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Optimal capacitor placement in a radial distribution system using Bat Algorithm

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Abstract

Optimal capacitor placement in the distribution system plays a significant role in minimizing the energy loss. This paper presents an efficient technique to find optimal size and location of the capacitor with the objective of minimizing the total active power losses of distribution system. The Bat Algorithm (BA) is proposed to solve the optimal capacitor placement problem satisfying the operating constraints. To demonstrate the applicability of the proposed method, it is tested on IEEE 33-bus radial distribution system. The simulation results obtained are compared with the previous method reported in the literature and found to be encouraging.

Key-words: *Optimal capacitor placement; Radial Distribution System; Bat Algorithm; Active Power Losses*.

Résumé

Le placement optimal des condensateurs dans le système de distribution joue un rôle important dans la réduction de la perte d'énergie. Cet article présente une technique efficace pour trouver la taille et l'emplacement optimaux du condensateur dans le but de minimiser les pertes de puissance active totales du système de distribution. L'algorithme Bat (BA) est proposé pour résoudre le problème de placement optimal de condensateur répondant aux contraintes de fonctionnement. Pour démontrer l'applicabilité de la méthode proposée, celle-ci est testée sur un système de distribution radiale IEEE 33 bus. Les résultats de la simulation obtenus sont comparés à la méthode précédente rapportée dans la littérature et se révèlent encourageants.

Mots-clés : *Placement Optimal des Condensateurs*; *Système de Distribution Radiale; Algorithme Bat; Pertes de Puissance Active.*

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1. Introduction

As Distribution Systems are growing large and their complexity increases, leading to higher system losses and poor voltage regulation, the need for an efficient and effective distribution system has therefore become more urgent and important. In this regard, dispersed generators are added on radial distribution system for Loss Reduction and Voltage profile improvement.

With these various objectives in mind, several attempts were made up in the literature for its corresponding placement and sizing based on classical and meth-heuristics techniques. The authors in [1] have used an analytical approach for the optimum capacitor location for minimizing active power losses. Further, the authors in [2-3] have developed a new analytical method for the voltage profile enhancement and compensation of active power losses. The authors in [4] have proposed a meta-heuristic called mixed-PSO algorithm for reducing the real power losses in distribution system. Furthermore, the authors in [5] have proposed a multi-objective optimization problem for improving the voltage profile and reduction of power loss using a Plant Growth Simulation Algorithm (PGSA). In research [6] presented Particle Swarm Optimization (PSO) Algorithm method for shunt capacitor location and size in distribution network to minimize the cost and reduce energy loss.

The presents research describes the employment of a novel meta-heuristic called Bat Algorithm (BA) for the optimal capacitor placement in radial distribution networks. This problem is formulated as an optimization problem. The proposed algorithm has been tested on IEEE 33 bus radial distribution system.

2. Problem Formulation

2.1 Active power loss

In this study, the optimal siting and sizing of capacitor units in 33 bus radial distribution networks is formulated as an optimization problem to reduce the total real power losses. This latest can be calculated by Eq. 1. Figure 1 shows the electrical equivalent of radial distribution system.

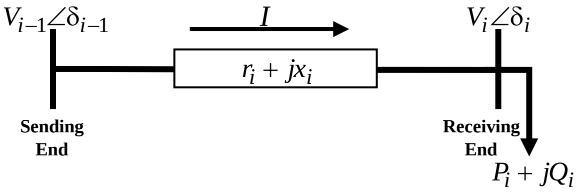

Fig. 1. Electrical equivalent of two node system.

From Figure 1, the following equation can be written:

$$PL(i) = r_i \frac{\left(P_i^2 + Q_i^2\right)}{V_i^2} \tag{1}$$

Therefore, the objective function is calculated using the following equation:

$$f = \sum_{i=2}^{N_{bus}} PL = \sum_{i=2}^{N_{bus}} PL(i) = \sum_{i=2}^{N_{bus}} r_i \frac{\left(P_i^2 + Q_i^2\right)}{V_i^2} \tag{2}$$

Where i-1 sending end node; i receiving end node; r_i+jx_i is the line impedance connected between i-1 and i; I current of branch j; V_{i-1} voltage of node i-1; V_i voltage of node i; P_i and Q_i active and reactive power load fed through node i.

