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RESEARCH ARTICLE

OPTIMAL LOAD DISPATCH USING HYBRID PSO TECHNIQUE FOR THERMAL SCHEDULING PROBLEMS

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ABSTRACT

Optimal Load Dispatch (OLD) plays an important role in power system operation. The objective of Optimal Load Dispatch of electric power generation is to schedule the committed generating units outputs so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints. This paper presents a new optimization approach to solve the Optimal Load Dispatch (OLD) problems with power flow constraints. The proposed Hybrid PSO method employs PSO combined with EP technique. In this approach the best features of both PSO and EP are incorporated. The proposed method, PSO and EP have been tested on IEEE 14, IEEE 118 and 66 Bus Utility System. The results clearly shows that the proposed method outperforms standard PSO method and EP method on the same problem and can save considerable cost of Optimal Load Dispatch problems and this proposed method is well suitable for large and practical systems.

INTRODUCTION

Optimal Load Dispatch (OLD) pertains to optimum generation in an interconnected power system to minimize the cost of generation subject to relevant system constraints. In this paper the line loading (MVA) and voltage constraints, important for any practical implementation of short term OLD, are taken into consideration. The control of voltages, real and reactive power limit (MVA limit) on the transmission line is one of the most important activities in the modern power system. The main objective of the control can generally be regarded as an attempt to achieve an overall improvement of system security, service, reliability and economy. The present work solves the OLD problem with power flow constraints through effective application of combined Particle Swarm Optimization with Evolutionary Programming (Hybrid PSO) considering the system transmission loss, power balance equation, limits on an inequality constraint on active power generation, voltage on each bus and MVA loading in different lines. A wide variety of optimization techniques are applied in solving the OLD problem such as Linear Programming, Quadratic Programming and Genetic Algorithm (GA). Heuristic algorithms such as GA, has been proposed for solving OLD problems [8] and the premature convergence of GA degrades its performance and reduces its search capability. Linear Programming methods are fast and reliable, but main disadvantage associated is with the piece- wise linear cost approximation. Non-linear programming methods have a problem of convergence and algorithm complexity. Recently, a new optimization technique called Particle Swarm Optimization technique [8] has been applied to solve the OLD problem. The main objective of the present work is to develop and study the absolute as well as relative performance of following techniques applied to the power system OLD problem with power flow constraints, voltage on each bus, minimum and maximum generating limits and power balance constraint. The power flow constrained OLD problem is solved and necessary software has been developed using the following techniques:

1. Evolutionary Programming (EP) [7].
2. Particle Swarm Optimization (PSO) [8].
3. Proposed Hybrid PSO

The performance of the proposed Hybrid PSO is compared with EP and PSO. The proposed Hybrid PSO method and other EP technique, PSO algorithm are tested on three different systems, two IEEE 14, 118 [1] [5] and 66-bus Indian utility system [6] here. The PSO techniques was applied to solve various Optimal Load Dispatch [OLD] [11,12,13] problems. The results of the proposed Hybrid PSO method are promising and quite encouraging.

Problem Formulation

Optimization of fuel cost for generation has been formulated based on a classical OLD problem with power flow constraints. For a given power system network, the optimized cost of generation is given by the following equation,

$$Min\ F_T(P) = \sum_{i=1}^{n} Fi(p_i) \qquad (1)$$

subject to

(i) Power balance equation

$$\sum_{i=1}^{n} Pgi = P_d + P_l \qquad (2)$$

(ii) The power flow equation of power network

$$g(|v|,\theta) = 0 \qquad (3)$$

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$$g(|v|,\theta)=\left|\begin{array}{l} P_i(|v|,\theta)-P_i^{net} \\ Q_i(|v|,\theta)-Q_i^{net} \\ P_m(|v|,\theta)-P_i^{net} \end{array}\right| \begin{array}{l} \leftarrow \boxed{\text{For each PQ bus}} \\ \\ \leftarrow \boxed{\text{For each PV bus m, not including the ref.bus}} \end{array}$$

(iii) The inequality constraint on real power generation P_{gi} of each unit i,

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \qquad (4)$$

(iv) The inequality constraint on voltage of each PQ bus

$$V_i^{min} \le V_i \le V_i^{max} \qquad (5)$$

(v) Power limit on transmission line

$$MVAf_{p,q} \le MVAf_{p,q}^{max} \qquad (6)$$

Total fuel cost of generation F_T in terms of control variables generator power can be expressed as

$$F\ (P_i) = \sum_{i=1}^{n} (a_i P_{gi}^2 + b_i P_{gi} + c_i)\ \$/\text{hr} \qquad (7)$$

