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GALAXY-BASED SEARCH ALGORITHM TO SOLVE COMBINED ECONOMIC AND EMISSION DISPATCH

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Abstract – The Galaxy-based Search Algorithm (GbSA) is an optimization technique developed recently by Hamed Shah-Hosseini at Shahid Beheshti University-Iran [1, 2]. GbSA is a meta-heuristic that uses a modified Hill Climbing algorithm as a local search and resembles the spiral arms of some galaxies to search the optimum.

In this paper, GbSA is proposed for solving the Combined Economic and Emission Dispatch (CEED) problem which is obtained by considering both the economy and emission objectives.

In this paper GbSA is tested on three generators system and its results are quite encouraging showing the good applicability of GbSA for CEED problem.

Keywords: Economic dispatch, emission dispatch, Combined Economic and Emission Dispatch, Galaxy-based Search Algorithm, Fast Harmony Search Algorithm

1. Introduction

The major concern of the owner of the electrical supply network is to satisfy the demand for any moment and to maintain balance between the production and the consumption of the electric power by preserving the quality of customer service at competitive price [3]. The production of this energy by power stations with fuels of fossil origin (coal, oil and natural gas) unfortunately has harmful effects on our environment. It represents the majority of the emissions in the atmosphere. The dominant emissions include: nitrogen oxides (NO_x), the sulphur dioxide (SO_2) and the carbon dioxide (CO_2). Small quantities of toxic metals, such as arsenic, the cardium, nickel and chromium are also released in the

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atmosphere. These emissions from power generation contribute to a range of human health and environmental problems.

The principal current concerns of the producers of electricity using power stations with fossil fuels is the production of electricity with a weak fuel cost and the minimization of the emissions of pollutant gases in the atmosphere.

This hard optimization problem constitutes one of the key problems in power system operation and planning in which a direct solution cannot be found and therefore metaheuristic approaches, such as the GbSA, have to be used to find the near optimal solutions.

Our work consists in optimizing the problem of the economic-environmental control system by applying GbSA. This algorithm is examined numerically with an IEEE 9-bus test system. Satisfactory results are demonstrated and also compared with the results obtained through the FHSA.

2. Problem formulation

2.1 Economic dispatch

Economic dispatch is the important component of power system optimization. It is defined as the minimization of the combination of the power generation, which minimizes the total cost while satisfying the power balance relation. The problem of economic dispatch can be formulated as minimization of the cost function subjected to the equality and inequality constraints [4].

In power stations, every generator has its input/output curve. It has the fuel input as a function of the power output. But if the ordinates are multiplied by the cost of $/Btu, the result gives the fuel cost per hour as a function of power output [5].

The practical cases, the fuel cost of generator i may be represented as a polynomial function of real power generation:

$$F(P_{Gi}) = \sum_{i=1}^{ng} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i)(i = 1,2,...,ng) \quad (1)$$

Where F is the total fuel cost of the system, ng is the number of generators, a_i, b_i and c_i are the cost coefficients of the i-th unit.

2.2 Emission dispatch

The emission function can be expressed as the sum of all types of emission considered, such as NO_x, SO_2, CO_2, particles and thermal emissions, ect, with suitable pricing of weighting on each pollutant emitted [6].

In the present study, only one type of emission (NO_x) is taken into account. The NO_x emissions of the system are expressed as follows:

$$E(P_{Gi}) = \sum_{i=1}^{ng} (\alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i) \quad (2)$$

Where E is the total NO_x emission of the system, α_i, β_i and γ_i are the emission coefficients of the i-th unit.

