Multi Objective Combined Emission Constrained Unit Commitment Problem Using Improved Shuffled Frog Leaping Algorithm

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Abstract: This paper presents a solution technique for combined emission constrained unit commitment problem (UCP) . The emission level is taken as a constraint in both the selection of units for generation and also in dispatching the real power among the committed units. The multi objective problem is converted into a single objective using max price penalty factor method. Since unit commitment problem is highly constrained and complex, we need a solution technique capable of solving such complex problems. Improved Shuffled Frog Leaping Algorithm (SFLA) is a memetic algorithm which deals with the behaviour of group of frogs searching for the location that has the maximum amount of available food. Leaping of the frog is improved by the introduction of cognitive component. This ensures the faster convergence and global optimal solution. The integer coded UC is used which avoids any extra penalty function for satisfying the minimum up/down constraint. The SFLA is used in two stages in this proposed method. This proposed algorithm has been implemented in Matlab 2011 environment. IEEE 14 bus system, IEEE 30 bus system, IEEE 56 bus system and IEEE 118 bus system are taken as the test system. We have taken 3 cases such as purely economical case, purely emission case and combined emission and economic case by varying the weighting factors for the constraints. The results of these cases are discussed to explain the effect of emission in selecting units and in economic dispatch.

Index terms: economic dispatch, emission dispatch, Shuffled frog Leaping Algorithm, local search, cognitive component

1. Introduction

Unit commitment is a problem of determining the status of the generating units and the real power dispatch among the committed units to meet the system demand while satisfying the system and unit such as power balance, spinning reserve ramp rate, minimum up/ down time and generator max/min generation limits of generators. The traditional UCP deals only with the economics regardless of environmental aspects. . Since, the power generation is mainly based on the fossil based fuel we cannot neglect the emission level. They are the main contributors of green house gases like Co2, So2, Nox, into the atmosphere. This is responsible for the climate change on our environment. The revolution in clean environment and clean energy several regulations were made such as clean Air Act Amendments of 1990, Kyoto

obtaining too small values. This should be of the order of the system maximum operating cost.

Step 3. Shuffling of memeplexes is carried out and again sorted, sub grouped into memeplexes. The local search process (step 2) is performed.

Step 4. The Step 2 &3 are repeated until the required convergence is reached.

B. Implementation of improved SFLA to emission constrained ED problem

The size of the frog(X) is 1X N vector. N is the no of generating units committed. A sample frog is as follows X=[X_1 X_2 X_3 ---- X_N]. Where X_i is a random no between (0,1000). X is a normalised value of P_i between P_{imin} and P_{imax}. The value of P_i can be calculated from the random X_i

$$P_i = \frac{X_i(P_{imax} - Pimin)}{1000} + P_{imin} \qquad (21)$$

Now, for any value of X_i, the value of P_i will always be within the limits P_{imin} and P_{imax}. Since, the generator limit constraint is satisfied in the coding stage itself there is no need for any penalty function for this constraint. The Steps involved in Improved SFLA based dispatch is same as discussed in sub section (a) for UC. Only the generation of random frog procedure varies. The sample frog for a 6 unit system is given in table(2).The followings steps are performed in generating a random frog and calculating its fitness value.

(i) Generate a random frog X.
(ii) Compute the values of P_i from X_i.
(iii) Calculate the error $\sum P_i - P_D$
(iv) Calculate the cost using the equation(2) for all generators.
(v) Calculate the fitness. Since it a minimisation problem the fitness=A/F(X).

$$F(X)=\sum \varphi_c(P_i) + (|\sum P_i - P_D|) * \omega \qquad (22)$$

Where, $\omega=\frac{\sum F(P_{imax})}{P_D}$ and A is a system dependent constant usually chosen a higher value to avoid the fitness to be very low.

TABLE (2) Sample frog for Improved SFLA for dispatch problem

Unit/ values	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6
X_i	1000	857	112	252	0	48
P_i	250	140	24.5	25.1	10	15.3

V. Simulation results

The test system taken are IEEE 14 bus, IEEE 30 bus, IEEE 56 bus and IEEE 118 bus system. The no., of generating units of the test systems considered varies from 5 to 19 units. The generator cost and emission data and system hourly load data are taken from motor.ece.iit.edu/data. The commitment schedule is obtained for 24 hours.

