Particle Swarm Optimization for the Optimal Wind–Thermal Coordination

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Abstract
The Economic Dispatch is an important optimization task in power system. Thermal power plants are the major electrical energy producers. Need for renewable energy occurs due to the extinction of fossil fuels. Hence, it is necessary to operate these renewable plants with the thermal plants. In India, especially in Tamil N adu, Wind is the renewable plant which is widely available. The problem with the wind plant is its unpredictability. Hence, better wind thermal coordination economic dispatch method is necessary to integrate wind power reliably and efficiently. In this paper, Particle swarm optimization (PSO) technique is utilized to coordinate the wind and thermal generation dispatch and to minimize the total production cost. Ten units of thermal system incorporating wind power plant is utilized for numerical simulation. Different simulations with and without wind power production are simulated. Simulation result shows the effectiveness of wind power generation in reducing total fuel cost when compared with the genetic algorithm.

1. Introduction

These days dependency on electrical machines for daily activities increased the overall load demand. Hence, the conventional plants alone cannot meet the demand, resulting in the necessity for the utilization of renewable energy sources such as solar, wind etc for electrical energy generation. Conventional method of electrical power generation from fossil fuel fired power plants causes emission of particulates such as ash and harmful gases like SO2, CO2, CO, NOx which causes environmental degradation. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while operating to meet the limits and constraints imposed on the generating units and environmental considerations. Renewable energy has many advantages that pollution fee, available free of cost, continuously available i.e., inexhaustible. In order to meet the load demand, it is necessary to operate both conventional and renewable energy in an integrated manner. In future, when the fossil fuels are depleted, the renewable le energy can be a good alternative. Among the various renewable energy sources, wind energy could be in short term, one of the most promising renewable energy sources. It could provide a much greater proportion of energy production in places with good wind velocity. Wind energy is also commonly considered as problematic for power system operation due to its limited predictability and variability. The output fluctuation of wind energy can be compensated by employing exchange schedules with neighboring systems.

Economic Dispatch is an important optimization task in power system. It is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements are minimized. More just, the soft computing method has received supplementary concentration and was used in a quantity of successful and sensible applications. Here, an attempt has been made to find out the minimum cost by using Particle Swarm Optimization (PSO) Algorithm using the data of ten thermal generating units and two wind units. Since wind power does not consume fossil fuel, the government has regulated in its renewable energy law that the power grid should buy all electricity produced by renewable energy plant. Thereafter, adoption and variation of high penetration wind power will have notable impact to economic dispatch of power system. Recently, metaheuristic methods are widely in use for the optimization applications and found to be more efficient than the conventional methods. This project focuses on the problems associated with the economic dispatch of the system with thermal and wind units integrated. The optimized dispatch is to be obtained using the particle swarm optimization technique and the result is analyzed by comparing with that of conventional method and using Particle swarm optimization.

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2. Problem Formulation

The main objective of this paper is to reduce the operating cost by properly allocating the Power generated by the thermal units as well as the wind units.
The objective function is,
$C = \Sigma C_i(P_{gi})$; for i=1,2,....,n
Where, $C_i(P_{gi})$ is the cost of ith generating unit
C is the total operating cost
Subject to the constraints
$\Sigma P_i - P_d - P_l = 0$; for i=1,2,....,n
$P_{gi}^{min} \le P_i \le P_{gi}^{max}$
P_i is the Power generation of ith unit
P_d is the total load demand
The operating cost of ith thermal unit is given by,
$C_i (P_{gi}) = a_i + b_i P_{gi} + c_i P_{gi}^2$
The wind power is alloted based on the constraints
Wind generation fluctuation constraints:
if $P_{wt}(t-1) \le P_{wt}(t)$, $P_{wt}(t) - P_{wt}(t-1) \le TDR(t)$
if $P_{wt}(t-1) \ge P_{wt}(t)$, $P_{wt}(t-1) - P_{wt}(t) \le TUR(t)$

Total available wind generation

$P_{wt}(t) = \Sigma P_{wt,j}(t)$, for j=1,2,...., NW

Total actual wind generation limit:

$0 \le P_{wt}(t) \le P_{wt}(t)$

3. Particle Swarm Optimization

Particle swarm optimization is one of the metaheuristic optimization methods. It has the advantages of Simple concept, Easy implementation, Computationally efficient etc,. When any optimization process is applied to the ED problem some constraints are considered. In this work two different constraints are considered. Among them the equality constraint is summation of all the generating power must be equal to the load demand and the inequality constraint is the powers generated must be within the limit of maximum and minimum active power of each unit. The sequential steps of the proposed PSO method are given below.

