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Multi-Region Combined Heat and Power Economic Emission Dispatch

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Abstract: Multi-Region Combined Heat and Power Economic Emission Dispatch (MRCHPEED) is an important chore in operational and planning problem. The valve point impact and restricted useful zone of regular thermal generators have been contemplated. In this work, Nondominated Sorting Genetic Algorithm-II (NSGA-II) is proposed for illuminating confounded MRCHPEED problem where power and heat generations have been distributed amongst the all committed units so that fuel cost and outflow echelon have been streamlined in chorus though gratifying every single operational requirement. The research consequence of a two-region investigation framework achieved from the prescribed technique are coordinated up to those acquired from Strength Pareto Evolutionary Algorithm 2 (SPEA 2).

Index Terms- banished useful region; co-generation units; Multi-region; tie line imperatives; valve point effect.

I. INTRODUCTION

Economic dispatch (ED) allocates the generation level of all devoted turbines in a most price- effective way whilst gratifying numerous constraints in a solo structure.

In preferred, generating units are separated among several power production areas connected by using interconnections. Multi-Region Economic Dispatch (MRED) is a growth of lone place economic dispatch. MRED reveals the electricity creation stage along with communication of energy among areas for reducing cost of all sections while satisfying miscellaneous constraint. Different strategies [1]-[8] are converse to explain MRED issue.

Vestige fuel is transformed into electricity in unproductive style. The best part of electricity production desecrated during the technique of change is high temperature. Creating power from a particular fuel source, for example, flammable gas, biomass, coal progress the use of flow due to the difference in temperature along with usefulness of the renovation method is accelerated. In contrast with different variety of energy transmitter, the usefulness of energy of cogeneration is extra which creates less significant pollution. The Combined Heat and Power Economic Dispatch (CHPED) method implies power and heat creation accordingly that production billing is minimized along with satisfying miscellaneous constraint. Different proposal have already been proposed to solve CHPED issues and those are mentioned in reference section.

Huge incorporated power system is generally comprised of divergent locales dependent on an assortment of model for instance topographical, functional, forecast and administration.

Every one of these areas has been correlated to its connecting section along with interconnections. Each locale has its capacity and heat creation and energy and heat requirement.

Limiting the complete cost for every spot through stacking of every dedicated generating units along with co-generation and heat-only units in this way that true power equilibrium limit, heat stability imperatives, production boundary requirements, heat production limit requirements with interconnection limit requirements have been fulfilled while from a particular fuel source, for example, flammable gas, biomass, coal are going in the course of limited heat vs. true power plane is the main point of Multi-Region Combined Heat and Power Economic Dispatch (MRCHPED) .

Electric power plants based on fossil-fuel release a variety of pollutants which creates air pollution in the ambiance. Declining ambiance greenhouse gasses is another challenge for different power producers. The 1990 Clean Air Act is proposed for reducing atmospheric pollution. So today's civilization wants adequate and safe electricity at the cost-effective as well as minimum echelon of greenhouse gasses.

Various methods are proposed to decrease ambience greenhouse gasses [9]-[15]. Among these tactics, dispatching taking into emission consideration is preferable.

The proposed approach is an expansion of Multi-Region Combined Heat and Power Economic Dispatch (MRCHPED) trouble. It plans a wide range of committed coal-fired generating units outputs, co-generation unit outputs, heat-only unit outputs and interchange power amongst regions with forecasted active power demand and heat request with the end goal that all out cost and outflow echelon in all sections are streamlined simultaneously satisfying an assortment of requirements.

This paper suggests NSGA-II to solve complicated multi-region combined heat and power economic emission dispatch (MRCHPEED) issues. For the given system, each region comprises coal-fired generating parts, co-generation parts and heat only parts. Every locale of the framework includes generation entity, co-generation entity and heat only entity.

To triumph over intricacy of binary version for trading with unremitting explore break with big proportions, Real-Coded Genetic Algorithm (RCGA) [16] is exploited. The Simulated Binary Crossover (SBX) and polynomial mutation are used here.

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The recommended method is confirmed by relating it with two-region analysis scheme. Analysis outcome attained in the course of NSGA-II procedure are matched up through the result which are attained from Strength Pareto Evolutionary Algorithm 2 (SPEA2).

