OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Economic Environmental Dispatch of Wind Integrated Thermal Power System

Suman Kumar Dey, Deba Prasad Dash, Mousumi Basu

***Abstract:** In electric power plant operation, Economic Environmental Dispatch (EED) of a thermal-wind is a significant chore to involve allocation of production amongst the running units so the price, NO_x extraction status and SO_2 extraction status are enhanced concurrently whilst gratifying each and every experimental constraint. This is an exceedingly controlled multi-objective optimizing issue concerning contradictory objectives having Primary and Secondary constraints. For the given work, a Non-dominated Sorting Genetic Algorithm-II (NSGA-II) is recommended for taking care of EED issue. In simulation results that are obtained by applying the two test systems on the proposed scheme have been evaluated against Strength Pareto Evolutionary Algorithm 2 (SPEA 2).*

***Keywords:** Economic environmental dispatch, wind power uncertainty, fuel charge, NO_x discharge intensity, SO_2 discharge intensity, NSGA-II.*

I. INTRODUCTION

Most electrical energy is produced by burning fossil fuels nowadays which releases various pollutants like oxides of sulfur (SO2), Nitrogen oxides (NOx), oxides of carbon (CO,CO2) etc into the air. One of the principles defies for electric utilities is to decrease air contamination. The act proposed in the year 1990 related to Clean Air is planned to diminish global warming. It necessitates that the conventional generation units ought to the above mentioned pollutants spread dimension [1].

More than one method has been projected in the writing to cut down the pollution of natural. This considers the installation of switching device that maintains the discharge level, utilization of low emanation raw materials, and replacement of the old combustion chamber through new models and get away with outflow thought[2]. These preliminary methods either call for the setting up of latest equipments or alteration of the existing equipments that involves significant funds disbursement. Therefore, the last method is more recommended. Diverse techniques [3]-[9] have been discussed related to the Economic Emission Dispatch (EED) problem. However, these techniques cannot handle the non-linear fuel charge and discharge level functions.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.
* Correspondence Author
Suman Kumar Dey*, Ph.D. in Electrical Engineering under the Department of Power Engineering, Jadavpur University, Kolkata.
Deba Prasad Dash, Associate Professor, Department of Electrical Engineering, Government College of Engineering, Kalahandi.
Mousumi Basu, Professor at Power Engineering Department of Jadavpur University.

The three aims- price, NO_x extraction and SO_2 extraction are contradictory in nature and for discovering overall optimal dispatch they have to be considered concurrently[10]-[12]. For arranging the on line generator productivity having the expected load requirement for getting most effective result in terms of price, NO_x extraction and SO_2 extraction at the same time while

satisfying each and every operational constraint the Economic environmental dispatch (EED) has been used.

Several methods related to EED problem are discussed in the text. Nanda et al. took up EED as a multiple, contradictory intentional issue & used goal-programming methods to resolve that [13].Optimization procedure based upon linear programming are discussed in [14] where the objectives are regarded one by one. In the previous ten years, the EED issue was changed into an issue with single target through linear combining of differing points as a weighted entirety [15]-[16]. It necessitates through changing weights to acquire a bunch of non-subservient answer. Regrettably, in case of problems with non-convex Pareto-optimal front it is of no use. For circumventing such problem, the ε -constraint technique is discussed in [17].It makes the most use of the most favorable aim and regards the other aims as constraints leaped through a number of acceptable levels. However, the stochastic search algorithms are very faster; accurate for example probabilistic technique for approximating the global optimum of a given.

Numerous investigations were done to assess the development of multi-objective evolutionary search strategies throughout the previous couple of years [18]-[20]. It is found that in all these approaches, the extraction function is formulated as a mixture of either sulphur dioxide (SO2) and oxides of nitrogen (NOx) or only nitrogen oxides (NOx). However, in this paper sulphur dioxide (SO2) and nitrogen oxides (NOx) extraction objectives are regarded as separate functions.

In reduction of the effect of Global Warming, wind power and solar PV plants are becoming popular along with fulfilling power stipulate at reasonable price having no dangerous extractions. But intermittent wind and solar power require schemes and dispatch strategies for upholding economy with dependability and safety measures.

