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Hybrid Optimization Based Technique for Ramp Rate Limit in Economic Dispatch Problem

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Abstract

The ramp rate limit (RRL) and valve point effect (VPE) are the two important components in economic dispatch involving a power transmission system. This is important to ensure whether the relevant electric utility could dispatch the power with minimal generation cost. Thus, a reliable optimization technique is a prerequisite for achieving the objectives. This paper presents Hybrid Evolutionary-Barnacles Mating Optimizer (HEBMO) approach in solving the non-convex dispatch problems with ramp rate limit (RRL). HEBMO optimization technique is derived based on the hybridization of Evolutionary Programming (EP) and Barnacles Mating Optimizer (BMO). The developed algorithm has been implemented in areliability test system (RTS), IEEE 30-Bus RTS with six generators. Several case studies have been selected to evaluate the efficiency of the proposed HEBMO. To prove the capability of the proposed technique, it is compared with the results attained from the traditional EP and BMO to solve the economic load dispatch problems. The computational times for all the scenarios have been investigated which revealed that the proposed HEBMO is significantly superior to EP and BMO. The results obtained from HEBMO show its competency in determining the optimal power dispatched with minimum generation cost.

Keywords – non-convex economic load dispatch, ramp rate limit, Evolutionary Programming, Barnacles Mating Optimizer

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Introduction

Power generation is a vital requirement for every country to meet the needs of residential, commercial and industrial. The major concern in power generation is the economic dispatch to ensure the high cost could be minimized for a great advantage to the power providers. Economic dispatch (ED) is a process for determining the best power output to meet the demand while keeping to equality and inequality limitations and producing the lowest cost. The link between generators and load demand is the focus of economic load dispatch. In general, load demand is dynamic, fluctuating constantly in response to customer needs. As a result, ED will ensure that the generators operate at a minimum cost while simultaneously maintaining all the generator limits.In real generator operating, the cost function is non-smooth, non-linear, discontinuous, and non-convex with the presence of valve point effect, ramp rate limit, prohibited operating zone and multiple fuel options [1]. Many existing local optima are triggered by significantly non-linear ED concerns.Many algorithms have been proposed to handle the ED optimization problem over the years. The conventional method, non-conventional method, and hybrid method are the three types of optimization approaches that have been identified [2]. Conventional methods have some significant drawbacks, such as the ability to immaturely converge into local optima, sensitivity to initial starting points, and the fact that many of them are inapplicable to certain types of cost functions, such as non-smooth, non-convex and non-monotonically increasing cost functions. The most popular method discovered to solve ED problems is meta-heuristic methods, which is under the non-conventional method. The Squirrel Search Optimizer [3], Bat Algorithm [4], improved Firefly Algorithm [5], Barnacles Mating Optimizer [6], grey wolf optimizer [7], moth flame [8], genetic algorithm [9] [10], artificial cooperative search [11], krill herd [12,13], crow search[14,15], wind-driven[16], PSO [17] [18], are among the popular techniques in solving ED problems.

On the other hand, an improved marine predator's algorithm [19], High Performance Cuckoo Search Algorithm (HPCSA) [20], parallel hurricane optimization algorithm [21] and many more are the meta-heuristic methods implemented in solving ED problems. The significant disadvantage of meta-heuristic methods is that they do not consistently perform well for the same problem; in other words, certain meta-heuristic techniques are better for specific functions than others [22]. Therefore, researchers are constantly refining and researching the new optimization method to be implemented.Various hybrid strategies were then introduced to maximize the benefits of each optimization approaches. The combination of two or more optimization techniques have proven to be effective in achieving superior results. Among the hybridized techniques that can be highlighted are the modified hybrid particle swarm optimization with bat algorithm parameter inspired acceleration coefficients (MHPSO-BAAC) [23], hybrid Moth Flame Optimization with Sequential Quadratic Programming (MFO-SQP) [24], Evolutionary Simplex Adaptive Hooke-Jeeves algorithm [25] and combination of adaptive simulated annealing (ASA) and genetic algorithms (GA) [22].