- *Total Loss reduction (TLR)*

Total Loss Reduction (TLR) is calculated using Eq. (3) :

$$TLR\% = \frac{\sum_{i=1}^{N_{bus}} PL_{W/C} - \sum_{i=1}^{N_{bus}} PL_{Wo/C}}{\sum_{i=1}^{N_{bus}} PL_{Wo/C}} \times 100 \tag{3}$$

Where, $PL_{W/C}$ is the total line losses in the system with the employment of capacitor and $PL_{Wo/C}$ is the total line losses in the system without capacitor.

2.2 Constraints

The objective function is subjected to main constraints in the optimization process in the proposed methodologies are:

- Power constraint
- Voltage constraint.
- Active power losses constraint.
- capacitor size constraint.

A. *Power constraint*

The equality constraints are active/reactive power flow equations as:

$$\begin{cases} P_{Gi} - P_{Di} - V_i \cdot \sum_{j=1}^{N_{bus}} V_j \cdot Y_{ij} \cdot \cos\left(\theta_{ij} + \delta_j - \delta_i\right) \\ \qquad\qquad\qquad\qquad\qquad\qquad i = 1,.., N_{bus} \\ Q_{Gi} - Q_{Di} - V_i \cdot \sum_{j=1}^{N_{bus}} V_j \cdot Y_{ij} \cdot \sin\left(\theta_{ij} + \delta_j - \delta_i\right) \end{cases} \tag{4}$$

Where P_{Gi} and Q_{Gi} are the active (resp. reactive) power generated at the ith bus; P_{Di} and Q_{Di} are the active (resp. reactive) load demand at the same bus; Y_{ij} and θ_{ij} are the admittance magnitude (resp. angle) of branch connecting bus i and j.

B. *Voltage constraint*

The voltage magnitude must keep within the specified limits at each bus [7]:

$$V_{\min} \le V_i \le V_{\max} \tag{5}$$

Where V_{min}, V_{max} are the lower and upper limits of bus voltage, respectively.

C. Active power losses constraint

The losses after installing capacitor in power grid should be less than or equal losses before installing capacitor [7].

$$PL\ with\ Capacitor \leq PL\ without\ Capacitor \tag{6}$$

D. Capacitor size constraint

To obtain a reasonable solution, the size of generator should not be so small or so high with respect to load value. The capacitor size is considered not less than zero and not more than the total reactive load demand as following [14]:

$$0 \leq size\ of\ Capacitor(Q_C) \leq \sum_{i=1}^{N_{bus}} Q_{Di} \tag{7}$$

Where Q_{Di} is the reactive load demand at the same bus.

3. Proposed Algorithm

Bat Algorithm is a nature inspired met-heuristic algorithm implemented by Yang, is inspired by echolocation of microbats. Echolocation is typical sonar which bats utilize to search prey and to avoid obstacles. These bats emit very loud sound pulse and listen for the echo that bounces back from the surrounding objects [8]. Thus a bat can compute how far they are from an object. Moreover bats can distinguish dramatically between an obstacle and a prey even in complete darkness [9]. In order to transform these characteristics of bats to algorithm, Yang idealized some rules [10]:

- All bats use echolocation to sense distance, as well as they also recognize the difference between food/prey and background barriers in some magical manner;
- Bats fly randomly with velocity v_i at position x_i with a frequency f_{min}, varying wavelength and loudness A_0 to look for prey. They can routinely tune the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0, 1]$, depending on the proximity of their target; and
- Although the loudness can vary in many manners, we assume that the loudness varies from a great (positive) A_0 to a least constant value Amin.

The frequency factor controls step size of a solution in BA. This factor is assigned to random value for every bat (solution) between lower and upper limits [f_{min}, f_{max}]. Velocity of a solution is proportional to frequency and new solution rest on its new velocity.

$$f_i = f_{\min} + \left(f_{\max} - f_{\min}\right) \cdot \beta \tag{8}$$

$$v_i^k = v_i^{k-1} + \left(x_i^k - x^*\right) \cdot f_i \tag{9}$$

$$x_i^k = x_i^{k-1} + v_i^k \tag{10}$$

Where $\beta \in [0,1]$ indicates randomly generated number, x^* represents current global best solutions.

