Optimal Sitting And Sizing Of Capacitor In Distribution Networks Using Bat Algorithm

Cholapandian.V[1], Yuvaraj.T[2]

[1,2]*Department of Electrical and Electronics Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, India*

Email: [1]vasanthapandian218@gmail.com, [2]yuvaraj4252@gmail.com

Abstract: This work proposes a new approach for the optimal sitting and sizing of capacitors in Radial Distribution Systems (RDS) with the objective of mitigation losses of the system subject to the constraints. In the present approach new combined approach of Voltage Stability Index (VSI) and Bat Algorithm (BA) are applied to decide the optimum placement of capacitors. BA is utilized to determine the optimum size of capacitors. The present approach is implemented to the IEEE 85 RDS. The simulated results validate the show and efficiency of the present approach capably.

Keywords: Capacitor, Bat algorithm, Voltage Stability Index, Radial Distribution Systems.

1. INTRODUCTION

In modern power distribution network, losses are measured as one of the major task towards the overall efficiency of the power system. The losses in power system are stated in terms of I^2R. Studies as on date mention that almost 10-13% of the total power generated is consumed as losses at the distribution level in power system [1]. It is known that losses in transmission network are considerably high compared to that of a distribution network. The distribution network has specific feature of reduction of voltage at nodes while moving away from substation. Such loss also has a direct impact on the financial issues as well as the overall efficiency of the power utilities. Therefore, the need of improving the overall efficiency of the power delivery has forced the power utilities to reduce the losses at distribution level. The ultimate reason for the losses in power system is inadequate amount of reactive power in distribution system. Reactive power support is provided to the power system in order to reduce the power losses and increase the overall efficiency of the power system. Many arrangements can be followed to reduce losses like network reconfiguration, shunt capacitor placement, distribution generator placement etc. Moreover, It is not possible to attain zero losses in a power system but it is possible to keep them to a minimum to reduce the system overall cost [2-4].

In recent years, alternate solutions to traditional power stations have been given a high priority due to the limited presence of fuel resources and also to meet electric energy demands. Thus, the renewable resources of energy are considered as the alternative solution to existing fuels. When compared with large fossil fuel based power plants, the sizes of renewable energy based generators are small. They are well suited for low voltage RDS.

A Capacitor is a device for storing charge. It is commonly made up of two plates separated by a thin insulating material known as the dielectric. One plate of the capacitor is positively charged and the other plate is negatively charged. The charge which is stored in a capacitor is

proportional to the potential difference between two plates. If C is the capacitance, then charge Q is represented in terms of CV.
Innumerable methods had been adopted for solving this problem with a view to minimizing losses have been suggested in the literature based on both traditional mathematical methods and more recent heuristic approaches. An elaborate survey of the literature from the last decade focusing on various heuristic optimization techniques applied to evaluate optimal capacitor placement (OCP) and size is presented in [5].
The paper is directed towards reducing losses in the distribution system by capacitor allocation. In large distribution networks it is very difficult to predict the optimum size and location of capacitor, which finally results not only in reducing losses but also, improves the overall voltage profile. Though many conventional models and techniques are used for this purpose but it becomes a cumbersome task as the complexity of the system increases.
In this research the capacitor placement problem is solved using BA and VSI. The objective function is taken as power loss that is to be mitigated as minimum as possible. In this paper capacitor size is taken as known discrete values. The optimum location for these capacitors is determined such that it minimizes the power losses and increase the bus voltage level of the distribution system under study.

2. PROBLEM FORMULATION

Study of load flow using traditional flow methods such as Newton-Raphson load flow method, Gauss-Seidal load flow method and Fast Decoupled load flow method does not provide accurate results of voltage flow and line flow in RDN, as it possess higher ratio of resistance to reactance (R/X). A direct approach for load flow of distribution system provides better solution as it is designed specially [6-9]. A simple distribution network is represented by single line diagram as shown in Figure 1.

