MINIMIZE POWER LOSS USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

Tarunkumar D. Patel

Student, M.E., Electrical Engineering, Shri Satsangi Saketdham Ram Ashram Group of Institutions College Vadasma, India

A. G. Acharya

Assistant Professor, Electrical department, Shri Satsangi Saketdham Ram Ashram Group of Institutions College vadasma, india

ABSTRACT

Abstract: This paper presents the solution of optimal power flow (OPF) using particle swarm optimization (PSO). The objective function is minimize power loss by adjustment the power control variables and at the same time satisfying the equality and inequality constraints. The proposed particle swarm optimization (PSO) method is compared with newton's Raphson method (conventional method) approach on the standard IEEE 14 bus system. The analysis indicated that Particle Swarm Optimization (PSO) method was the most efficient method in terms of minimizing the power loss. This can be concluded that the Artificial Intelligence (AI) method such as Particle Swarm Optimization (PSO) is the most suitable and efficient method for analysing the Optimal Power Flow (OPF) problem in terms of minimizing power loss.

Keywords: Economic Load dispatch, OPF – optimal power flow, PSO – particle swarm optimization, NR Method, IEEE-14 Bus test system, minimize power loss using PSO.

Cite this Article: Tarunkumar D. Patel and A. G. Acharya, Minimize Power Loss using Particle Swarm Optimization Technique, International Journal of Electrical Engineering and Technology, 10(2), 2019, pp. 69-80.
<http://iaeme.com/Home/issue/IJEET?Volume=10&Issue=2>

1. INTRODUCTION

The main task in electrical power system is to optimize a selected objective function such as minimization of power loss by adjusting the state variable as well as at the same time satisfying the equality and inequality constraints. The control variables are generator real power, generator bus voltage, transformer tap changer and the Reactive power source such as shunt capacitor. There are many techniques available to handle such OPF problems such as non linear programming, quadratic programming, linear programming; Newton based method sequential unconstrained minimization and interior point method. These methods have the drawback-the convergence characteristics are sensitive to the initial condition. Generally the

OPF problems are non convex, non smooth and non differential. So we have to develop such a new optimization technique that is efficient to overcome their drawbacks and to handle the difficulties easily. Heuristic algorithm such as GA, gradient method and evolutionary computation technique has been recently proposed for solving the OPF problem. Recently some deficiencies have been identified in GA performance. A new evolutionary technique called particle swarm optimization has been proposed and introduced by The Kennedy. This technique is based on the sociological behaviour such as fish schooling and bird flocking. In this paper a novel PSO based approach is proposed to solve OPF problem. Since the PSO handle the both continuous and discrete variable easily. Therefore this method can be easily applied to mixed integer nonlinear program. PSO is suitable for cost minimization because it can handle such constraints easily. Here the proposed PSO approach is tested for 14 bus system and compare with NR method.

2. METHODOLOGIES

The OPF methods are broadly grouped as Conventional and Intelligent. The conventional methodologies include the well known techniques like Gradient method, Newton method, Quadratic Programming method, Linear Programming method and Interior point method. Intelligent methodologies include the recently developed and popular methods like Genetic Algorithm, Particle swarm optimization.

1. Conventional (classical) methods
2. Intelligent methods

OPF Solution methodologies

Table 2.1 OPF Solution methodologies[12]

Conventional method	intelligent method
Gradient method	Genetic algorithm
Newton method	Ant colony method
Linear method	Evolutionary programming
Quadratic programming	Artificial neural network
Interior method	Particle swarm optimization

2.1. CONVENTIONAL METHOD

conventional methods are used to effectively solve OPF. The application of these methods had been an area of active research in the recent past.

The conventional methods are based on mathematical programming approaches and used to solve different size of OPF problems. To meet the requirements of different objective functions, types of application and nature of constraints

2.1.1. Newton Method

In the area of Power systems, Newton's method is well known for solution of Power Flow. It has been the standard solution algorithm for the power flow problem for a long time the Newton approach is a flexible formulation that can be adopted to develop different OPF algorithms suited to the requirements of different applications. Although the Newton approach exists as a concept entirely apart from any specific method of implementation, it would not be possible to develop practical OPF programs without employing special sparsity techniques. The concept and the techniques together comprise the given approach. Other Newton-based approaches are possible.