The spinning reserve is taken as 10% of the hourly load. Before implementing, certain parameters are to be determined in advance. After several random check the parameters like population size, no of memeplexes, no of frogs in a memeplex, no of iterations in the local search are chosen for both master and sub problem as tabulated in table(3).

TABLE (3) Parameters of Improved SFLA

Sl No	Problem	Total frogs	No.of memeplexes	No, of frogs in a memeplex	Iterations in Local search
1	Master Problem	200	20	10	10
2	Sub Problem	100	10	10	10

TABLE: 4 Commitment schedule for IEEE 14 bus system (case:1 ED)

Hour	Power Generations of Units(MW) Operating Cost=$11279					Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5		
1	87.1	25.9	15.0	10.0	10.0	354.6	163.1
2	107.6	30.6	15.0	10.0	10.0	422.9	199.6
3	145.0	38.6	16.3	10.0	10.0	561.5	296.6
4	162.5	43.2	18.3	10.0	10.0	637.3	357.4
5	176.9	43.3	18.7	10.0	10.0	686.5	406.9
6	168.8	43.7	15.5	10.0	10.0	650.7	376.4
7	149.9	40.1	16.9	10.0	10.0	583.3	313.2
8	131.3	34.9	15.7	10.0	10.0	506.9	255.7
9	110.1	30.8	15.0	10.0	10.0	431.3	204.7
10	75.7	23.3	15.0	10.0	10.0	318.1	147.7
11	45.0	20.0	15.0	10.0	10.0	234.5	126.1
12	72.3	22.7	15.0	10.0	10.0	307.8	143.9
13	94.6	27.4	15.0	10.0	10.0	378.7	174.9
14	103.6	29.4	15.0	10.0	10.0	408.9	191.4
15	125.9	34.1	15.0	10.0	10.0	486.2	241.3
16	158.2	40.6	16.1	10.0	0.0	576.1	310.5
17	171.4	44.0	18.6	10.0	0.0	637.4	360.9
18	169.9	43.6	17.4	10.1	0.0	627.6	354.3
19	161.7	40.6	17.4	10.3	0.0	592.0	322.6
20	145.2	37.8	17.1	10.0	0.0	529.0	268.8
21	118.6	32.4	15.0	10.0	0.0	427.4	195.7
22	102.8	29.2	15.0	10.0	0.0	373.6	162.3
23	87.2	15.8	15.0	10.0	0.0	322.1	135.5
24	66.6	21.4	15.0	0.0	0.0	224.4	82.70
	Total Emission						5792

In order to identify the effect of emission on economics and economics on emission, we have taken three cases. Here three cases are considered depending on the values of the weighting factor. The fully economic constrained (wfuel=1; wemi=0;), fully emission constrained (wemi=1; wfuel=0), and the combined emission economic (wfuel=1; wemi=1;) cases are considered.

IEEE 14 bus system

The optimal cost of all the above cases are obtained in 6 to 8 shuffling iterations. The improved SFLA for dispatch problem takes 5 to 8 shuffling iterations to obtain the optimal frog.

TABLE: 5 Commitment schedule for IEEE 14 bus system (case:2 EMD)

Hr	Power Generations of Units(MW) Operating Cost=$11993					Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5		
1	78.4	34.6	15.0	10.0	10.0	356.2	162.4
2	92.3	44.6	16.1	10.0	10.0	427.5	195.6
3	105.0	43.8	39.1	21.9	10.0	604.6	259.7
4	101.5	28.9	21.2	48.8	43.6	712.9	311.7
5	116.1	61.4	40.0	31.5	10.0	739.3	.332.4
6	116.7	51.7	31.4	35.2	13.0	682.7	305.3
7	114.9	29.5	29.2	21.2	32.2	623.8	266.4
8	79.4	40.6	38.4	20.8	22.8	565.4	227.2
9	68.5	44.5	15.6	18.6	28.8	468.4	196.3
10	73.1	25.9	15.0	10.0	10.0	318.2	147.4
11	65.0	0.0	15.0	10.0	10.0	240.7	104.5
12	79.1	0.0	24.9	16.0	10.0	331.9	132.4
13	103.3	0.0	27.2	0.0	26.4	417.0	154.6
14	97.6	37.6	16.0	0.0	16.8	410.9	170.1
15	105.9	40.0	24.9	0.0	23.3	501.8	206.0
16	119.4	46.3	27.8	0.0	31.6	606.2	258.1
17	162.9	81.1	0.0	0.0	0.0	682.3	359.5
18	160.3	80.7	0.0	0.0	0.0	672.2	349.9
19	152.8	77.2	0.0	0.0	0.0	632.5	316.4
20	110.4	60.1	39.6	0.0	0.0	572.1	235.9
21	103.6	47.6	24.8	0.0	0.0	433.6	172.7
22	81.7	45.3	19.9	10.0	0.0	381.9	159.3
23	79.1	0.0	29.4	29.5	0.0	368.2	129.2
24	74.8	0.0	18.2	0.0	10.0	241.9	87.9
	Total Emission						5241