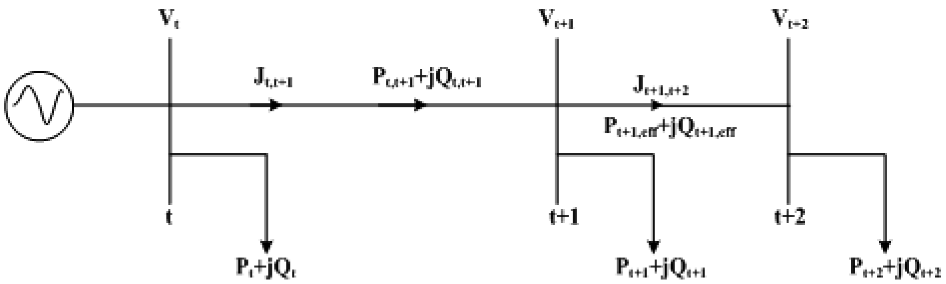

Fig.1. Simple distribution network.

At node t in the figure 1, equivalent injected current is obtained as shown in equation (1)

$$I_t = \left(\frac{P_t + jQ_t}{V_t} \right)^* \quad (1)$$

Using Kirchhoff's current law, branch current can be obtained from figure 3 between the buses t and t+1 as shown in equation (2).

$$J_{t,t+1} = I_{t+1} + I_{t+2} \quad (2)$$

Equation (2) can be represented in matrix form by utilizing Bus Injected to Branch Current Matrix (BIBC).

$$[J] = [BIBC][I] \quad (3)$$

Kirchhoff's voltage law is applied at buses t+1 in the figure 3 for calculating the voltage at that node as given by equation (4).

$$V_{t+1} = V_t - J_{t,t+1}(R_{t,t+1} + jX_{t,t+1}) \quad (4)$$

In the figure 3, real power and reactive power in the line section occurring between buses t and t+1 as given by equation (5) & (6) respectively.

$$P_{Loss(t,t+1)} = \left(\frac{P_{t,t+1}^2 + Q_{t,t+1}^2}{\left| V_{t,t+1} \right|^2} \right) * R_{t,t+1} \quad (5)$$

$$Q_{Loss(t,t+1)} = \left(\frac{P_{t,t+1}^2 + Q_{t,t+1}^2}{\left| V_{t,t+1} \right|^2} \right) * X_{t,t+1} \quad (6)$$

Hence total power loss P_{TLoss} occurring in the distribution system is obtained by adding all the losses occurring in the line section as given by equation (7).

$$P_{TLoss} = \sum_{t=1}^{nb} P_{(Loss,t,t+1)} \quad (7)$$

Objective Function

Main objective of placing capacitor in appropriate location in the RDS is to reduce significantly the total loss of active power which satisfies both equality constraints and inequality constraints. Objective function can be formulated mathematically as given by equation (8).

$$Min(F) = \sum_{t=1}^{nl} P_{TLoss} \quad (8)$$

Voltage Stability Index for location

Location of capacitor in the RDS is identified by utilizing the voltage stability index (VSI). Computation of VSI at each of the node is done by using equation (9). Any node that has lowest value of VSI is termed as the weakest node from where, phenomenon of voltage collapsing starts. In a particular system, computation of VSI for all the buses can be obtained from the load flow where arrangement of values is in ascending order. Sequence for allocation of compensator for buses under consideration is chosen by VSI.

$$VSI(t+1) = |V_t|^4 - 4\left[P_{t+1,eff} * X_t - Q_{t+1,eff} * R_t\right]^2 - 4\left[P_{t+1,eff} * R_t + Q_{t+1} * X_t\right]|V_t|^2 \quad (9)$$

3. BAT ALGORITHM

In current era, best solution for power optimization problems is provided by nature inspired algorithms which are considered to be the most powerful algorithms. The animal Bat locates its food based on its behavior of echolocation. Based on this concept, a new algorithm inspired by nature is the meta-heuristic algorithm known as “Bat Algorithm” proposed by Xin-Sha Yang in 2010 [10]. Bats are mammals with wings having advanced capability of finding their prey based on echolocation hence are interesting animals. These animals radiate sound signal termed as echolocation in order to detect the objects in its environment which makes it possible for the animals to find their way even in darkness.

Development of Bat algorithm is done by idealizing or approximating the characteristics of bats. Three rules framed by idealizing or approximation are discussed as follows:

1. Bat is able to sense an object whether it is food or obstacle along with its distance by utilizing its echolocation characteristics based on the property possessed by these animals known as echolocation property.
2. Bat moves in random motion from position x_i, velocity v_i and a minimum frequency of f_{min} that varies with respect to wavelength λ and loudness A_0 in order to find the prey. These bats are able to regulate the frequency or wavelength of the pulse emitted hence

regulates pulse rate of emission *r* within the range of [0, 1] based on the closeness of the prey.

