Optimal placement of capacitor for voltage improvement using Particle Swarm Optimization

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***Abstract*: Capacitor placement plays a very important role in operation and distribution system planning. Optimal capacitor placement can result in system loss reduction, voltage profile improvement, power factor correction and feeder capacity release. In this paper the artificial intelligence method particle swarm optimization (PSO) is discussed for optimal placement of capacitor. Particle swarm optimization is artificial intelligence method for solving optimization problem. Particle swarm optimization (PSO) is a popular and robust strategy for optimization problems. The shunt-capacitor placement problem is a non-linear mixed integer optimization problem with a set of inequality and equality operating constraints. The proposed method can be used to search for optimal locations and sizes of capacitors to be placed.**

Keywords: capacitor placement, voltage, particle swarm optimization

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I. INTRODUCTION

Studies show that approximately 13% of generated power is consumed as loss at the distribution level. Also with the application of loads, the voltage profile declines along distribution feeders below acceptable operating limits. Increase in demand of power day by day requires upgradation of the infrastructure of distribution. In such conditions capacitors are very useful for the power system. Optimal placement of capacitors in power system results in voltage profile improvement and power factor improvement. It also reduces the losses and releases the capacity of power system. All this achievements of capacitor placement depends upon how optimally the capacitors are installed in power system. [1]

A number of techniques have been used to solve capacitor placement problem which are classified in four categories which are Analytical method, numerical programming method, heuristic search methods and artificial intelligence based methods. The most useful method is the analytic method. This method supposes that the feeder hasn't any sub branches. Its cross-section is the same in all parts and has been distributed equally in the feeder. The analytic methods need a few numerical data from the distributive system and their application is very easy in practice. So, in spite of the existing unreal hypotheses in them, some of the regional electricity companies have established the basis of their capacitor placement programs on this law, or some of the capacitor manufacturing factories, recommend this law in the manual of their manufactured products. [3] Some of the analytical methods were based on assumptions. So when real world problem were to be solved considering all the factors analytical, heuristic and numerical programming methods don't work well. In recent years artificial intelligence methods used for optimal capacitor placement showed promising results. The artificial intelligence techniques used for this problem are genetic algorithm and particle swarm optimization.

AI-based methods include genetic algorithms, simulated annealing, expert systems, artificial neural networks, and fuzzy logic. [4]A modern artificial intelligence method, particle swarm optimization is used to solve the capacitor placement with all the realistic problem formulation considerations. This optimization technique can be used to solve many of the same kinds of problems as GA, and does not suffer from some of GA's difficulties. [2]

II PROBLEM FORMULATION

For minimizing the load voltage magnitude deviation and loss of power system the determination of the optimal location and the optimal parameter setting of the capacitor in the power system is the main objective.

$$F_{min}=F_1+F_2$$
$$=P_{loss}+ VD$$

Where, P_{loss}= network real power loss
VD=voltage deviation

$$F1=P_{loss}=\sum_{k=1}^{nl} G_{ij}[V_i^2 + V_j^2 -2V_iV_j\cos\Theta_{ij}]$$

$$F_2 = VD = \frac{\sum N_{PQ}\ |Vi-V_{ref.}|}{N_{PQ}}$$

Where G_{ij} =mutual conductance of transmission line between bus i and bus j

V_i =Voltage at ith bus
V_j =voltage at jth bus
V_{ref} = reference voltage magnitude
Θ_{ij} = Voltage angle difference between bus i and busj
N_{PQ} = Number of PQ bus
Vmin=minimum bus voltage limit
Vmax=maximum bus voltage limit

The voltage magnitude at each bus must be maintained within its limits and is expressed as:
$Vmin<|Vi|<Vmax$

