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Optimal Allocation of Capacitor in Radial Distribution System using PSO

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Abstract – The losses at distribution level contribute a major portion of power system losses. Proper sizes of shunt capacitors in unbalanced radial distribution systems can reduce some portion of this loss and can improve the voltage profile of the feeder section. The PSO-DV approach consists of classical Particle Swarm Optimization (PSO) and differential evolution approach in combination. For capacitor placement problem, the power losses occurring in the system are minimized while voltage profile is improved. Initially to find site of capacitor allocation, candidate nodes using sensitivity analysis reactive power injection is done. Then PSO-DV is implemented to find size and number of capacitors considering minimization of power losses as an optimization problem.

Index Terms – PSO, DE, Power Losses & Sensitivity Analysis.

1. INTRODUCTION

There are several methods have been proposed [Abdul-Salam, et.al,(1994), Baran, M.E ;et al,(1989)] to analyze this Capacitor placement problem in the past in the area of reactive power compensation for radial distribution networks. [Bridenbaugh, C. J; Di Mascio,et al,(1992)] Voltage improvement through capacitor and Capacitor optimization is analyzed.[Sundhararajan and Pahwa et al,(1994)] used genetic algorithm for obtaining the optimum values of shunt capacitors. They have treated the capacitors as constant reactive power load. [T.S.Abdul salma et al,(1994)] proposed a heuristic technique, which brings about the identification of the sensitive buses that have a very large impact on reducing the losses in the distribution systems. [C.S.Chen et al,(1995)] developed a systematic method of optimally locating and sizing of the shunt capacitors compensation on distribution feeders by taking into account the mutual coupling effect among phase conductors. The capacitor placement and sizing problem is a nonlinear integer optimization problem, with locations and ratings of shunt capacitors being discrete values. Series capacitors and shunt capacitors [Carlise, J.C.; El-Keib et al,(2000):] are widely used in distribution systems due to various limitations in the usage.

Capacitor allocation is non-linear non differential optimization problem. In capacitor allocation problem, most of the authors considered cost of capacitor and cost of losses as a minimization optimization problem [1-4]. While some authors considered power loss reduction as an optimization problem [5-9]. To solve capacitor allocation problem, different approaches based on dynamic programming [10], local variation method [11], mixed integer [12-13] and integer quadratic programming and genetic algorithms are developed to find optimal solution of the problem [14]. For last few decades, Evolutionary Algorithms based optimization methods are most commonly implemented for capacitor allocation problem [14-15]. These evolutionary algorithms are inspired by biological and sociological behavior of the individuals. Among these methods, PSO has become very common due to its ease of application and less tuning of parameters. PSO has ability to ensure an optimal solution because of its implicit parallelism. It is observed that sometimes PSO traps in local minima. Now a day another population based Differential Evolution (DE) algorithm is also very common. DE has inherent feature of not trapping in local minima due to randomness in its search space. Hence in this paper, to enhance the search capability of PSO, PSO is applied in combination with Differential Evolution (DE) technique. In classical PSO, velocity vector is updated using cognitive and social term to find an optimal solution. In PSODV (Particle Swarm Optimization with Differentially Perturbed Velocity), PSO cognitive term in velocity vector is replaced with the DE mutant vector. The mutant vector is generated by weighted difference vector of randomly chosen two position vectors from the swarm. The purpose of applying this mutant vector is to increase the diversity of PSO which helps to escape it from the local minima. In this paper, to find optimal site, size and number of capacitors in order to minimize the power losses in the distribution system. At first step, to reduce the search space, and find sensitive nodes for capacitor allocation, sensitivity analysis of all nodes is carried out.

2. RELATED WORK

2.1 Implementation of PSO

2.1.1 Initialization of PSO Parameters

Particle swam optimization is a population basic stochastic optimization technique developed by Dr.Eberhart and D.V Kennady in spite by social behavior of bird flocking or fish schooling in 1995. Initialize the PSO parameters like Swarm size(P), number of generations(NG), Initial weight of the weighting function (Wmax), Final weight of the weighting function (Wmin), weighting factors(C1,C2), input system data, control parameters such as lower and upper bounds of bus voltage and maximum number of capacitor banks to be installed at a compensation node. Randomly generate an initial swarm (array) of particles with random positions and velocities.

2.1.2 Evaluation of Fitness Function

The fitness function should be capable of reflecting the objective and directing the search towards optimal solution. The system is initialize with a population of random solutions and search for optima by updating generations. Since the PSO proceeds in the direction of evolving best-fit particles and the fitness value is the only information available to the PSO, the performance of the algorithm is highly sensitive to the fitness values. For each particle or swarm, the calculated capacitors are placed at the sensitive nodes and the load flow method is run and the losses, net savings are calculated using Eqn.(1) and these net savings becomes the fitness function of the PSO (as savings are maximized).