- Initialize the Fitness Function ie. Total cost function from the individual cost function of the various generating stations.
- Initialize the PSO parameters Population size, C_1, C_2, W_{max}, W_{min}, error gradient etc.
- Input the Fuel cost Functions, MW limits of the generating stations along with the total power demand.
- At the first step of the execution of the program a large no(equal to the population size) of vectors of active power satisfying the MW limits are randomly allocated.
- For each vector of active power the value of the fitness function is calculated. All values obtained in iteration are compared to obtain Pbest.

$V_i(k+1) = \omega * V_i(k) + c_1 * random_1() * (pbest_i - P_i(k)) + c_2 * random_2() * (gbest - P_i(k))$

- At each iteration all values of the whole population till then are compared to obtain the Gbest.

$$P_i(k+1) = P_i(k) + V_i(k+1)$$

- At each step error gradient is checked and the value of Gbest is plotted till it comes within the pre-specified range.
- This final value of Gbest is the minimum cost and the active power vector represents the economic load dispatch solution.

4. Result and Discussions

The system contains ten conventional thermal generation units and the demand of the system is divided into 24 hours interval for the whole day. The data of the ten thermal units are listed in Table 1. The load demand and wind power generation for each hour are listed in Table 2. Economic dispatch is calculated using particle swarm optimization algorithm with and without wind generation

The table 5 describes that the operational cost reduces with the coordination of the wind power plant with the thermal power plant. In the above table, the cost of generation of the case with wind power is found to be comparatively lower than that of the case without wind power.

Table 1 Test Data for Ten Unit System

Units	Pmax	Pmin	a($/MWh)	b($/MWh)	c($/h)	d($/h)	e($/h)
1	470	150	0.00043	21.60	958.20	450	0.041
2	460	135	0.00063	21.05	1313.6	600	0.036
3	340	73	0.00039	20.81	604.97	320	0.028
4	300	60	0.00070	23.90	471.60	260	0.052
5	243	73	0.00079	21.62	480.29	280	0.063
6	160	57	0.00056	17.87	601.75	310	0.048
7	130	20	0.000211	16.51	502.70	300	0.086
8	120	47	0.00480	23.23	639.40	340	0.082
9	80	20	0.10908	19.58	455.60	270	0.098
10	55	55	0.00951	22.54	692.40	380	0.094

Table 2 Load demand and wind power for 24 hours

Hour	Load Demand	Pwind1	Pwind2	Hour	Load Demand	Pwind1	Pwind2
1	1036	72	0.12	13	2072	68.6	0.09
2	1110	106	0.11	14	1924	61.6	0.10
3	1258	113	0.10	15	1776	58.9	0.08
4	1406	103	0.10	16	1554	52.1	0.08
5	1480	139	0.10	17	1480	45.6	0.11
6	1628	116	0.11	18	1628	34.8	0.12
7	1702	122	0.10	19	1776	31.6	0.13
8	1776	88	0.13	20	2072	31.1	0.15
9	1924	42.1	0.10	21	1924	36.8	0.16
10	2072	57.1	0.09	22	1628	27.8	0.13
11	2146	44	0.13	23	1332	20.6	0.11
12	2220	65.4	0.10	24	1184	23.8	0.13

