Optimal Power Flow by Particle Swarm Optimization for Reactive Loss Minimization

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Abstract- Optimal Power Flow (OPF) problem in electrical power system is considered as a static, non-linear, multi-objective or a single objective optimization problem. As the power industrial companies have been moving into a more competitive environment, OPF has been used as a tool to define the level of the inter utility power exchange. Basically, this research work provides a new approach to solve the single objective OPF problem considering critical objective function of reactive loss minimization for utility/ industrial companies, while satisfying a set of system operating constraints, including constraints dedicated by the electrical network. Particle Swarm Optimization (PSO) has been used for this purpose. Particle Swarm Optimization (PSO) is a population based stochastic optimization technique. The system is initialized with a population of random feasible solutions and searches for optima by updating generations. The IEEE- 30 bus system is considered throughout this research work to test the proposed algorithm.

Keywords— OPF-optimal power flow, PSO-particle swarm optimization.

I. INTRODUCTION

The Optimal Power Flow (OPF) has been widely used for both the operation and planning of a power system. Therefore, a typical OPF solution adjusting the appropriate control variables, so that a specific objective in operating a power system network is optimized (maximizing or minimizing) with respect to the power system constraints, dictated by the electrical network. In this thesis single objective OPF problem considering reactive loss minimization optimization. For optimization any optimization technique is required and Particle Swarm Optimization (PSO) is used in this research. Particle Swarm Optimization (PSO) is a relatively new evolutionary algorithm that may be used to find optimal (or near optimal) solutions to numerical and qualitative problems. Particle Swarm Optimization was originally developed by a social psychologist (James Kennedy) and an electrical engineer (Russell Eberhart) in 1995, and emerged from earlier experiments with algorithms that modelled the flocking behavior seen in many species of birds.

II. OPTIMAL POWER FLOW SOLUTION METHODS

CLASSICAL METHODS [2]:

1. Linear Programming (LP) Method
2. Newton-Raphson (NR) Method
3. Quadratic Programming (QP) Method
4. Nonlinear Programming (NLP) Method
5. Interior Point (IP) Method

Artificial Intelligence (AI) Methods:

1. Artificial Neural Network (ANN)
2. Fuzzy Logic Method (FL)
3. Genetic Algorithm (GA) Method
4. Evolutionary Programming (EP)
5. Ant Colony Optimization (ACO)
6. Particle Swarm Optimization (PSO)

A. *COMPARISON OF ABOVE METHODS*

Even though, excellent advancements have been made in classical methods, they suffer with the following disadvantages: In most cases, mathematical formulations have to be simplified to get the solutions because of the extremely limited capability to solve real-world large-scale power system problems. They are weak in handling qualitative constraints. They have poor convergence, may get stuck at local optimum, they can find only a single optimized solution in a single simulation run, they become too slow if the number of variables are large and they are computationally expensive for the solution of a large system. Whereas, the major advantage of the AI methods is that they are relatively versatile for handling various qualitative constraints. AI methods can find multiple optimal solutions in a single simulation run. So they are quite suitable in solving multi-objective optimization problems. In most cases, they can find the global optimum solution.The main advantages of ANN are: Possesses learning ability, fast, appropriate for non-linear modelling, etc. whereas, large dimensionality and the choice of training methodology are some disadvantages of ANN.The

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advantages of Fuzzy method are: Accurately represents the operational constraints and fuzzified constraints are softer than traditional constraints. The advantages of GA methods are: It only uses the values of the objective function and less likely to get trapped in a local optimum. Higher computational time is its disadvantage. The advantages of the EP are adaptable to change, ability to generate good enough solutions and rapid convergence. ACO and PSO are the latest entry in the field of optimization. The main advantages of the ACO are positive feedback for recovery of good solutions, distributed computation, which avoids premature convergence. It has been mainly used in finding the shortest route in the transmission network, short-term generation scheduling and optimal unit commitment. PSO can be used to solve complex optimization problems, which are non-linear, non-differentiable and multi-model. The main merits of PSO are its fast convergence speed and it can be realized simply for less parameters need adjusting. PSO has been mainly used to solve Bi-objective generation scheduling, optimal reactive power dispatch and to minimize total cost of power generation. Yet, the applications of ACO and PSO to solve Security constrained OPF, Contingency constrained OPF, Congestion management incorporating FACTS devices etc. Of a deregulated power system are to be explored out.

