$ and $Q_{eff}[q]$ is the total active and reactive power supplied beyond the node'q'.

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{\left(2 * Q_{eff}[q] * R[k]\right)}{(V[q])^2} \quad (13)$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = \frac{\left(2 * Q_{eff}[q] * Q[k]\right)}{(V[q])^2} \quad (14)$$

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CANDIDATE NODE SELECTION

The loss sensitivity factors ($\partial P_{lineloss} / \partial Q_{eff}$) are calculated from the base load flows and the values are arranged in descending order for all lines in given system. A vector bus position "$bpo[i]$" is used to store the respective end bus of the lines arranged in descending order of the values ($\partial P_{lineloss} / \partial Q_{eff}$). The descending order of elements of "$bpo[i]$" vector will decide the sequence in which the buses are to be considered for compensation. This sequence is governed by ($\partial P_{lineloss} / \partial Q_{eff}$) and hence the proposed loss sensitivity factors become powerful. At these buses of '$bpo[i]$' vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given by $(nor[i] = V[i]/0.95)$. Now for the buses whose $nor[i]$ value is less than 1.01 are considered as the candidate buses requiring the placement of capacitor.

These candidate buses are stored in "rank bus" vector. It is worth note that the "loss sensitivity factors" decide the sequence in which the buses are to be considered for compensation placement and the "$nor[i]$" decides whether the bus needs Q-compensation or not. If the voltage in the bus sequence list is healthy (i.e. $nor[i]$>1.01), then the bus don't need compensation that bus will not be listed in the "rank bus" vector. This offers the info about the possible potential or candidate buses for capacitor placement.

IV.SHUFFLED FROG LEAPING ALGORITHM

The shuffled frog-leaping algorithm (SFLA) is an algorithm base on memetic meta-heuristic.it was brought forward and developed by Eusuff and Lansey in 2003. The shuffled frog-leaping root in the frog groups behavior of looking food. This algorithm uses the mode of memetic evolvement among frog subgroups in local exploration. The algorithm uses the shuffled strategy and allows the message changing in local exploration.

This algorithm combine the advantages of memetic evolvement algorithm and particle swarm optimization (PSO) The algorithm change message not only in the local exploration but also in the global exploration.so the local and the global are combined well in the SFLA. The local search makes memetic to transfer among the individuals and the shuffled strategy make memetic to transfer among the global. As genetic algorithm (GA) and PSO, SFLA is an optimization based on colony. The SFLA has good ability for the global exploration and it is easy to realize. The SFLA can resolve many non-linear, non-differentiable, multimode questions.

V RESULTS AND DISCUSSION

To illustratethe performance of the proposed SFLA method, it was tested on a 69-bus RDS and the results have been obtained to evaluate its effectiveness. It was programmed in MATLAB environment and run on a Pentium IV, 3-GHz personal computer with 0.99 GB RAM. The results obtained are explained as follows.Theproposedmethodwas testedon69-bus radial distributionsystem andresultshave been obtained toevaluateitseffectiveness. The algorithm ofthismethodwas programmedinMATLAB environmentand run onaPentium IV,3-GHzpersonal computerwith 0.99GBRAM.Theresults obtainedin thesemethodsareexplainedin thefollowingsections

69-BUS TEST SYSTEM

The single line diagram for the 69-bus system is shown in figure.

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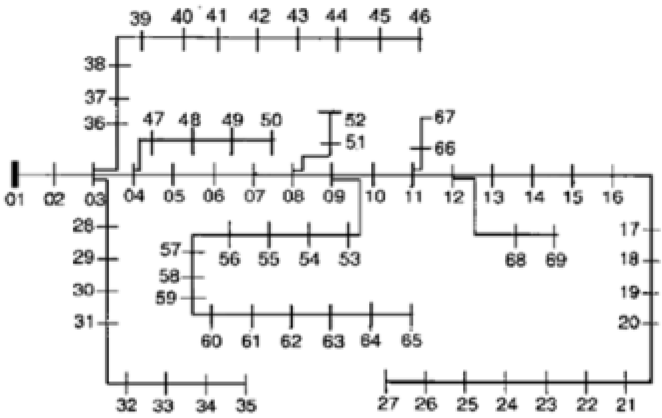

Fig.2. IEEE 69 Bus Radial Distribution system

The base values are taken as 12.66kV and 100MVA. The sensitivity analysis method is used to select the candidate node for the installation of capacitor and the buses are ordered according to their values as (19, 22, 20, 21, 23, 24, 25, 26, and 27). Here the capacitor values are taken as a continuous variable. The capacitor allowable range is 100kVAr to 1000kVAr with step of 2kVAr. Top three nodes are selected as candidate locations (nodes 19, 22 and 20) to reduce the search space.

