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# A Canonical Complementary PSO Approach in Radial Distribution System for Reduction of Total Line Loss and Improvement of Voltage Profile

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**Abstract:** This study presents a new and efficient approach for capacitor placement in radial distribution systems with an objective of improving the voltage profile and reduction of power loss. In this study, optimal distributed generation allocation for loss reduction in distribution network. The main purpose of this study is to discuss the basic understanding of power quality in relation to the distributed generation. A Canonical Complementary Particle Swarm Optimization Algorithm (CCPSOA) was used as solving tool. This algorithm is used to minimize an objective function. For applying CCPSOA, software is programmed under Matlab software is prepared. This proposed CPSO method is implemented on IEEE 30 and IEEE 69-bus systems and the results may show that the proposed method is better than the other methods. The results prove the efficiency of the proposed method.

**Key words:** Distributed generation, element incidence matrix, loss reduction, radial distribution power flow, power loss, India

## INTRODUCTION

It has been seen that as much as 13% of total power generated is wasted in the form of losses at the distribution level (Song *et al*., 1997). The capacity of the radial lines is often limited, it is thus necessary to consider how future load additions will be served. Schmill (1965) developed his well-known 2/3 rule for the placement of one capacitor assuming a uniform load and a uniform distribution feeder. Baran and Wu (1989) distinguished capacitor placement problem separately into a master problem and a slave problem. The master problem is used to determine the location of the capacitors while the slave problem is used to determine the type and size of the capacitors. Dura (1968) considered the capacitor sizes as discrete variables and employed dynamic programming to solve the problem. Grainger and Lee (1981) developed a non-linear programming based method in which capacitor location and capacity were expressed as continuous variables.

Chen *et al*. (1995) considered the mutual coupling effect of conductors to install capacitors in unbalanced distribution systems. Grainger and Civanlar (1985) formulated the capacitor placement and voltage regulator problem and proposed decoupled solution methodology for general distribution system. Sundharajan and Pahwa (1994) proposed the genetic algorithm approach to determine the optimal placement of capacitors based on experiences in the selection of the probability parameters.

When costs of building or upgrading transmission lines are weighed against the costs of distributed generation, it is easy to envision cases where distributed generation would be more cost effective. In addition to economic concerns, questions regarding power quality, reliability, storage and stability need to be addressed in the design and operation of distributed generation. Because of the unique power requirements of an industrial site, the distributed generation needs such sites which are much different from those of residential, agricultural or urban sites. The installation of DG units at inappropriate places can result in an increase in system losses and costs. In the last few years, various techniques have been developed to find the optimal location and size of the DG. Teng *et al*. (2007) has used GA for finding the optimal placement, size and type of DGs in distribution networks to maximize the reliability.

In Wang and Nehrir (2004), an analytical method is proposed to find the optimal location of DG to minimize the line loss. Hedayati *et al*. (2008) employed another analytical method which is based on the analysis of continuation power flow and the most sensitive bus to the voltage collapse, to allocate the DGs. A Kalman filter algorithm is employed by Lee and Park (2009) to minimize the line loss by determining the optimal location of DGs. As Jabr and Pal (2009), optimal locations and sizes of DGs are found using the ordinal optimization approach. As Wang and Singh (2008), reclosers along with DGs are optimally allocated to improve the reliability using Ant

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Colony System (ACS). Sookananta *et al*. (2010) have proposed Particle Swarm Optimization Technique to determine the optimal location and sizing of DG with an objective of minimizing line losses.

## MATERIALS AND METHODS

**Problem formulation:** The problem of DG placement and capacitor allotment with their proper capacities is of great importance. The installation of both DG units and shunt capacitors at non-optimal places can result in an increase in system losses and costs. For that reason, a power system planning engineer requires an efficient and fast optimization method capable of indicating the best solution for a given distribution network. The selection of the best places for installation and the preferable size of the DG units and shunt capacitor banks in large distribution systems is a complex discrete optimization problem.

The optimal placements and sizings of DGs and shunt capacitors on the distribution network have been studied in order to achieve different ends. Real power flow while incorporating installation of DG:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} + Ap_{i+1} \cdot \mu P \qquad (1)$$

Reactive power flow with shunt capacitor placement:

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}.\frac{P_i^2 + Q_i^2}{|V_i|^2} + Rp_{i+1} \cdot \mu Q \qquad (2)$$

Computation of voltages at the buses including of both Shunt capacitor and DG sets:

$$V_{i+1}{}^2 = V_i^2 - 2(R_{i,i+1}.P_i + X_{i,i+1}.Q_i) + (R_{i,i+1}{}^2 + X_{i,i+1}{}^2)$$

$$\frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (3)$$

**Formulation of the objective function:** The installation of DG units and capacitor banks should not result in an increase in the system losses and costs. So, the model described in these installation units should not result in an increase in the system losses and costs. So, the model described in this section explicitly assumes the multi-objective nature of the problem by considering minimization of losses as an objective function subjected to quality of service requirements of an acceptable voltage profile. The power loss of the line section connecting buses I and i+1 is computed. The objective function may be formulated as:

$$\text{Minimize}(f)$$
$$\text{Subject to } V_{min} \le |V| \le V_{max}$$

Where:

$V_{min}$ = Minimum value of bus voltage (set to 0.985 in this research)
$V_{max}$ = Maximum value of bus voltage (set to 1.0 in this research)

**Canonical Complementary Particle Swarm Optimization (CCPSO):** Particle Swarm Optimization (PSO) is an algorithm developed by Kennedy and Eberhart that simulates the social behaviors of bird flocking or fish schooling and the methods by which they find roosting places, foods sources or other suitable habitats. In the basic PSO Technique, suppose that the search space is d-dimensional then each member is called particle and each particle (ith particle) is represented by d-dimensional vector and described as:

$$X_i = [x_{i1}, x_{i2}, x_{i3}, \ldots\ldots x_{id}]$$

The set of n particles in the swarm is called population and described as:

$$pop = [X_1, X_2, X_3, \ldots. X_n]$$

The best previous position for each particle (the position giving the best fitness value) is called particle best and described as:

$$PB_i = [pb_{i1}, pb_{i2}, pb_{i3}, \ldots\ldots pb_{id}]$$

The best position among all particles, best positions achieved so far is called global best and described as:

$$GB = [gb_1, gb_2, gb_3, \ldots\ldots gb_d]$$

The rate of position change for each particle is called the particle velocity and described as:

$$V_i = [v_{i1}, v_{i2}, v_{i3}, \ldots\ldots v_{id}]$$

Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest). This information corresponding to personal experiences of each agent. Moreover, each agent knows the best value so far in the group (gbest) among pbests. Namely, each agent tries to modify its position using the following information:

- The distance between the current position and pbest
- The distance between the current position and gbest

Mathematically, velocities of the particles are modified according to following equations:

$$v_i^{k+1} = c_1 r_1 \left(pb_{id}^k - x_{id}^k\right) + c_2 r_2 \left(gb_d^k - x_{id}^k\right) + c_1 v_{id}^k$$

The i particle position is updated by:

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1}$$

Where:

$v_i^{k+1}$ = The velocity of ith particle at kth iteration
$v_i^{k+1}$ = The velocity of the ith particle at (k+1)th iteration
$r_1$-$r_3$ = The random values in the range [0, 1]
$x_{id}^k$ = The current position of ith particle in d-dimensional vector at kth iteration

## RESULTS AND DISCUSSION

The propose CCPSO algorithm has been implemented on IEEE 30-bus (Eminoglu and Hocaoglu, 2005) and IEEE 69-bus (Ranjan and Das, 2003) test system. Optimal location of DG and Shunt capacitor with their magnitude by CCPSO is shown in Table 1 and 2. Convergences characteristic is shown in Fig. 1 and 2 for IEEE 30 for Total Line Loss (TLL) minimization and convergence characteristic of IEEE 69-bus Total Voltage Deviation (TVD) minimization, respectively (Fig. 3 and 4). It is shown from Table 1, four DG sets and four Shunt capacitors are required for TLL minimization. Here, base voltage is taken as 23 KV and base MVA taken as 10 MVA for IEEE 30-bus system. Total active power and reactive power is to be found as 174 kW and 107.4 kVAR. Line is determined as 87.46 kW without integration of DG sets and shunt capacitors. Line loss is brought down by Canonical Complementary PSO technique from 87.46-51.236 kW. DG sets are placed in main feeder only while lateral and sublaterals feeders are free from injection of active power. It is observed from Table 1, four DG sets are placed optimally for minimizing maximum loss reduction at bus 4, 6, 9 and 10th position. Shunt capacitors are also optimally arranged along with DG sets in the main feeder of the distribution feeder at bus no 6, 7, 9 and 11.

From Table 1, it is noticed that four DG sets, each of 25 kW capacity, equivalent to 100 kW and four shunt capacitors, each of 25 kVAR capacity, equivalent to total 100 kVAR are optimally placed for loss minimization from 174-68.737 kW In case of IEEE 69-bus, base voltage and base MVA are taken as 11 KV and 10 MVA. Total active power and reactive power is to be obtained as 3802.19 kW and 2694.6 kVAR. Line is obtained as 138.4 kW without integration of DG sets and shunt capacitors.