A non-dominated sorting genetic algorithm-II is recommended in this paper for economic environmental dispatch of thermal wind sun oriented power framework with battery vitality stockpile framework where price, sulphur dioxide (SO2) extraction and oxides of nitrogen (NOx) extraction are contending ideas. Here difficulty arrived as a nonlinear restricted multi-objective optimization [21].

Real-Coded Genetic Algorithm (RCGA)has been utilized in order to get rid of the cumbersome binary notation of dealing with continuous search space with large dimensions. Moreover, the Simulated Binary Crossover (SBX) and polynomial mutation is employed in the current proposition. Extensive experiments have been carried out for validating the proposed scheme by pertaining it on two separate modules as considered. The results reported from the investigation on NSGA-II is compared and analyzed to that obtained from SPEA2

II. PROBLEM FORMULATION

Here Thermal-Wind-Solar integrated scheme is proposed to standardize respective target capacities - rate, arrival of SO2 and NOx in chorus while gratifying the operational restriction. The resulting goal and variables that are utilized in current work are as talked about individually.

A.Fuel charge

The prepared expense of a thermal-wind-solar system involves the raw material rate for coal-based units alongside the expense of wind energy creating entity. The complete expense can be expressed as:

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

The raw material charge capacity of every coal based unit, thinking about the valve point impact, is articulated like.

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

The expense of wind power incorporates three segments - an immediate fuel charge, an under estimation penalty fuel charge and a spare fuel charge due to over estimation of wind control. Henceforth, the charge related to wind energy conversion of i[th] generated entity at m[th] time is figured as (Hetzer, J., et each of the, 2008):

$$f_{wk} = \left\{(d_k\times P_{wk}) + C_{pk}(W_{k,av} - P_{wk}) + C_{rk}(P_{wk} - W_{k,av})\right\} \quad (3)$$

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

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

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

The wind power categorization is ended via employing Weibulpdf, $f_w(w)$. At this point $h = \frac{v_r}{v_{in}} - 1$.Detail description can be found in [15] and[16].

B. NO_x Discharge

NOx outflows of coal-fired unit are increasingly hard to imitation in view of the fact that has originated from various causes and their creation is connected in the company of a few aspects, for example, hotness of boiler and atmospheric contamination. Simple way to deal with describes NOx outflow is a blend of polynomial and exponential expressions and be able to be expressed in the following way.

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

C. SO_2 Discharge

SO_2 emanation of coal-fired plant relies upon the measure of coal consumed and be able to be reproduced as quadratic polynomial capacity expressed in the following way

$$D_{SO_2} = \sum_{i=1}^{N_s}\left[\alpha_{si} + \beta_{si}P_{si} + \gamma_{si}P_{si}^2\right] \quad (8)$$

Constraints

D. Real power balance constraint

The complete active power production must adjust the anticipated power request in addition to active power losses in the transmission lines.

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

where P_L is computed via the B coefficients which can be articulated in the quadratic form stated as:

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

At this juncture, entire quantity of plants $N = N_s + N_w$ and P_i is the relevant coal-fired and wind power production.

E. Real power operating limits

$$P_{si}^{\min} \le P_{si} \le P_{si}^{\max} \; i \in N_s \quad (11)$$

$$\text{And } P_{wk}^{\min} \le P_{wk} \le P_{wk}^{\max} \; k \in N_w \quad (12)$$

III. FINDING OF GENERATION POINT OF RELAXED GENERATOR

N dedicated coal-fired stations along with the output involve allocation of their based on the power balance restraints (9) and the relevant capacity restraints (11) and (12). By knowing the respective burden of $(N-1)$ generators, the power altitude of the N^{th} unit (i.e. the relaxed generator) is acknowledged as

$$P_N = P_D + P_L - \sum_{i=1}^{N-1} P_i \quad (13)$$

The transmission loss P_L is a function of all generator outputs together with the relaxed generator and it is stated by

$$P_L = \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_i B_{ij} P_j + 2P_N\left(\sum_{i=1}^{N-1} B_{Ni}P_i\right) + B_{NN}P_N^2 + \sum_{i=1}^{N-1} B_{0i}P_i +$$

Retrieval Number: F9528038620/2020©BEIESP
DOI:10.35940/ijrte.F9528.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
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$B_{0N}P_N \qquad\qquad + B_{00}$
(14) Escalating and rearranging, equation (13) becomes

$$B_{NN}P_N^2 + \left(2\sum_{i=1}^{N-1} B_{Ni}P_i + B_{0N} - 1\right)P_N +$$

$$\left(P_D + \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} P_i B_{ij} P_j + \sum_{i=1}^{N-1} B_{0i}P_i - \sum_{i=1}^{N-1} P_i + B_{00}\right) = 0 \qquad (15)$$

The loading of the relaxed generator (i.e. N th) can then be acquired by resolving equation (15) utilizing standard algebraic technique.