The evolutionary particle swarm optimization (E-PSO) [26], modified particle swarm optimization and genetic algorithm (MPSO-GA) [27], a hybrid algorithm of Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) and Harmonic Search [28], Immune-Commensal-Evolutionary Programming (ICEP)-EP, AIS and SOS [29], Particle Swarm Optimization (PSO) and Artificial Fish Swarm Algorithm (AFSA) [30] are other integrated optimization techniques that can be highlighted. The implementation of hybridized or embedded techniques managed to achieve better results in terms of reduced cost and minimal computational time.

This paper presents a new optimization technique termed as HEBMO for Ramp Rate Limit Economic Dispatch. The proposed optimization technique integrates the element of evolutionary programming (EP) and barnacles mating technique to achieve better optimization solution. The proposed technique addresses the computational time in solving RRL in ED problem. Validation process conducted on the IEEE 30-Bus reliability test system (RTS) under base case and stress conditions revealed that the proposed HEBMO is worth in solving the chosen RRL ED problems.

Problem Formulation

Optimization in economic load dispatch involves the minimization of total fuel cost and simultaneously considering various constraints such as power balance and generation limits. Valve point effect (VPE) and Ramp Rate Limit (RRL) are two important components in ED studies. In this study only the ramp rate limit is addressed as it is significant in a power system study.

Ramp Rate Limit

The ramp rate limit (RRL)is considered as it had an impact on the total operating cost of thermal power generation [31][32] The physical limitations of starting and shutting down generators cause ramp rate limits. The up-ramp rate limit regulates the increasing operating point at a given level in the real operating process, whereas the down-ramp rate limit determines the dropping level of the operating point. The operation of RRL can be characterised by several problem formulations. The up-ramp limit, UR for generator*i*should be higher that the difference between the operating output power, $P_i$and the previous output power. The general equation to represent the first phenomenon is given in equation (1) and (2).

$$P_i - P_i^0 \leq UR_i \tag{1}$$

$$P_i^0 - P_i \leq DR_i \tag{2}$$

$P_i^0$is the previous output power, UR_i is the up-ramp limit, and DR_i is the down-ramp limit for the i^{th} generator respectively. The generation limitations for inequalities are stated as (3) - (5).

$$P_{i_{lower}} \leq P_i \leq P_{i_{upper}} \tag{3}$$

$$P_{i_{lower}} = max\left(P_i^{min}, P_i^0 - DR_i\right) \tag{4}$$

$$P_{i_{upper}} = min(P_i^{max}, P_i^0 + UR_i) \quad (5)$$

Proposed HEBMO Optimization Technique

The proposed Hybrid Evolutionary Barnacles Mating Optimization (HEBMO) is the integration between Evolutionary Programming (EP) and Barnacles Mating Optimizer (BMO). Element of barnacle mating is integrated into the original EP algorithm. The process flowchart of HEBMO is presented as in Figure 1. The optimization process started with initialization, mutation process, combination, ranking and selection, combination and lastly convergence test.

Step 1: Initialization

The first process is random numbers generation. The random numbers are generally expressed as: -

$$X = \begin{bmatrix} x_1^1 & x_1^2 & \dots & x_1^N \\ x_2^1 & x_2^2 & \dots & x_2^N \\ \vdots & \vdots & \vdots & \vdots \\ x_n^1 & x_n^2 & \dots & x_n^N \end{bmatrix} \quad (6)$$

where N is the control variables number and n is the number of individuals. In ED optimization, x_1, x_2,..$x_n$represent the generated power P_g at the generator buses. The control variable numbers, N depends on the upper or lower boundaries of the problem to be solved, given as;

$$ub = \left[ub_1, \dots ub_j\right] \quad (7)$$

$$lb = \left[lb_1, \dots lb_j\right] \quad (8)$$

where *ub* and *lb*represent for upper and lower bounds of the j_{th} variable.

