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 protocol approved by European parliament, which imply new emission limitations, and Acts by Japanese governments. Emission constraint has the top priority in utility management concerns. So the UCP should be capable of including the emission constraint. Now the single economic objective has now become a bi objective including emission level.

Various solution techniques for traditional UCP problem are available in literature such as Linear programming (LP), Mixed Integer Programming (MIP), Dynamic Programming (DP)[1]-[4], Genetic Algorithm (GA)[5]-[7], Particle Swarm Optimization (PSO)[8], Bacterial Foraging Algorithm (BFA)[9]. Purely economic dispatch may lead to higher emission level, and purely emission constrained may lead to higher cost. It is really complex to bring a tradeoff between emission and cost.

Several Authors have discussed various solution techniques for emission constrained dispatch. Variation in weight for optimal emission was done by [10]. Linear programming based emission dispatch was applied by Farag [11] where emission is taken as a constraint. Nanda [12] has used goal programming Technique. ξ- constrained technique which use multiple performance indices was done by Yokoyama[13]. Hirerchial system approach and Fuzzy linear programming[14] and genetic algorithm[15] were also discussed. All the above techniques consider emission constraint only at the economic dispatch (ED) level, But the emission can be controlled much effectively when it was considered at the selection of units. Shuffled Frog Leaping Algorithm is a memetic algorithm introduced by Eusuff and lancey in 2003.[16] It is capable of solving non linear, complex , multi modal optimization problem. It is applicable for complex engineering problems like bridge deck repair, pipe size determination etc. The most promising benefit of this algorithm is its faster convergence speed.This algorithm is based on the behaviour of group of frogs searching for the location that has the maximum amount of available food. It involves repeated local search and shuffling processes until a required convergence is reached. In improved SFLA, the efficiency and effectiveness of the original SFLA is improved by the introduction of cognitive component [17]-[19].

Recent research works are mainly focused on deregulated market, modelling and optimization[20]-[34] of power system network and energy management. Emission is also a major criteria in the energy market which is the most needed for the eco friendly environment.

In this work, a two stage improved SFLA is used. Emission constrained UC problem is divided into two sub problems. The master problem takes the system data and gives the commitment schedule satisfying the min up/ down time constraint and minimum emission level. The sub problem takes the commitment schedule from the master problem and solves the Economic dispatch(ED) , Emission dispatch (EMD) or Combined Emission and economic dispatch (CEED) depending on the weighting factor given to each constraint to dispatch the real power among the committed units.

2. Mathematical Modeling of emission constrained UC and Dispatch problem

(A) Formulation of objective function for dispatch problem

(a) Economic Dispatch Problem(ED)

The economic dispatch is a problem of dispatching the real power such that the cost is minimised. The major cost involved in a thermal generating unit is the fuel cost. In general the fuel cost curve is quadratic (1) and smooth.

$$F_c(P_i) = A_i + B_iP_i + C_iP_i^2 \quad (1)$$

Where, A_i, B_i, C_i are coefficients of cost matrix of i^{th} generator.

(b) Emission dispatch problem(EMD)

In this the dispatch of real power is done such that the total emission (kg/hr) is minimised while meeting the demand. The emission curve is given by a quadratic equation.

$$E_c(P_i) = d_i + e_iP_i + f_iP_i^2 \quad (2)$$

(c) Combined Economic Emission Dispatch (CEED)

The bi–objective of cost and emission is converted into a single objective by expressing the emission in implied cost form. The combined objective is given as

$$F_{ce}(P_i) = \left(A_i + B_i P_i + C_i P_i^2\right) + h_i\left(d_i + e_i P_i + f_i P_i^2\right) \quad (3)$$

The price penalty factor h_i coordinates the fuel and implied emission cost. Various methods are available in literature [35][36] to calculate the price penalty factor. Maximum price penalty factor[36] is good among the methods for emission restricted least cost condition. The max price penalty factor is given by

$$h_i = \frac{\left(A_i + B_i P_{imax} + C_i P_{imax}^2\right)}{\left(d_i + e_i P_{imax} + f_i P_{imax}^2\right)} \quad (4)$$

All the above three cases are taken into a single objective function by considering the weight factors.

$$\varphi_c(P_i) = w_{fuel} F_c(P_i) + w_{emi}\ hE_c(P_i) \quad (5)$$

W_{fuel}= 1.0 and W_{emi}=*0.0* for ED , W_{fuel}= *0.0* and W_{emi}=1.0 for EMD and for CEED W_{fuel}= *1.0* and W_{emi}=1.0.