TABLE I
SUITABLE METHODS FOR SOLVING THE VARIOUS OPTIMIZATION PROBLEMS OF ELECTRICAL ENGINEERING.

Objective function to be optimized	Suitable method(s)	Reason to use that method
Economic dispatch	LP, NR	Fast methods
Economic dispatch with non-smooth cost function	AI	Nonlinear problem
Economic emission dispatch	Fuzzy	Suitable for conflicting objectives
Reactive power optimization	NLP, OP, IP, AI	Accurate methods
Optimal location of FACTS device	AI	Multi objective non-linear problem
Social welfare	QP, AI	Multi objective non-linear problem
Congestion management	AI	Multi objective non-linear problem
Security constrained OPF	NLP, IP	Stable convergence

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a relatively new evolutionary algorithm that may be used to find optimal (or near optimal) solutions to numerical and qualitative problems. Particle Swarm Optimization was originally developed by James Kennedy and Russell Eberhart in 1995, and emerged from earlier experiments with algorithms that modelled the flocking behaviour seen in many species of birds.In simulations, birds would begin by flying around with no particular destination and spontaneously formed flocks until one of the birds flew over the roosting area. Due to the simple rules the birds used to set their directions and velocities, a bird pulling away from the flock in order to land at the roost would result in nearby birds moving towards the roost. Once these birds discovered the roost, they would land there, pulling more birds towards it, and so on until the entire flock had landed. Finding a roost is analogous to finding a solution in a field of possible solutions in a solution space. The manner in which a bird who has found the roost, leads its neighbours to move towards it, increases the chances that they will also find it. This is known as the "socio-cognitive view of mind". The "socio-cognitive view of mind" means that a particle learns primarily from the success of its neighbours.The concept of the PSO consists of, at each time step, changing the velocity of (accelerating) each particle toward its pbest and lbest locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and lbest locations. In the past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods.

A. *Basic Terms Used in PSO*

The basic terms used in PSO technique are stated and defined as follows [11]:

1. **Particle X (I)**: It is a candidate solution represented by a k-dimensional real-valued vector, where k is the number of optimized parameters. At iteration i, the jth particle X (i,j) can be described as:

$X_i(i) = [X_{j1}(i); X_{j2}(i);.....X_{jk}(i);.....X_{jd}$

Where:

x's are the optimized parameters

d represents number of control variables

2. **Population:** It is basically a set of n particles at iteration i.

pop (i)= [X 1 (i), X 2 (i), ...X n (i)]T

Where: n represents the number of candidate solutions.

3. **Swarm:** Swarm may be defined as an apparently disorganized population of moving particles that tend to

cluster together while each particle seems to be moving in a random direction.

4. **Particle velocity V (i)**: Particle velocity is the velocity of the moving particles represented by a d-dimensional real-valued vector. At iteration i, the jth particle Vj (i) can be described as:

V j (i) = [V j1 (i);V j2 (i);.....V jk (i);.....V jd (i);]

Where:

V jk (i) is the velocity component of the jth particle with respect to the kth dimension.

5. **Inertia weight w (i)**: It is a control parameter, which is used to control the impact of the previous velocity on the current velocity. Hence, it influences the trade-off between the global and local exploration abilities of the particles. For the initial stages of the search process, large inertia weight to enhance the global exploration is recommended while it should be reduced at the last stages for better local exploration. Therefore, the inertia factor decreases linearly from about 0.9 to 0.4 during a run. In general, this factor is set according to the following equation :

W = Wmax –((Wmax - Wmin) / itermax)* iter

Where: itermax is the maximum number of iterations and iter is the current number of iterations.

6. **Individual best X* (i):** When particles are moving through the search space , it compares its fitness value at the current position to the best fitness value it has ever reached at any iteration up to the current iteration. The best position that is associated with the best fitness encountered so far is called the individual best X* (i).

For each particle in the swarm, X*(i)can be determined and updated during the search.

For the jth particle, individual best can be expressed as:

X j (i) = [X j ,1 *(i), X j ,2. *(i),..........X j ,d *(i)]

In a minimization problem with only one objective function f, the individual best of the jth particle Xj*(i) is updated whenever f (Xj*(i)) < f (Xj*(i-1)). Otherwise, the individual best solution of the jth particle will be kept as in the previous iteration.