II. PROBLEM FORMULATION

Here framework consisting of generation segment, segment related to power from a particular fuel source, for example, flammable gas, biomass, coal and heat-only segment has been taken into consideration. Figure 1 uncovers heat-power reasonable serviceable zone of a joined cycle co-age unit. The warmth and force preparations are inseparable. The heat-power practical functional zone has been encompassed by the wilderness curve ABCDEF.

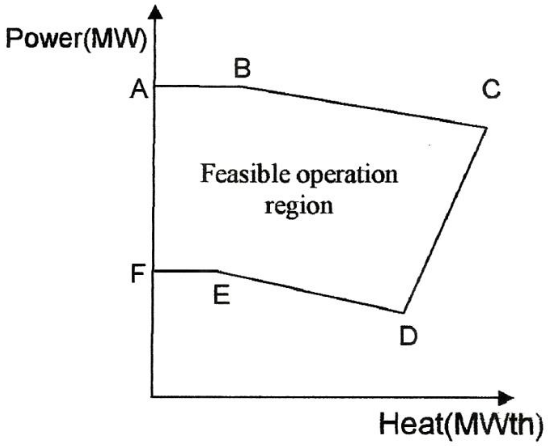

Fig.1. Heat-Active power viable workable area for a cogeneration

The power output of the thermal generators and the heat output of heat-only units are bounded by their individual maximum and minimum frontiers. The power is produced by thermal generators and co-generation units and the heat is produced by co-generation units and heat-only units.

The MRCHPEED issue chooses the active power and heat creation with the goal that the complete cost and outflow of all locales is upgraded through running every dedicated generating units, units produced power from a particular fuel source, for example, flammable gas, biomass, coal and heat only units in this way where different limitation are fulfilled but units produced power from a particular fuel source, for example, flammable gas, biomass, coal are attempted in an encompassed heat in opposition to power plane. Here MRCHPEED issue is communicated as:

Objectives

A. Cost

The total price is stated as

$$C_{\mathrm{T}} = \sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{ti}} \left[a_{ij} + b_{ij} \mathrm{P}_{tij} + c_{ij} \mathrm{P}_{tij}^{2} + \left| d_{ij} \times \sin \left\{ e_{ij} \times \left(\mathrm{P}_{tij}^{\min} - \mathrm{P}_{tij} \right) \right\} \right| \right]$$

$$+ \sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{ci}} \left[\alpha_{ij} + \beta_{ij} \mathrm{P}_{cij} + \gamma_{ij} \mathrm{P}_{cij}^{2} + \right.$$

$$\left. \delta_{ij} \mathrm{H}_{cij} + \varepsilon_{ij} \mathrm{H}_{cij}^{2} + \xi_{ij} \mathrm{P}_{cij} \mathrm{H}_{cij} \right] +$$

$$\sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{hi}} \left[\phi_{ij} + \eta_{ij} \mathrm{H}_{hij} + \lambda_{ij} \mathrm{H}_{hij}^{2} \right] \qquad (1)$$

B. Emission

The ambience green house gases consisting of different air pollutants produced as a result of coal-fired generating unit is represented one by one. On the other hand, for assessment cause, the whole secretion of these green house gases is affirmed as the summation of a quadratic and an exponential characteristic. The general discharge from thermal segments, cogeneration segments and heat-only segments in the system may be stated as

$$E_{\mathrm{T}} = \sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{ti}} \left[\mu_{ij} + \kappa_{ij} \mathrm{P}_{tij} + \pi_{ij} \mathrm{P}_{tij}^{2} + \sigma_{ij} e^{\left(\theta_{ij} \mathrm{P}_{tij} \right)} \right] +$$

$$\sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{ci}} \left[\tau_{ij} \mathrm{P}_{cij} \right] + \sum_{i=1}^{\mathrm{N_A}} \sum_{j=1}^{\mathrm{N}_{hi}} \left[\rho_{ij} \mathrm{H}_{hij} \right] \qquad (2)$$

Constraints

C. Power equilibrium constraints

The general real power production for every generating section and co-generation section need to be same to the region where real power utility in the company of the reflection of incoming and outgoing real power and is acknowledged in the following way:

$$\sum_{j=1}^{\mathrm{N}_{tii}} \mathrm{P}_{tij} + \sum_{j=1}^{\mathrm{N}_{ci}} \mathrm{P}_{cij} = \mathrm{P}_{Di} + \sum_{k,k \neq i} \mathrm{T}_{ik} \quad i \in \mathrm{N_A},$$

Where T_{ik} is the interconnection real power transmission in between section i to section k. T_{ik} is positive at the same time as energy transfer from section i to section k and T_{ik} is negative while energy transfer from section k to section i.

