Solution of Stochastic Economic Dispatch Problem using Modified PSO Algorithm

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ABSTRACT

The main objective of the Economic Dispatch (ED) problem is to find optimal allocation of output power among the various generators available to serve the system load. It is necessary to incorporate wind and pumped storage plants in classical economic dispatch problem due to the increase in the use of renewable energy sources. The cost of power generation will be considerably reduced due to the renewable energy resources. This paper proposes a Stochastic Economic Dispatch (SED) model incorporating wind and pumped storage generators in addition with the thermal generators. Premature convergence and high computation time are the main drawbacks of the traditional PSO algorithm to solve the optimization problems. In this work a Modified PSO (MPSO) algorithm is proposed to remove the drawbacks of the traditional PSO to solve the proposed SED problem.

Index Terms

Stochastic economic dispatch, Wind generators, Pumped storage plants, Modified particle swarm optimization.

1. INTRODUCTION

Power system scheduling is one of the most important problems in planning and management [1-2]. The main objective of economic power dispatch problem is to determine the optimal combination of power outputs for all generating units, which minimizes the total fuel cost while satisfying load demand and operating constraints of a power system. This makes the ED problem a large-scale non-linear constrained optimization problem.

Renewable energy generation sources, such as solar, photovoltaic, wind, geothermal, etc. became attractive alternatives to fossil plants. Due to increase in fuel prices and environmental concern, it is necessary to include renewable energy sources into classical economic dispatch problem. Wind power generation is environmentally friendlier than the impacts of thermal energy sources [3]. Because of the uncertain nature of power generation in wind power, classical economic dispatch problem becomes stochastic in nature.

The main risk involved in the inclusion of wind is the future wind speed is unknown at any future time [4]. The predictions of the power output of wind farms are mainly used for grid operation, power plant scheduling and trading [5].There are many methods are used to predict the wind speed like fuzzy logic[6], neural network[7], and time series The penalty cost for not utilizing all available wind capacity is added[8]. The Takagi,Sugeno, and Kang (TSK fuzzy model) was developed to forecast the wind speed [6]. The factors like overestimation and underestimation should be included in the model to make the ED for general case, so that it will adaptable for all situations, regardless of who owns the wind generation facilities. A Recurrent Neural Network was developed for wind energy prediction cascaded with neural network [7]. In this paper, it is assumed that the Probability Distribution Function (PDF) of the wind speed is known. Then it is transformed to the corresponding wind power distribution for use in the ED model. Pumped storage plants scheduling save the fuel costs by generating power during peak load hours and pumping during off peak hours. The output powers from these units are the function of water in the upper reservoir and water discharged through turbines [10].

So the ED problem with the incorporation of the wind and pumped storage plant is termed as SED problem. SED problem is a non-linear, non-convex problem with multiple local optimal points due to multiple fuel options with diverse equality and inequality constraints. Conventional methods have failed to solve such problems. Because they are sensitive to initial estimates and converge into local optimal solution and computational complexity.

Modern heuristic optimization techniques such as, evolutionary algorithms [11]&[17], Genetic Algorithm (GA) [12]&[19], Particle Swarm Optimization (PSO) [13], hybrid algorithms[14]&[19],Taguchi method[15],Simulated Annealing (SA)[18] are provided better solution for this type of problems. Traditional PSO algorithm has some drawbacks such as large computational time, premature convergence, cannot be guarantee the global value. Some modifications are proposed to overcome this problem [16]. In this paper a modified PSO method is proposed to overcome the draw backs of the conventional PSO algorithm.

The main aim of this paper is to solve the proposed SED problem using the modified PSO method. The problem formulation for this SED problem is given in section II. Wind power generator is modeled for economic dispatch problem in section III. Modeling of pumped storage generators are explained in section IV. The proposed algorithm is explained in section V. The simulation results of the modified IEEE 30 bus system for 24 hours are discussed in section VI.

2. PROBLEM FORMULATION

The main goal is to find the optimum allocation of output power among various available generators within the system constraints. The objective function of the SED problem and its constraints are explained in the following sections.

2.1 Objective function

The primary objective of any ED problem is to reduce the total fuel cost by satisfying all constraints.