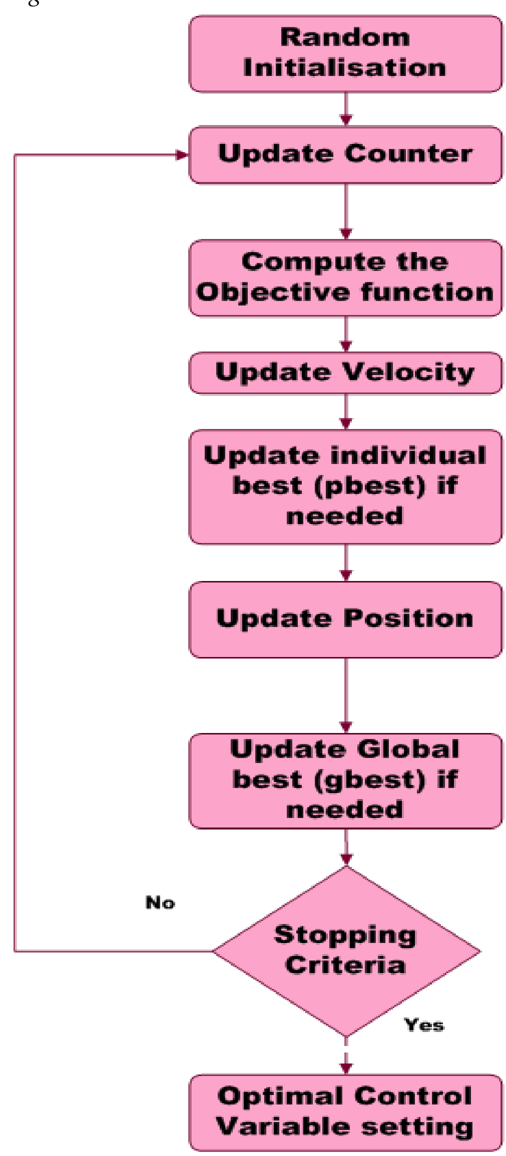
7.**Global best X** (t):** Global best is the best position among all of the individual best positions achieved so far.

8. **Stopping criteria:** Termination of the search process will take place whenever one of the following criteria is satisfied:

B. *Advantages of PSO*

Many advantages of PSO over other traditional optimization techniques can be summarized as follows :PSO is a population-based search algorithm. This property ensures PSO to be less susceptible in being trapped on local minima. PSO makes use of the probabilistic transition rules and not deterministic rules. Hence, PSO is a kind of stochastic optimization algorithm that can search a complicated and uncertain area. This makes PSO more flexible and robust than conventional methods. PSO can easily deal with non-differentiable objective functions because PSO uses payoff (performance index or objective function) information to guide the search in the problem space. Additionally, this property relieves PSO of assumptions and approximations, which are often required by traditional optimization models. 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 which makes it different from Genetic Algorithm (GA) and other heuristic algorithms.

C. *Flowchart for Basic Particle Swarm Optimization Algorithm*



IV. OPF using PSO

A. *The Objectives: Minimization of Reactive Power Transmission Loss*

Static network-related system Voltage Stability Margin (VSM) depends on the availability of reactive power to support the transportation of real power from sources to sinks. In practice, the Q_L is not necessarily positive. The expression for reactive power loss minimization is as below:

$$Q_L=\sum Qgi-\sum Qdi$$

B. *The various steps involved in the implementation of PSO to the OPF problem are[3]*

Step 1: Firstly read the Input parameters of the system (bus, line and generator data) and also specify the lower and upper boundaries of each variable. For N generators, optimization is carried out for N-1 generators and generator of large capacity is considered at slack bus.

Step 2: Then the particles of the population are randomly initialized i.e. are randomly selected between the respective minimum and maximum values. Also assign the velocity V initially between [-1 and 1].

Step 3: Obtain power flow solution and compute losses by Newton-Raphson method.

Step 4: The best fitness is assign ed as *pBest* . At this stage the *pBest* is also the *gBest* .

Step 5: Iteration i = i+1 is updated.

Step 6: Update the inertia weight w given by

$$W =– (W_{max} - W_{min}) / iter_{max} = iter$$

Step 7: Modify the velocity v of each particle according to the mentioned equation.

V (k,j,i+1) = w*V(k,j,i) + C1*rand*(pbestx (j,k) - x(k,j,i)) + C2*rand*(gbestx (k) - x(k,j,i)) .....(a)

Step 8: Position of each particle is also modified according to the mentioned equation.
If a particle violates the its position limits in any dimension, its position is set at the proper limit.