(B)Unit commitment problem

The main objective of UC is to determine the optimal cost generator schedule while satisfying some of the system and unit constraints. The total operating cost which includes fuel cost, startup cost and shut down cost. The fuel costs are determined by Economic Dispatch(ED) among committed units.

$$TFC = \sum_{t-1}^{T} \sum_{i=1}^{N} \varphi_c(P_i) * X_i\, h\,(t) \quad (6)$$

Where $\varphi_c(P_i)$ is taken from equation (5) to include the effect of valve point loading on fuel cost. $X_i(t)$ is the status of i[th] unit at t[th] hour. Startup cost is the cost involved in bringing the thermal unit online. Startup cost(SUC_i) is expressed as a function of the number of hours the units has been shut down, (Exponential when cooling and linear when banking). Shut down costs are defined as a fixed amount for each unit/shutdown. However it is not taken into account in this paper. A simplified startup cost model is used as follows.

$$SUC_i = \begin{cases} HSC_i\ , if\ MDT_i \le DT_i < MDT_i + CSH_i \\ CSC_i\ , if\ DT_i > MDT_i + CSH_i \end{cases} \quad (7)$$

Where, HSC_i,CSC_i are the hot and cold start up costs of i[th] unit respectively. CSH_i represents the cold start hour of i[th] unit.There are several constraints that must be satisfied by the UCP.

i) System spinning reserve requirements

An excess capacity of generation is essentially required to ensure certain degree of reliability. A fixed reserve policy is used in this paper and the mathematical equation is given by

$$\sum_{i=1}^{N} X_i\,(t) P_{Gi}(t) \le P_D\,(t) + P_R(t), \quad t = 1,2 \ldots\ldots T \quad (8)$$

Where, $P_D(t)$ gives the real power demand at the t[th] hour and P_{Gi}^{t} is the real power generation of i[th] unit at t[th] hour.

ii) Min up/down time

Every unit should satisfy its minimum up/down time before it is turned OFF/ON respectively.

$$\begin{cases} T_i^c \ge MUT_i if T_i^c > 0 \\ -T_i^c \ge MDT_i if T_i^c < 0 \end{cases} \quad (9)$$

MUT_i and MDT_i gives the minimum up/down time of i[th] unit.

iii) Maximum/Minimum power limits

Every unit has its own maximum/minimum power level of generation, beyond and below which it cannot generate

$$P_{Gi}^{min} \le P_i^t \le P_{Gi}^{max} \quad (10)$$

iv) Ramp rate constraints

Since, the temperature of a thermal unit can only be increased or decreased gradually; the output also can either be increased or decreased within a limit. The response rate constraints of the unit limits the power generation and is given by

$$P_{imax}(t) = min(P_{imax}, P_i^{(t-1)} + \tau RD_i)$$
$$P_{imin}(t) = max(P_{imin}, P_i^{(t-1)} + \tau RD_i) \quad (11)$$

Where τ=60 min. RD_i gives the allowable change in real power of i[th] unit.

3. Improved shuffled frog leaping algorithm

The SFLA involves a population of possible solutions defined by a set of virtual frogs. This set of virtual frogs is partitioned into subsets know as memeplexes. The memeplexes can be perceived as a set of parallel frog cultures attempting to reach some goal. Frog leaping improves an individual frog and enhances its performance towards the goal. Within each memeplex each frog holds different ideas and the idea of each frog can be used to infect the ideas of other frogs. The process of passing information between the frogs of a memeplex is known as local search or memetic evolution step. After a defined number of memetic evolution step the virtual frogs are shuffled and reorganized so that the quality of memeplex is improved. Shuffling enhances the meme quality after infection and ensures the cultural evolution towards any particular interest. The process of memetic evolution and shuffling are repeated unit a required convergence is reached.