Newton's method is a very powerful solution algorithm because of its rapid convergence near the solution. This property is especially useful for power system applications because an

initial guess near the solution is easily attained. System voltages will be near rated system values, generator outputs can be estimated from historical data, and transformer tap ratios will be near 1.0 p.u

Newton's Raphson method is solving a set of non linear algebraic equation. NR method is solving power flow based problem. Has also good convergence characteristics even for large system it take only two to four iteration to converge.

2.1.2. COMPUTATIONAL ALGORITHMS FOR NEWTON RAPHSON LOAD FLOW METHOD

Step 1: Form the nodal admittance matrix (Y_{ij}).

Step 2: Assume an initial set of bus voltage and set bus n as the reference bus as:

$$V_i = V_i, \text{ spec} \angle 0^0 \text{ (at all PV buses)}$$

$$V_i = 1 \angle 0^0 \text{ (at all PQ buses)}$$

Step 3: Calculate the real Power P_i using the load flow equation:

$$|V|^2 G_{ii} + \sum_{n=1, n \neq i}^N |V_i| |V_n| |Y_{in}| \cos(\theta_{in} + \delta_n - \delta_i) = P_i$$

Step 4: Calculate the real Power Q_i using the load flow equation:

$$-|V|^2 B_{ii} + \sum_{n=1, n \neq i}^N |V_i| |V_n| |Y_{in}| \sin(\theta_{in} + \delta_n - \delta_i) = Q_i$$

Step 5: from the Jacobian matrix sub matrix H, N, K, and L can be calculated as follows:

$$\begin{aligned} H_{ii} &= -Q_i - |V_i|^2 B_{ii} & N_{ii} &= P_i + |V_i|^2 G_{ii} \\ M_{ii} &= P_i - |V_i|^2 G_{ii} & L_{ii} &= Q_i - |V_i|^2 B_{ii} \\ H_{ij} &= -|V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) & N_{ij} &= |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) \\ M_{ij} &= -|V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) & L_{ij} &= -|V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \end{aligned}$$

The dimension of the sub matrix are as follows:

$$\begin{aligned} H & (N_1 + N_2) \times (N_1 + N_2) & N & (N_1 + N_2) \times N_1 \\ M & N_1 \times (N_1 + N_2) \text{ and} & L & N_1 \times N_1 \end{aligned}$$

Where N_1 is the number of P-Q buses N_2 is P-V buses .

Step 6: Find the power differences ΔP_i and ΔQ_i for all $i=1, 2, 3 \dots (n-1)$;

$$\Delta P_i = P_{i,spec} - P_{i,cal}, \quad \Delta Q_i = Q_{i,spec} - Q_{i,cal},$$

Step 7: Choose the tolerance values.

Step 8: Stop the iteration if all ΔP_i and ΔQ_i are within the tolerance values.

Step 9: Update the values of V_i and $\Delta \delta_i$ using the equation $X^{k+1} = X^k + \Delta$

2.1.3. FLOW CHART FOR NEWTON RAPHSON LOAD FLOW METHOD

In context to various steps involved in carrying out load flow studies with Newton Raphson method, following detailed flow chart has been designed.

Figure 2.1 flow chart of newton Raphson method for power loss[12]

2.2. INTELLIGENT METHOD

The major advantage of the intelligent method is that they are relatively versatile for handling various qualitative constraints. These methods can find multiple optimal solution in single simulation run. So they are quit suitable in solving multi objective optimization problem. In most case, they can find the global optimum solution.

PARTICLE SWARM OPTIMIZATION METHOD

The PSO is a relatively new and powerful intelligence evolution algorithm for solving optimization problems. It is a population-based approach.

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behaviour of bird flocking or fish schooling. was first developed in 1995 by Dr. James Kennedy and Dr. Russell Eberhart.

In PSO, the search for an optimal solution is conducted using a population of particles, each of which represents a candidate solution to the optimization problem. Particles change their position by flying round a multidimensional space by following current optimal particles until a relatively unchanged position has been achieved or until computational limitations are

exceeded. Each particle adjusts its trajectory towards its own previous best position and towards the global best position attained till them.

The aim of this method is to find the best performing individual among the whole group. It is used to solve wider ranges of complex different optimization problems such as function minimization and maximization.

2.2.1. PSO ALGORITHM TO IEEE 14-BUS TEST SYSTEM

1. Define the control variables within their allowable range as well as the population size and the number of iterations. Include the PSO parameters and define the data of the 14-bus test system.