3. Loudness value can be varied but generally we assume it varies from a large positive value A_0 to a constant minimum value A_{min}.

Bat algorithm can be implemented step by step based on above idealization and approximation for the process of optimization which is described as follows:
Step 1: Firstly system input data is read both load data and bus data.
Step 2: Real and reactive power losses along with voltage are determined by running the distribution load flow of base case.
Step 3: Candidate buses are identified by proper placement of compensating devices.
Step 4: Upper and lower bounds are set for the constraints namely the control parameters of bat algorithm which includes pulse rate, pulse frequency and loudness along with maximum iterations.
Step 5: Initial bat population is generated in the feasible area randomly where each bat is indicated by encouraging optimal size in the distribution network for the compensation devices.
Step 6: Fitness function is evaluated along with computation of expected active power loss and expected reactive power loss including objective function's voltage deviation by utilizing Direct Load Flow Method for each bat or solution.
Step 7: Best bat with minimum power loss is chosen in the population.
Step 8: Bat population is updated.
Step 9: Active power loss of the updated population and reactive power loss of the updated population is determined by running the load flow.
Step 10: Termination criterion is checked where it can be maximum possible iterations for updating the population of Bat Algorithm such that a minimum value is reached by the objective function. If this condition is satisfied then stop the algorithm else return to step 5.
Step 11: Optimal solutions are displayed.
Above steps are followed for minimizing the objective function.

4. RESULTS AND DISCUSSION

In this case IEEE 85-bus radial distribution system is analyzed. The line data and bus data are available from [11] with a real and reactive power loads of 2570.28 kW and 2621.936 kVAr. The base values are Sbase 100 MVA, Vbase 11 kV. The single line diagram of this system is shown in Fig.2. The total real and reactive power losses of the base case are 315.3278 kW and 198.1867 kVAr. The optimal location of this system is chosen as 8, 33 and 61 based on VSI, then the optimal size is obtained using BA. The performance analysis of this case such as optimal size of capacitor at optimal location, minimum voltage, power loss reduction before and after capacitor placement is shown in Table 1. The total kVAr is used in the present approach is less when compared with other existing techniques at the same time the real and reactive power reduction are also found to be better. The real power loss obtained from the proposed method are 150.98 kW which is less when compared to 159.87 kW by MINLP, 174.01 kW by PGS, 163.32 kW by PSO. The voltage profile enhancement of 85 bus system with and without capacitor sitting is depicted in figure 3. It can be observed that the voltage profile is enhanced larger when capacitor is optimally allocated in the RDS.

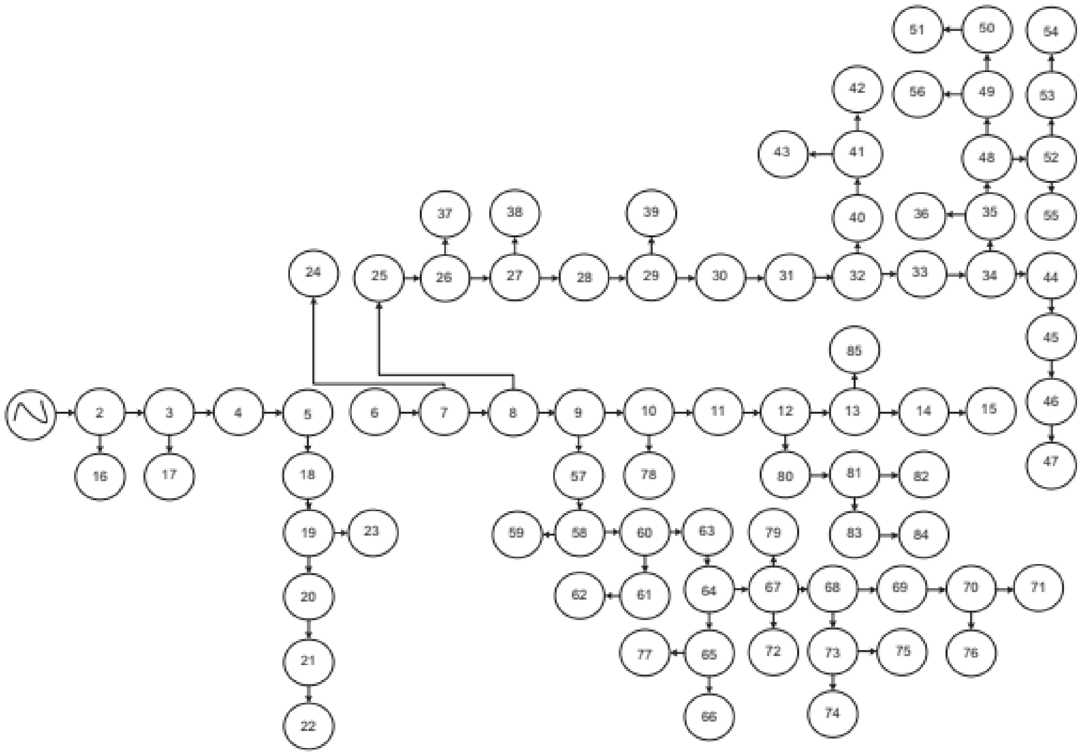
Fig.2. IEEE 85-Bus Radial Distribution System