In the original SFL algorithm, every frog update its position according to the best solution because of the influence of the local best solution, every frog will converge towards the best solution quickly. The ability and stability of the algorithm is improved by the introduction of the cognition component [13]. Introduction of this component allows the frog to adjust its position according to the thinking of the frog itself along with best frog within the memeplex or the global best frog of the population. The coordinates of current position of each frog is entered into the formulas for the measure of error of the estimate of target values, and it is moved towards the new position. This is repeated for a defined number of times.

While moving towards the multivariate space, the individuals compare their current error value with the best error value they have attained at any point up to that iteration. The lowest error value is termed as the best error value $Pbest_{j}$., and the position where the $Pbest_j$ is evaluated is termed as P_j. The difference P_i-X_i indicates the distance between the individual's previous and current position. Each element of the above distance vector is weighted by a positive random number in the range [0 1]. This vector is now added to the change vector, and the equations become

$$D_i = rand(1) * (P_w - X_w) + rand(1) * (X_b - X_w) \quad (12)$$

$$X_w = X_w + D_i \quad D_{imin} < |D_i| < D_{imax}$$

The following steps are involved in improved SFLA. It is illustrated in fig(1). The leaping of frog is illustrated in fig(2).

Step:I *Formation of Initial population*

1) Population size (number of frogs) P is chosen.

2) P number of frogs are generated randomly within the search space.

3) The position of every frog is defined as $X_i = X_{i1}, X_{i2}, \ldots \ldots \ldots \ldots \ldots \ldots .. X_{iD}$, Where D is the number of variables

4) The fitness of search frog is calculated as

$$fitness = \begin{cases} 1/f(x) + c \ \ for\ minimization\ problems \\ f(x) + c \quad for\ maximization\ problems \end{cases}$$

f(x) is the objective function and c is a constant to ensure the fitness a positive value.

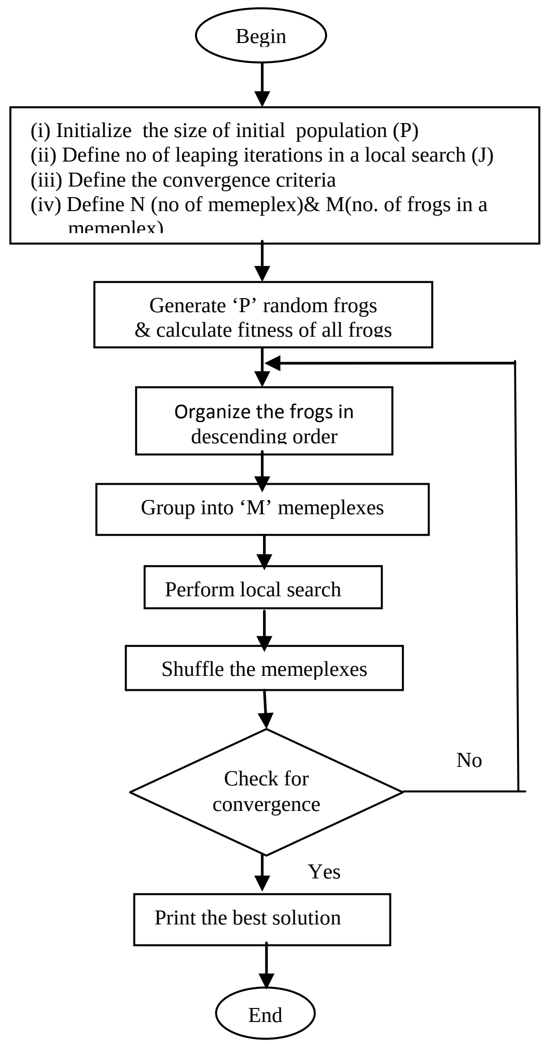

Fig.1 Flow chart of SFLA

Step:II *Grouping of Frogs into Memeplexes*

The frogs are sorted in descending order according to their fitness values.The entire population of 'P' frogs are grouped into 'M' memeplexes, and each memeplex is formed so that each memeplex consists of 'N' no of frogs (P=MXN). The partitioning of memeplexes is done so that each memeplex have frogs with lower and higher fitness values. For this the first frog goes to 1st memeplex, the second frog goes to 2nd memeplex, the mth frog to mth memeplex and m+1th frog goes to 1st memeplex.