D. Interconnection power capacity constraints

Power transmission through interconnection T_{xy} from section x to section y should lie within the interconnection real power transfer capacity boundary.

$$-\mathrm{T}_{xy}^{\max} \le \mathrm{T}_{xy} \le \mathrm{T}_{xy}^{\max} \qquad (3)$$

Where $\mathrm{T}_{ik}^{\max}$ the active power flow is limit from region i to region k and $-\mathrm{T}_{ik}^{\max}$ is the active power flow limit from region k to region i.

E. Capability frontiers of thermal generators

$$\mathrm{P}_{tij}^{\min} \le \mathrm{P}_{tij} \le \mathrm{P}_{tij}^{\max}, \; i \in \mathrm{N_A} \; and \; j \in \mathrm{N}_{ti} \qquad (4)$$

F. Restricted effective region of coal-fired generating units

The physically possible functional section of the j^{th} generation unit in the section i with restricted achievable vicinity is affirmed as:

$$\begin{aligned} &\mathrm{P}_{tij}^{\min} \le \mathrm{P}_{tij} \le \mathrm{P}_{tij,1}^{l} \\ &\mathrm{P}_{tij,m-1}^{u} \le \mathrm{P}_{tij} \le \mathrm{P}_{tij,m}^{l}\,;\ m = 2,3,\ldots,n_{ij} \\ &\mathrm{P}_{tij,n_{ij}}^{u} \le \mathrm{P}_{tij} \le \mathrm{P}_{tij}^{\max} \end{aligned} \tag{6}$$

Where m signifies the quantity of restricted achievable vicinity. $\mathrm{P}_{tij,m-1}^{u}$ is the maximum limit of $(m-1)$th proscribed workable area of j th thermal generator in region i. $\mathrm{P}_{tij,m}^{l}$ is the minimum limit of m th proscribed workable area of j th thermal generator in region i. Total number of proscribed workable areas of j th thermal generator in region i is n_{ij}.

G. Heat equilibrium constraints

$$\sum_{j=1}^{\mathrm{N}_{ci}} \mathrm{H}_{cij} + \sum_{j=1}^{\mathrm{N}_{hi}} \mathrm{H}_{hij} = \mathrm{H}_{Di} + \sum_{k,k\neq i} \mathrm{H}_{ik} \quad i \in \mathrm{N}_{\mathrm{A}}\,, \tag{7}$$

Where H_{ik} is the temperature transfer through interconnection from section i to section k. H_{ik} is positive when temperature depart from section i to section k and H_{ik} is negative while temperature depart from section k to section i.

H. Tie line heat capacity constraints

Temperature transfer through interconnection H_{ik} from region i to region k should be within the tie line heat transfer capacity limits.

$$-\mathrm{H}_{ik}^{\max} \le \mathrm{H}_{ik} \le \mathrm{H}_{ik}^{\max} \tag{8}$$

Where $\mathrm{H}_{ik}^{\max}$ is the heat transfer capability in between section i to section k and $-\mathrm{H}_{ik}^{\max}$ is the heat transfer capability in between section k to region i.

I. Capability frontiers of cogeneration units

Heat and power outputs of the units produced power from a particular fuel source, for example, flammable gas, biomass and coal are undividable and one output interrupt with other $\mathrm{P}_{c}^{\min}(\mathrm{H}_{c})$, $\mathrm{P}_{c}^{\max}(\mathrm{H}_{c})$, $\mathrm{H}_{c}^{\min}(\mathrm{P}_{c})$ and $\mathrm{H}_{c}^{\max}(\mathrm{P}_{c})$ are the linear primary constraints which render the possible effective part of the cogeneration segments.

$$\mathrm{P}_{cij}^{\min}(\mathrm{H}_{cij}) \le \mathrm{P}_{cij} \le \mathrm{P}_{cij}^{\max}(\mathrm{H}_{cij}),\ i \in \mathrm{N}_{\mathrm{A}} \text{ and } j \in \mathrm{N}_{ci} \tag{9}$$

$$\mathrm{H}_{cij}^{\min}(\mathrm{P}_{cij}) \le \mathrm{H}_{cij} \le \mathrm{H}_{cij}^{\max}(\mathrm{P}_{cij}),\ i \in \mathrm{N}_{\mathrm{A}} \text{ and } j \in \mathrm{N}_{ci} \tag{10}$$