Table(4) & (5) &(6) list the commitment schedule for case1 & case2 & case 3 respectively for IEEE 14 bus system. The operating cost of the ED case is the least but the emission is higher by 12.3 % than EMD case. The amount of emission in EMD is reduced by 11.02% than ED whereas there is a increase of 6.3% of operating cost.

The CEED case brings a little balance between these two cases, in which the emission is increased by 4.2% than the emission in EMD case, whereas there is an increase of only 1.82 % in operating cost as that of ED case. The best of the 100 runs is taken and the operating cost is obtained in 7 and 6 and 8 shuffling iterations respectively for all the three cases of the test system.

TABLE: 6 Commitment schedule for IEEE 14 bus system (case: 3 CEED)

Hr	Power Generations of Units(MW) Operating Cost=$11484					Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5		
1	83.9	29.1	15.0	10.0	10.0	354.83	162.26
2	100.7	37.3	15.0	10.0	10.0	423.94	196.29
3	131.0	37.4	16.2	25.5	10.0	569.35	274.37
4	125.3	58.1	16.6	32.1	11.9	656.18	311.25
5	130.4	56.6	15.3	26.4	30.4	715.18	331.56
6	168.1	42.5	17.4	10.0	10.0	650.30	373.74
7	151.3	38.3	17.3	10.0	10.0	583.30	314.94
8	118.5	40.3	23.2	10.0	10.0	511.31	242.13
9	105.5	35.5	15.0	10.0	10.0	431.81	202.00
10	77.7	21.3	15.0	10.0	10.0	318.15	148.12
11	45.0	20.0	15.0	10.0	10.0	234.50	126.06
12	70.0	25.0	15.0	10.0	10.0	307.96	143.79
13	90.9	31.1	15.0	10.0	10.0	379.04	173.58
14	103.6	29.4	15.0	10.0	10.0	408.92	191.36
15	111.1	37.9	26.1	10.0	10.0	494.14	227.56
16	119.1	56.7	15.6	21.6	12.0	591.38	277.59
17	136.2	41.6	24.5	31.6	10.0	650.95	312.93
18	130.4	34.4	25.9	22.7	27.6	653.19	295.22
19	143.7	0	29.2	40.5	16.7	649.33	307.05
20	130.8	39.7	19.7	0	19.9	536.03	245.44
21	106.5	38.2	21.3	0	10.0	430.07	185.82
22	102.9	31.9	22.2	0	0	372.18	144.84
23	91.4	31.6	15.0	0	0	315.97	119.53
24	103.0	0	0	0	0	245.78	63.96
	Total Emission						5371.4

IEEE 30 bus system

Table (7) & (8) & (9) list the commitment schedule for case1 & case2 & case 3 respectively for IEEE 30 bus system.

The operating cost of the ED is case less than the other two cases. But the environment factor is increased by 15.6 % than EMD case. Similarly in EMD case the economic factor is increased by 15.27% than ED whereas there is a decrease of 13.5% in emission as that of ED case.

TABLE: 7 Commitment schedule for IEEE 30 bus system (case:1 ED)