During initialization process is done, 20 individuals will fill up the initialization pool for the optimization process. The surviving individuals among candidates of solution are defined by the top value of fitness evaluation. The fitness identified in this research is the total generation cost as shown in equations (3)-(5) for non-convex ELD problem with the ramp rate limit.The limit of mating location, *ml* must be arranged to breed the offspring in the BMO operator. The limit of *ml* decided in this research is 14 barnacles, taken from 70 % of the total population size. To achieve global optima, this number is utilized since the process of exploitation and exploration are well balanced.

Step 2: Mutation

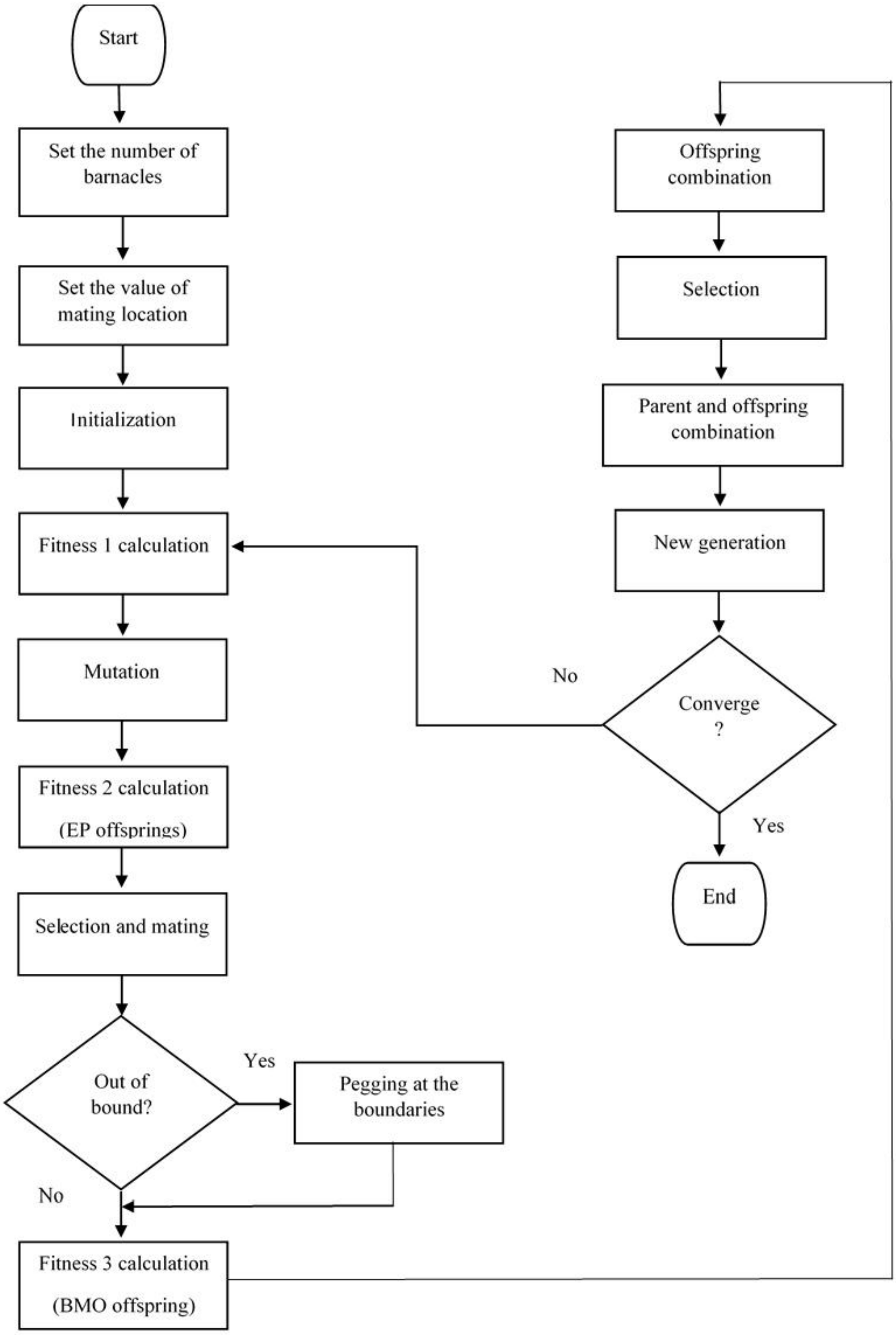

Figure 1: Flowchart of the proposed HEBMO optimization algorithm

This proposed technique executes two types of mutation, Gaussian Mutation, and BMO reproduction. The Gaussian Mutation formula is explained in equation (10). While the BMO reproduction equation is detailed in (9) and (10).