J. Fabrication frontiers of heat-only units

$$\mathrm{H}_{hij}^{\min} \le \mathrm{H}_{hij} \le \mathrm{H}_{hij}^{\max},\ i \in \mathrm{N}_{\mathrm{A}} \text{ and } j \in \mathrm{N}_{hi} \tag{11}$$

III. NONDOMINATED SORTING GENETIC ALGORITHM-II

N. Srinivas and K. Deb [7] recognized an algorithm based on genetic technique abbreviated as "NSGA" to compete with multifaceted optimization issues. Non-domination is used as grading criteria of result, and fitness distribution is used for diversification control in the investigated section. Like NSGA is incredibly responsive to fitness distribution factors, Deb et al. [8] established non-domoinated sorting genetic algorithm-II (NSGA-II), which produces advance consistent way out quickly than its ancestor. Owing to inadequacy of space details of NSGA-II cannot be provided in this paper.

IV. SIMULATION RESULTS

The recommended NSGA-II is used to solve a complicated MRCHPEED problem. Here a system has been considered having two separate frameworks. Simulation results have been utilized to coordinate the viability of the suggested NSGA-II along with strength pareto evolutionary algorithm 2 (SPEA 2).Fuel charge and discharge are major conflicting issues. To illuminate opposing connections among the goal capacities, every one for example fuel cost and discharge is limited independently by utilizing genuine coded hereditary calculation (RCGA). The populace size, most extreme number of cycles, hybrid and transformation probabilities are preferred like 100, 300, 0.9 and 0.2 separately.

NSGA-II is confirmed to improve different goals for example fuel cost and discharge at the same time. To analyze the outcomes, SPEA 2 is utilized to take care of this issue.

The population size, upper limit of iterations, crossover and mutation probabilities are preferred 20, 30, 0.9 and 0.2 respectively in NSGA-II and SPEA 2.The NSGA-II, SPEA 2 and RCGA are abused by using MATLAB 7.5 on a PC (Dual core, 1TB, 3.3 GHz).

Section 1 consist of of 13 Nos of generation units with restricted effective area and valve point effect, 6 Nos of co-generation units and 5 Nos of heat-only units. Detailed data is summarized in Table A.1 and Table A.2 in the appendix. The other data of co-generation units is taken from [4].

Section 2 comprises 26 Nos of conventional generation unit restricted effective area and valve point effect, 12 Nos of units which produced power from a particular fuel source, for example, flammable gas, biomass, coal and 10 heat-only units. Records of section 2 are managed by replicating records of section 1.

The active power stream border commencing section 1 to section 2 or commencing section 2 to section 1 is 300MW. The heat stream border commencing section 1 to section 2 or commencing section 2 to section 1 is 300 MWth. Whole active power and heat requirement separated between section 1 and section 2 are 30% and 70% respectively.

Total active power requirement is 7500 MW and entire heat requirement is 5000 MWth.

Multi-region combined heat power economic dispatch problem and multi-region combined heat and power emission dispatch problem are solved by using RCGA. It is examined that under multi-region combined heat and power economic dispatch, total cost is 207472 $/hr and emission is 287.1266 Kg/hr. But price boosts to 521942 $/hr and emission reduces to 183.8696 Kg/hr in case of multi-region combined heat and power emission dispatch.

Multi-region combined heat power economic emission dispatch (MRCHPEED) issue is fathomed via using recommended NSGA-II and SPEA 2. Contingent upon MRCHPEED using NSGA-II, fuel cost is 305630 $/hr and emission is 241.4702 Kg/hr. MRCHPEED using SPEA 2, fuel charge is 317390 $/hr and discharge is 241.9414 Kg/hr.

The active power and heat production of section 1 and section 2 accomplished from the multi-region combined heat and power economic dispatch along with others by utilizing NSGA-II and SPEA 2 have been pointed out in Table I and Table II correspondingly.