2.3 Constraints

- Equality constraints

The total power generation must cover the total demand P_d and the transmission loss of the system P_L. Hence,

$$\sum_{i=1}^{ng} P_{Gi} - P_d - P_L = 0 \quad (3)$$

- Inequality constraints

Generation power should be within the minimum output $P_{Gi\min}$ and the maximum output $P_{Gi\max}$.

$$P_{Gi\min} \le P_{Gi} \le P_{Gi\max} \quad (4)$$

2.4 Combined economic and emission dispatch

Aggregating equations (1) to (4), the power dispatch problem is expressed as a bi-objective optimisation problem as follows:

$$Min[F(P_{Gi}), E(P_{Gi})] \quad (5)$$

Combined Economic Emission Dispatch (CEED) engages the concurrent optimization of fuel cost and emission control that are contradictory ones. The bi-objective economic and emission dispatch problem is converted into single optimisation problem by introducing price penalty factor P_f as follows:

$$Minimize\ T(P_{Gi}) = F(P_{Gi}) + P_f E(P_{Gi}) \quad (6)$$

Subject to the power constraints given by (3) and (4).

The price penalty factor P_f is the ratio between the maximum fuel cost and maximum emission of corresponding generator [7].

$$P_{fi} = \frac{F(P_{Gi})}{E(P_{Gi})} \tag{7}$$

The steps to determine the price penalty factor for a particular load demand are:

Find the ratio between maximum fuel cost and maximum emission of each generator.

Arrange P_{fi} $(i = 1,2...,ng)$ in ascending order.

Add the maximum capacity of each unit $(P_{Gi\max})$ one at a time, starting from the smallest P_{fi} until $\sum P_{Gi\max} \geq P_d$.

In this stage, P_{fi} associated with the last unit in the process is the price penalty factor of the given load.

Once the value of P_{fi} is known, then (6) can be rewritten in terms of known coefficients and the unknown output of the generators.

$$Min\ T(P_{Gi}) = \sum_{i=1}^{ng} (A_i P_{Gi}^2 + B_i P_{Gi} + C_i) \tag{8}$$

Where: $A_i = a_i + P_f \alpha_i$, $B_i = b_i + P_f \beta_i$, $C_i = c_i + P_f \gamma_i$

2.5 Modified CEEDP formulation

The modified CEEDP formulation is based on its transformation into an unconstrained problem with (ng-1) variables [8]. In order to achieve the modified CEEDP, we apply two eliminations separately: Firstly, to eliminate the linear inequality constraints, new variable θ has to be introduced. The inequality constraints given by (4) can be formulated as

$$0 \leq \frac{P_{Gi} - P_{Gi\,min}}{P_{Gi\,max} - P_{Gi\,min}} \leq 1 \tag{9}$$

The function limited between 0 and 1 is the function $\sin^2\theta$:

$$0 \leq \sin^2\theta \leq 1 \tag{10}$$

Comparing equations (9) and (10)

$$P_{Gi} = P_{Gi\min} + D_i \sin^2\theta_i \tag{11}$$

Where $D_i = P_{Gi\max} - P_{Gi\min}$ and θ is an unconstrained variable (angle).

Secondly, to eliminate the linear equality constraints, we express P_{Gng} as a function of P_{Gj}.

$$P_{Gng} = P_{ch} + P_L - \sum_{j=1}^{ng-1} (P_{Gj\,min} + D_j . \sin^2\theta_j) \tag{12}$$

$$P_{Gng} = L - \sum_{j=1}^{ng-1} D_j . \sin^2\theta_j \tag{13}$$

Where $L = P_{ch} + P_L - \sum_{j=1}^{ng-1} P_{Gj\min}$.

Substitution of the expressions (11) and (13) in (8) gives:

$$Min \;\; G(\theta_j) = \sum_{j=1}^{ng-1} [A_j (P_{Gj\,min} + D_j \sin^2\theta_j)^2 + B_j (P_{Gj\,min} + D_j \sin^2\theta_j) + C_j] + A_{ng} (L - \sum_{j=1}^{ng-1} D_j \sin^2\theta_j)^2$$

$$+ B_{ng} (L - \sum_{j=1}^{ng-1} D_j \sin^2\theta_j) + C_{ng} \tag{14}$$

After development, equation (14) can be represented in the following general form:

$$Min \; G(\theta_j) = (\sin^2\theta_j)^T M (\sin^2\theta_j) + (\sin^2\theta_j)^T V + K \tag{15}$$

M and V are (ng-1)-by-(ng-1) and (ng-1)-by-1 array of total cost coefficients and K is a constant total coefficient scalar.