***Step: III** Local search process*

Within each memeplex, the frogs with worst (X_w) & best (X_b) fitness values are identified. Also the frog with global fitness X_g is also identified.

1) The frog with worst fitness is leaped towards the best frog by a random vector.
$D_i = rand(1) * (P_w - X_w) + rand(1) * (X_b - X_w)$
$X_w = X_w + D_i \quad D_{imin} < |D_i| < D_{imax}$ (13)
2) The fitness of the new leaped worst frog is calculated. If there is no improvement in fitness, the leaping vector is calculated with X_g
$D_i = rand(1) * (P_w - X_w) + rand(1) * (X_g - X_w)$
$X_w = X_w + D_i \quad D_{imin} < |D_i| < D_{imax}$ (14)
3) Within each memeplex, the frogs with worst (X_w) & best (X_b) fitness values are identified. Also the frog with global fitness X_g is also identified.
4) The steps 1, 2, 3, & 4 are repeated for some specific number of iterations.

***Step: IV** Shuffling Process*

After local search in every memeplex is completed shuffling of memeplex is done, and the frogs are reorganized in descending order of fitness values and again grouped into memeplex and local search process is carried out.

Step: V The above all steps I, II, III, IV are repeated until

i) The relative change in the fitness of the global frog within a number of consecutive shuffling iterations is less than a pre-specified tolerance.

ii) The maximum predefined numbers of shuffling iterations have been reached.

4. Implementation of Improved SFLA to emission constrained UC

In this work, the improved SFLA is used in two stages. The block diagram Fig (3) shows the input and output details of the master and sub problem.

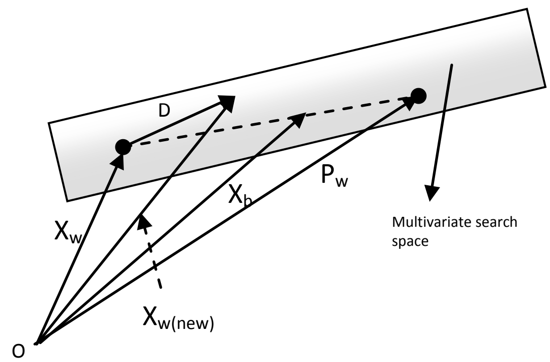

Fig.2. Frog Leaping Rule

The master problem gets the system data and provides a commitment schedule which satisfies the minimum up/down time constraints of the generating units. The fitness of the frogs produced in the master problem is computed from the dispatch obtained from the sub problem. The fitness function includes the effect of emission on cost. The sub problem takes the commitment schedule from the master problem and determines the optimal cost and emission dispatch schedule. From this the master problem computes the fitness of the commitment schedule.

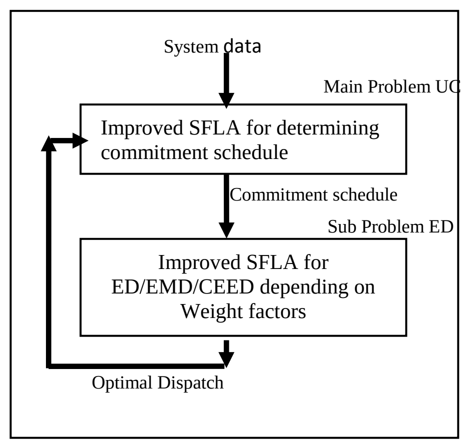

Fig (3) Block Diagram of Improved SFLA for UC with Emission constraint

A. Implementation of improved SFLA to Emission constrained UC

The integer coded method [37] of coding is used. Since it uses cycle duration (sequence of alternatively signed integers representing the duration of ON/OFF cycles) instead of status of units, it directly satisfies the minimum up/down time constraint directly at the coding stage itself. And hence there is no need for any penalty function for this constraint.