Table 1: Optimum location and sizing of DG set and shunt capacitors for IEEE 30-bus system

| DG | Location | Size (p.u.) | Shunt capacitors | Location | Size (p.u). |
|---|---|---|---|---|---|
| 4 | 4, 6, 9, 10 | 0.01 | 4 | 6, 7, 9, 11 | 0.01 |

Table 2: Optimum location and sizing of DG set and shunt capacitors for IEEE 69-bus system

| DG | Location | Size (p.u.) | Shunt capacitors | Location | Size (p.u.) |
|---|---|---|---|---|---|
| 4 | 1, 12, 20, 24 | 0.04 | 5 | 7, 11, 19, 22, 27 | 0.05 |

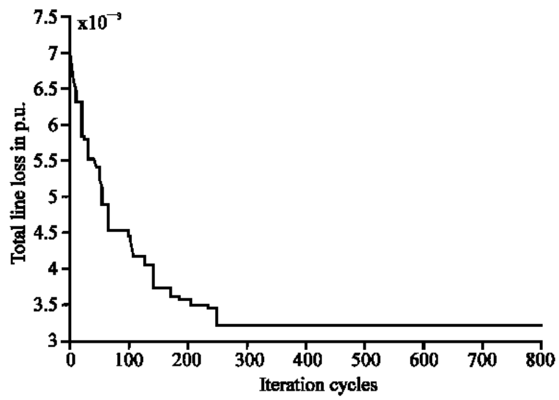


Fig. 1: Convergence characteristic of IEEE 30-bus System (TLL)

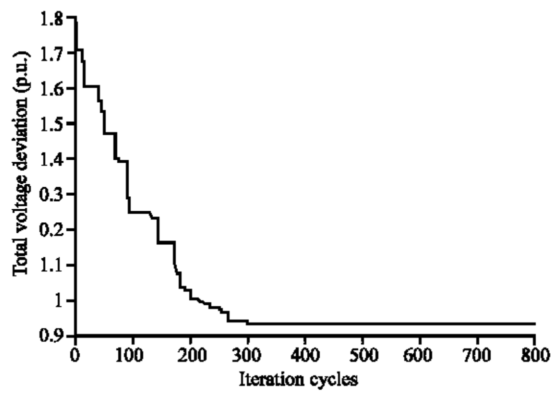


Fig. 2: Convergence characteristic of IEEE 30-bus systems (TVD)

Line loss is cut down by Canonical Complementary PSO Technique from 138.4-135.1 kW. DG sets are placed in main feeder only while lateral and sublaterals feeders are free from injection of active power. It is observed from Table 2, four DG sets are placed optimally for minimizing maximum loss reduction at bus 1, 12, 20 and 24th position. Five shunt capacitors are also optimally arranged along with DG sets in the main feeder of the distribution feeder at bus no. 7, 11, 19, 22 and 27. From Table 2, it is observed that four DG sets, each of 100 kW capacity, equivalent to total 400 kW and five shunt capacitors, each of 100 kVAR capacity, equivalent to total 500 kVAR are optimally placed for loss minimization.

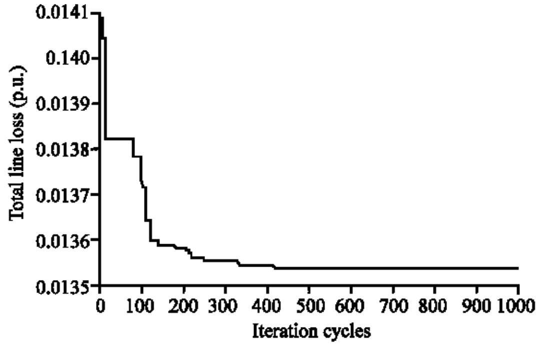


Fig. 3: Convergence characteristic of IEEE 69-bus system (TLL)

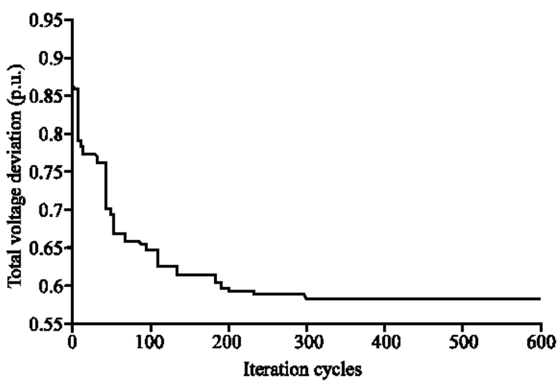


Fig. 4: Convergence characteristic of IEEE 69-bus system (TVD)

## CONCLUSION

In this study, optimal placements and sizings of both DG sets and shunt capacitors in radial distribution network are proposed using Canonical Complementary Particle Swarm Optimization Algorithm (CCPSOA). Minimization of line losses is considered as the objective function and voltage limits are treated as inequality constraints.

The proposed algorithm was examined on IEEE 30 and IEEE 69-bus radial feeder. Results show that combination of DG along with shunt capacitors significantly reduces system losses and total voltage deviation.

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