IV. PRINCIPLE OF MULTI-OBJECTIVE OPTIMIZATION

Multi-target optimization issue involving various destinations and constraints like primary and secondary may be expressed like:

Minimize $f_i(x)$, $i=1,\ldots,N_{obj}$(16) area under

$$\text{discussion}\begin{cases} g_k(x) = 0 & k = 1,\ldots,K \\ h_l(x) \le 0 & l = 1,\ldots,L \end{cases} \qquad (16)$$

where f_i is the i^{th} intent function, x is a assessment vector.

V. NONDOMINATED SORTING GENETIC ALGORITHM-II

To deal with multi-target optimization issues, NSGA has been proposed in the year of 1995. Non-domination is utilized to offer position to arrangements, and strength contribution is profited in support of expansion command over in the investigation area. Because of not highly susceptible to fitness sharing parameters of NSGA, (K Deb, K., et all, 2002) have instigated NSGA-II as it produce more authentic and dependable solution speedy than its precursor. Because of word constraints, the fact depiction of NSGA-II isn't given in the paper.

i) Fast nondominated sorting procedure

To accumulate way out of the initial nondominated the face in a inhabitants of dimension, each answer be able to be matched up to all extra answer inside the inhabitants to unearth if it's far conquered. By the side of the particular step, all community inside the first nondominated the front are created. In order to unearth the individuals inside the next nondominated front, the solutions of the first front are marked down for the time being and every answer of the residual populace can be matched as much as each different answer of the residual inhabitants to unearth if it is to governed. Accordingly the entire particular inside the next nondominated face are created. This is right for creating third and higher tiers of nondomination.

In support of every way out two components are computed: a) dominion count n_q, the quantity of arrangements which overwhelm the arrangement q, and b) S_q, a lot of arrangements that the arrangement overwhelms. The approach for the rapid nondominated category can be stated as:

So as to uncover the people in the following nondominated front, the arrangements of the principal front are discounted for the present and every arrangement of the lingering populace can be coordinated up to each other arrangement of the remaining populace to uncover on the off chance that it is ruled. In this manner all people in the subsequent nondominated face are made. This is directly for making third and maximum no. of non-domination.

Various steps for above method can be stated as:

Algorithm1: Fast non dominated category.

In every $p \in P$

$S_p = \phi$

$n_p = 0$

In every $q \in P$

if $(p \prec q)$ then — if p dominates q

$S_p = S_p \cup \{q\}$ — add q to the set p

else if $(q \prec p)$ then

$n_p = n_p + 1$ augmentation of p

if $n_p = 0$ then — p fit in to the initial face

$P_{rank} = 1$

$F_1 = F_1 \cup \{p\}$

Every one inhabitants is given a grade identical to its nondomination degree or the face wide variety (1for the exceptional stage and 2 for the following-great degree and so forth).

ii) Fast crowded distance estimation procedure

To collect an estimation of the concentration of answers contiguous a specific clarification within the populace, the common space of spots on both part of this thing beside all the targets is computed. This number provides as an estimation of the outer limits of the cuboid primarily based by the use of the closest pals because the vertices which may defined as crowding distance. This computation necessitates categorization of the populace in keeping with every goal feature fee in rising array of significance. Subsequently, in favour of every goal characteristic, the boundary populations (populations among nominal and biggest characteristic standards) are provided especially excessive distance fuel rate in order that boundary elements are constantly chosen. All different transitional inhabitants are supplied a distance price identical to the fixed regularized distinction inside the function standards of adjoining inhabitants. This computation is kept on with added goal capabilities. The crowding-distance assessment is computed because the total of individual distance values matching to every goal. Every purpose characteristic is regularizing ahead of computing the crowding distance. The set of rules underneath portrays the crowding distance calculation method of the entire answers in a nondominated set G.