The size of a frog is decided by the no of units (N) and no of cycles(C). No of cycles(C) is determined by the load peaks and minimum up and down time of units. For a 6 unit, 5 cycle system the size of the frog for a one day scheduling is 1×6×5. Definition of frog from ON/OFF cycle duration of units and the UC schedule is illustrated in Table. 1. The following steps are involved.

Step 1. *Creating Initial Population*

A part of a frog representing the operating schedule of a particular unit during the scheduling horizon should be formed such that $\sum_{c=1}^{C}|T_i^c| = T$.

The values of T_i^c of the initial population are randomly generated such that each and every cycle duration satisfies the minimum up/down time of the units.

Step 2. *Leaping of worst solution*

After formation of memeplex, the local search process is carried out in each memeplex. Leaping of worst frog towards the best frog is done by the random vector $D_i = rand(1) * (X_b - X_w)$ or by $D_i = rand(1) * (X_g - X_w)$. Addition of this vector to the X_w may lead to change in X_w and it needs the following modifications.

i) Sum of all T_i^c of unit 'i' will not be equal to 'T'. 1To adjust the following correction is done.

$$(T_i^1, T_i^2, \ldots . T_i^C) = \frac{T.*\left(T_i^1, T_i^2, \ldots . T_i^C\right), i=1,2,\ldots .N}{\sum_{k=1}^{C}|T_i^k|} \quad (15)$$

(ii) The rand (1) function generates a random number between 0 and 1 the parameter which is a non-integer number and this may lead the parameter of X_w to a non-integer values. But X_w should be an integer vector. Hence to convert the non integer parameters of X_w to integer the following correction is done by X_w^1 = Round (X_w)

(iii) The above round of correction may again lead to the sum not equal to 'T' Hence to adjust the values of T_i^c, the last non-zero cycle is adjusted as follows,

$$T_i^l = T - \sum_{k=1}^{l-1}|T_i^k|, i = 1,2, \ldots . N \quad (16)$$

iv) After generation of new X_w, the minimum up / down time should be adjusted so that there is no violation in this constraint.

After all the above corrections are carried out, on X_w, the Economic Dispatch (ED) should be carried out for each hour of scheduling horizon for all committed units. Then the fitness value is calculated. The sample frog is given in Table.1

TABLE: 1 Sample frog for 5 unit 5 cycle system

Unit	1	2	3	4	5
1	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5
	24	0	0	0	0
2	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5
	24	0	0	0	0
3	T_3^1	T_3^2	T_3^3	T_3^4	T_3^5
	-4	19	-1	0	0
4	T_4^1	T_3^2	T_3^3	T_3^4	T_3^5
	-5	17	-2	0	0
5	T_5^1	T_5^2	T_5^3	T_5^4	T_5^5
	15	-9	0	0	0

Step 3.*Computation of fitness function*

The objective function of UC using SFLA has two terms, and they are the total operation cost including the emission constraint which is taken from the dispatch problem. The penalty functions for violating system constraints (spinning reserve & power balance).

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} \varphi_i\,(P_i^t) * X_i(t) + SU_T + SD_T \quad (17)$$

The penalty function has two terms. The first term for spinning reserve violation and is given by

$$\prod_{res} = \omega \sum_{t=1}^{T} \frac{1}{D^t}\, R((P_D^t + R^t) - \sum_{i=1}^{N} X_i(t) P_{imax}^t \quad (18)$$

The second term for excessive capacity is given by

$$\prod_{cap} = \omega \sum_{t=1}^{T} \frac{1}{D^t}\, R(\sum_{i=1}^{N} X_i(t) P_{imin}^t - P_D^t) \quad (19)$$

where 'ω' depends on maximum operating cost of the system over a scheduling period 'T'.

ω = α T $\sum_{i=1}^{N} FC_i\,(P_{imax})$, where α is a constant.