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a artificial intelligence method. Particle swarm optimization is a metaheuristic search method that was developed by Dr Kennedy and Eberhart. Particle swarm optimization method is inspired social behaviour of flocking of birds and fish school. While searching for food, the birds are either scattered or go together before they locate the place where they can find the food. While the birds are searching for food from one place to another, there is always a bird that can smell the food very well, that is, the bird is perceptible of the place where the food can be found, having the better food resource information. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another, conduced by the good information, the birds will eventually flock to the place where food can be found. As far as particle swam optimization algorithm is concerned, solution swam is compared to the bird swarm, the birds' moving from one place to another is equal to the development of the solution swarm, good information is equal to the most optimist solution, and the food resource is equal to the most optimist solution during the whole course. The most optimist solution can be worked out in particle swarm optimization algorithm by the cooperation of each individual. The particle without quality and volume serves as each individual, and the simple behavioral pattern is regulated for each particle to show the complexity of the whole particle swarm. This algorithm can be used to work out the complex optimist problems [6] Particle swarm optimization is an iterative method. In this method, numbers of particles are generated randomly. Each particle represents a solution to the problem. Each particle is moves in the search space with initial velocity. In each iteration velocity and position of the particles is updated. Each particle is influenced by its own best position and by swarm's best position. [5][1]Each particle adjust its position according its own experience , and the experience of the neighbouring particles , making use of the best position encountered by itself and its neighbours as shown in fig.1. as follows.[5]

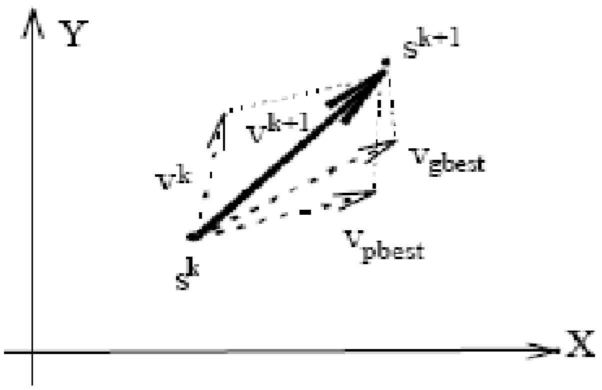

Fig1: The swarm direction of a particle is defined by the set of particle neighboring the particle and its history experience.[5]

S_k = current searching point,
S_{k+1}= modified searching point,
V_k = current velocity,
V_{k+1} = modified velocity,
V_{pbest}= velocity based on Pbest,
V_{gbest}= velocity based on Gbest.

PSO is easy to implement as it does not involve genetic operators such as crossover and mutation of genetic algorithm. Particles update themselves with the internal velocity. Particles also have memory, which is important to the algorithm. In PSO, only global best gives out the information to others. It is a one -way information sharing mechanism. The evolution only looks for the best solution. [2]

IV.BASIC PSO ALGORITHM

Flow chart of basic PSO algorithm is shown in fig 2. In the basic particle swarm optimization algorithm, particle swarm consists of number of particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition according to old velocity, personal best position of the particle and swarm's best position that is the global best. The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (swarm experience). [8]

The velocity term presents the rate of change in the position of the particle. So, the changes induced by the velocity update equation represent acceleration, which is the reason the name of acceleration coefficients for the constants c1 and c2. The acceleration coefficients can be thought of as a balance between exploration that is searching for a good solution by particle itself and exploitation taking advantage of someone else's success that is of swarm. Too little exploration and the particles will all converge on the first good solution encountered, while too little exploitation and the particles will never converge, i.e. they will just keep searching. There is another way of looking at this rather than behaviors (exploration and exploitation). What must be properly balanced is individuality and sociality,i.e.traits that influence behavior. Ideally, individuals prefer being individualistic yet they still like to know what others have achieved so that they can learn from. [4]

To ensure convergence of PSO adjustments of various parameters need to be carefully adjusted in order to achieve better performance of the algorithm. In a PSO algorithm, the population has n particles that represent candidate solutions. Each particle is a k-dimensional real-valued vector, where k is the number of the optimized parameters. Therefore, each optimized parameter represents a dimension of the problem space. The PSO technique steps can be described as below. [6]

PSO is a computational intelligence-based technique that is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge. It can, therefore, be effectively applied to different optimization problems in power systems. A number of papers have been published in the past few years that focus on this issue. Moreover, PSO has some advantages over other similar optimization techniques such as GA, namely the following.

1) PSO is easier to implement and there are fewer parameters to adjust.