Algorithm 2: Crowding distance assignment

$l = |G|$ digit of answer in G

In initialization for i, set $F[i]_{distance} = 0$

in favour of every intention n

$G = \text{Sort}(G,n)$ Arrange by means of every objective assessment

$G[1]_{distance} = F[l]_{distance} = \infty$

in favour of $j = 2$ to $(k-1)$

$$G[j]_{distance} = G[j]_{distance} + (G[j+1].n - G[j-1].n)/(f_m^{max} - f_m^{min})$$

Here, $G[i].n$ indicates the m th primary value of the i th entity of position G. f_m^{max} and f_m^{min} are the greatest and least standards of the m th objective purpose.

iii) Crowded-comparison manipulator

The crowded- comparison manipulator conducts the collection technique at a selection of tiers of the set of rules closer to pareto-optimal front. All individual within the populace belongs to two categories aspects:

a) nondomination rank (i_{rank})

b) crowding distance $(i_{distance})$

$i \prec j$ if $i_{rank} < j_{rank}$ or $((i_{rank} = j_{rank})$ and $(i_{distance} > j_{distance}))$

Between populaces with varying nondomination positions, the individuals with the lower (better) position are wanted. On the off chance that the two populaces have a place with the equivalent front, at that point the masses with bigger swarming separation is supported.

VI. SIMULATION RESULTS

The counselled NSGA-II, SPEA 2 and RCGA had been accomplished in MATLAB 7.0 on a PC (Dual-core, 160 GB, 3.3 GHz).

Fuel charge, NOx outflow and SO2 discharge are taken as the three target capacities. So as to clarify clashing relations among the goal capacities, every target work for example fuel charge, NOx discharge and SO2 outflow is limited exclusively by using genuine coded hereditary calculation (RCGA). Here, the populace level, greatest figure of cycles, hybrid and change possibilities have been picked as 100, 200, 0.9 and 0.2, separately for these two test frameworks.

First, NSGA-II has been pertained to optimize separately both fuel charge and NO_x discharge objectives all together and both fuel charge and SO_2 discharge objectives all together.

At that point, NSGA-II has been related to streamline specified targets i.e. Fuel charge, NOx discharge and SO2 discharge targets concurrently. For evaluation, SPEA 2 has been prevailed for fixing this trouble.

Here, the inhabitants' magnitude, most quantity of iterations, hybrid and transformation probabilities were preferred as 10, 30, 0.9 and 0.2.

A. Test System 1

This test system comprises nine thermal generating units and two wind power generators. Thermal unit data has been adopted from [21]. The wind power accessibility is formed as probabilistic restriction in power stability representation. The Weibull shape factor and scale factor for the two wind power generators are $k_{s1} = 1.5$, $k_{s2} = 1.5$ and $c_1 = 15$, $c_2 = 15$ respectively. The reserve and penalty fuel charge coefficients for the two wind power generating units are chosen as $K_{r1} = 5$, $K_{r2} = 5$, $K_{P1} = 5$, $K_{P2} = 5$ correspondingly. The wind power generators having specification is $P_{wr1} = 175$ MW and $P_{wr2} = 175$ MW respectively. The cut in, cut out and rated wind speeds are $v_{in} = 5$, $v_o = 45$ and $v_r = 15$ respectively. Load demand is 2400 MW.

Fuel Charge, NOx discharge and SO2 discharge goals are minimized separately with the aid of utilizing RCGA. Results received on or after fuel charge reduction, NOx discharge reduction and SO2 discharge reduction, are précised in Table 1.Fig.1 portrays fuel charge, NOx discharge and SO2 discharge meeting characteristics. Results received from each fuel charge and NOx discharge targets optimized at the same time and each Fuel charge and SO2 discharge goals optimized concurrently through the usage of NSGA-II and SPEA 2 are précised in Table 1. Results obtained from Fuel charge, NOx discharge and SO2 discharge targets optimized simultaneously by way of the usage of NSGA-II and SPEA 2 also are summarized in Table 1. Fig. 2 portrays the allocation of 10 nondominated clarifications received in the final new release of recommended NSGA-II and SPEA2 obtained from both Fuel charge and NOx discharge targets optimized concurrently and both price and SO2 discharge targets optimized concurrently and from Fuel charge, NOx discharge and SO2 discharge targets optimized concurrently.