Hr	Power Generations of Units(MW) Operating Cost=$12821						Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5	6		
1	92.2	26.9	15.0	10.0	10.0	12.0	410.2	199.9
2	116.8	32.2	15.0	10.0	10.0	12.0	493.8	248.5
3	142.3	38.2	16.5	10.0	10.0	12.0	591.9	317.8
4	173.4	44.1	17.6	10.0	10.0	12.0	712.8	423.6
5	184.3	47.5	19.6	10.0	10.0	12.0	767.6	470.9
6	174.4	46.3	19.3	10.0	10.0	12.0	729.4	432.7
7	152.7	43.3	17.9	10.0	10.0	12.0	645.4	356.4
8	130.7	33.9	16.3	10.0	10.0	12.0	543.5	2826
9	143.5	0.0	16.5	10.0	10.0	12.0	503.2	270.5
10	123.5	0.0	15.5	10.0	0.0	12.0	407.6	192.8
11	110.0	0.0	15.0	10.0	0.0	12.0	367.4	164.8
12	122.6	0.0	15.4	10.0	0.0	12.0	404.7	190.7
13	111.8	0.0	15.4	10.0	0.0	12.0	410.8	182.1
14	124.5	33.5	15.0	0.0	0.0	12.0	454.1	211.2
15	143.5	35.9	16.6	0.0	0.0	12.0	523.0	262.7
16	160.5	42.3	17.3	0.0	0.0	12.0	598.2	322.4
17	170.6	43.9	19.5	0.0	0.0	12.0	643.8	360.2
18	179.6	43.1	18.3	0.0	0.0	0.0	627.3	360.3
19	176.0	45.0	15.0	0.0	0.0	0.0	611.4	347.6
20	179.4	45.6	0.0	0.0	0.0	0.0	595.7	329.4
21	162.1	41.9	0.0	0.0	0.0	0.0	526.8	264.5
22	144.3	37.7	0.0	0.0	0.0	0.0	457.5	205.4
23	126.8	34.2	0.0	0.0	0.0	0.0	394.2	156.8
24	131.0	0.0	0.0	0.0	0.0	0.0	326.4	121.3
	Total Emission							6675

TABLE: 8 Commitment schedule for IEEE30 bus system (case:2 EMD)

Hr	Power Generations of Units(MW) Operating Cost=$14779						Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5	6		
1	113.8	52.2	0.0	0.0	0.0	0.0	415.2	158.3
2	133.0	63.0	0.0	0.0	0.0	0.0	512.1	224.6
3	128.2	39.2	39.1	0.0	0.0	22.6	628.3	272.0
4	124.4	45.8	48.2	0.0	0.0	48.7	822.0	345.5
5	149.3	81.0	0.0	0.0	0.0	53.2	868.7	419.3
6	157.3	60.5	0.0	0.0	0.0	54.2	813.4	390.3
7	137.6	68.7	0.0	0.0	0.0	39.7	707.5	318.3
8	124.6	55.4	0.0	0.0	0.0	32.9	584.2	242.3
9	114.6	47.7	0.0	0.0	0.0	29.7	512.9	200.4
10	78.2	37.4	24.2	0.0	0.0	21.3	404.9	157.6
11	77.2	32.8	15.0	0.0	10.0	12.0	354.1	160.3
12	89.0	34.0	15.0	0.0	10.0	12.0	388.6	175.8
13	89.0	32.0	27.0	0.0	10.0	12.0	426.2	186.9
14	91.8	34.4	0.0	0.0	26.6	32.3	516.2	190.4
15	103.0	46.6	0.0	0.0	23.3	35.1	584.9	226.9
16	108.4	40.6	0.0	0.0	39.2	43.9	696.2	273.9
17	129.8	46.9	0.0	0.0	28.9	40.4	713.0	301.2
18	113.5	49.1	0.0	25.1	33.4	19.8	687.9	287.8
19	105.4	45.1	0.0	45.2	0.0	40.4	692.5	282.8
20	113.8	53.9	0.0	27.6	0.0	29.8	628.6	257.7
21	85.0	46.6	0.0	34.0	0.0	38.4	588.9	225.0
22	77.4	42.1	0.0	28.1	22.4	12.0	499.2	201.4
23	77.8	32.5	0.0	19.2	31.6	0.0	438.6	161.4
24	70.5	41.6	0.0	0.0	19.0	0.0	328.4	112.9
	Total Emission							5773

TABLE: 9 Commitment schedule for IEEE 30 bus system (case:3 CEED)