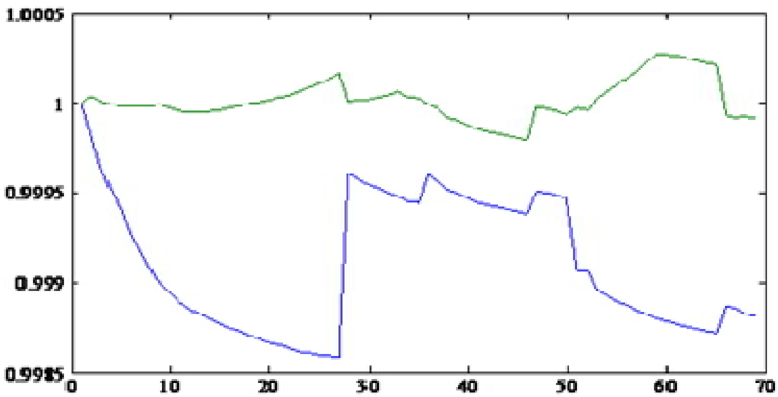

Fig.3. Voltage profile of 69 Bus RDS system before and after capacitor installation.

The fig.3 shows the improvement in the voltage profile of the system after capacitor installation. The amount to be injected in the selected nodes is optimized by SFLA. The amount of kVAr injected for the nodes is 900, 986 and 150 kVArrespectively. The power loss before and after capacitor placement are 221.67 and 168.8 kW respectively. The minimum and maximum voltages before capacitor placement are 0.9417(at bus 27) and 0.9941(at bus 2) in p.u which are improved to 0.9504 and 0.995 in p.u after capacitor placement respectively. The time needed by the CPU by proposed method is 3.07 sec. From the results obtain it can be said the proper installation of the capacitor improve the voltage profile of the system which in turn reduces the losses and minimizes the total cost of the system. The total cost reduces by 0.22% with capacitor in the bus from the buses without capacitor.

The convergence characteristics of SFLA algorithm is given in the fig .4. From the figure it can be said as the number of iterations increase the cost decrease and becomes steady around 30 iterations. In this total number of iterations carried out is 50.

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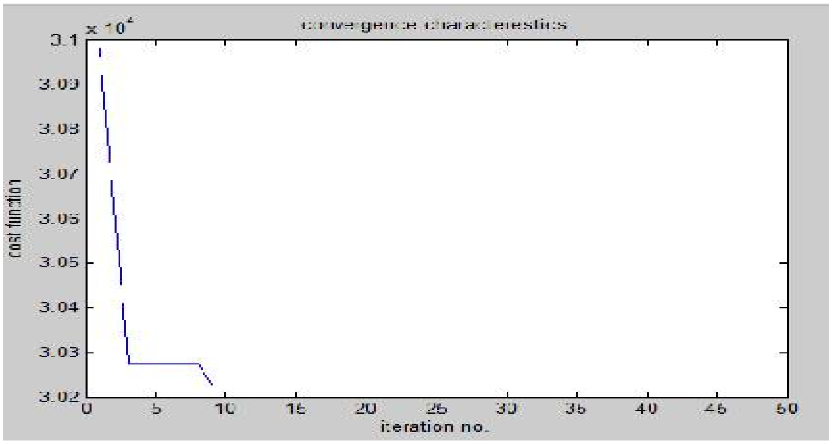

Fig.4. Convergence Characteristics

The optimal capacitor location and size are calculated for the selected bus and it is given in below table.The table gives the capacitor value that can be placed in the bus and the position in the selected bus. The buses selected are 3, 5, 7.

Bus Number	3	5	7
Place	2,12,16	2,6,7,13,15	2,4,9,10,14,18,20
Presumable capacity range[MVAr]	0.025	0.025	0.05
	0.05	0.05	0.1
	0.1	0.1	0.2
	0.2	0.2	0.4
	0.25	0.25	0.5
	0.4	0.4	0.8
	0.5	0.5	1.0
LRI[%]	0.9296	0.7627	0.9754

Table 1: Results summary of 69 bus RDS system

Capacitors are installed in these buses to improve the voltage of the system and to reduce the losses.

VI. CONCLUSION

In this paper, the capacitor placement problem is solved by using SFLA. Simulations are carried out on 69-Bus system and the result obtained by this method is better than the other methods in terms of quality of solution and computational efficiency. The main advantage of this algorithm is that it does not require external parameters such as cross over mutation rate etc., as in case of genetic algorithm, differential evolution and evolutionary algorithm and these are hard to determine in prior. The other advantage is that the global search ability in the algorithm is implemented by introducing neighborhood source production mechanism which is similar to mutation process.

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Vol. 5, Issue 3, March 2016

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