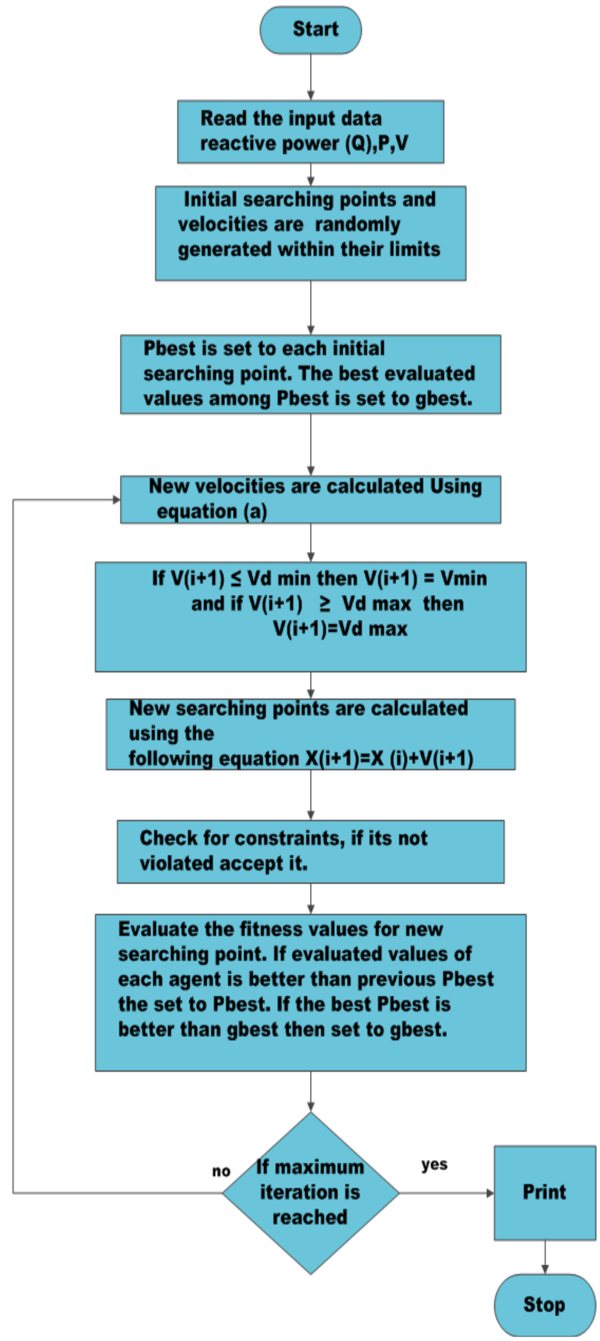
$$x(k,j,i ⊚ 1) ⊚ x(k,j ⊚ 1,i) ⊚ v(k,j,i)$$

Step 9: Evaluation of each particle is done according to its updated position by running power flow and calculate the fitness function. If the evaluation value of each particle is better than the previous *pBest* then the current value is set to be *pBest* . If the best *pBest* is better than *gBest* , the value is set to be gbest.

Step 10: If one of the stopping criteria is satisfied then we go to Step 11. Otherwise, we go to Step 5.

Step 11: *gBest* is the optimal value that is latestly generated by the particle.

C. *Flow chart for PSO based OPF*



D. *The parameters that must be selected carefully for the efficient performance of PSO algorithm are:-*

1. Both acceleration factors C1 & C2. (0-4)
2. Number of particles.
3. Inertia factor w

The search will terminate if one of the below scenario is encountered:

-gbest f(i) – gbest f(i-1)∣ < 0.0001 for 50 iterations
Maximum number of iteration reached (500 iterations)

V. SIMULATION RESULTS

The OPF using PSO has been carried out on the IEEE 30 bus system. The specifications of the IEEE 30 bus system are given in Appendix A. The OPF solution has been attempted for minimizing the reactive power loss by considering the (i) Generated PV and slack bus voltages, (ii) Voltage limits for load bus voltages as control variables.
The simulation has been carried out on the system having an Intel core i5 2.67 GHz processor with 4 GB of RAM in MATLAB 7.7.0 environment. Results are viewed as reactive power loss as objective function. For the studies, the population size is considered as 50 Generated PV and slack bus voltages between 0.95 to 1.15, Voltage limits for load buses are 0.95 to 1.05