Table 3 Thermal dispatch without wind

Hour	1	2	3	4	5	6	7	8	9	10	Pw ind1	Pw ind2	Demand
1	150.00	135.00	133.88	60.00	73.00	160.00	130.00	47.00	20.00	55.00	72.00	0.12	1036
2	150.00	135.00	173.89	60.00	73.00	160.00	130.00	47.00	20.00	55.00	106.00	0.11	1110.00
3	150.00	135.00	314.90	60.00	73.00	160.00	130.00	47.00	20.00	55.00	113.00	0.10	1258.00
4	150.00	267.90	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	103.00	0.10	1406.00
5	150.00	305.90	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	139.00	0.10	1480.00
6	160.57	460.00	340.00	60.00	79.32	160.00	130.00	47.00	20.00	55.00	116.00	0.11	1628.00
7	212.81	460.00	340.00	60.00	95.09	160.00	130.00	47.00	20.00	55.00	122.00	0.10	1702.00
8	285.25	460.00	340.00	60.00	130.62	160.00	130.00	47.00	20.00	55.00	88.00	0.13	1776.00
9	410.64	460.00	340.00	60.00	199.16	160.00	130.00	47.00	20.00	55.00	42.10	0.10	1924.00
10	470.00	460.00	340.00	60.00	243.00	160.00	130.00	76.72	20.09	55.00	57.10	0.09	2072.00
11	470.00	460.00	340.00	134.52	243.00	160.00	130.00	88.70	20.64	55.00	44.00	0.13	2146.00
12	470.00	460.00	340.00	180.13	243.00	160.00	130.00	95.45	20.92	55.00	65.40	0.10	2220.00
13	470.00	460.00	340.00	60.00	243.00	160.00	130.00	65.31	20.00	55.00	68.60	0.09	2072.00
14	395.36	460.00	340.00	60.00	194.94	160.00	130.00	47.00	20.00	55.00	61.60	0.10	1924.00
15	303.30	460.00	340.00	60.00	141.72	160.00	130.00	47.00	20.00	55.00	58.90	0.08	1776.00
16	167.19	449.62	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	52.10	0.08	1554.00
17	150.00	399.29	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	45.60	0.11	1480.00
18	207.72	460.00	340.00	60.00	113.36	160.00	130.00	47.00	20.00	55.00	34.80	0.12	1628.00
19	313.62	460.00	340.00	60.00	158.65	160.00	130.00	47.00	20.00	55.00	31.60	0.13	1776.00
20	470.00	460.00	340.00	81.20	243.00	160.00	130.00	81.31	20.24	55.00	31.10	0.15	2072.00
21	412.66	460.00	340.00	60.00	202.38	160.00	130.00	47.00	20.00	55.00	36.80	0.16	1924.00
22	215.11	460.00	340.00	60.00	112.96	160.00	130.00	47.00	20.00	55.00	27.80	0.13	1628.00
23	150.00	276.29	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	20.60	0.11	1332.00
24	150.00	135.00	330.07	60.00	73.00	160.00	130.00	47.00	20.00	55.00	23.80	0.13	1184.00

Table 4 Wind-Thermal Dispatch

Hour	P1	P1	P3	P4	P5	P6	P7	P8	P9	P10	Demand
1	1.50.00	135.00	206.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1036.00
2	150.00	135.00	280.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1110.00
3	150.00	223.00	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1258.00
4	150.00	371.00	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1406.00
5	178.88	415.83	340.00	60.00	73.29	160.00	130.00	47.00	20.00	55.00	1480.00
6	242.60	460.00	340.00	60.00	113.40	160.00	130.00	47.00	20.00	55.00	1628.00
7	271.38	460.00	340.00	60.00	158.62	160.00	130.00	47.00	20.00	55.00	1702.00
8	338.75	460.00	340.00	60.00	165.25	160.00	130.00	47.00	20.00	55.00	1776.00
9	434.73	460.00	340.00	60.00	217.27	160.00	130.00	47.00	20.00	55.00	1924.00
10	470.00	460.00	340.00	108.93	243.00	160.00	130.00	84.61	20.46	55.00	2072.00
11	470.00	460.00	340.00	172.28	243.00	160.00	130.00	94.84	20.87	55.00	2146.00
12	470.00	460.00	340.00	236.62	243.00	160.00	130.00	104.08	21.30	55.00	2220.00
13	470.00	460.00	340.00	108.38	243.00	160.00	130.00	85.15	20.47	55.00	2072.00
14	427.11	460.00	340.00	60.00	224.89	160.00	130.00	47.00	20.00	55.00	1924.00
15	340.01	460.00	340.00	60.00	163.99	160.00	130.00	47.00	20.00	55.00	1776.00
16	201.79	448.53	340.00	60.00	91.67	160.00	130.00	47.00	20.00	55.00	1554.00
17	166.12	428.73	340.00	60.00	73.15	160.00	130.00	47.00	20.00	55.00	1480.00
18	238.45	460.00	340.00	60.00	117.55	160.00	130.00	47.00	20.00	55.00	1628.00
19	344.48	460.00	340.00	60.00	159.52	160.00	130.00	47.00	20.00	55.00	1776.00
20	470.00	460.00	340.00	108.46	243.00	160.00	130.00	85.05	20.49	55.00	2072.00
21	426.73	460.00	340.00	60.00	225.27	160.00	130.00	47.00	20.00	55.00	1924.00
22	252.86	460.00	340.00	60.00	103.14	160.00	130.00	47.00	20.00	55.00	1628.00
23	150..00	297.00	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1332.00
24	150.00	149.00	340.00	60.00	73.00	160.00	130.00	47.00	20.00	55.00	1184.00