Fuel cost, emission, interconnection active power transmission and interconnection heat transmission acquired commencing multi-region combined heat and power economic dispatch problem along with others are accumulated inside chart 3 as given. The cost convergence and emission convergence characteristics acquired by utilizing RCGA has been revealed in Fig. 2 and Fig. 3 respectively. Figure 4 reveals the distribution of 20 nondominated solutions attained in the final iteration of recommended NSGA-II and SPEA2 attained from MRCHPEED.

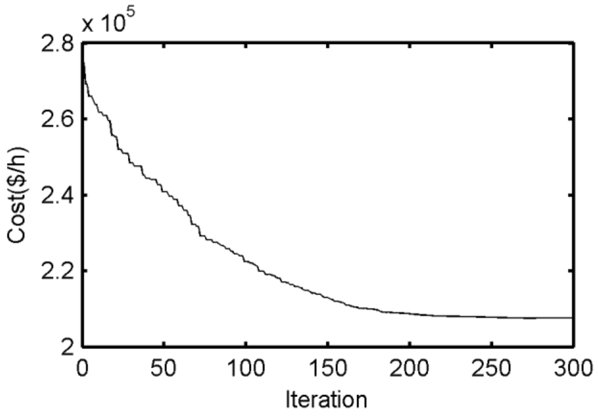

Fig. 2. Cost convergence characteristic

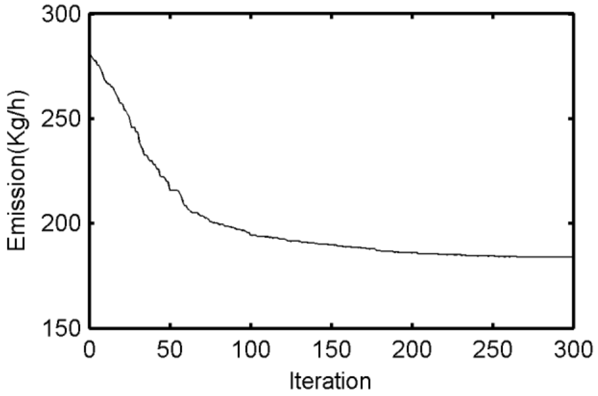

Fig. 3. Emission convergence characteristic

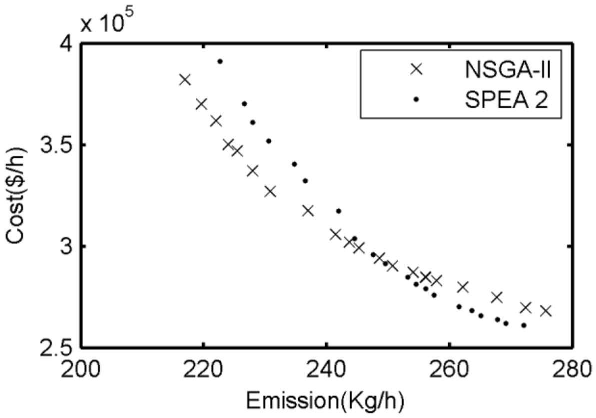

Fig. 4. Pareto-optimal front of the final iteration

Table III: Assessments of concert

Parameter	**Multi-region combined heat and power economic dispatch**	**Multi-region combined heat and power emission dispatch**	**Multi-region combined heat and power economic emission dispatch**	
			NSGA-II	**SPEA 2**
Cost ($/h)	207472	521942	305630	317390
Emission (Kg/h)	287.1266	183.8696	241.4702	241.9414
T_{12} (MW)	42.1859	246.8647	200.0926	100.9626
H_{12} (MWth)	173.3398	116.7972	-271.5332	149.8350

Table I: Active power production (MW) and Heat-production (MWth) of section 1 acquired from multi-region combined heat and power dispatch