Minimize

$$\sum_{i}^{M} C_i(p_i) + \sum_{i}^{M} C_{wj}(w_i) + \sum_{i}^{N} C_{p,wj}(W_{i,av} - w_i) + \sum_{i}^{N} C_{r,w,i}(w_i - W_{i,av}) \quad (1)$$

where

M Number of conventional power generators

N Number of wind powered generators

S Number of pumped storage generators

P_i Power from i^{th} conventional generator

w_i Scheduled wind power from the i^{th} wind powered generator

$W_{i,av}$ Available wind power from the i^{th} wind powered generator

$W_{r,l}$ Rated wind power from the i^{th} wind powered generator

C_i Cost function for the i^{th} conventional generator

$C_{w,l}$ Cost function for the i^{th} wind powered generator

$C_{r,w,l}$ Required reserve cost function

In (1) the first term is the cost function of thermal generators. It is a quadratic function given by

$$C_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where a_i, b_i, c_i are the cost coefficients of i^{th} thermal generators. The second term in (1) is the direct cost function of the wind powered generators. The third term is penalty cost for not using all available wind energy. Last one is reserve cost for overestimation of the wind powered generators.

2.2 Equality and Inequality constraints

(i) Power balance equation:

The power output should be equal to load plus losses.

$$\sum_i^M p_i + \sum_i^N w_i + \sum_i^S ph_i = L \quad (3)$$

(ii) Power generation limits:

$$p_{i,min} \le p_i \le p_{i,max} \quad (4)$$

$$0 \le w_i \le w_{r,i} \quad (5)$$

$$0 \le ph_i \le ph_{i,max} \quad (6)$$

$$pp_{i,min} \le pp_i \le 0 \quad (7)$$

$p_{i,min}, p_{i,max}$, are the minimum and maximum limits of generation for thermal plants. $w_{r,i}$ is the rated limit of wind power generation. $ph_{i,max}$ is the maximum limit of pumped storage generator when it is in generating mode. $pp_{i,min}$ is the minimum power limit of pumped storage generator when it is in pumping mode.

(iii) Reservoir storage limits:

$$V_{i,min} \le V_i \le V_{i,max} \quad (8)$$

$V_{i,min}, V_{i,max}$ are the minimum and maximum volume limits of the reservoir.

(iv) Water discharge limits:

$$q_{i.min} \le q_i \le q_{i,max} \quad (9)$$

$q_{i,min}, q_{i,max}$ are the minimum and maximum water discharge limits of the pumped storage generators.

3. MODELLING OF WIND GENERATORS FOR SED PROBLEM

Economic dispatch problem is a classical optimization problem. In order to be able to rationally approach the economic dispatch with WECS problem, some characterization of the uncertain nature of the wind speed is needed. M.R.Patel [5] has shown that the wind speed profile at a given location most closely follow a Weibull distribution over time.

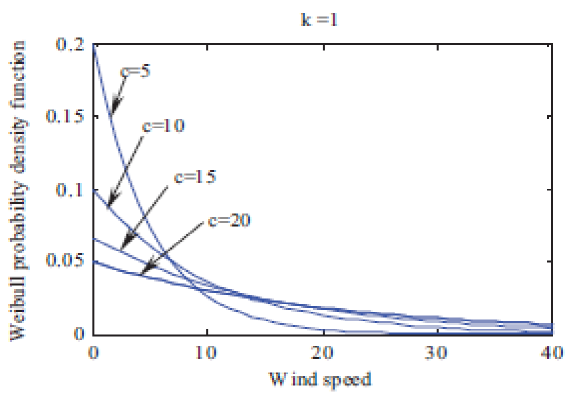


Fig.1 Weibull probability density function for k=1

where k is the shape factor.

The pdf for a Weibull distribution is given by

$$f_v(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} (e)^{-(vc)^k}, 0 < v < \infty \quad (10)$$

Conjunction with the wind power probability function, the Weibull PDF is given by

$$F_V(v) = \int_o^v f_v(\tau) = 1 - e^{-(v/c)^k} \quad (11)$$

In this work, the ED model developed for the most general type, so that it is adaptable to all situations, regardless of who owns the generation facilities. Because of the uncertainty of the wind energy available at any given time, factors for overestimation and underestimation of available wind energy are included.

A linear cost function is assumed for the wind generated power given as,

$$C_{w,i}(w_i) = d_i w_i \quad (12)$$

where d_i is direct cost coefficient of the i[th] wind generator.