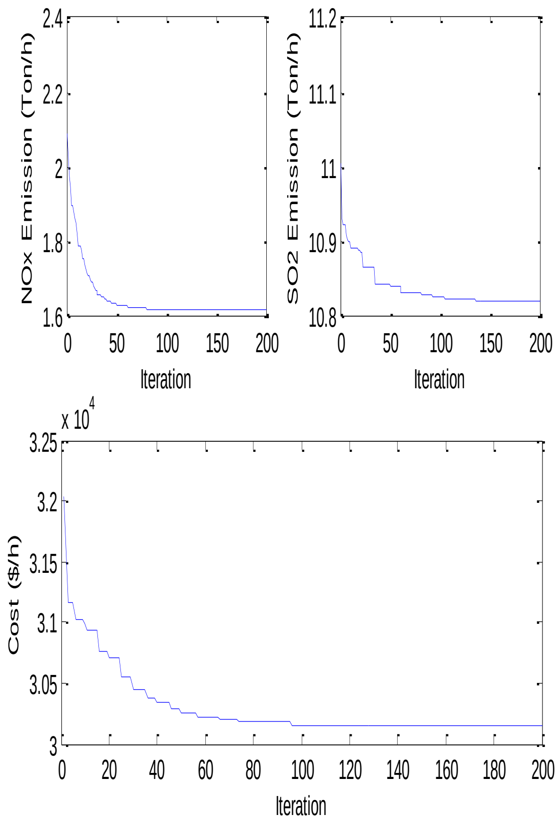

Fig. 1. NO_x discharge, SO_2 discharge and fuel charge

convergence for test system 1.

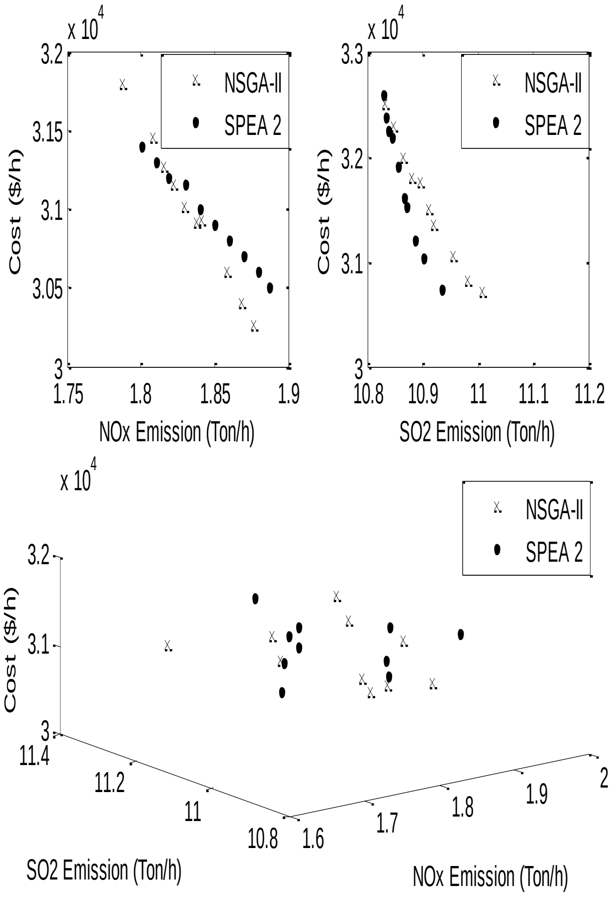

Fig. 2. Pareto-optimal front gained from the final iteration for test system 1

B. Test System 2

Twelve Thermal divisions have been comprised. Thermal unit data has been adopted from [20]. Two wind power generators data is same as test system 1. Load demand is 3600 MW.