Economic Dispatch	Emission Dispatch	Economic Emission Dispatch	
		NSGA II	SPEA 2
P_{t1} 175.3269	131.3751	238.6961	121.4263
P_{t2} 240.2568	220.0097	169.3303	269.6463
P_{t3} 262.1979	225.0039	252.0785	259.3150
P_{t4} 122.4446	148.1775	137.6074	165.9348
P_{t5} 171.2847	149.4530	180.0000	100.9899
P_{t6} 106.1885	151.0677	107.4919	139.3710
P_{t7} 137.3948	76.0717	86.5014	60.0000
P_{t8} 143.3005	76.1873	136.9679	60.0000
P_{t9} 131.5079	75.4632	120.3673	71.5266
P_{t10} 77.5608	96.4404	101.4402	106.8052
P_{t11} 75.2351	97.5335	119.5742	120.0000
P_{t12} 55.0000	77.5996	57.8323	94.8652
P_{t13} 55.9525	77.0394	57.3955	81.6566
P_{c1} 147.0936	246.9580	177.5651	185.7836
P_{c2} 87.0206	125.7733	93.0103	82.0021
P_{c3} 170.5433	247.0000	225.3918	239.8347
P_{c4} 83.6526	125.7509	119.4748	72.5157
P_{c5} 10.7658	60.0000	33.4432	39.6768
P_{c6} 39.4589	89.9604	35.9243	79.6128
H_{c1} 141.7551	0	65.3837	53.9485
H_{c2} 115.5269	32.3889	48.3176	80.0202
H_{c3} 154.8795	0	0	0
H_{c4} 112.6807	32.1705	13.4316	50.2808
H_{c5} 40.3284	0	0.0941	28.3155
H_{c6} 21.9781	24.1873	5.1975	0.0005
H_{h1} 60.0000	1.4000	36.7000	56.7000
H_{h2} 59.9822	0	60.0000	44.7000
H_{h3} 119.9857	0	105.1000	87.2000
H_{h4} 119.9984	1.0000	120.0000	112.2000
H_{h5} 726.2247	1525.60	774.3	1136.4

Table II: Power production (MW) and heat production (MWth) of section 2 acquired from multi-region combined heat and power dispatch.

Economic Dispatch	Emission Dispatch	Economic Emission Dispatch	
		NSGA II	SPEA 2
P_{t1} 175.1141	131.2701	47.8544	125.2241
P_{t2} 242.6539	220.0054	157.7517	270.0507
P_{t3} 304.6120	225.0104	285.2191	243.0064
P_{t4} 147.6799	147.5379	147.5379	176.5720
P_{t5} 166.2134	150.3602	124.0388	163.4945
P_{t6} 136.7123	149.5807	180.0000	133.8819
P_{t7} 173.7326	76.4833	60.0000	117.9709
P_{t8} 154.9804	77.1193	179.4743	60.0577
P_{t9} 121.5496	74.9862	91.3939	125.0197
P_{t10} 40.3942	95.6814	108.0711	80.5614
P_{t11} 40.4158	95.9912	40.2763	119.9426
P_{t12} 56.2225	76.1652	61.9070	55.0000
P_{t13} 55.0172	55.0118	107.3403	55.8733
P_{t14} 421.4253	135.3546	243.2763	257.7605
P_{t15} 234.3023	90.2354	284.8780	266.3629
P_{t16} 252.2307	225.0035	236.0131	227.6083
P_{t17} 146.8343	148.1660	180.0000	63.6185
P_{t18} 147.2141	149.1256	120.8225	152.0744
P_{t19} 174.7218	150.1015	126.8398	153.4561
P_{t20} 161.7564	73.8703	60.0000	79.5739
P_{t21} 148.2109	76.5604	119.8093	135.8604
P_{t22} 180.0000	73.7084	154.0689	76.2866
P_{t23} 55.4384	95.7966	78.8220	120.0000
P_{t24} 41.4238	97.1463	120.0000	120.0000
P_{t25} 57.7860	76.1090	88.2034	98.9655
P_{t26} 55.5977	76.2695	112.2056	74.3555
P_{c1} 117.6495	246.9607	195.6818	215.7340
P_{c2} 70.9362	125.7974	60.4244	74.7606
P_{c3} 148.8926	246.9461	222.8787	130.2030
P_{c4} 103.4972	125.8000	97.6660	118.7039