The off-diagonal elements of matrix M are:

$$M_{ij} = D_i D_j A_{ng} \tag{16}$$

and the diagonal elements of matrix M are:

$$M_{jj} = D_j^2 (A_j + A_{ng}) \tag{17}$$

The elements of vector V are:

$$V_j = D_j(2A_j P_{Gj\,min} + B_j - 2LA_{ng} - B_{ng}) \quad (18)$$

The constant K is:

$$K = A_{ng} L^2 + B_{ng} L + C_{ng} + T_j(P_{Gj\,min}) \quad (19)$$

3. Galaxy-based search algorithm

Recently, Hamed Shah-Hosseini developed a new Galaxy-based Search meta-heuristic Algorithm that is an optimization technique inspired from nature.

He applied GbSA to solve the principal components analysis problem [1] and multilevel image thresholding [2].

The GbSA imitates the spiral arm of spiral galaxies to search its surrounding. This spiral movement is enhanced by chaos to escape from local optimums. A local search algorithm is also utilised to adjust the solution obtained by the spiral movement of the GbSA (SpiralChaoticMove). The pseudo-codes of the GbSA are:

```
Procedure GbSA
        SG ← GenerateInitialSolution
        SG ← LocalSearch(SG)
While (termination condition is not met) do
        Flag ← false
        SpiralChaoticMove (SG, Flag)
        If (Flag) then
        SG ← LocalSearch(SG)
        Endif
Endwhile
Return SG
Endprocedure
```

GbSA is composed of two main components: SpiralChaoticMove and the LocalSearch.

The SpiralChaoticMove has the role of searching around the current solution denoted by SG. When the SpiralChaoticMove finds an improved solution better than the SG, it updates the SG with the improved solution, and the variable Flag is set to true. When Flag is true, the LocalSearch component of the GbSA is activated to search locally around the updated solution SG.

The SpiralChaoticMove is iterated maximally for MaxRep number of times. However, whenever it finds a solution better than the current solution, the

SpiralChaoticMove is terminated. If SpiralChaotic Move finds a better solution, Flag is set to true and LocalSearch is called to search locally around the newly-updated solutionSG. The whole process above is repeated until a stopping condition is satisfied [2].

The SpiralChaoticMove searches the space around the current best solution using a spiral movement enhanced by a chaotic variable generated by the chaotic sequence:

$$x_{n+1} = \lambda . x_n . (1 - x_n) \qquad n = 0,1,2,... \tag{20}$$

4. Application

The GbSA was tested on the IEEE 9-bus 3-generator tests system in order to investigate its effectiveness. The single-line diagram of IEEE test system is shown in figure 1 and the detailed data are given in [9]. This power system is interconnected by 9 transmission lines and the total system demand for the 3 load buses is 315 MW. Generator 1 is a hydropower station, generator 2 and 3 are two thermal power plants.

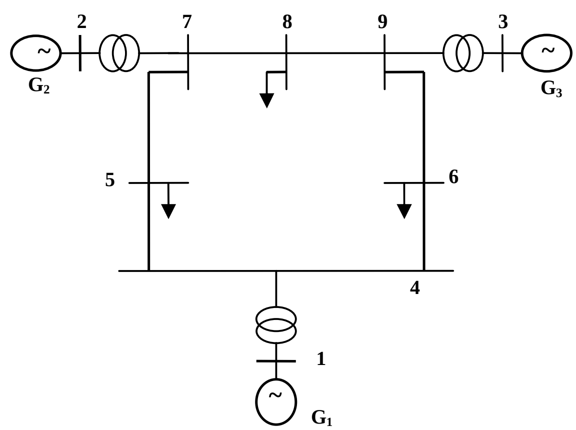

Fig.1. IEEE 9-bus test system

Generators characteristics, that is, cost and emission coefficients and generation limits, are taken from [8, 10].

The generator fuel cost, and NO_x emission functions are given in Tables 1 and 2.