Overview of EP and PSO

Four decades earlier EP was proposed for evolution of finite state machines, in order to solve a prediction task. Since then, several modifications, enhancements, and implementations have been proposed and investigated. Mutation is often implemented by adding a random number or a vector from a certain distribution (e.g., a Gaussian distribution in the case of EP to a parent. The degree of variation of Gaussian mutation is controlled by its standard deviation, which is also known as a 'strategy parameter' in an evolutionary search. PSO is a population based optimization method first proposed by Kennedy and Eberhart. According to the background of PSO and simulation of swarm of bird, Kennedy and Eberhart [3] [4] developed a PSO concept. PSO is basically developed through simulation of bird flocking in two- dimensional space. The position of each agent is represented by XY axis position and also the velocity is expressed by Vx (velocity of X axis) and Vy (velocity of Y axis). Modification of the agent (particle) position is realized by the position and velocity information. Bird flock- ing optimizes a certain objective function. Each agent knows its best value so far (pbest) and its XY position. This information is analogy of personal experiences of each agent. Moreover, each agent knows the best value so far in the group (gbest) among pbests. This information is analogy of knowledge of how other agents around them have performed. Each agent tries to modify its position using the fol- lowing information:

- The current position (x, y),
- The current velocities (Vx, Vy),
- The distance between the current position and pbest,
- The distance between current position and gbest.

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation

$$V_i^{t+1} = W\ V_i^t + C_1 * rand_1 * (pbest_i - s_i^t) + C_2 * rand_2 * (gbest - s_i^k) \qquad (8)$$

The following weighing function is usually utilized in eqn (8)

$$W = W_{max} - \frac{(W_{max} - W_{min}) * iter}{iter_{max}} \qquad (9)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position can be modified by the following equation

$$S_i^t+1 = S_i^t + V_i^{(t+1)} \qquad (10)$$

The first term of the right hand side of (8) is corresponding to diversification in the search procedure. The second and third terms of that are corresponding to intensification in the search procedure. The PSO method has a well-balanced mechanism to utilize diversification and intensification in the search procedure efficiently. Figure 1 shows the concept of modification of a searching point by PSO. Figure 2 shows the flowchart of HPSO method.

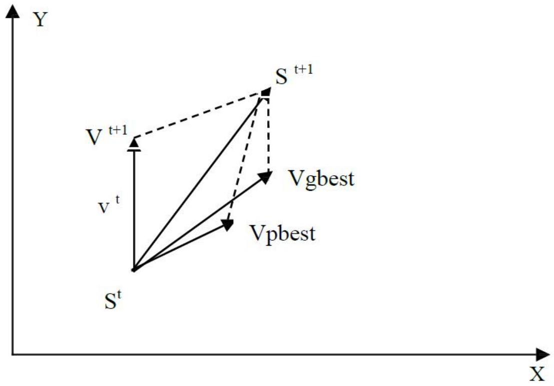

Fig. 1. Concept of modification of a searching point by PSO

S^t Current searching point
S^{t+1} Modified searching point
V^k Current velocity
V^{k+1} Modified velocity
Vpbest Velocity based on pbest
Vgbest Velocity based on gbest

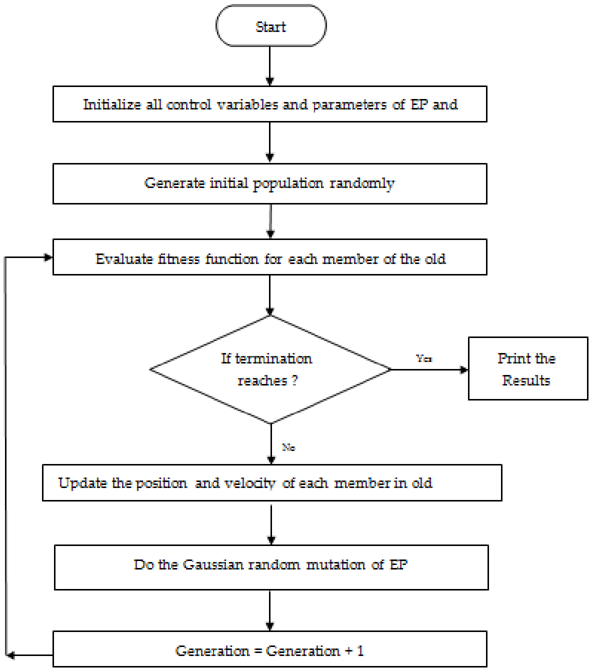

Fig. 2. Flowchart of HPSO method

Step-by-step Procedure of Proposed Hybrid PSO Method with Power Flow Constraints

The search procedure of the proposed Hybrid PSO method for OLD problems with power flow constraints is given below.