2. Let iter = 0

3. Generate randomly the population of the particles as well as their velocities.

4. Run NR load flow for each particle to find out losses.

5. For each particle, calculate the fitness function using equation

$$F_p = \sum_{k \in N_E} P_{loss} + \text{Penalty Function}$$

where ,

The Penalty Function is given by

$k_1 \times \sum_{i=1}^{N_G} f(Q_{gi}) + k_2 \times \sum_{i=1}^N f(V_i) + k_3 \times \sum_{m=1}^{N_L} f(S_{lm})$, and k_1, k_2, k_3 are constants called penalty factor.

$$f(x) = \begin{cases} 0 & \text{if } x^{\min} \leq x \leq x^{\max} \\ (x - x^{\min})^2 & \text{if } x > x^{\max} \\ (x - x^{\min})^2 & \text{if } x < x^{\min} \end{cases}$$

6. For all particles, find out from their fitness, their P_{best} and g_{best} particle.

7. Let iter = iter+1.

8. calculate each particle velocity and adjust it, if there is violation of its limits

9. Calculate the new position of each particle.

10. Run NR load flow for each particle to find out losses.

11. For each particle, calculate the fitness function using equation $F_p = \sum_{k \in N_E} P_{loss} + \text{Penalty function}$

where ,

The Penalty Function is given by

$k_1 \times \sum_{i=1}^{N_G} f(Q_{gi}) + k_2 \times \sum_{i=1}^N f(V_i) + k_3 \times \sum_{m=1}^{N_L} f(S_{lm})$, and k_1, k_2, k_3 are constants called penalty factor.

$$f(x) = \begin{cases} 0 & \text{if } x^{\min} \leq x \leq x^{\max} \\ (x - x^{\min})^2 & \text{if } x > x^{\max} \\ (x - x^{\min})^2 & \text{if } x < x^{\min} \end{cases}$$

12. If current fitness p for each particle is better than P_{best} then set $P_{best} = p$.

13. Let g_{best} be set as best of P_{best}

14. Repeat at step 7 until the maximum number of iterations is completed

15. The optimized values of the control variables are given by the coordinates of g_{best} particle and the minimized value of the losses by the corresponding fitness function.

2.2.1. PARTICLE SWARM OPTIMIZATION FLOW CHART FOR MINIMIZE POWER LOSS

Figure 2.2 Flow chart of PSO [12]

3. THE PROBLEM FORMULATION

The LM mode of the OPF problem can be formulated as follows

Minimize $f(x, u)$

subject to $g(x, u) = 0$, equality constrain

and $h(x) \leq 0$, inequality constrain

where, f is the objective function to be minimized.

x is the vector of the dependent variable consisting of

1) Generator active power output stack bus P_{G1}

2) Load bus voltage V_L

3) Generator reactive power output Q_G

4) Transmission Line

Loadings S_l

Hence, x can be expressed as given below

$$X^T = [P_{G1}, V_{L1} \dots V_{L_{NL}}, Q_{G1} \dots Q_{G_{NG}}, S_l \dots s_{nl}]$$

Where, NL, NG and nl are number of load buses, number of generators and number of transmission line respectively

u is the vector of independent variable consisting of

- 1) Generator bus voltage V_G
- 2) Generator active power output at PG at PV buses except at the slack bus P_{G1}
- 3) Transformer Tap setting T
- 4) Shunt VAR compensation Q_C

Hence, u can be expressed as given below

$$u^T = [V_{G1} \text{ --- } V_{G_{NG}}, P_{G1} \text{ --- } P_{G_{NG}}, T_1 \text{ --- } T_{NT}, Q_{C1} \text{ --- } Q_{C_{NC}}]$$

Where, NT and NC are the number of the regulating transformers and shunt compensators, respectively

g is the equality constraint represents the typical load flow equation

$$P_{Gi} - P_{Di} - \sum_{j=1}^{NB} |V_i| |V_j| |V_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{NB} |V_i| |V_j| |V_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0$$

3.1. OBJECTIVE FUNCTION FOR POWER LOSSES OPTIMIZATION

The optimal reactive power dispatch problem is a complex optimization problem where a specific objective function is minimized while satisfying a number of constraints.

The objective is basically to minimize the system's total active power transmission losses by optimally adjusting various control variables while satisfying a given set of constraints.