Table 1

The generator fuel cost

BUS	$P_{G\min}$ (MW)	$P_{G\max}$ (MW)	$F(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i$		
			a_i	b_i	c_i
1	10	250	0.11	5	150
2	10	300	0.085	1.2	600
3	10	270	0.1225	1	335

Table2

The NO$_x$ emission function

BUS	$E(P_{Gi}) = \alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i$		
	α_i	β_i	γ_i
1	-	-	-
2	6.49.10-6	-5.554.10-4	4.091.10-2
3	3.38.10-6	-3.550.10-4	5.326.10-2

The initial conditions of the optimization are the results of the load flow solution.

The transmission line losses are calculated by Newton-Raphson method and maintained fixed: $P_L = 4.64MW$. The cost coefficients of the modified optimal power flow are:

$$M = \begin{bmatrix} 13392 & 8526 \\ 8526 & 17450.75 \end{bmatrix} \quad V = \begin{bmatrix} -16149.35 \\ -20760.80 \end{bmatrix} \quad K = 12488.15 .$$

The cost and emission of the initial operating state based on the load flow without optimization are respectively 5428.17 \$/h and 0.1703 ton/h,

The GbSA parameters are taken as follow:

$\lambda = 4,\ x_0 = 0.2,\ \Delta\alpha = 0.5,\ \Delta\theta = 0.01,\ r = 0.001,\ K_{\max} = 100,\ Maxrep = 500.$

The GbSA terminates when the iteration count exceeds 50 (prespecified maximum iteration)

The simulations were run for three different goals as follows:

Case 1: Minimize total fuel cost.

Case 2: Minimize total emission.

Case 3: Minimize fuel cost and emission simultaneously (CEED).

4.1 Minimization of each objective individually

The minimum value of a single objective is obtained by giving full consideration to one of the objectives, and neglecting the other. The best results of cost and emission functions are reported in Table 3.

Table 3

The best solutions for cost and emission optimized individually

Bus	P_{G0} (MW)	θ_0 (rd)	Case 1		Case2	
			θ_{opt} (rd)	P_{Gopt} (MW)	θ_{opt} (rd)	P_{Gopt} (MW)
1	71.64	0.531	-13.14	87.90	-4.38	224.33
2	163.0	0.813	14.98	136.1	-9.08	42.79
P_{G3opt} (MW)			95.64		52.52	
Fuel cost ($/h)			5323.77		8338.55	
Emission (ton/h)			0.1357		0.07297	

In case 1, fuel cost is 5323.77 $/h and emission is 0.1357 ton/h. The cost increases to 8338.55 $/h and emission decreases to 0.07297 ton/h for the case of emission minimization. The hydraulic unit is more requested in case 2. Its optimal generated power is close to the maximum output.

From the results, it is inferred that, the fuel cost and emission are conflicting objectives. Emission has maximum value when cost is minimized.

Convergence characteristics of best fuel cost (case 1) and best emission (case 2) are shown in Fig. 2.

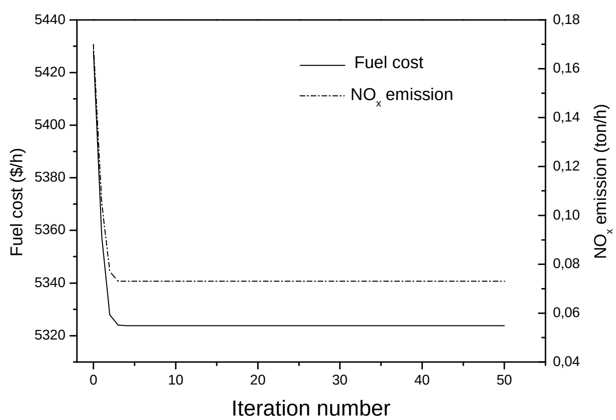

Fig. 2. Convergence of fuel cost (case1) and NO_x emission (case 2)

These graphs clearly indicate that GbSA converges rapidly to the optimal solution.

4.2 Minimization of CEED

In CEED problem, fuel cost and emission are minimized simultaneously, subject to the imposed constraints.

The optimum solution for CEED is given in Table 4.

