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Economic environmental dispatch of combined wind and thermal power system

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Abstract

For successful operation of a power generating station, Economic Emission Dispatch (EED) of a thermal and wind power combination becomes a serious concern as it commits the distribution of production among all the generating units which are on line so that the cost, level of emission including NOx, SO_2 both are magnified concurrently satisfying each of the experimental constraints. This is an exceptionally restricted multi-objective optimizing case which has conflicting objectives having both primary as well as secondary constraints. In this paper, an Oppositional Base Differential Evolution (OBDE)is suggested to take care of EED matter. The results of simulation here are obtained by realizing the proposed scheme

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taking two test cases for two systems and then evaluating it against Non dominated Sorting Genetic Algorithm-II (NSGA-II).

Subject Classification: *65H10.*

Keywords: *Economic emission dispatch, Wind farm uncertainty, Fuel price, NO_x, SO_2 emission level, OBDE.*

1. Introduction

Electrical energy that is generated by igniting fossil fuels liberates varied pollutants including sulfur dioxide (SO2) and oxides of carbon, nitrogen (NOx) etc to the atmosphere. It is indispensable for electric utilities to reduce impurities present in air. So to reduce the effect of global warming, there is an act which was proposed and planned in 1990 with concern for production of clean air. It entails that the typical generating units should consider the specified pollutants spread mentioned above [1].

The three objectives here - cost, emission of NO_x and SO_2 all are conflicting with the other. Also to satisfy comprehensive optimal dispatch all the three have to be considered together. The EED is used here for arranging the productivity of all online generating units to fulfill the anticipated demand of load achieving most competent result simultaneously satisfying each operational constraint [2].

Various techniques related to EED problem are explained here considering EED as a controversy problem & applied for goal-attainment methods to get the solution [3],[5].Evolutionary programming techniques are discussed in [6],[9] where all the objectives are evaluated. In the past few years, this problem was changed into an issue with one objective with a weighted entirety [10],[11]. Multi-Objective Genetic Algorithm [12]etc., comprise evolving multi-purpose techniques which are pertained towards solving the EED issues.

Due to emerging changes in the scenario of climate and demand of pure energy, wind power is gaining its demand for generation due to its low cost and effect of emission is nil [13],[17]. Wind energy needs various strategies to sustain economic emission with reliability of different renewable sources which has been explained by various authors [18],[22] and [24],[27].

Nevertheless, SO_2 and NO_x emission objectives are regarded as different functions for this paper. For proper validation of the suggested method, experiments are carried out thoroughly implementing it on two test systems. The results derived from the investigation on OBDE is then compared and studied to the results already obtained from NSGA II.

2. Objective

The problem of EED taking wind farm and thermal unit together is projected to normalize three functions- cost, emission of SO_2 as well as NO_x which need to be optimized simultaneously while satisfying the different limitations. The subsequent objectives are discussed one by one:

2.1 *Cost*

The price of a hybrid model comprises of two costs, one is cost of fuel for thermal plants and the other is for wind power generation. So the overall cost is expressed as:

$$F_C = \sum_{i=1}^{N_s} f_{si}(P_{si}) + \sum_{k=1}^{N_w} f_{wk}(P_{wk}) \tag{1}$$

Here F_c is the Fuel cost function, P_{si}, P_{wk} are the available thermal and wind power; N_s,N_w denotes different number of generation units.

The cost of fuel for a single thermal generating unit, studying the valve-point effect, can be conveyed as:

$$f_{si}(P_{si}) = a_{si} + b_{si}P_{si} + c_{si}P_{si}^2 + \left| d_{si} \times \sin\{e_{si} \times (P_{si}^{\min} - P_{si})\} \right| \tag{2}$$

Here P_{si}^{min} is the minimum thermal power generation unit, a_{si} to e_{si} are the cost coefficients thermal generator.

The overall cost of wind power unit consists of three types of costs, a direct cost, penalty cost (C_{pk}) and (C_{rk}) reserve cost (for both underestimation and overestimation) for k^{th} wind power unit can be calculated as [19]:

$$f_{wk} = \{(d_k \times P_{wk}) + C_{Pk}(W_{k,avg} - P_{wk}) + C_{rk}(P_{wk} - W_{k,avg})\} \tag{3}$$

$$C_{pk}(W_{k,avg} - P_{wk}) = K_{Pk}(W_{k,avg} - P_{wk}) = K_{Pk} \times \int_{P_{wk}}^{P_{w,rk}} (w - P_{wk}) f_w(w)dw \tag{4}$$

$$C_{rk}(P_{wk} - W_{k,avg}) = K_{rk} \times \int_{0}^{P_{wk}} (P_{wk} - w) f_w(w)dw \tag{5}$$

$$f_w(w) = \frac{k_s h v_{in}}{P_{wr} c} \left[\frac{\left(1 + \frac{hw}{P_{wr}}\right) v_{in}}{c} \right]^{k_s - 1} X \quad \exp\left\{ -\left[\frac{\left(1 + \frac{hw}{P_{wk}}\right) v_{in}^{k_s}}{c} \right] \right\} \tag{6}$$