OBJECTIVE FUNCTION

The objective function can be written as

$$\text{Min } P_L = \text{Min } \sum_{k=1}^{NTL} P_{k \text{ loss}} = \sum_{k=1}^{NTL} G_K (v_i^2 + v_j^2 - 2v_i v_j \cos \theta_{ij})$$

Where, v_i , v_j : voltage of the i-th and the j-th bus, and NTL : number of transmission lines

3.2. CONSTRAINTS FOR OBJECTIVE FUNCTION OF POWER LOSS MINIMIZATION

There are many alternatives available for reducing losses at the distribution level: reconfiguration, capacitor installation, load balancing, and introduction of higher voltage levels.

The controllable system quantities are generator MW, controlled voltage magnitude, reactive power injection from reactive power sources and transformer tapping.

The objective use herein is to minimize the power transmission loss function by optimizing the control variables within their limits. Therefore, no violation on other quantities (e.g. MVA flow of transmission lines, load bus voltage magnitude, generator MVAR) occurs in normal system operating conditions.

The OPF problem solution aims at optimizing specific objective functions such as loss of power by adjusting the power control variables and at the same time satisfying the equality and the inequality constraints. The inequality constraints are the upper and the lower limits at the control and some state variables, while the equality constraints are the power flow equations.

These are system constraints to be formed as equality and inequality constraints as shown below:

Equality Constraints b) Inequality Constraints

3.3. EQUALITY CONSTRAINTS

System constraints are generator MW, controlled voltage, reactive power injection from reactive power sources and transformer tapping. The objective is to minimize the power transmission loss function by optimizing the control variables within their limits. Hence there will be no violation on other quantities (e.g. MVA flow of transmission lines, load bus voltage magnitude, generator MVAR) occurs in normal system operating conditions. These are system constraints to be formed as equality and inequality constraints as follows.

$$P_{Gi} - P_{Di} - \sum_{j=1}^{NB} |V_i| |V_j| |V_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{NB} |V_i| |V_j| |V_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0$$

Where,

P_{Gi} = is the real power generation at bus i
at bus j

P_{Di} = is the real power demand

Q_{Gi} = is the reactive power generation at bus i
demand at bus i

Q_{Di} = is the reactive power

NB = is the total number of buses
admittance element i,

θ_{ij} = is the angle of bus

V_{ij} = is the magnitude of bus admittance element i; j

3.4. INEQUALITY CONSTRAINTS

The inequality constraints are the system operating constraints. They are grouped into control variables and state variables. The control variables are self-restricted and include the generator bus voltages, the reactive power generated by the capacitor and the transformer tap settings. The state variables are restricted by adding a quadratic penalty term to the objective function and include reactive power generation, load bus voltages, active power generation at the slack bus, and line flow limit. These constraints are given by

Generators real power outputs

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad i = 1, 2, L, \dots, NG$$

The voltage magnitude limits for each bus

$$v_i^{min} \leq v_i \leq v_i^{max}, \quad i = 1, 2, L, \dots, NB \quad \text{where } N_B \text{ is the total number buses}$$

The reactive power generation limit for each generator bus is given by

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad i = 1, 2, L, \dots, NG \quad \text{where } N_g \text{ is the total number of generator buses}$$

The reactive power output of compensators

$$Q_{ci}^{min} \leq Q_{ci} \leq Q_{ci}^{max} \quad i = 1, 2, L, \dots, NC$$

The transformer tap-setting constraint

$$T_k^{min} \leq T_k \leq T_k^{max}$$

The power flow limit constraint of each transmission line

$$s_l \leq s_l^{max} \quad i = 1, 2, L, \dots, NTL$$

Where,

v_i^{min} and v_i^{max} = upper and lower limits of voltage magnitude of bus i

T_k^{min} and T_k^{max} = are upper and lower limit of tap positions of transformer k

Q_{ci}^{min} and Q_{ci}^{max} = upper and lower limits of reactive power source i

NG , NL : number of generator and load buses respectively, NTL : number of transmission lines

NT : number of regulating transformers, NC : number of shunt compensators,

3.5. FORMATION OF FITNESS FUNCTION

The fitness function FP is given by

$$f_p = \sum_{k \in N_E} P_{k \text{ loss}} + \text{Penalty Function}$$

Where, the Penalty Function is given by

$$k_1 \times \sum_{i=1}^{N_G} f(Q_{gi}) + k_2 \times \sum_{i=1}^N f(V_i) + k_3 \times \sum_{m=1}^{N_L} f(S_{lm})$$

and k_1, k_2, k_3 are constants called penalty factor.

$$f(x) = \begin{cases} 0 & \text{if } x^{min} \leq x \leq x^{max} \\ (x - x^{min})^2 & \text{if } x > x^{max} \\ (x - x^{min})^2 & \text{if } x < x^{min} \end{cases}$$

In x represents all control variables, x^{min} and x^{max} represent the minimum and maximum limits for all the control variables. The penalty function guarantees that, if there is violation of the system in case the control variables exceed their limits, the fitness function satisfies the inequality constraints.