2.1.3 Optimal Solution

Particle position is updated by adding velocity to its iterative process continued till hundred iterations. So n=100. The advantage of PSO is easy to implement and there are few parameters to adjust optimal solution gives the best position and the corresponding fitness value to the target problem. Information of the best position includes the optimal locations and numbers of capacitor banks at each load level, and the corresponding fitness value represents the maximizing the total savings of the system.

2.1.4 Algorithm for Optimal Location and Size of the Capacitor

The detailed algorithm to determine optimal location and size of the capacitor is given below.

Step 1: Read system data such as Line data and Load data of the Distribution system.

Step 2: Initialize the PSO parameters such as Swarm size(P), initial weight & final weight of the weighting function (Wmax & Wmin), weighting factor(Cj), number of generations (NG).

Step 3: Obtain the optimal location of capacitor by using PLI(Power Loss Indices) as input.

Step 4: Randomly create initial particles where each particle is a solution to the optimal location and size of the capacitor problem.

Step 5: Initialize the velocities for the particles.

Step 6: Run the load flow for each particle and Compute the value of voltages, total active and reactive power losses at all the nodes.

Step 7: Set the local best values for each particle and global best value for the current iteration.

Step 8: Update the particle positions & velocity using eqns (4) & (5).

Step 9: If the particle position is out of boundary then it is brought back to its nearest boundary value using eqns (5).

Step 10: Execute steps 6-9 in a loop for maximum no of generations (NG).

Step 11: Stop the execution and display the global best values as the final result of optimal size of the capacitor.

3. PORPOSED MODELLING

PSO-DV approach in combination is presented for optimal capacitor allocation in radial distribution systems. Capacitor size and number on each node is solved as constrained optimization problem when voltage is constraint on the problem. In PSO-DV, the classical PSO algorithm is implemented except the velocity vector of PSO is modified using a differential random position vector (obtained by difference of two randomly chosen particles) in place of cognitive term in velocity vector. In this section, detail of proposed algorithm is discussed along with brief introduction of sensitivity analysis factor and PSO and DE.

3.1 Sensitivity Analysis

Sensitivity analysis is a systematic procedure to select the most sensitive nodes in the given network. It is basically performed to reduce the search space of the problem. In capacitor allocation problem, sensitivity analysis is used to select the candidate locations for capacitor placement in distribution system. In this paper, the sensitivity of active power losses reactive power injection is calculated using expression given in [16] and the nodes having maximum impact on the system real power nodal reactive power are considered as candidate locations for capacitor placement [16].

3.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization is a population based evolutionary technique and it (PSO) was introduced by Kennedy and Eberhart [17] as an alternative to Genetic Algorithms. PSO has the flexibility to control the balance between the global and local exploration of the search space. This unique feature of a PSO overcomes the premature convergence problem and enhances the search capability and ensures the convergence to the optimal solution. It was originally proposed for continuous problems, and attempts have been made recently to extend it to discrete optimization problems [18-19]. In PSO, initially a populations of individuals (particles) is generated randomly within the given search space of variables termed as swarm. Each particle *p* at iteration *k* has velocity (*kp Vel*) and position (*kp pos*) vector within *n*-dimensional search space. For each particle *p* at iteration *k*, fitness function corresponding to the objective function to be optimized is evaluated. At iteration *k*, find *pbest* and *gbest* for each particle *i* and swarm respectively. Initially at iteration *k*, consider *gbest* is equal to *pbest*. Compare the fitness value of the particle *i* at *k+1* with that of the previous best one and update velocity and position vector of particle *i* using *gbest* and *pbest* till iteration *k+1* using following equations.

3.3 Differential Evolution (DE)

Differential Evolution (DE) is developed by Price and Storn and most popular population-based technique in these days. DE belongs to class of evolutionary algorithms that include Evolution Strategies (ES) and Genetic Algorithms (GA). DE differs from GA in its use of perturbing vectors, which are difference between two randomly chosen vectors. In DE, during optimization process four basic operations are carried: initialization, mutation, crossover and selection.

3.3.1 Initialization

Initially at generation *G=1*, a random population vector (*N*) of size *n* is generated. Each individual (*D*∈*N*) represents the solution of the problem in the given search space. Evaluate fitness function of each individual for the given objective function.

3.3.2 Mutation

In order to produce population for next iteration, *G=G+1*, a mutation operator is applied at the current population at *G=1*. The mutation operation produces mutant vectors by considering vector difference of randomly selected individual vectors from the population. In literature, different mutation mechanisms are available but the basic concept is difference of randomly selected two, three or more individuals are always considered as given below: Where *MutD* is the mutant vector obtained by random selection of individuals *D1,G*, D2,G and D3,G from the population. *F* is real valued weight factor to control the amplification of differential variation between two chosen vectors. It has real value between 0 & 1.