The characterization of power generated in the wind units is obtained by applying Weibull pdf, $f_w(w)$.

2.2 *NOx Emission*

NO_x Emission level of this approach can be expressed as:

$$E_{NO_x} = \sum_{i=1}^{N_s} [\alpha_{ni} + \beta_{ni} P_{si} + \gamma_{ni} P_{si}^2 + \eta_{ni} \exp(\delta_{ni} P_{si})] \tag{7}$$

Here α_{ni}, β_{ni}, γ_{ni}, η_{ni}, and δ_{ni} are coefficients emission function.

2.3 *Emission of SO_2*

SO_2 Emission level of a thermal power unit, which is a quadratic polynomial, can be expressed as:

$$E_{SO_2} = \sum_{i=1}^{N_s} [\alpha_{si} + \beta_{si} P_{si} + \gamma_{si} P_{si}^2] \tag{8}$$

3. Constraint

3.1 *Constraint for power balance*

Overall active power generation should remain same as the addition of total power demand and the transmission line power losses.

$$\sum_{i=1}^{N_s} P_{si} + \sum_{k=1}^{N_w} P_{wk} - P_D - P_L = 0 \tag{9}$$

Here P_L is given by considering the B coefficients that is presented as a quadratic form as:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j \tag{10}$$

3.2 *Operating limits of real power*

$$P_{si}^{\min} \le P_{si} \le P_{si}^{\max} i \in N_s \tag{11}$$

And

$$P_{wk}^{\min} \le P_{wk} \le P_{wk}^{\max}, k \in N_w \tag{12}$$

4. Function of Bi-objective Method:

Multi-objective optimization problem, consisting of different objectives as well asconstraints, is explained as:

$$\text{Minimize} \quad f_i(x),\ I = 1,\ldots..,N_{obj} \tag{13}$$

$$\text{Area under discussion} \begin{cases} g_k(x) = 0 & k = 1,\ldots.,\mathrm{K} \\ h_l(x) \le 0 & l = 1,\ldots.,L \end{cases} \tag{14}$$

Here f_i denotes i^{th}objective function and x represents a decision vector.

5. Overview of Opposition Based Differential Evolution (OBDE) method

Opposition-based learning was established by Tizhoosh [23] to modify the candidate solution by studying recent population and its reverse simultaneously. This process starts with an initial population and tries to modify it to a different optimal solution. The different searching methods complete when various predefined criteria are satisfied. This method starts randomly without the knowledge of any previous information about the solution. This technique is upgraded by beginning with a fittest solution by inspecting the opposite solution together. Then the fittest one may be selected for initial solution by performing this. Then the process begins with these two guesses.Similar method could be applied to the initial and to every solution as well in recent population.

5.1 *Defining opposite number*

Supposing x is a real number in the range [lb, ub], the opposite number of it can be specified by

$$\overline{x} = lb + lu - x \tag{15}$$

5.2 *Defining opposite point*

Suppose $X = (x_1, x_2, \ldots., x_n)$ is a point in n-structural space and $x_i \in [lb_i, ub_i],\ i \in 1,2,\ldots,n.$ The opposite point $\overline{X} = \left(\overline{x_1}, \overline{x_2}, \ldots.., \overline{x_n}\right)$ can be interpreted considering its components as shown below:

$$\overline{x_i} = lb_i + ub_i - x_i \tag{16}$$

6. Opposition-based optimization

Let $X=(x_1, x_2, ..., x_n)$ is a point in n- structural space implies this is a candidate solution. Assuming $f=(\bullet)$ is a fitness function that is utilized to evaluate the fitness of the candidate. As per the description of opposite point, $\overline{X}=\left(\overline{x_1}, \overline{x_2}, ..., \overline{x_n}\right)$ is the opposite of $X=(x_1, x_2, ..., x_n)$. If $f(\overline{X})< f(X)$ then point X is changed with $\overline{X}$; Or else this process can be continued with X. So to continue with a fitter one, the points as well as its opposite point both can be assessed at the same time.