4. MODIFICATION CONCEPT OF SEARCHING POINT BY PSO

The basic concept of PSO lies in accelerating each particle toward its P_{best} and the G_{best} locations. with a random weighted acceleration at each time step as shown in figure.

Figure 4.1 Modification concept of PSO [2]

Where,

S^K = current searching point

S^{K+1} = modified searching point

V^K = current velocity

V^{K+1} = modified velocity

$V_{P_{best}}$ = velocity based on P_{best}

$V_{G_{best}}$ = velocity based on G_{best}

4.1. VELOCITY UPDATE MACHANIM

Each particle tries to modify its position using the following information

The current positions, and The current velocity,

The distance between the current position and P_{best} , The distance between the current position and G_{best}

The modification of the particle's position can be mathematically modelled according the following equation:

$$V_i^{k+1} = wV_i^k + c_1 \text{rand}_1(.) \times (p_{best_i} - s_i^k) + c_2 \text{rand}_2(.) \times (g_{best_i} - s_i^k) \quad [7]$$

Where,

V_i^{k+1} = The velocity of i^{th} particle at $k + 1^{th}$ iteration, V_i^k = The velocity of i^{th} particle at k^{th} iteration

c_1, c_2 = Positive constants having values between $[0, 2.5]$, rand = uniformly distributed random number between 0 and 1,

w = Inertia weight of the particle, s_i^k = The position of i^{th} particle at k^{th} iteration

4.1.1. THE WEIGHTING FUNCTION IS USUALLY UTILIZED

$$w = w_{max} - \frac{w_{max} - w_{min}}{\text{iter}_{max}} \times \text{iteration} \quad [1]$$

A large inertial weight (w) facilitates a global search while a small inertia weight facilitates a local search. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run gives the best PSO performance compared with inertial weight settings.

Large w ----- greater global search ability, And Smaller w ----- greater local search ability.

Where,

w_{max} = initial weight,

w_{min} = final weight

Max. iteration = maximum iteration number,

Iteration = current iteration number

4.2. CURRENT POSITION CAN MODIFEIED

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad [2]$$

Where,

S^k = current searching point ,

S^{k+1} = modified searching point

V_i^{k+1} = new updated velocity of agent i at iteration $k+1$,

5. NR METHOD RESULTS

SYSTEM DIAGRAM

Figure 5.1 system diagram [2]

NEWTON RAPHSON METHOD DATA

Table 5.1 Newton Raphson method data

Total bus	14
Total transmission line	17
Total transformer	3
Total PV data	4
Total PQ data	11
Tolerance	0.001
Jacobian matrix	22*22
Iteration	10

Total real power losses in the system = 0.133859

Total reactive power losses in the system = 0.089733

PSO RESULTS

number of population size	20
Number of iteration	150
Number of decision variable	5
Inertia weight factor(w)	1
C1=C2	2.05

PSO DATA

Table 5.2 PSO data

No.	Benchmark function	Lower bound	Upper bound	Best loss
1.	Sphere function $F(x) = \sum_{i=1}^n x_i^2$	0	1	0.21784
2.	Ackley function $F(x, y) = -20 \exp[-0.2 \sqrt{0.5} (x^2 + y^2)]$ $-\exp[0.5(\cos 2\pi x + \cos 2\pi y)] + e + 20$	-5	5	14.3014
3.	Beale function $F(x, y) = (1.5 - x + xy)^2 +$ $(2.25 - x + xy^2)^2 + (2.625 - x + xy^3)^2$	-4.5	4.5	2.4661
4.	Booth function $F(x, y) = (1x + 2y - 7)^2 + (2x + y - 5)^2$	-10	10	14.5940

6. CONCLUSION

Particle swarm optimization for OPF problem has been proposed. The proposed approach has been tested and examined on the standard IEEE 14 bus system and benchmark function of optimization. The simulation results show the effectiveness and robustness of proposed algorithm to solve the OPF problem. As a results, the PSO method proves that it can find a place among the effective search method in order to find global solution. when comparing both newton Raphson method and particle swarm optimization method the minimum losses are obtained from particle swarm optimization method

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