3.3.3 Crossover

To extend diversity in search process, in DE crossover operation is performed. In this process trial vectors are produced by combing target and mutant vector e.g. let *a1----a7* and *w1, w2----w7* are values of design variables of target and mutant vector respectively. In crossover, a trial vectors is

produced as shown in Fig 2. In trial vector, *jth* (*j*∈*n*) design variable is obtained by comparing the random number generated between 0 and 1 and crossover probability (*Cr*).If random number is greater than the *Cr*, *jth* design variable of trial vector is chosen as in mutant vector otherwise as in target vector.

3.3.4 Selection

After generating trial vectors, next is to decide whether these

trail vectors will be individuals of population at next level *G=G+1* or not. To decide this, fitness of trial vector is compared with the target vector. If the value of fitness function of trial vector is better than target vector then trial vector will be considered as new individual otherwise the target vector will be taken in *G=G+1*.

4. RESULTS AND DISCUSSIONS

The proposed approach is tested on 69-bus test system as shown in Fig 1. The line data and bus data is as given in [12]. The other parameters used are as:

Cr=0.3

Minimum value of capacitor=200 kVar

Maximum value of capacitor=1200 kVar

Firstly, sensitivity analysis is carried out. The results obtained using sensitivity analysis is shown in Fig 2. The results of the sensitivity analysis are also tabulated in Table I. As it is clear from the 2nd column of Table I that most sensitive nodes are

54, 53, 52, 51, 50 etc. In this paper, all the nodes having sensitivity value less than 0.015 are considered as candidate nodes. For these candidate nodes, a swarm of population is generated with the available discrete sizes of the capacitors and is optimized for given maximum number of iterations.

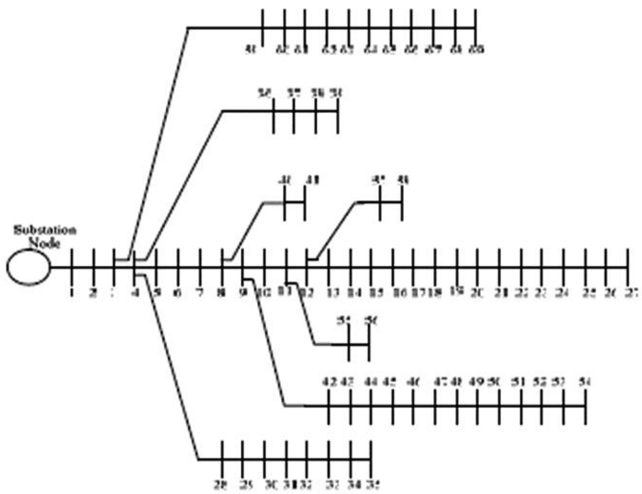

Fig. 1 69-bus test system

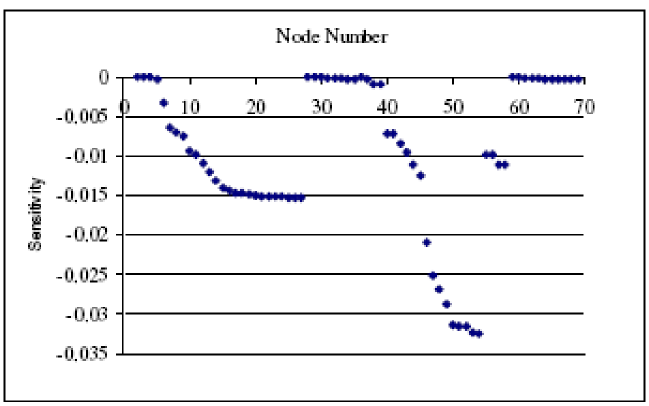

Fig. 2- Sensitivity Analysis of Power Losses

5. CONCLUSION

In this paper 69-bus unbalanced radial distribution systems is considered for analysis to determine capacitor location and ratings of capacitor banks. This paper presents a simple method to determine suitable candidate buses based on power loss indices for capacitor placement in unbalanced loading is considered for analysis in distribution systems and also addresses capacitor sizing problem for loss minimization using PSO algorithm. The size and number of capacitors are optimized using a PSO-DV approach which minimizes the power losses while voltage profile is within the limits. The developed PSODV approach combines advantages of PSO and DE and produces an optimal solution without trapping into local minima. The proposed approach is tested on 69 bus test system. On comparison with existing approach it is observed that the proposed approach gives better results than the earlier existing one. The developed approach is easy to implement for capacitor placement problem in radial distribution system.

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