Fuel rate, NOx discharge and SO2 discharge goals are reduced personally through employing RCGA. Results received from Fuel rate reduction, NOx discharge reduction and SO2 discharge reduction, are précised in Table 2. Fig. 3 portrays Fuel rate, NOx discharge and SO2 discharge convergence. Results obtained from each price and NOx discharge objectives optimized concurrently and both Fuel rate and SO2 discharge goals optimized in chorus via means of the usage of NSGA-II and SPEA 2 are précised inside Table 2.Results obtained from different criteria i.e. fuel rate, NOx discharge and SO2 discharge goals optimized concurrently through the usage of NSGA-II and SPEA 2 are also précised in Table 2. Fig. 4 portrays the circulation of 10 nondominated answers gained inside the remaining generation of recommended NSGA-II and SPEA2 received from each price and NOx discharge targets optimized concurrently and both fuel rate and SO2 discharge optimized all together and from fuel rate, NOx discharge and SO2 discharge objectives optimized concurrently.

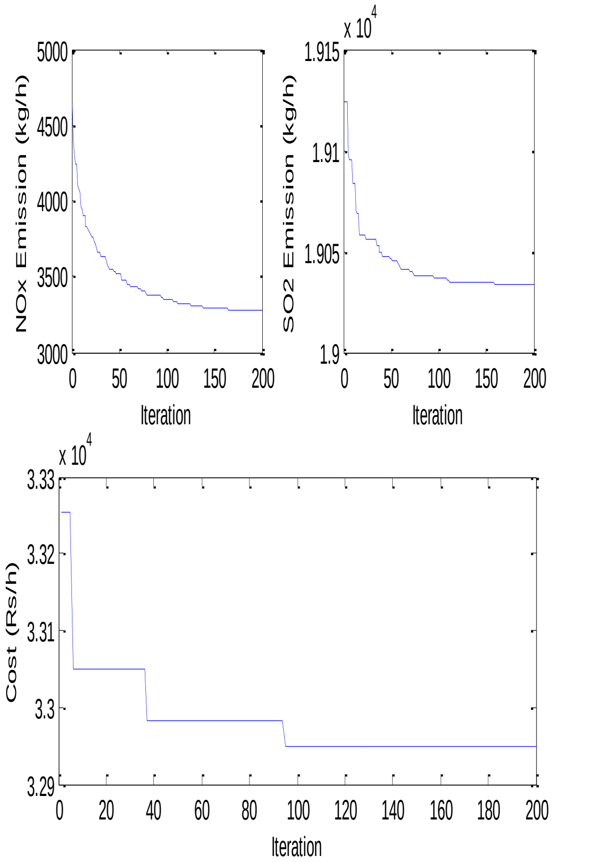

Fig. 3. NO_x discharge, SO_2 discharge and fuel charge convergence for test system 2.

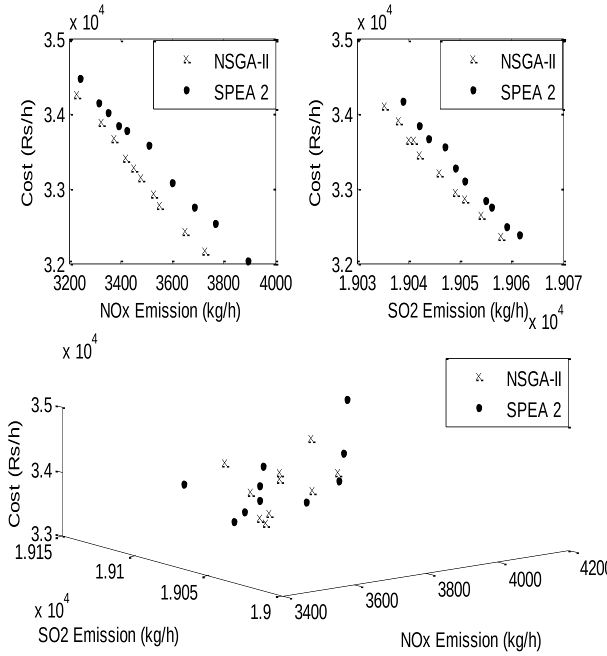

Fig. 4. Pareto-optimal front acquired from the last iteration for test system 2.

V. CONCLUSIONS

Here, NSGA-II has been referred as finding solution of economic environmental dispatch of wind integrated coal-fired generating unit.

The problem has been devise as multi-objective optimization problem with challenging fuel charge; NO_x discharge and SO_2 discharge targets. Analysis outcome gained from the recommended proposal have been evaluated by means of those obtained from SPEA 2. It is seen from the similarity that the recommended idea tendered a viable presentation in provisions of clarification.