Now the objective is to minimize the fitness function

$$\text{Fitness} = A/(TC + \Pi_{res} + \Pi_{cap}) \quad (20)$$

A= 10^8. 'A' is a system dependent constant added for avoiding the fitness value from 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

IEEE 56 bus system

Table (10) & (11) & (12) list the commitment schedule for case1 & case2 & case 3 respectively for IEEE 56 bus system. The comparison of the operating cost is listed in table(7). The emission is decreased by 43.1 % as that of ED where as the combined emission case yields a compromising result between the economics and environment.

IEEE 118 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.

The comparison of the operating cost is listed in table (13). Though ED case has 7% less operating cost than EMD, it as a 44% higher emission as that of EMD. Also EMD has a lesser emission .It has a 6.57% of high operating cost than ED. The CEED case has a better emission than ED and a better operating cost of EMD. CEED has a 2.3 % of increase in emission as that of the EMD which is much better than te emission of ED.

Similarly the opearating cost is higher by 3.84 % as that of ED. Whereas the emission is 28.5% reduced than that of EMD.

Comparison of Operation Cost of various Test systems

The comparison of operation cost and emission of all the test systems are included in the table13. The emission is very high in fully economic constrained UCP. There is a perfect compensation between emission and economics is obtained in CEED.

Though emission constrained UCP is a multi objective optimization problem, Improved SFLA is capable of converging faster.

TABLE: 11 Commitment schedule for IEEE 56 bus system (case:1 EMD)

Hour	Power Generations of Units(MW) Operating Cost=$ 89039							Hourly Operating cost($)	Hourly Emission (Kg)
	1	2	3	4	5	6	7		
1	139.9	26.11	44.3	46.8	95.1	73.3	114.5	2652.0	249.4
2	147.3	46.3	77.0	76.9	101.7	45.7	125.1	3223.0	320.3
3	270.8	33.7	131.9	76.9	248.1	79.8	112.8	4570.7	877.1
4	274.1	68.3	106.2	40.6	271.0	71.9	193.9	4559.3	1000.0
5	271.4	82.3	69.7	34.5	277.1	90.1	176.9	4512.2	966.5
6	270.9	69.2	116.4	68.4	262.9	38.8	165.4	4473.6	928.6
7	265.1	96.3	98.7	95.5	232.3	73.4	116.6	5084.9	862.7
8	244.1	61.1	70.0	0.0	256.2	91.7	232.8	3997.7	914.6
9	240.9	70.1	91.9	0.0	271.0	58.2	209.9	3847.1	880.2
10	241.5	79.4	81.2	91.4	241.5	50.0	137.2	4451.6	761.7
11	277.9	72.7	139.2	86.2	263.9	62.1	0.0	4731.8	949.5
12	243.6	96.1	113.3	50.2	183.3	66.5	0.0	4093.7	626.8
13	214.1	92.5	103.6	79.8	160.9	0.0	0.0	3481.0	485.3
14	196.8	46.4	65.7	22.7	145.6	0.0	110.9	2230.0	296.8
15	213.7	49.1	87.6	0.0	140.0	0.0	111.7	2238.0	321.1
16	304.7	96.2	0.0	0.0	200.7	0.0	166.4	2656.5	683.6
17	276.7	70.4	0.0	0.0	268.0	0.0	260.9	2787.1	955.0
18	366.2	0.0	126.2	80.2	290.4	0.0	0.0	3431.5	1129.2
19	352.5	0.0	132.9	93.2	264.4	0.0	0.0	3529.7	1042.1
20	230.4	55.5	119.5	93.0	303.7	0.0	0.0	3769.0	843.3
21	271.7	60.9	84.0	81.7	190.5	95.3	0.0	4235.9	690.5
22	216.2	14.6	88.1	75.5	213.9	93.7	0.0	3598.1	575.6
23	304.3	97.7	120.7	92.4	0.0	77.0	0.0	4565.7	779.7
24	256.5	0.0	0.0	98.1	290.4	0.0	0.0	2318.3	674.2
	Total Emission								17814

TABLE: 12
Commitment schedule for IEEE 56 bus system (case:1 CEED)