A. Various Case studies:

TABLE II

THE ABOVE STUDY HAS BEEN SUMMARIZED UNDER THE FOLLOWING CASES

Case no.	Name
Case 1	Base case power flow solution Newton-Raphson method.(before optimization)
Case 2	Optimal Power Flow solution by Particle swarm optimization for Minimizing Reactive Power Loss

TABLE III

COMPARISON OF VOLTAGE MAGNITUDE

Bus No.	Voltage Magnitude as per IEEE specification In p.u.	Voltage Magnitude before applying PSO In p.u.	Voltage Magnitude after applying PSO In p.u.
1	1	1	1.032481
2	1	0.98	1.015079
3	1	0.953318	0.994568
4	1	0.944309	0.98718
5	1	0.95	0.987554
6	1	0.944243	0.989664
11	1	1	1.046949
12	1	0.983506	1.031638
13	1	1	1.047678
14	1	0.967354	1.016218
15	1	0.962282	1.011325
16	1	0.969677	1.01818
17	1	0.963589	1.012103
18	1	0.951564	1.000944
19	1	0.948617	0.998025
20	1	0.952909	1.002041
21	1	0.955973	1.004804
22	1	0.956607	1.005427
23	1	0.950896	1.000395
24	1	0.944794	0.994448
25	1	0.942281	0.992299
26	1	0.923133	0.974157
27	1	0.949998	0.999746
28	1	0.94009	0.986903
29	1	0.928441	0.979388
30	1	0.91598	0.967615

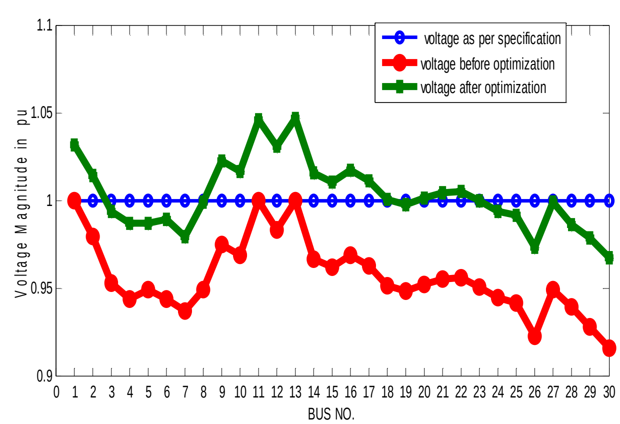


Fig. I Voltage Magnitude –bus no.

TABLE:IV
COMPARISON OF REACTIVE LOSSES

Reactive loss before applying PSO In Mvar	Reactive loss after applying PSO In Mvar
79.5	73.5

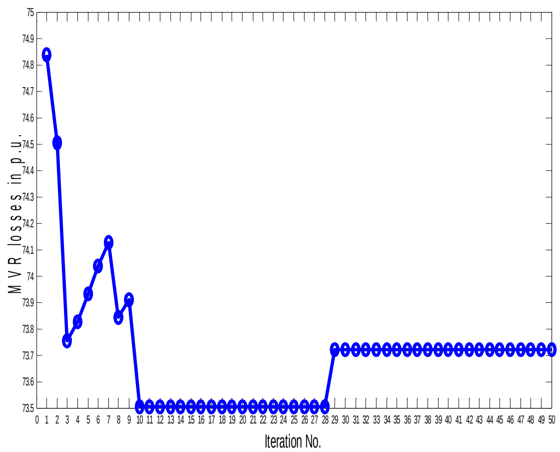


Fig. II MVR losses-Iteration No.

B. Interpretation of result

After applying optimization technique (PSO)

- Reactive loss decreases.
- Nodal Voltage uplift

VI. CONCLUSION

This thesis work has significantly accomplished many attainments in the area under discussion which is the single objective Optimal Power Flow. The various achievements can be summarized as follows, implementing a single OPF objective function optimization algorithm based on the Particle Swarm Optimization (PSO). An algorithm is developed and applied to a practical power system network. The developed OPF algorithm offers the following: Provides a flexibility to add or delete any system constraints and objective functions. Having this flexibility will help electrical engineers analysing other system scenarios and contingency plans. Calculate the optimum generation pattern as well as all control variables in order to minimize reactive loss together with meeting the transmission system limitations. Reactive loss decrease after applying PSO and bus voltages uplift after applying PSO. To find the optimum setting for system control variables that achieve a minimum objective function. These control variables include: active power generation except the slack bus; all PV-bus voltages; all transformer load tap changers; and the setting of all switched reactors or static VAR components.

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