Economic Dispatch	Emission Dispatch	Economic Emission Dispatch	
	NSGA II	NSGA II	SPEA 2
P_{c5} 10.4163	59.9163	47.7762	38.3283
P_{c6} 47.9396	89.8480	82.6971	80.1689
P_{c7} 149.0130	246.8992	156.5276	213.4789
P_{c8} 74.6154	125.6641	121.5002	105.6402
P_{c9} 147.3443	246.9531	135.0682	227.6502
P_{c10} 105.2674	125.7584	82.4985	110.1486
P_{c11} 10.1667	59.9512	36.7629	26.9498
P_{c12} 80.2413	89.9919	84.2810	77.5090
H_{c1} 125.2917	0.0016	60.0660	21.1935
H_{c2} 101.7223	32.1396	63.6122	10.9137
H_{c3} 142.6570	0	89.1739	1.6623
H_{c4} 129.7772	32.3555	5.1826	17.9133
H_{c5} 40.1778	0.0590	9.2503	33.9861
H_{c6} 25.8558	24.5429	21.3635	1.5788
H_{c7} 142.9650	0.1691	65.0978	18.7457
H_{c8} 104.7792	33.1855	0.3305	93.3041
H_{c9} 142.0037	0.1392	94.7179	29.1193
H_{c10} 131.3721	32.2791	104.3493	113.3349
H_{c11} 40.0617	0.1407	4.5180	10.1226
H_{c12} 0.5230	24.4440	7.8781	0
H_{h1} 59.9604	0.6000	57.4000	60.0000
H_{h2} 59.9817	8.8000	51.3000	31.3000
H_{h3} 119.9880	8.6000	113.4000	83.6000
H_{h4} 119.9375	0	106.5000	62.1000
H_{h5} 717.0273	2607.9	1250.8	1146.0
H_{h6} 59.9968	4.3000	33.9000	60.0000
H_{h7} 59.9686	0.8000	27.5000	59.5000
H_{h8} 119.9926	12.6000	120.0000	56.9000
H_{h9} 119.9976	3.2000	113.1000	97.3000
H_{h10} 722.6231	557.000	1372.0	1341.6

V. CONCLUSION

In the current work, NSGA-II is recommended to solve complex multi-region combined heat and power economic emission dispatch problem. Simulation results attained from the recommended technique are compared with those attained from SPEA 2. It is seen that the recommended technique proffers a cutthroat performance.

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APPENDIX

Table A.1: Data of section 1

Thermal generators

Unit	P^{min}	P^{max}	a	b	c	μ	κ	π
1	0	680	160	3.6	0.0021	5.4289	0.0351	0.00024
2	0	360	130	3.8	0.0017	4.2895	0.0411	0.00040
3	0	360	130	3.8	0.0017	4.2895	0.0411	0.00040
4	60	180	100	4.0	0.0023	4.2669	0.0545	0.00028
5	60	180	100	4.0	0.0023	4.2669	0.0545	0.00028
6	60	180	100	4.0	0.0023	4.2669	0.0545	0.00028
7	60	180	120	3.5	0.0035	4.2669	0.0254	0.00036
8	60	180	120	3.5	0.0035	4.2669	0.0254	0.00036
9	60	180	120	3.5	0.0035	4.2669	0.0254	0.00036
10	40	120	150	4.6	0.0105	1.3859	0.0327	0.00032
11	40	120	150	4.6	0.0105	1.3859	0.0327	0.00032
12	55	120	140	3.8	0.0015	1.4385	0.0232	0.00034
13	55	120	140	3.8	0.0015	1.4385	0.0232	0.00034

Cogeneration units

Unit	α	β	γ	δ	ε	ξ	τ
1	2650	14.5	0.0345	4.20	0.030	0.031	0.00165
2	1250	36.0	0.0435	0.60	0.027	0.011	0.00220
3	2650	14.5	0.0345	4.20	0.030	0.031	0.00165
4	1250	36.0	0.0435	0.60	0.027	0.011	0.00220
5	2650	34.5	0.1035	2.20	0.025	0.051	0.00140
6	1565	20.0	0.0720	2.34	0.020	0.040	0.00110

Heat-only units

Unit	H^{min}	H^{max}	φ	η	λ	ρ
1	0	60	950	2.0109	0.038	0.0018
2	0	60	950	2.0109	0.038	0.0018
3	0	120	480	3.0651	0.052	0.0017
4	0	120	480	3.0651	0.052	0.0017
5	0	2695.2	950	2.0109	0.038	0.0016

Table A.2: Restricted effective area of l thermal generators of section 1

Unit	Precinct 1, MW	Precinct 2, MW	Precinct 3, MW
1	[180, 195]	[260, 335]	[390, 420]
2	[30, 40]	[180, 220]	[305, 335]
3	[30, 45]	[190, 225]	[305, 335]
10	[45, 55]	[65, 75]	-
11	[45, 55]	[65, 75]	-

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