In the case of underestimation penalty, if the available wind power is actually more than what was assumed, that power will be wasted, and reasonable for the system operator to pay a cost to the wind power producer for the waste of available capacity. Penalty cost for not using all the available wind power will be linearly related to the difference between the available wind power and the actual wind power used. The penalty cost function will then take the following form

$$C_{p,w,i}(W_{i,av} - w_i) = k_{p,i}(W_{i,av} - w_i)$$

$$= k_{p,i} \int_{w_i}^{w_{r,i}} (w - w_i) f_w(w) dw \quad (13)$$

Where $k_{p,i}$ the penalty cost coefficient for ith is wind power generator and $f_W(w)$ is the WECS wind power pdf.

If a certain amount of wind power is assumed and that power is not available at the assumed time, power must be purchased from alternate source or load must shed. In this case reserve cost will be calculated

$$C_{r,w,i}(w_i - W_{i,av}) = k_{r,i}(w_i - W_{i,av})$$

$$= k_{r,i} \int_0^{w_i} (w_i - w) f_w(w) dw \quad (14)$$

where $k_{p,i}$ the reserve cost coefficient for the ith wind is powered generator. The equation (13),(14) are solved using MATLAB built-in "quad" function.

4. MODELLING OF PUMPED STORAGE GENERATORS FOR SED PROBLEM

A Pumped storage plant is designed to reduce total fuel costs by generating during peak hours, and pumping water to upper reservoir during off peak hours. The discharge generation characteristic of a pumped storage unit in generating mode is similar to that of a traditional hydroelectric unit. The generation output of an equivalent pumped storage plant is a function of water discharged and the content of the upper reservoir. The general expression is given as,

$$ph_i^t = f(q_i^{t-1}, V_i^{t-1}) \quad (15)$$

In pumping mode, the efficiency of a reversible turbine pump unit tends to decrease when the pump is operated away from the rating of the unit. Therefore, in practice, most power utilities operate their pumped storage units at a fixed pumping power in pumping mode.

5. MODIFIED PARTICLE SWARM OPTIMIZATION (MPSO)

PSO algorithm is a population based stochastic optimization technique used in various areas of applications. This technique is based on the choreography of a bird flock, which can be seen as a distributed behavior algorithm that performs multidimensional search. The major shortcoming of the classical PSO algorithm is its very large computation time, due to the large number of iterations required to obtain a global optimum. It also suffers from premature convergence like most stochastic search techniques. Hence, there is a need to accelerate the convergence .

At iteration *iter+1*, the trajectory of the *i*[th] particle in *k*[th] dimension, $x_k^{i\ \text{iter+1}}$ converges to a weighted mean of particle best, *pbest* and global best, g_{best} . Whenever the particle converges, it fly to the personal best position and the global best position. This information sharing mechanism tends the PSO to a very fast convergence. However, due to this mechanism, the PSO cannot guarantee the global value, as the particles usually converge to a local optimum. Once the particles trap into a local optimum, the velocity update equation is a function of the inertia weight alone. Since the inertia constant varies slowly, the change in velocity of the particle is close to zero. After that, the position of the particle $x_k^{i\ \text{iter+1}}$ will not change. Due to this problem, the PSO often fails to obtain the global optimum. Hence, there is a need to provide more diverse solution space to avoid premature convergence.

In the Modified PSO (MPSO) the second best position of the particle is also considered in the velocity equation. By doing this the number of iterations will be reduced and the computation time is also reduced. The problem of premature convergence is avoided by randomly changing the values of the cognitive components instead of fixing it as constant value.

The modified velocity equation is as follows,

$$V_k^{p+1} = wV_k^p + C1 * rand_1 * \left(pbest - x_p^k\right) + C2 * rand_2 * \left(gbest - x_p^k\right) + C3 * rand_3 * \left(pnei - x_p^k\right) \quad (16)$$

where $pnei$ is the second best position of the particle. The cognitive component is computed as similar to the inertia component. The cognitive component is calculated within the maximum limits of cognitive component .The formula for calculating cognitive component is given below

$$c1 = c_{1\max} - (c_{1\max} - c_{1\min}) * \frac{iter}{iter_{\max}} \quad (17)$$

$$c2 = c_{2\max} - (c_{2\max} - c_{2\min}) * \frac{iter}{iter_{\max}} \quad (18)$$

where $iter$ is the corresponding iteration and $iter_{\max}$ is the maximum number of iterations.

6. TEST SYSTEM

The modified IEEE 30 bus system is considered as test system with minor modification. The test system consists of three thermal units, two wind farms and one pumped storage unit. The cost coefficients and minimum, maximum limits of three thermal units are given in table 1.1.