Step 1: Initialize randomly the real power generation Pg $_i$ of the population according to the limit of each unit (except slack bus) including the individual dimensions, searching points and velocities. Initial velocity limits of each individual are as

$$V_d^{max} = 0.5\,P_d^{max}\ ,\quad V_d^{min} = -\,0.5\,P_d^{min}$$

Where, $P_d^{MIN} = \sum_{i=1}^{n} P_t^{MIN} \qquad P_d^{MIN} = \sum_{i=1}^{n} P_t^{max}$

Step 2: Compute slack bus generator vector (P_S), losses and power flows using New- ton-Raphson load flow method for the above generators.

Step 3: To account for slack unit limit violation, branch power flow limit violation, and voltage limit violation, the total operating cost is augmented by non-negative penalty terms K_1, K_2 and K_3.Augmented cost F_T calculated using (11).

$$F_T^* = F_T + K_1 * \sum_{i=1}^{nl}\left(I_i - I_i^{max}\right)^2 + K_2 * \left(P_{G1} - P_{G1}^{lim}\right)^2 + K_3 \sum_{i=1}^{N}\left(V_{Li} - V_{Li}^{lim}\right)^2 \qquad (11)$$

Step 4: The minimum augmented fuel cost value among the population is taken as best value. The best augmented fuel cost value in the population is denoted as gbest and remaining individuals are assigned as pbest.

Step 5: Modify the member velocity V of the each individual Pgi using (12)

$$(12)\qquad v_{id}^{(t+1)} = w * v_{id}^{(t)} + c_1 * rand() * \left(pbest_{id} - pg_{id}\right) + c_2 * Rand() * \left(gbest_d - pg_{id}\right)$$

i =1, 2,……..n d = 1, 2,…………….m

where ‘n’ is the population size; ‘m’ is the number of units and the ‘w’ value is set using (9).

Step 6:

$$\text{If} \quad V_{id}^{(t+1)} > V_d^{max}, \text{ then } V_{id}^{(t+1)} = V_d^{max}$$

$$\text{If} \quad V_{id}^{(t+1)} < V_d^{min}, \text{ then } V_{id}^{(t+1)} = V_d^{min}$$

Step 7: Modify member position of each individual Pgi using (13)

$$Pg_{id}^{(t+1)} = Pg_{id}^{(t)} + V_{id}^{(t+1)}$$

Step 8: $Pg_{id}^{(t+1)}$ Must satisfy the capacity limits of the generator as in (14)

$$\text{If} \quad Pg_{id}^{(t+1)} > Pg_{id}^{max} \text{ then, } Pg_{id}^{(t+1)} = Pg_{id}^{max}$$

$$\text{If} \quad Pg_{id}^{(t+1)} < Pg_{id}^{min} \text{ then, } Pg_{id}^{(t+1)} = Pg_{id}^{min}$$

Step 9: Modified member positions in Step 8 are taken as initial value for N-R load flow method. Compute slack bus power loss and power flows using N-R load flow method.

Step 10: Calculate the augmented fuel cost using equation (11). Assign gbest and pbest value. If the current gbest value is better than gbest value in Step 4 current value is set to gbest. If current pbest value is better than pbest value in Step 4 cur- rent value is set to pbest.

Step 11: $Pg_{id}^{(t+1)}$ is created using Gaussian mutation as in (15) and (16).

$$Pg_{id}^{(t+1)'} = Pg_{id} + N_i\,(0, \sigma_i) \qquad (15)$$

$$\sigma_i = \beta * \frac{fi}{fi\,\min}\left(Pgi\max - Pgi\min\right) \qquad (16)$$

Check capacity limits of the generating units using (14), replacing $Pg_{id}^{(t+1)}$ by $Pg_{id}^{(t+1)'}$

Step 12: Modified member positions in Step 11 are taken as initial value for N-R load flow method. Compute slack bus power loss and power flows using N-R load flow method.

Step 13: Calculate the augmented fuel cost using (11). Assign gbest and pbest value. If the current gbest value is better than gbest value in Step 10 current value is set to gbest. If current pbest value is better than pbest value in Step 10 current value is set to pbest.

Step 14: If the iteration reaches the Maximum go to Step 15, otherwise go to Step 4, the gbest and pbest values in Step 4 replaced by latest gbest and pbest values from Step 13.

Step 15: Individual that generates the latest gbest value is the optimal generation of each unit with minimum fuel cost satisfying all the power flow constraints.

RESULTS AND DISCUSSIONS

A comparative study of EP, PSO and proposed Hybrid PSO algorithms was performed on three different systems, two IEEE 14, 118 bus and 66 bus Indian utility system here. The power flows were computed using Newton-Raphson method. The upper and lower voltage limits at all buses except slack bus were 1.10 and 0.95 respectively. The slack bus voltage was fixed to its specified value 1.06. Line loading limits 120 % of base case were considered. For implementing the Evolutionary Programming technique and PSO technique, the population size of 20 was taken and the maximum number of generation (iterations) was taken as 100. Software has been developed in MatLab to solve OLD problem with power flow constraints on Intel Core i5 Processor, 500 GB Hard Disk and 4 GB RAM personal computer.