Hr	Power Generations of Units(MW) Operating Cost=$13122						Hourly Operating cost($)	Hourly Emission (kg)
	1	2	3	4	5	6		
1	97.4	33.6	15.0	10.0	10.0	0.0	403.8	186.1
2	102.0	39.9	15.4	29.7	10.0	0.0	503.6	223.5
3	142.8	41.6	24.6	10.0	10.0	0.0	593.5	304.1
4	124.1	68.4	27.1	26.6	20.9	0.0	746.2	344.9
5	161.2	39.5	32.2	29.9	20.7	0.0	790.3	398.7
6	126.4	55.0	28.5	42.9	19.2	0.0	762.8	351.6
7	116.0	40.3	17.2	0.0	0.0	0.0	671.4	310.3
8	155.5	40.3	17.2	0.0	0.0	0.0	536.3	274.8
9	128.8	46.9	16.3	0.0	0.0	0.0	473.3	213.2
10	105.6	40.4	15.0	0.0	0.0	0.0	381.4	153.8
11	97.0	35.0	15.0	0.0	0.0	0.0	341.4	131.9
12	113.8	31.2	15.0	0.0	0.0	0.0	376.9	156.8
13	116.2	36.5	17.3	0.0	0.0	0.0	406.2	170.2
14	124.0	38.9	22.1	0.0	0.0	0.0	452.9	195.2
15	137.6	51.6	18.8	0.0	0.0	0.0	524.0	246.0
16	143.7	50.5	37.8	0.0	0.0	0.0	624.9	288.8
17	173.2	42.7	18.1	0.0	0.0	0.0	643.7	365.8
18	137.7	55.7	29.1	0.0	0.0	18.5	644.4	302.3
19	135.0	62.0	16.1	0.0	0.0	22.9	628.2	298.9
20	124.1	57.8	22.4	0.0	0.0	20.7	592.2	267.3
21	112.8	52.9	26.3	0.0	0.0	12.0	524.0	230.8
22	132.6	49.4	0.0	0.0	0.0	0.0	460.3	194.4
23	116.8	44.2	0.0	0.0	0.0	0.0	396.3	149.7
24	97.4	33.6	0.0	0.0	0.0	0.0	308.9	99.4
	Total Emission							5858.6

TABLE: 10 Commitment schedule for IEEE 56 bus system (case:1 ED)

Hr	Power Generations of Units(MW) Operating Cost=$ 57866							Hourly Operating cost($)	Hourly Emission (Kg)
	1	2	3	4	5	6	7		
1	420.0	10.0	20.0	10.0	40.0	10.0	30.0	1635.3	870.0
2	500.0	10.0	20.0	10.0	40.0	10.0	30.0	1902.0	1261.6
3	497.6	13.2	59.7	19.6	323.8	10.0	30.0	3036.0	1733.1
4	531.3	12.1	77.9	13.9	350.7	10.0	30.0	3314.2	2039.7
5	506.7	14.5	30.6	13.9	396.2	10.0	30.0	3021.9	2051.5
6	417.2	12.6	44.7	35.3	442.2	10.0	30.0	3189.2	1847.7
7	552.8	0.0	22.2	17.2	345.8	10.0	30.0	2849.8	2079.7
8	375.1	0.0	22.5	28.6	399.6	29.4	100.8	2944.8	1451.9
9	496.1	0.0	20.5	10.7	374.8	10.0	30.0	2659.2	1869.9
10	474.5	0.0	41.1	12.2	354.2	10.0	30.0	2692.2	1682.5
11	470.3	0.0	39.2	25.4	327.1	10.0	30.0	2717.7	1562.6
12	451.9	0.0	32.4	21.9	204.9	10.0	30.0	2226.5	1131.9
13	222.5	0.0	29.8	10.7	347.9	10.0	30.0	1829.2	772.6
14	229.9	0.0	36.2	12.3	269.7	10.0	30.0	1681.7	530.4
15	482.0	10.0	20.0	10.0	40.0	10.0	30.0	1840.0	1166.5
16	405.6	25.0	42.9	13.1	241.4	10.0	30.0	2419.7	1036.4
17	251.4	21.0	31.3	14.6	338.7	0.0	219.0	2615.4	1015.5
18	229.1	36.8	24.1	11.0	244.5	0.0	317.5	2731.3	1009.2
19	427.9	29.6	28.4	0.0	311.0	0.0	46.1	2433.3	1272.8
20	315.5	23.3	26.7	0.0	302.5	0.0	134.0	2241.8	869.9
21	458.2	20.8	37.8	0.0	227.3	10.0	30.0	2335.7	1211.0
22	330.4	0.0	0.0	18.0	313.6	10.0	30.0	1871.9	900.2
23	379.0	0.0	0.0	21.6	281.4	10.0	0.0	1884.9	965.1
24	436.2	14.4	0.0	17.7	176.7	0.0	0.0	1792.0	971.3
	Total Emission								31303