Table 4

The best solutions for cost and emission optimized simultaneously (case 3)

Bus	P_{G0} (MW)	θ_0 (rd)	θ_{opt} (rd)	P_{Gopt} (MW)
1	71.64	0.531	25.88	120.71
2	163.00	0.813	-3.73	98.58
P_{G3opt} (MW)			100.35	
Total cost ($/h)			7459.8	
Optimal fuel cost ($/h)			5564.62	
Emission (ton/h)			0.1009	

Relative to case 1, the fuel cost is increased by 240 $//h and NO_x emission is reduced by 34.8 kg/h.

Relative to case 2, the fuel cost is reduced by 2774 $/h and NO_x emission is increased by 28 kg/h.

Convergence of total cost is shown in Fig. 3.

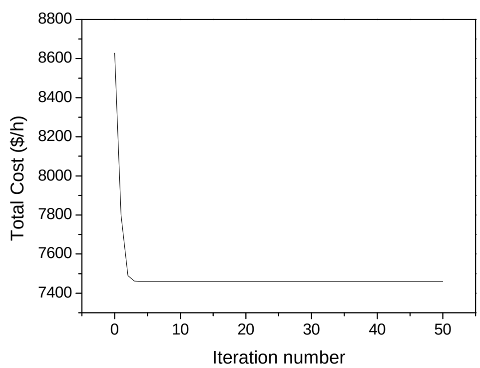

Fig. 3. Convergence of total cost (case 3)

The graph clearly indicate that GbSA converges rapidly to the optimal solution.

4.3 Comparison

In order to demonstrate the performance of the GbSA, a comparison for the power demand of 315 MW emerges between GbSA and FHSA [11, 12], as are shown in table 5 and fig. 5.

The FHSA parameters are taken as follow:

HMCR = 0.99, PAR = 0.5, HMS = 2, $bw = \frac{P_{G\max} - P_{G\min}}{50}$, $\delta = 10^{-3}$ and $\varepsilon = 10^{-12}$

The optimal values of the generated powers, Fuel cost and NO_x emission for three different cases are shown in table 5.

Table 5

Comparison results

PGiopt (MW)	Case 1		Case2		Case3	
	GbSA	FHSA	GbSA	FHSA	GbSA	FHSA
P_{G1}	87.90	87.73	224.33	222.98	120.71	120.61
P_{G2}	136.1	136.21	42.79	44.15	98.58	98.75
P_{G3}	95.64	95.70	52.52	52.51	100.35	100.28
Fuel cost ($/h)	5323.77	5323.78	8338.55	8276.47	5564.62	5562.69
Emission (ton/h)	0.1357	0.1359	0.07297	0.07298	0.1009	0.1010

GbSA is performing well in the solution of CEED. The results are similar to those obtained by FHSA.

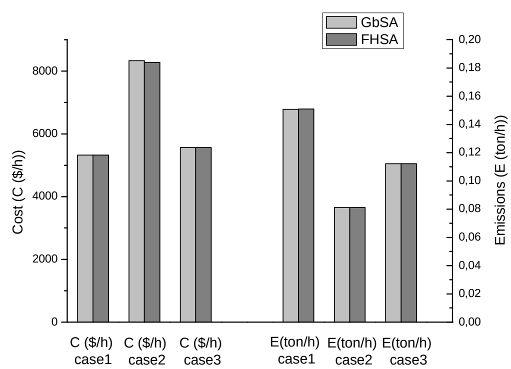

Fig.4. Comparison results

5. Conclusion

In this paper, economic and emission dispatch problems are combined and converted into a single objective function. The converted objective function is solved by a newly introduced metaheuristic GbSA to minimize the fuel cost and NO_x emission for a given load. The GbSA imitates the arms of spiral galaxies to look for optimal solutions and also utilizes a local search algorithm for fine-tuning of the solutions obtained by the spiral arm.

The performance of GbSA is demonstrated for IEEE 9 bus, 3 unit test system and compared with FHSA. The results showed that the GbSA is well suited for obtaining minimum fuel cost and emission. The computing time of GbSA is insignificant since the number of iterations needed by the process to stop is very low. As a result, GbSA is acceptable and applicable for CEED problem solution.

Further extensions of GbSA should be explored to include more objective functions or constraints with regard to more realistic problems, as well as other data sets and standard test problems.

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