$$X_{i+m,j} = X_{i,j} + N\left(0, b\left(X_{jmax} - X_{jmin}\right)\left(\frac{f_i}{f_{max}}\right)\right) \tag{9}$$

where $X_{i,j}$ is the parents, b is the search step, X_{jmax} is the maximum parents, X_{jmin} is the minimum parents, f_i is the fitness of $\mathrm{i_{th}}$ and f_{max} is the maximum fitness. In this research, N=20, which is the number of candidates, and *b*=0.005.

$$X^{N}{}_{i}\_new = px^{N}barnacle\_d + qx^{N}barnacle\_\mathrm{m} \qquad (10)$$

$$\mathrm{X_i}^{n\text{–}new} = rand\,() \times x^{n}barnacle\_\mathrm{m} \qquad (11)$$

where *p=randn, q=(1-p), barnacle_m,* and *barnacle_d* are the parents to be mated.

The modification has been done at the reproduction process, the generation of random numbers method, *p=randn (1,1)* * $a+b$ is applied. The formula of p is the normally distributed pseudo-random numbers between 0 and 1. To ensure satisfactory results, the minimum, b, and offset, a must be determined.The assessment of fitness is required once more to determine the best offspring. The total number of best offspring generated is 20, which is the same as the population size. For the next phase, the best values are preserved in the offspring pool.

Step 3: Offsprings Combination

The combination is a merging process of two offspring populations, between EP and BMO offspring. The size of the offspring population becomes larger, with a size of 40.

$$Combine\ offspring\ population = \begin{bmatrix} EP\ offspring\ population \\ BMO\ offspring\ population \end{bmatrix} \qquad (12)$$

Step 4: Ranking and Selection

The combination of offsprings and parents' population is then ranked according to the best fitness values. In this study, the objective function is minimization process, therefore the individuals will be sorted based on the lowest fitness value. The worst individuals will be placed in the last row. And this is vice versa for the maximization process. Finally, the best 20 offspring individuals will be selected to go for the next process.

Step 5: Combination

The best 20 offspring individuals from the previous process will be selected to recombine with the 20 accepted parents that are first calculated by fitness equation. Once again, the total population size becomes double.

$$Population = \begin{bmatrix} Accepted\ parent \\ Offspring\ individuals \end{bmatrix} \qquad (13)$$

Step 6: Ranking and Selection

The survivors will be nominated once again by ranking them according to their fitness value. The 20 survivors are classified as a new generation, indicating that they are getting ready to be employed in the following iteration until HEBMO converges.

Step 7: Convergence Test

When an optimization process converges to a specific value, it is termed converge. As illustrated in the equation, this process is signaled by a halting criterion, which is defined as the difference between the maximum and minimum fitness (14). Until the problem is solved, the algorithm will keep repeating the same process. The desired difference value is determined by the relevance of the experiment.

$$fitness_{max} - fitness_{min} \leq 0.0001(14)$$

The finalresults revealed ideal solution populations, with all individuals having the same value.

Result and Discussion

To access the effectiveness of the proposed HEBMO optimization technique, the IEEE 30-Bus RTS model was utilized for validation purposes. The information of the studied system is taken from [33],[35] and [36] summarised in Table 1. Two scenarios are considered, simulated under different loading conditions to ensure the proposed technique is robust enough and feasible for solving broad spectrum. The detail scenarios are listed as in Table 2. For performance evaluation, the proposed algorithm is compared against EP and BMO.