Hour	Power Generations of Units(MW) Operating Cost=$ 53399							Hourly Operating cost($)	Hourly Emission (Kg)
	1	2	3	4	5	6	7		
1	244.6	0.0	24.9	0.0	230.5	10.0	30.0	1403.0	430.90
2	298.3	0.0	30.3	0.0	251.4	10.0	30.0	1643.9	618.30
3	394.0	0.0	50.2	0.0	321.0	19.3	169.5	2781.4	1278.5
4	328.1	0.0	29.9	0.0	483.3	17.4	167.3	2933.3	1763.4
5	388.0	0.0	24.0	0.0	323.8	18.6	247.7	2832.6	1438.6
6	432.9	0.0	29.2	0.0	325.9	12.8	191.2	2762.4	1493.0
7	244.6	0.0	42.1	0.0	454.1	10.0	226.8	2823.1	1516.4
8	249.4	0.0	21.0	0.0	402.6	20.6	262.5	2739.1	1371.7
9	327.2	0.0	36.9	0.0	372.5	13.1	192.3	2648.6	1267.5
10	387.8	0.0	30.3	0.0	463.9	10.0	30.0	2568.5	1768.8
11	454.4	0.0	21.2	0.0	386.4	10.0	30.0	2452.7	1681.4
12	342.0	0.0	0.0	0.0	323.4	10.5	75.1	1877.9	946.80
13	324.1	0.0	0.0	0.0	286.9	10.0	30.0	1592.8	766.50
14	226.2	0.0	0.0	0.0	192.0	14.2	155.6	1480.5	370.90
15	299.0	0.0	0.0	0.0	263.0	10.0	30.0	1454.7	622.10
16	233.8	0.0	0.0	0.0	323.6	31.3	179.3	2118.4	781.50
17	414.8	0.0	0.0	0.0	342.4	14.1	104.7	2279.6	1316.0
18	267.7	0.0	0.0	0.0	315.9	11.9	267.5	2292.4	1057.1
19	433.5	17.6	0.0	0.0	351.9	10.0	30.0	2299.2	1443.1
20	298.3	20.4	0.0	0.0	377.6	16.1	89.7	2228.1	1056.5
21	451.6	0.0	0.0	17.7	314.7	0.0	0.0	2070.4	1357.8
22	268.3	0.0	37.3	15.9	304.7	0.0	75.9	1950.0	699.40
23	531.5	13.6	24.0	12.3	55.2	0.0	55.4	2099.9	1408.0
24	561.4	10.7	20.8	10.0	0.0	10.4	31.9	2066.9	1615.7
	Total Emission								28070

TABLE:13

Comparison of operational cost and Emission of various test systems

Sl.no	System	Case	Emission(Kg)	Operating Cost ($)
1	IEEE 118 Bus	ED	188950	252654
2		EMD	131160	270434
3		CEED	134260	260040
4	IEEE 56 Bus	ED	31303	57866
5		EMD	17814	89039
6		CEED	28070	53399
7	IEEE 30 Bus	ED	6675	12821
8		EMD	5773	14779
9		CEED	5858	13122
10	IEEE 14 Bus	ED	5792	11279
11		EMD	5154	11993
12		CEED	5371	11484

6. Conclusion

In this paper, we presented a new evolutionary algorithm known as improved SFLA for UC problem with emission constraints. The integer coding is used to code the parameters of UCP. The effect of emission is efficiently handled in the improved SFLA based ED problem. The effect of emission on economics is clearly observed in EMD case. The optimal frog obtained in EMD case is a frog with lower emission. Also the effect of economics on emission is observed in ED case. The optimal frog obtained in ED case is a frog with lower cost. The CEED case is effective in bringing a compromise between ED and EMD. The optimal frog of CEED case gives a frog with better emission than ED and a better cost than EMD.

Also the convergence of SFLA is faster and the optimal result is obtained in 6 to 12 shuffling iterations for all the test systems and cases. The Improved SFLA for optimal dispatch also takes a maximum of 15 shuffling iterations to obtain the optimal dispatch .

7. References

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