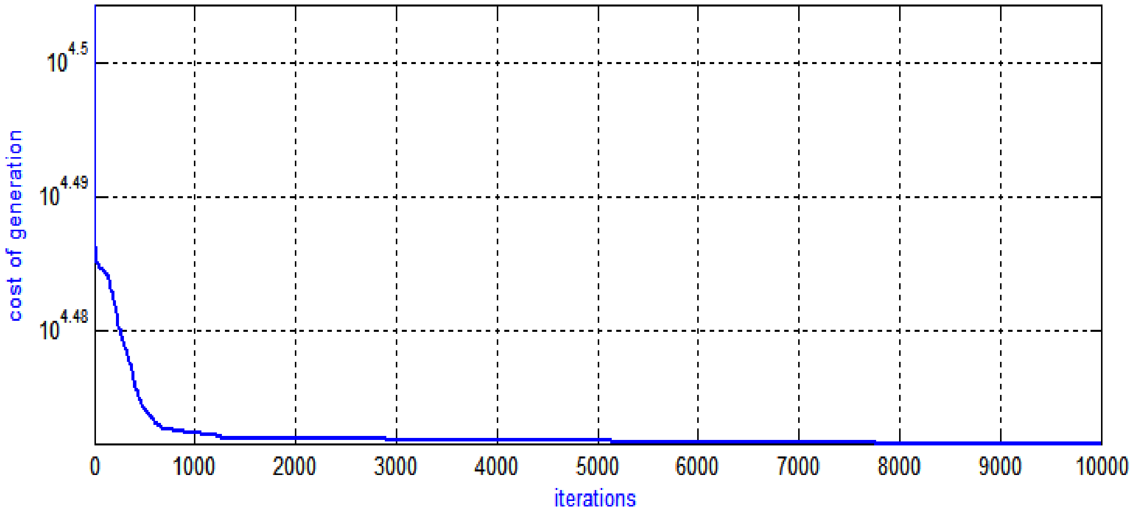

Fig. 1 Total operating cost for different iterations

Table 5 Cost comparison with and without wind power

HOUR	COST OF GENERATION WITHOUT WIND POWER	COST OF GENERATION WITH WIND POWER
1	28336.550297	27245.644167
2	30013.278681	27825.746732
3	33070.73569	30906.681231
4	36014.378613	33949.478369
5	37844.198664	34873.14747
6	41053.078894	38283.364287
7	42467.54952	39823.794081
8	44334.847651	42304.972997
9	47729.473963	46537.386515
10	51137.148245	49917.430416
11	52541.558746	51537.494157
12	54336.44909	52882.78873
13	51131.190534	49600.972162
14	47617.470925	46096.045124
15	44195.381342	42928.658342
16	39360.036477	38326.087597
17	37712.154258	36817.814596
18	41270.296943	40286.420027
19	44219.935153	43559.110695
20	51184.633725	50282.218329
21	47470.810021	46533.430033
22	40881.929708	40497.721911
23	34611.105809	34178.541552
24	31451.130677	30890.515329

Table 6 Cost Comparison of Existing System With Proposed System

	Genetic Algorithm	Particle Swarm Optimization
Cost of generation without wind power generation ($/day)	1064814.34	1009985.32
Cost of generation with wind power generation ($/day)	1026048.84	976085.46

5. Conclusions

In this study, the formulation and implementation of solution methods to obtain the solution of Economic Dispatch problem using Particle swarm optimization is carried out successfully for coordinated thermal and wind power generation. The cost of the best solution without wind power generation is 1009985 ($/day) while the cost for best solution with wind power generation 976085.46 ($/day). The profit by using wind energy is 33899.86 ($/day). The simulations for with/without wind power production shows that the total system operating costs and consumption of fossil fuel can be reduced notably by utilizing wind power generation.

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