For local search part of algorithm (exploitation) one solution is selected among the selected best solutions and random walk is applied.

$$x_{new} = x_{old} + \varepsilon A^t \tag{11}$$

Where A^t is average loudness of all bats at this time step ε is a random number in the interval [0, 1].

Figure 3 describes the general flowchart of BA algorithm for evaluating the objective function.

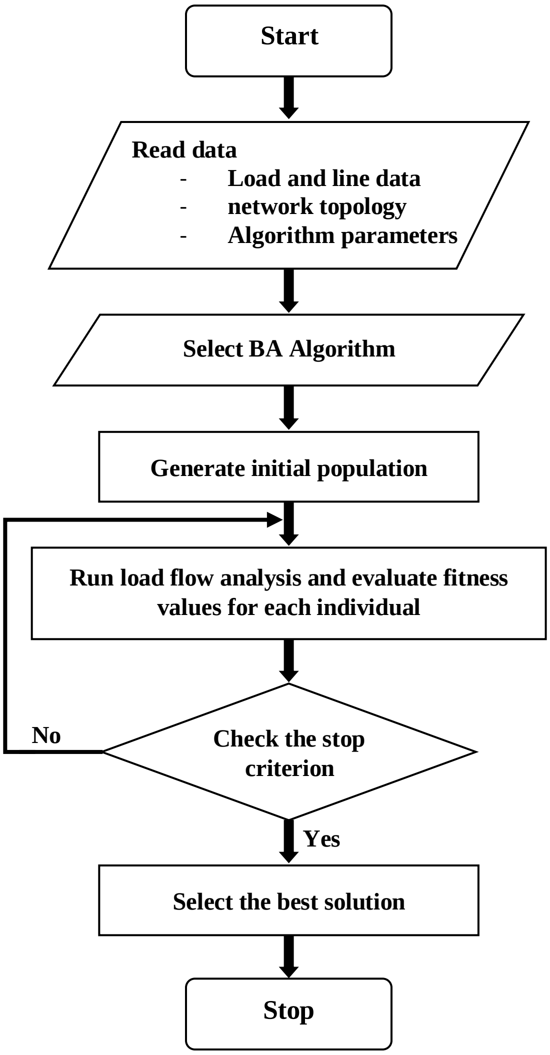

Fig. 2. Flowchart of capacitor placement and sizing using BA algorithm.

4. Results and Discussions

In this study, the proposed algorithms are used to determine the optimal capacitor placement and sizing and they have been carried out on IEEE-33 bus radial distribution system.

- *IEEE 33-bus Radial Distribution System*

The test system is IEEE 33-bus radial distribution system, with the total load is 3.715 MW and 2.3 MVar, its voltage level is 12.66 kV, this system contains 33 bus and 32 branches. Its corresponding scheme is presented in Figure 3 [11].

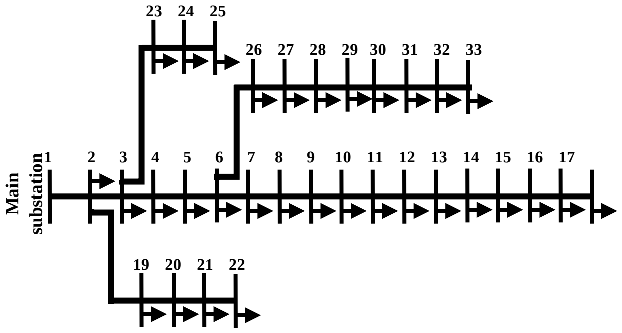

Fig. 3. IEEE 33-Bus radial distribution system

4.1 Results

The capacitor localization, corresponding sizes and active power losses in the cases without and with capacitor using the proposed algorithm and the analytical approach find by [10] are respectively summarized in TABLE I. The voltage profile, voltage stability index and the real power losses are presented in Figures. (4-6) simultaneously.

4.2 Discussion

The impact of capacitor placement is also measured by calculating the real power loss, the voltage profiles and the voltage stability index. Table II shows the effect of capacitor placement on system performance. From these results, we can observe the advantage of capacitor units in improvement of system performances, as reduction of total system losses and the voltage index stability enhancement. In order to validate the performance of the proposed algorithm in this study, we have used IEEE-33 bus test distribution system.