Table 1: Power generator limits and cost coefficient for IEEE 30-Bus RTS system

Generator	Pg_{min}	P_{gmax}	Cost Coefficient			Ramp Rate Limits		
			a_i ($/h)	b_i ($/MWh)	c_i ($/MW^{2}h)	UR (MW)	DR (MW)	Pio (MW)
P_{g1}	50	200	240	7	0.007	60	80	150
P_{g2}	20	80	200	10	0.0095	28	10	35
P_{g3}	15	50	220	8.5	0.009	10	20	39
P_{g4}	10	35	200	11	0.009	10	5	20
P_{g5}	10	30	220	10.5	0.008	10	5	18
P_{g6}	12	40	190	12	0.0075	15	6	20

Table 2: Several Scenarios for Solving ED Problem

Scenario No	Description
Scenario 1	Base case: The system is operating in a normal condition.
Scenario 2	Stressed condition: Increment of real power load, $P_d$with a factor value, k.

Scenario-1: Base Case Condition

Table 3tabulates the resultsfor comparison of generation cost solved by EP, BMO and the proposed HEBMO for solving ED problem with RRLimplemented on the IEEE 30-Bus RTS. Taking the lowest generation cost as the objective function, it can be observed that HEBMO achieves the lowest cost as compared to EP and BMO. EP managed to achieve $/MWh 3.9331x10^{3}as the generation cost, as compared to HEBMO which managed to achieve a generation cost of $/MWh 3.8746x10^3. On the other hand, BMO only managed to achieve $/MWh 3.8956 x 10^3. The proposed HEBMO outperformed EP and BMO in terms of achieving the lowest cost of generation.

Table 3: Comparison of Generation Cost ELD with Ramp Rate Limit for IEEE 30-Bus RTS (Scenario-1)

Optimization Technique	EP (MW)	BMO (MW)	HEBMO (MW)
P1	171.4643	183.8706	157.8136
P2	27.4145	26.694	25.0054
P5	29.8266	37.1779	64.8631
P8	15.8389	16.2876	15.4522
P11	24.4913	14.3172	13.0862
P13	22.6578	14.0071	14.0001
Generation cost ($/MWh)	3.9331E+03	3.8990E+03	3.8746E+03

This implies HEBMO achieved 1.49 % lower cost as compared to EP and 0.53% lower than BMO. It is worth to mention that the proposed HEBMO is superior to EP and BMO in addressing this issue. These percentage values are worth and significant in ED studies as it will affect the performance of a utility in managing their generation cost. The optimal sizing of power to be generated for achieving the lowest generation cost, solved using the proposed HEMBO are P1=157.8136 MW, P2=25.0054 MW, P5=8631 MW, P8=15.4522 MW, P11=13.0862 MW and P13=14.0001 MW. P1, P2, P5, P8, P11 and P13 are all the generated powers of the generators at buses 1, 2, 5, 8, 11 and 13.

Further assessment on the optimization performance is also investigated for both scenarios. The convergence performance of the implemented techniques for ED problem with RRL for IEEE 30-Bus RTS (Scenario-1), optimized using the proposed HEBMO, EP and BMO is depicted in Figure 2. The performance of the proposed HEBMO is outstanding as compared with EP and BMO as highlighted in the figure. This implies that the integration between the traditional EP and BMO, termed as BMO has resulted to a very convincing performance in terms of achieving the significantly lowest generation cost. This will ne very useful to power system operators and planning at the relevant utilities to plan for the economic planning action at their utilities. The proposed optimization technique could also be very useful for solving other optimization problems at their utilities with considerable modification and data tuning.