2) In PSO, every particle remembers its own previous best value as well as the neighborhood best; therefore, it has a more effective memory capability than the GA.

3) PSO is more efficient in maintaining the diversity of the swarm (more similar to the ideal social interaction in a community), since all the particles use the information related to the most successful particle in order to improve themselves, whereas in GA, the worse solutions are discarded and only the good ones are saved; therefore, in GA the population evolves around a subset of the best individuals.

PSO is based on two fundamental disciplines: social science and computer science. In addition, PSO uses the swarm intelligence concept, which is the property of a system, whereby the collective behaviours of unsophisticated agents that are interacting locally with their environment create coherent global functional patterns. [9]

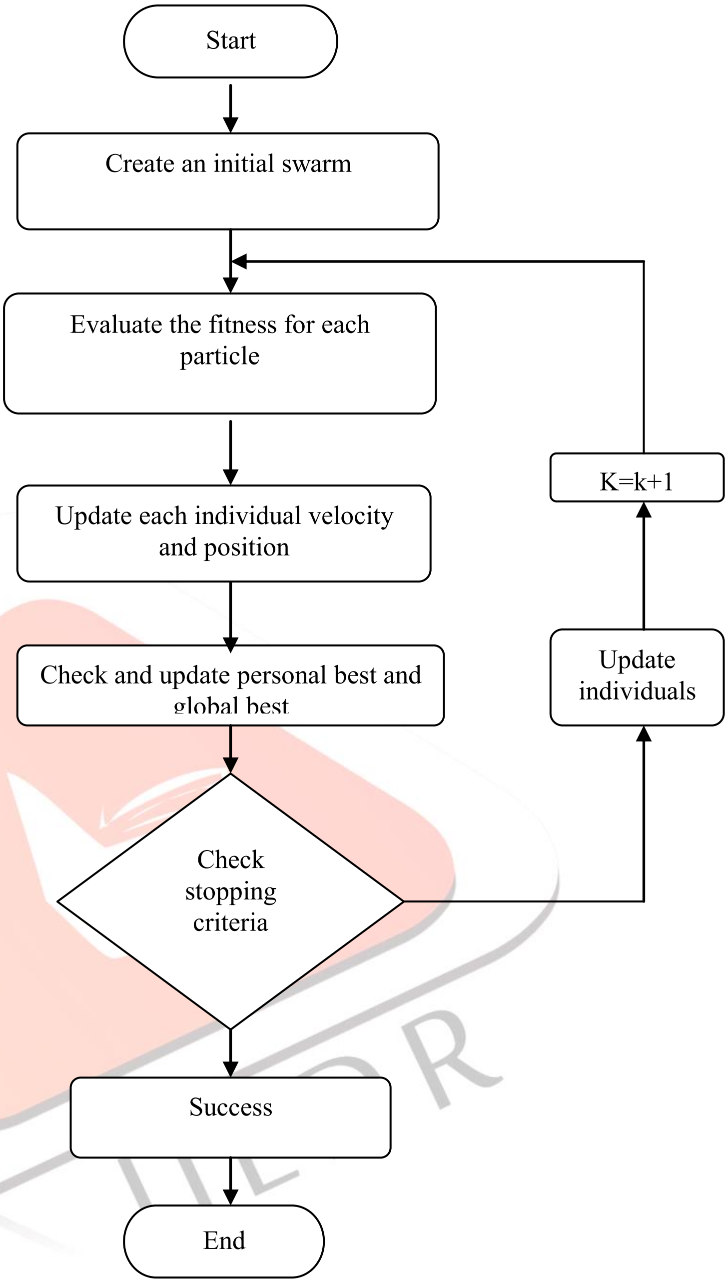

Fig 2: Flow chart of PSO

X_k^i = Particle position
V_k^i = Particle velocity
P_k^i = Best "remembered" individual particle position
P_k^g = Best "remembered" swarm position
c_1,c_2 = Cognitive and social parameters
r_1,r_2 = Random numbers between 0 and 1[7]

IV.STEPS FOR BASIC PSO

Step 1: Initialization

In particle swarm optimization a set of random particles is generated within limits. Each set represents a solution. [3]Also PSO parameters are defined in beginning. Initially assign random velocities and position for the particles. Also set the values of constant. [7]

Find the personal best of particle P_{best} and global best of swarm G_{best}.