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Table 1: Test results of test system 1 for P_D =2400 MW

PARAMETERS	RCGA			NSGA-II	SPEA 2	NSGA-II	SPEA 2	NSGA-II	SPEA 2
	Economic dispatch	NO_x Emission Dispatch	SO_2 Emission Dispatch	Economic NO_x Emission Dispatch		Economic SO_2 Emission Dispatch		Economic NO_x emission SO_2 Emission Dispatch	
P_{s1} (MW)	238.29	117.26	46.403	240.000	194.168	46.509	45.000	240.000	187.457
P_{s2} (MW)	238.29	127.59	45.357	240.000	186.082	92.622	161.381	186.284	240.000
P_{s3} (MW)	387.39	449.83	277.512	450.000	450.000	357.011	325.057	418.291	450.000
P_{s4} (MW)	346.34	150.14	349.923	201.201	150.000	3500.00 0	350.000	289.347	244.381
P_{s5} (MW)	346.34	150.00	349.982	331.431	350.000	350.000	350.000	240.241	350.000
P_{s6} (MW)	350.00	349.17	390.789	350.000	558.404	381.232	363.876	408.286	350.000
P_{s7} (MW)	35.000	35.301	175.000	35.000	35.000	98.487	53.530	35.000	37.100
P_{s8} (MW)	35.000	35.000	175.000	35.000	35.000	175.000	175.000	35.000	35.000
P_{s9} (MW)	93.327	235.725	239.967	176.288	97.382	212.605	227.153	197.549	70.140
P_{SP} (MW)	174.99	175.00	174.995	170.001	170.149	171.551	175.000	175.000	163.343
P_{PV} (MW)	75.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000	75.000
P_{δ} (MW)	100.00	100.00	99.869	96.077	98.813	100.000	100.000	100.000	97.576
cost ($/h)	30302	32113	32634.6	30944.6	35411.0	32199.0	32212.9	31105.3	31025.2
NO_x emission (Ton/h)	1825	1620	2098	1737	1709	2005	1976	1738	1764
SO_2 emission (Ton/h)	11.062	11.281	10.820	11.192	11.225	10.882	10.885	11.136	11.170
CPU time (sec)	5.106	5.365	4.951	2.857	3.254	2.873	3.289	2.947	3.427

Table 2: Test results of test system 2 for P_D = 3600 MW

PARAMETERS	RCGA			NSGA-II	SPEA 2	NSGA-II	SPEA 2	NSGA-II	SPEA 2
	Economic dispatch	NO_x Emission Dispatch	SO_2 Emission Dispatch	Economic NO_x Emission Dispatch		Economic SO_2 Emission Dispatch		Economic NO_x emission SO_2 Emission Dispatch	
P_{s1} (MW)	195.5458	169.7943	174.0721	196.1332	147.1229	170.3731	166.7979	154.8322	132.6029
P_{s2} (MW)	207.2631	134.3472	135.3581	175.9556	164.8763	138.4695	120.5896	208.7082	160.6085
P_{s3} (MW)	303.1709	202.5747	333.3608	199.5556	189.3675	315.2444	299.4612	308.1817	305.2935
P_{s4} (MW)	417.6651	409.9324	364.3608	401.5015	412.8770	375.6765	395.6275	432.2073	300.6408
P_{s5} (MW)	2761157	2960889	2484841	2733824	3189817	2830298	2459271	1855071	2009566
P_{s6} (MW)	408.1876	394.0200	365.6295	380.3015	385.8568	328.7003	308.7346	382.4503	414.2666
P_{s7} (MW)	137.2497	163.7624	174.0261	177.1500	178.1792	199.1772	161.6504	110.7381	193.0985
P_{s8} (MW)	259.2775	172.1556	126.4824	131.3394	134.0506	191.6687	161.6332	1380.192	127.9719
P_{s9} (MW)	298.7176	187.0481	330.0058	203.8097	219.9331	321.4179	329.7314	277.3178	332.4684
P_{s10} (MW)	3068860	4064648	3640228	4372593	4104208	3628832	4338098	4422067	3297150
P_{s11} (MW)	100.000	290.743	257.948	307.990	287.464	197.438	241.190	269+.72	308.709
P_{s12} (MW)	279.921	394.067	373.301	339.689	401.102	365.911	344.511	364.105	435.021
P_{SP} (MW)	175.0000	175.0000	174.9480	171.8715	174.7872	175.0000	175.0000	175.0000	175.0000
P_{PV} (MW)	75.0000	75.0000	75.0000	75.0000	75.0000	75.0000	75.0000	75.0000	75.0000
P_{δ} (MW)	100.0000	100.0000	99.9999	100.0000	100.0000	100.0000	99.9857	100.0000	99.6659
cost ($/h)	32849.38	33892.69	34089.15	33839.29	33689.11	34028.28	34062.72	33984.72	34063.62
NO_x emission (Ton/h)	3957.02	3274.31	3610.96	3440.07	3485.82	3626.28	3556.98	3572.42	3685.16
SO_2 emission (Ton/h)	19119.74	19135.21	19034.61	19146.61	19128.50	19046.07	19049.08	19082.76	19067.39
CPU time (sec)	5.7521	5.8091	5.9347	2.8853	3.6043	2.9058	3.5800	2.9756	3.6091