When the proposed algorithm is applied on test system, it was found that the proposed algorithm gives much better voltage profile as compared to the base case. Fig. 4 shows voltage profile of IEEE-33 bus test distribution system (with and without capacitor placement). From Table. I, it can be observed that the minimum voltage is raised from 0.9037 pu in the case without capacitor unit to 0.9165 pu in the case with capacitor unit using the proposed algorithm.

Fig. 6 shows the voltage stability indices of test system. The weakness of voltage stability indices for all buses in the distribution system before power compensation is obvious. But after power compensation, the buses stability indexes are considerably enhanced. From Table. I, it can be see that the minimum voltage stability index is raised from 0.6672 in the case without capacitor unit to 0.7055 in the case with capacitor unit using the proposed algorithm.

The proposed method also results in total power loss reduction. TABLE I shows the effect of capacitor placement on loss reduction, using the proposed and another existing method. From TABLE I, it can be observed after power compensation, the real power losses have been significantly reduced. The proposed algorithm is found better in performance than analytical approach. Fig. 5 shows the real power loss at buses with and without capacitor for IEEE-33 bus test system.

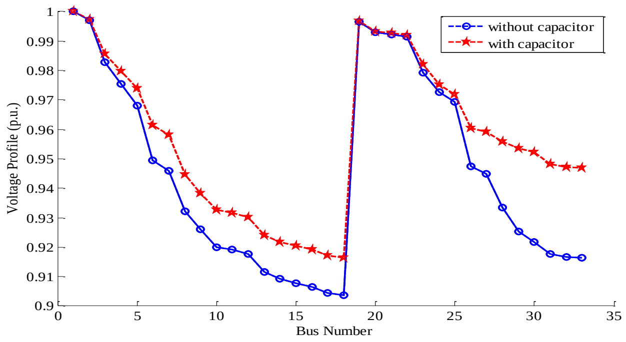

Fig. 4. Voltage profiles of IEEE-33 bus system.

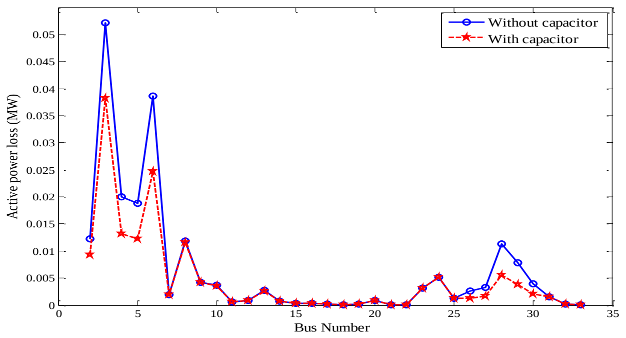

Fig. 5. real power loss of IEEE-33 bus system.

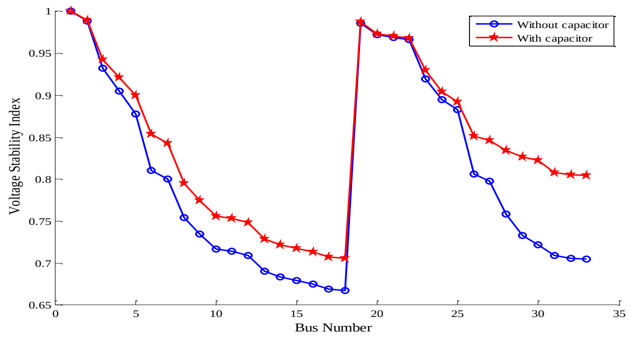

Fig. 6. Voltage stability index of IEEE-33 bus system

TABLE I. APPLICATION OF PROPOSED ALGORITHM ON IEEE 33 TEST SYSTEM

	Approach	**Installed DG units**		**Ploss (kW)**	**TAPLR (%)**	**Min(V)**	**Min(SI)**
		Bus	***Size(MW)***			**(pu)**	
Without Capacitor		**-**	**-**	**211**	**-**	**0.9037**	**0.6672**
With Capacitor	BA	30	1.2580	151.38	28.25	0.9165	0.7055
	IA [4]		1.24	151.39	28.25	0.9163	0.7050

1. Conclusions

In this paper, a recently developed metaheuristic Bat algorithm has been applied to find the optimal location and size of capacitor to be placed in the radial distribution system with the objective of minimizing the total active power losses of distribution system. Computational results showed that the performance of the Bat algorithm is better than another classical algorithm compared. The bus voltage profile and the voltage stability index are also improve

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