Step 2: Evaluate the fitness of each particle
Compute the objective function in this step. [7] Evaluate the fitness value of each particle F_k^i.

Step 3: Check and update for local best and global best

If $F_k^i \leq F_{best}^i$ then $F_{best}^i = F_k^i$, $P_k^i = X_k^i$. If $F_k^i \leq G_{best}$ then $G_{best} = Fk^i$, $P_k^g = X_k^i$[7]

Step 4: Update velocity and position of particle

The Equation to update position:

$$X_k^{i+1} = X_k^i + V_{k+1}^i$$

The equation to update velocity is:

$$V_{k+1}^i = wV_k^i + c_1r_1(P_k^i - X_k^i) + c_2r_2(P_k^g - X_k^i)$$

In the above equation the term "$c_1r_1(P_k^i - X_k^i)$" is called the cognitive parameter whereas other term " $c_2r_2(P_k^g - X_k^i)$" is called the social parameter. The cognitive parameter causes the particle to move towards personal best. The social parameter moves the particle towards the global best position. [5]

w is the inertia weight. The inertia weight governs how much of the previous velocity should be retained from the previous time step. The inertia weight is set to decrease linearly from 0.9 to 0.4 during the course of a simulation. This inertia allows the PSO to explore a large area at the start of the simulation that is when the inertia weight is large, and to refine the search later by using a small inertia weight. In addition, damping the oscillations of the particles around gbest is another advantage gained by using a decreasing inertia weight. These oscillations are recorded when a large constant inertia weight is used. Accordingly, damping such oscillations assists the particles of the swarm to converge to the global optimal solution.[4]

Step 5: Check stopping criteria
If one of the stopping criteria is satisfied, then stop otherwise go to Step 2.[6][7] This is the condition to terminate the search process. It can be achieved either if the number of the iterations exceeds pre-specified number or the number of iterations reaches a pre-specified maximum value. [2]

Step 6: Terminate

If the success is achieved then stop. [7]

V. PSUEDOCODE

Pseudocode typically omits details that are not essential for human understanding of the algorithm, such as variable declarations. The purpose of using pseudocode is that it makes easier for people to understand than conventional programming language code, and that it is an efficient description of the key principles of an algorithm. It is commonly used in textbooks and scientific publications that are documenting various algorithms, and also in planning of computer program development, for sketching out the structure of the program before the actual coding takes place. This code is very useful for construction of the program of particle swarm optimization in the programming language like matlab.

The psuedocode for the proposed algorithm is: [6]

```
Beginning
        Generation of the swarm initial parameters;
        For each iteration
                For each particle
                Buses voltages receive particle values;
                Calculate the PV buses reactive power;
                Calculate the slack bus power;
                Calculate the load flow in the system lines;
                Calculate the mean of buses apparent
                        Power Mismatches;
                Local best updating criterion;
        End For each particle
        Global best updating criterion;
        Update all the particles velocities;
        Update all the particles positions;
   End For each iteration
End
```

VI.CONCLUSION

The particle swarm optimization algorithm can be used for optimization purpose. Particle swam optimization is a new heuristic optimization method based on swarm intelligence. Compared with the other algorithms, the method is very simple, easily completed and it needs fewer parameters, which made it fully developed.In ref [1] this method is successfully applied to solve the problem of optimal placement of capacitors. In [6] the same method is successfully applied for optimal placement of Facts devices. Particle swarm optimization is a fast and promising method for solving the problem of optimal placement of capacitor. [1] The power losses of radial distribution system can be efficiently reduced by proper placement of shunt capacitor. In addition of power factor improvement, power loss reduction, the voltage profile can be improved as well by the particle swarm optimization method. An effective approach for optimum location of capacitor in radial distribution system has been proposed. [2]Thus the particle swarm optimization method is a novel and promising method for optimal placement of capacitor in power system.

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