Table 1.1 Cost coefficients, minimum and maximum limits of thermal generators

Units	a_i	b_i	c_i	$p_{i,min}$	$p_{i,max}$
1	0.00375	2	0	50	200
2	0.0075	1.75	0	20	80
3	0.0625	1	0	15	50

The direct cost coefficients of the wind farms are assumed as d_1=1,d_2=1.25. The wind speed parameters are v_i=5,v_r =15,v_o = 45.The Minimum and Maximum limits of the wind farms and pumped storage units are $w_{1,min}, w_{2,min} = 5$, $w_{1,max}, w_{2,max} = 100$, $ph_{min} = 0, ph_{max} = 30$. The volume limits of the reservoir is $V_{min} = 47\ acre - ft, V_{max} = 51.5\ acre - ft$. The present volume of the reservoir is taken as 50 $acre - ft$. The role of the acceleration component c1 ,c2 is to push the Particle toward the local best and global best respectively. Small acceleration component allow a particle to fly far from the target regions. Conversely, large acceleration component result in the abrupt movement of particles toward target regions .In this work the cognitive and social component are generated randomly within the upper and lower bounds of components. The upper and lower limits for cognitive component c1mi0.1,c1max=1, c2min=0.1,c2max=1, c3min=0.1,c3max=1 are set. The inertia component limits are taken as wmin=0.1 and wmax=1.

7. SIMULATION RESULTS

Simulations were carried out on a Intel Core i3, 2.10 GHz, 4–GB RAM processor. The coding is written in MATLAB 2010 version. The MPSO algorithm is used for solving the SED problem for 24 hours. In this simulation 300 particles and maximum of 300 iterations were taken. The maximum limits of velocities of the particles are the maximum power generation limits of the units. The natural inflow into the reservoir also considered and assumed as constant. The classical ED problem is solved by taking partial derivatives. But due to integrals in (13) and (14) the derivatives cannot be in closed form. The load pattern for 24 hours is given in fig.2

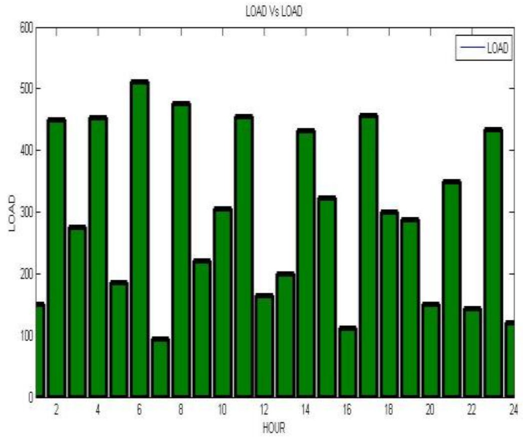


Fig.1.2 Load variation for 24 hours

The cognitive component are calculated using the formula (17),(18). By doing so, the search space for the optimum solution increased and also this avoids the premature convergence. The inertia component also obtained like cognitive component. The first local best(pbest) and second best(pnei) also used to update velocity of the particle. The other steps in the MPSO algorithm is similar to the traditional PSO algorithm.

Table 1.2 Minimum,Maximum and Average cost of SED problem for 24 hours using MPSO

Hour	1	2	3	4	5	6
Load	150	450	275	453	186	511
best	212	837	431	854	289	974
worst	266	993	483	898	362	998
average	235.7	917.5	479	907	330.5	984
std	23.56	31.69	35.2	27	40.52	11.8

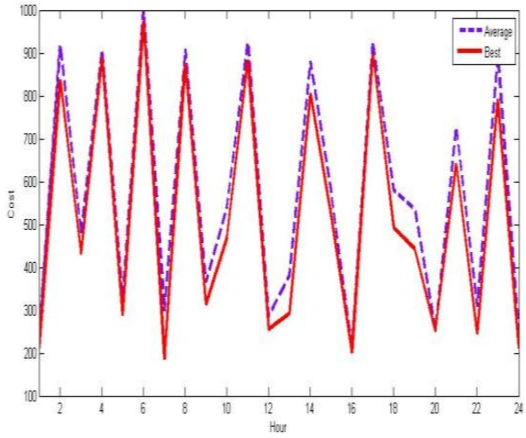
Hour	7	8	9	10	11	12
Load	95	476	221	305	455	164
best	185	873	313	470	883	255
worst	187	929	385	550	939	335
average	186	908.7	365	540	924	285
std	5.21	19.63	34.6	29.52	24.72	43.74