Nomenclature

F_C : function representing the expenditure.

E_{NO_x} : outcome representing the NO_x discharge

E_{SO_2} : outcome representing the SO_2 discharge

P_{si} : power output of i^{th} generator

P_{si}^{min} , P_{si}^{max} : lower and upper generation limits for i^{th} generating unit

$a_{si}, b_{si}, c_{si}, d_{si}, e_{si}$: cost coefficients of i^{th} generator

$\alpha_{ni}, \beta_{ni}, \gamma_{ni}, \eta_{ni}, \delta_{ni}$: NO_x emission coefficients of i^{th} generator

$\alpha_{si}, \beta_{si}, \gamma_{si}$: SO_2 emission coefficients of i^{th} generating unit

P_{ti} : planned breeze intensity of i^{th} wind turbine unit

$W_{avg,i}$: accessible breeze intensity of i^{th} wind turbine unit

P_{wri} : apprised capacity of i^{th} wind energy convertor

P_{wi}^{min} , P_{wi}^{max} : lowermost and uppermost production limits for i^{th} wind generator

d_{wi} : parameters related to direct cost for the i^{th} wind generator

J_{ci} : parameters related to penalty cost for the i^{th} wind generator

K_{ri} : spare charge parameters for the i^{th} wind energy convertor

k_s : the factor related to shape for given area

c : the factor related to scale for given area

v_{in} : speed at which the turbine first starts to rotate and generate power

v_r : rated wind speed

P_{PVi} :received output through i^{th} solar based plant

P_{PVr} : comparable evaluated power yield of the solar cell

G : sun oriented projected light

G_{std} : sun based light for the given condition

R_c : a specific light point

K_{si} : parameters related to straight rate for the i^{th} solar plant

P_b : The most extreme charge and release limit to/from battery

P_b^{max} : introduced limit of battery storage

P_{Dm} : requirement of load at specific time m

P_{Lm} : transmission losses occurs at specific time m

B_{ij}: Coefficient of loss in transmission

N_s : number of thermal generators

N_w : wind Structure

AUTHORS PROFILE

Suman Kumar Dey received his B.Tech in Electrical Engineering from Makaut (Formerly WBUT) in 2008 and M.Tech in Electrical Power from Calcutta University in 2013. Currently, he is pursuing his Ph.D. in Electrical Engineering under the Department of Power Engineering, Jadavpur University, Kolkata. His area of interest is Power System, Electric Drives and renewable energy.

Deba Prasad Dash received his B.Tech and M.Tech degrees under Utkal University and VSSUT in 1997 and 2001, respectively. He has done his Ph.D. from Jadavpur University, Kolkata in 2011. Currently, he is working as Associate Professor, Department of Electrical Engineering, Government College of Engineering, Kalahandi. His area of interest includes power system optimization and renewable energy sources.

Mousumi Basu received the bachelor degree, master degree and Ph.D. degree from Jadavpur Universty, Kolkata, India, in 1991, 1993 and 2003 respectively. She is a professor at Power Engineering Department of Jadavpur Universty. Her research is focused on power system optimization, soft computing techniques and renewable energy sources.