7. Experimental Discussion

The submitted approach is solved for two test cases comprising two systems. To validate the realization of suggested OBDE approach, NSGA II is implemented to realize the solution of this problem. The proposed method OBDE, NSGA-II, RCGA all are executed using MATLAB on a PC. In this work the size of population, maximum number of iterations, probabilities for crossover and mutation are taken as 100, 200, 0.9 and 0.2, for the test cases. For OBDE and NSGA II, the size of population, maximum number of iterations, probabilities for crossover and mutation are taken as 10, 30, 0.9 and 0.2 for the two cases.

7.1 *Case 1*

The case 1 includes nine thermal with two wind generating units. The data for the thermal unit has been selected from [19]. For wind power units, both Weibull shape factor as well as scale factor are taken as $k_{s1}=1.5$, $k_{s2}=1.5$, $c_1=15$, $c_2=15$. For these plants the reserve and penalty cost coefficients are considered as $\mathrm{K}_{r1}=5$, $\mathrm{K}_{r2}=5$, $\mathrm{K}_{\mathrm{P}1}=5$, $\mathrm{K}_{\mathrm{P}2}=5$ respectively. The specifications of wind power generating units are P_{wr1}=175 MW, P_{wr2} =175 MW. Load demand is kept as 2400 MW. Cost and both the emission are reduced separately by applying RCGA. Results acquired from minimization of cost, as well as two emissions (NO_x, SO_2) are compiled in Table 1. Figure 1 represents cost, NO_x as well as SO_2 emission convergence characteristics. The results found from both cost and NO_x emission objectives optimized simultaneously. Also both cost as well as SO_2 emission objectives are optimized with OBDE and NSGA II simultaneously and are presented below (Table1).

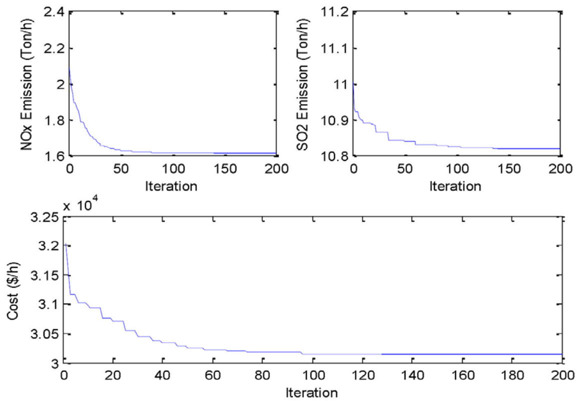

Fig. 1

Emission of NO_x and SO_2 and cost convergence for case 1

7.2 *Case 2*

The case 2 comprises of twelve thermal and 2 wind generating units. All the data of thermal plant has been taken from [19]. The data for two wind generating units is same as case 1. Load demand is decided as 3600 MW. Cost and both the emission objectives of NO_x and SO_2 are minimized individually by utilizing RCGA. The results of all these three parameters are outlined in Table 2. Figure 2 displays the cost, NO_x as well

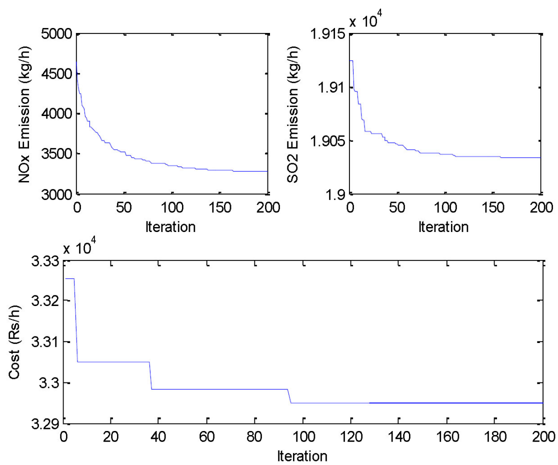

Figure 2

Emission of NO_x and SO_2 and cost convergence for case 2

as SO_2 emission convergence. Results acquired from both the cost and NO_x emission are optimized simultaneously with OBDE and NSGA II. Also cost and SO_2 emission both are optimized with these two techniques. All the results are outlined in Table 2.