Hour	13	14	15	16	17	18
Load	200	432	322	111	456	300
best	291	805	515	201	897	493
worst	331	889	586	229	993	580
average	311	850	572	208	926.5	570
std	39.53	41.09	37.53	40.63	27.83	52.4

Hour	19	20	21	22	23	24
Load	288	150	350	143	433	120
best	444	251	640	245	792	211
worst	552	293	785	359	860	271
average	534	234.9	726.4	309.7	832.4	237.4
std	27.83	13.49	39.87	26.32	43.82	35.62

This results signifies that the MPSO is more consistent to solve like this optimization problems. The standard deviation which shows the deviation from the optimum solution are calculated. The small values of standard deviation proves the effectiveness of the Modified algorithm.To differentiate the minimum and average cost of the SED problem for 24 hours the variation is shown in figure 1.3

Fig 1.3 Comparison of Minimum cost with average cost for 24 hours obtained by MPSO



To understand the effectiveness of the MPSO algorithm it is compared with the traditional PSO algorithm results for first hour as given in table 1.4.

Table 1.4 Comparison of Results with traditional PSO output for 1st hour

method	Best cost	Worst cost	Avg cost	Std cost	Min time	Max time
MPSO	212	266	235	32.5	6024.4	6121
PSO	230	275	242	37.4	6070.3	6204

It shows that MPSO algorithm is more consistent than traditional PSO algorithm. The time taken to solve the SED problem also compared.

Table 1.4 Optimum results of SED problem for 24 Hours using MPSO algorithm

HOUR	LOAD (Mw)	P1 (Mw)	P2 (Mw)	P3 (Mw)	W1 (Mw)	W2 (Mw)	PH (Mw)	VOLUME (acre-ft)	COST ($)
1	150	50.00	20.00	15.00	5.00	30.6723	29.32	4941.3	212
2	450	187.48	42.15	38.21	5.00	5.00	9.637	4938.5	837
3	275	50.00	63.158	24.866	100.00	18.011	18.964	4845.7	431
4	453	200.0	68.36	15.00	86.823	68.160	14.655	4823.4	854
5	186	66.03	20.00	15.00	6.7950	66.566	11.605	4792.2	289
6	511	168.97	65.645	46.427	100.00	100.00	30.00	4732.2	974
7	95	50.00	20.00	15.00	5.00	5.00	0	4732.2	185
8	476	170.14	70.00	30.393	99.90	77.214	28.337	4727.8	873
9	221	58.57	30.160	16.217	54.213	37.639	24.193	4700.0	313
10	305	184.20	33.366	47.305	100.00	90.12	0	4700.0	470
11	455	50.00	33.80	15.850	26.2504	38.093	0	4700.0	883
12	164	52.95	20.00	15.00	66.956	45.090	0	4700.0	255
13	200	146.31	38.411	47.78	99.71	99.7679	0	4700.0	291
14	432	136.182	48.650	26.716	29.631	80.820	0	4700.0	805
15	322	50.00	20.00	15.00	5.6986	20.301	0	4700.0	515
16	111	200.0	22.228	33.77	100.00	100.0	0	4700.0	201
17	456	173.57	25.212	15.00	46.83	39.37	0	4700.0	897
18	300	86.246	20.00	31.25	64.89	97.602	0	4700.0	493
19	288	54.33	62.78	15.00	68.852	87.037	0	4700.0	444
20	150	50.00	24.42	17.36	48.36	9.8436	0	4700.0	251
21	350	131.94	20.00	34.802	90.813	72.434	0	4700.0	640
22	143	50.00	29.59	15.00	8.949	39.459	0	4700.0	245
23	433	172.78	52.51	15.110	99.528	93.063	0	4700.0	792
24	120	50.00	20.00	15.00	21.404	13.5952	0	4700.0	211

8. CONCLUSION

This work has been applied to solve SED problem by taking various generator constraints, reservoir volume constraints, water discharge constraints into consideration. The drawbacks of the traditional PSO algorithm like premature convergence and large computation time were overcome by this proposed algorithm. In MPSO algorithm the second best position of the particle also considered in the velocity equation, which reduce the number of iterations and also the computation time. The cognitive component is calculated randomly within the maximum limit and minimum limits, which avoids the premature convergence. To understand the effectiveness of the MPSO algorithm the results obtained are compared with the traditional PSO method results. It clearly shows that MPSO is more consistent than traditional PSO algorithm.

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