Case study 1: IEEE - 14 bus system

The system contains three generators, 14 bus and 14 transmission lines [1]. The load demand is 259 MW and cost co-efficient are taken from [9]. Table 1 shows that generation schedule obtained by EP and PSO methods which satisfies all the power flow constraints taken into the problem formulation. The numerical results clearly show that the proposed method is capable of obtaining minimum fuel cost than the other EP and PSO methods.

Table 1. Summary of results of IEEE 14 bus system with power flow constraints

Methods	P1 (MW)	P2 (MW)	P3 (MW)	Losses (MW)	Optimum Fuel Cost $/hr
EP	90.68	79.90	95.42	7.01	1103.9
PSO	87.99	89.07	88.72	6.83	1114.9
Hybrid PSO	109.21	59.12	97.98	7.35	1092.9

Example 2: 66 - bus Indian utility system

EP and PSO techniques were successfully employed to solve a practical Indian utility system, contains four generating units, 66 buses, 93 lines and the demand of 1250 MW were considered. Table 2 shows the generation schedule obtained by using various methods. Minimum fuel cost obtained by the proposed method is promising and encouraging. It clearly shows that proposed method outperforms other methods and is suitable for the practical system.

Table 2. Summary of 66-bus Indian utility system with power flow constraints

Method	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	Losses (MW)	optimum Fuel Cost $/hr
EP	555.28	308.53	298.29	114.63	26.63	806970
PSO	479.16	353.99	324.28	120.00	27.33	739480
Hybrid PSO	478.88	354.34	324.22	120.00	27.34	739230

Table 3. Summary of IEEE 118-bus system with power flow constraints

Unit Power Output	EP	PSO	Hybrid PSO
P1 (MW)	522.45	357	328
P2 (MW)	56.98	179	180
P3 (MW)	214.06	320	162
P4 (MW)	219.14	239	263
P5 (MW)	91.30	100	100
P6 (MW)	88.58	109	110
P7 (MW)	164.19	277.21	50
P8 (MW)	32.21	115.69	150
P9 (MW)	214.23	243.55	250
P10 (MW)	148.88	204.33	260
P11 (MW)	330.36	271.25	253
P12 (MW)	408.67	228.13	347
P13 (MW)	501.19	461.21	525
P14 (MW)	430.02	485.27	395
P15 (MW)	34.10	20.00	20
P16 (MW)	373.24	531.80	438
P17 (MW)	329.46	202.51	350
P18 (MW)	130.02	139.85	138
P19 (MW)	65.12	38.40	20
Losses (MW)	112.4	283.00	101
Optimum Fuel Costs $./Hr	22061	23015	21849

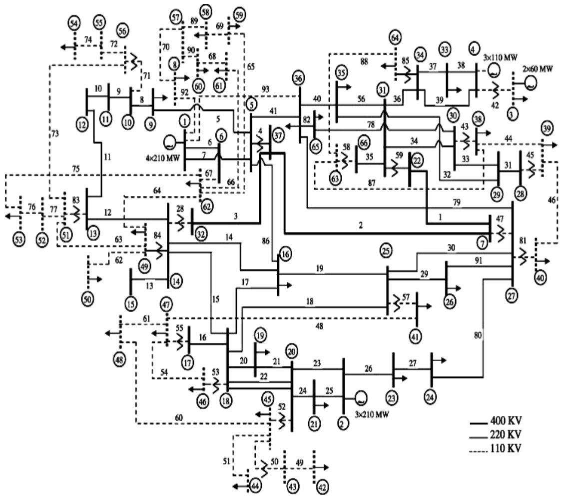

Fig. 3. 66 Bus Indian Utility System Layout

Example 3: IEEE - 118 bus system

In this case, the proposed method and other techniques are used to solve large 118 bus system [5]. The test system has 19 generators, 186 lines and demand is 4242 MW. The cost coefficients are taken from [5]. Table 3 shows the generation schedule and minimum fuel cost obtained by using various techniques. Results clearly show that the proposed method outperforms other methods.

Method	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	Losses (MW)	optimum Fuel Cost $/hr
EP	555.28	308.53	298.29	114.63	26.63	806970
PSO	479.16	353.99	324.28	120.00	27.33	739480
Hybrid PSO	478.88	354.34	324.22	120.00	27.34	739230

Conclusion

This paper presents a Hybrid PSO based approach to solve the power flow constrained OLD problem. For any practical implementation of OLD problem, power flow and voltage constraints are considered to be important and these constraints are taken into consideration here. The proposed approach utilizes the global and local exploration capabilities of PSO and EP techniques. The effectiveness of the proposed approach has been tested on a two IEEE sample systems and practical utility system. The proposed approach is relatively efficient, reliable and well suitable for large and practical utility systems.

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