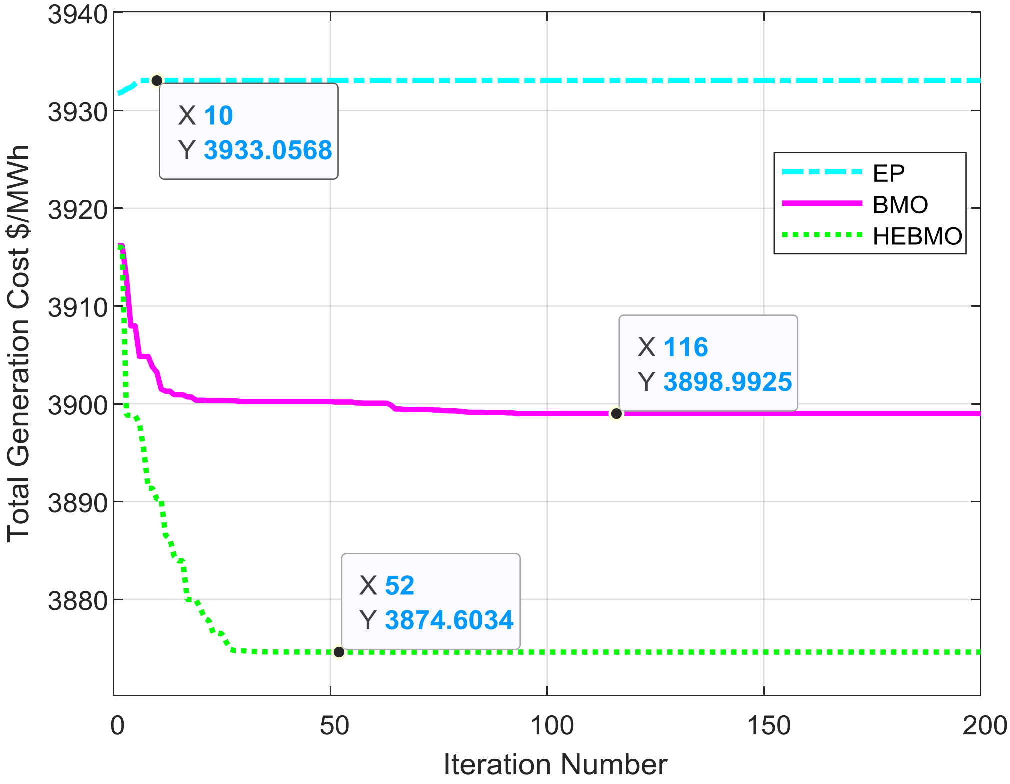

Fig. 2: Convergence performance of the various techniques for ED problem with RRL for IEEE 30-Bus RTS (Scenario-1).

Scenario-2: Stressed Condition, P_d

The second scenario underwent the process is Scenario-2, where the system is subjected to stressed condition. When such a system experienced a stressed condition, reactive power or active power loading at several chosen buses or in the whole system is increased which may cause low voltage phenomenon. However, this is important and useful to ensure that any proposed technique is robust and could manage a complex situation. The results for generation costs for the ED problems with RRL under stressed condition are tabulated in Table 4. The real power P_d was increased up to 120% of its base case value. The generation cost are \$/MWh 4.4939x10^3, \$/MWh 4.5143x$10^3$and \$/MWh 4.5069x10^3 solved by HEBMO, EP and BMO respectively. It appears that HEBMO achieved the lowest generation cost by 0.45 % and 0.29 % compared to EP and BMO. Apparently, HEBMO demonstrates excellent result in solving ED problems under RRL consideration.The optimal sizing of power to be generated for achieving the lowest generation cost, solved using the proposed HEMBO are P1=212.7858 MW, P2=35.524MW, P5=50.3355 MW, P8=16.2174MW, P11=23.091MW and P13=14.2187MW. P1, P2, P5, P8, P11 and P13 are all the generated powers of the generators at buses 1, 2, 5, 8, 11 and 13.