Table 1 Simulation result of 85-bus system

Items	Base Case	PSO	PG	MINLP	BA
Optimal size and Location	NA	324(7) 796(8) 901(27) 453(58)	200(7) 1200(8) 908(58)	300(4) 600(10) 100(14) 500(18) 300(22) 1000(27)	1050(8) 650(33) 550(61)
Total kVAr	NA	2474	2308	2400	2250
P_{Loss}(KW)	315.33	163.32	174.01	159.87	150.98
% Reduction in P_{Loss}	NA	48.2	44.18	49.3	52.12
V_{Min}(p.u.)	0.8708	0.9153	0.9089	0.9171	0.9309

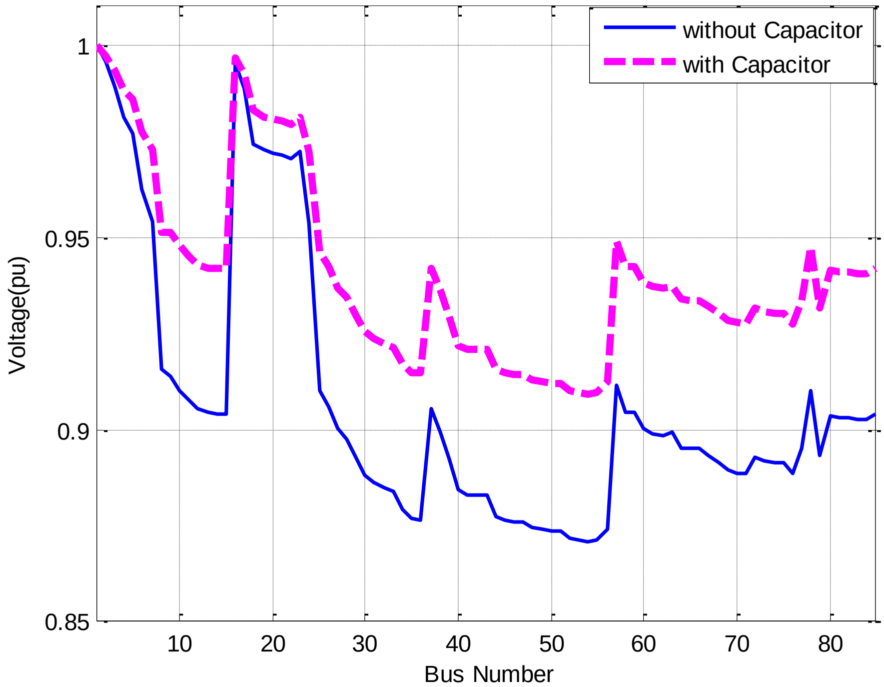

Fig-3 Voltage profile improvement of 85 bus system

5. CONCLUSION

Capacitor sitting and sizing in the RDS is utilized to compensate the reactive power which leads to mitigate the power loss, improve the bus voltage, enhance the overall system stability, etc., It is essential to site the capacitor in correct place with best kVAr to confirm the extreme profits of the system. In this article, the new method of determining the optimal sitting is presented and the optimal size is calculated by using BA. The present approach is implemented on 85-bus RDS. The simulated results are compared with the results of MINLP, PGS, PSO, HS-based methods. The result obtained by the proposed BA is found to be better than the other existing techniques. Hence, the present approach can be easily applied to any kind of radial distribution system.

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