Table 1

Test results of case 1 (P_D = 2400 MW)

	RCGA			OBDENSGA II		OBDENSGA II	
	Economic Dispatch	NO_x Emission Dispatch	SO_2 Emission Dispatch	Economic Emission, NO_x	Dispatch	Economic Emission, SO_2	Dispatch
P_{s1} (MW)	238.8618	116.8063	45.8385	240.0000	240.0000	171.3920	45.0000
P_{s2} (MW)	239.8346	123.5643	45.6175	240.0000	191.2500	77.9983	84.5182
P_{s3} (MW)	413.6009	449.9787	278.4732	275.0000	275.0000	313.1270	316.7107
P_{s4} (MW)	346.3529	150.0000	350.0000	350.0000	350.0000	350.0000	348.3497
P_{s5} (MW)	346.3492	150.0640	349.8431	302.3261	299.7022	350.0000	350.0000
P_{s6} (MW)	350.0005	749.9168	390.9326	412.9652	544.8275	350.0000	350.0000
P_{s7} (MW)	35.0000	35.0000	174.9998	35.0000	35.0000	35.0000	169.3134
P_{s8} (MW)	35.0000	35.0000	174.3827	35.0000	35.0000	175.0000	161.4336
P_{s9} (MW)	45.0010	239.7015	239.9125	161.7241	79.2203	227.4827	224.6744
P_{w1} (MW)	175.0000	174.9594	175.0000	172.9846	175.0000	175.0000	175.0000
P_{w2} (MW)	174.9990	175.0000	175.0000	175.0000	175.0000	175.0000	175.0000
cost ($/h)	30156.93	32023.37	32538.75	30927.92	31161.70	31760.70	32187.36
NO_x emission ((Ton/h)	1.8088	1.6191	2.0976	1.7008	1.8302	1.9667	2.0694
SO_2 emission (Ton/h)	11.0935	11.2791	10.8202	11.0296	11.0919	10.1246	10.8446
CPU time (sec)	5.1069	5.2656	4.9531	2.8571	3.2541	2.8732	3.2893

Table 2

Test results of case 2 (P_D = 3600 MW)

	RCGA			OBDE NSGA II		OBDE NSGA II	
	Economic Dispatch	NO_x Emission Dispatch	SO_2 Emission Dispatch	Economic NO_x	Emission Dispatch	Economic SO_2	Emission Dispatch
P_{s1} (MW)	136.6835	172.4744	170.8884	173.5034	170.2775	173.6838	159.2879
P_{s2} (MW)	159.6111	165.7323	139.4248	130.9766	186.5490	122.0843	125.7219
P_{s3} (MW)	295.6915	188.6364	332.8327	218.0564	194.0164	309.4964	321.1332
P_{s4} (MW)	309.2575	411.9170	360.1400	423.6883	429.5412	344.6321	368.4502
P_{s5} (MW)	274.2676	292.1082	265.8107	294.0465	293.5335	250.7542	303.9382
P_{s6} (MW)	281.1441	396.1910	370.7510	417.6621	367.5663	371.6694	382.2655
P_{s7} (MW)	193.5746	162.0455	173.8196	170.8810	148.0623	175.7222	174.5199
P_{s8} (MW)	238.1019	168.4807	143.3534	175.7174	177.1436	131.2018	129.7462
P_{s9} (MW)	289.7695	180.2281	327.1866	190.2644	243.5589	332.3847	295.7578
P_{s10} (MW)	418.4738	418.4262	361.2585	386.7985	385.5710	398.1257	327.0056
P_{s11} (MW)	279.0729	296.7425	242.8893	291.5907	279.2421	290.5672	294.7562
P_{s12} (MW)	377.8373	397.0176	361.6494	378.2099	377.5322	350.0062	368.0299
P_{w1} (MW)	174.1792	175.0000	174.9955	173.6049	172.4060	174.9967	174.3877
P_{w2} (MW)	172.3354	175.0000	175.0000	175.0000	175.0000	174.6752	175.0000
Cost (Rs/h)	32948.93	33955.92	34171.68	33442.90	34587.28	33432,76	34562.20
NO_x emission (kg/h)	3589.83	3271.64	3603.75	3372.23	3508.39	3402.80	3464.86
SO_2 emission (kg/h)	19096.88	19151.04	19034.48	18123.74	18126.49	18004.75	18027.26
CPU time (Sec)	5.7521	5.8091	5.9347	2.8853	3.6043	2.9058	

8. Conclusion

The OBDE has been recommended to solve different issues of hybrid model of EED with wind farm system. The proposed model belongs to a multi-objective optimization problem which includes various vital parameters like cost, emission of NO_x and SO_2. The experimental results realized in the submitted technique are matched with the results realized executing NSGA II. From the comparison it has been noted that, the presented approach offers the best result.

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