Table 4: Comparison of Generation Cost ELD with Ramp Rate Limit for IEEE 30-Bus RTS (Scenario-2)

Load Multiplier	1.2		
Optimization Technique	EP (MW)	BMO (MW)	HEBMO (MW)
P1	199.8248	208.7858	212.7858
P2	39.4645	36.0846	35.5240
P5	46.2471	47.2407	50.3355
P8	26.4571	22.303	16.2174
P11	20.4587	19.8247	23.0910
P13	18.8478	17.6666	14.2187
Generation cost ($/MWh)	4.5143E+03	4.5069E+03	4.4939E+03

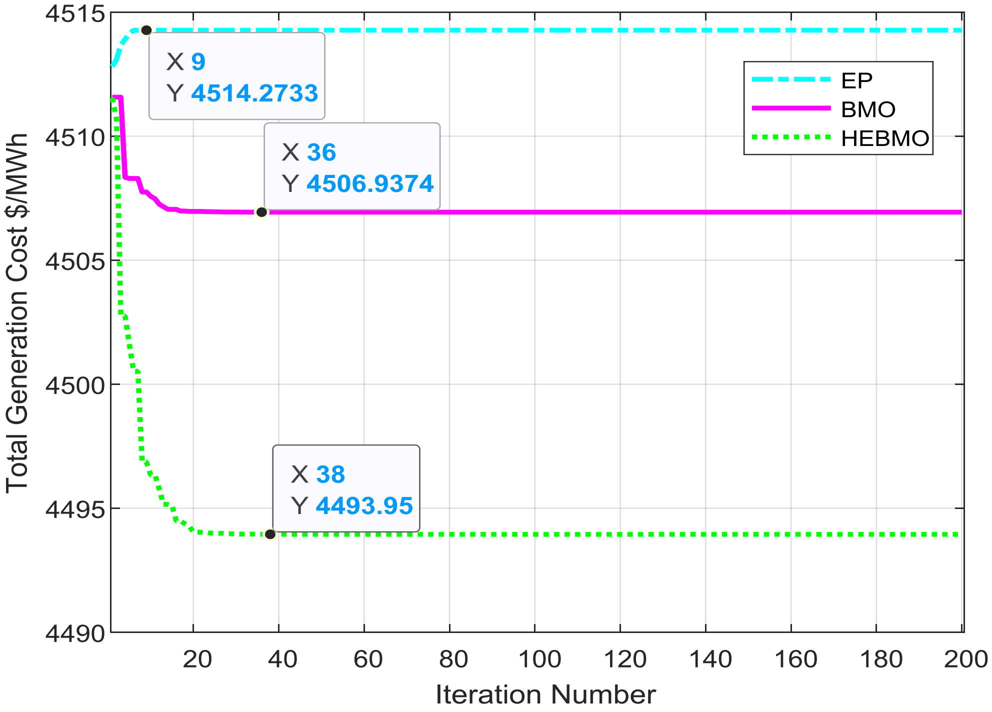

Fig. 3: Convergence performance of the various techniques for ED problem with RRL for IEEE 30-Bus RTS (Scenario-2).

The convergence performance of the implemented techniques for ED problem with RRL for IEEE 30-Bus RTS (Scenario-2), optimized using the proposed HEBMO, EP and BMO is depicted in Figure 3. The performance of the proposed HEBMO is outstanding as compared with EP and BMO as highlighted in the figure. This implies that the integration between the traditional EP and BMO, termed as BMO has resulted to a very convincing performance in terms of achieving the significantly lowest generation cost. This will be very useful to power system operators and planning at the relevant utilities to plan for the economic planning action at their utilities. The proposed optimization technique could also be very useful for solving other optimization problems at their utilities with considerable modification and data tuning.

From the results in both scenarios, it is worth to mention that the proposed HEBMO optimization technique is robust in addressing the ED study under base case and stressed condition.

Conclusion

This paper has presented a Hybrid Optimization Based Technique for Ramp Rate Economic Dispatch. The proposed technique is termed as HEBMO. In this study a newly optimization technique has been introduced to address the setback in the traditional techniques involving EP and BMO. HEBMO is used to assess RRL to solve economic load dispatch problems. HEBMO was compared with EP and BMO, to address two single optimization techniques. The IEEE 30 Bus RTS which has six generators, was chosen as the test system; validated under base case and stressed condition. In terms of generation costs, all the scenarios showed that HEBMO outperformed EP and BMO in achieving the lowest generation cost. The newly proposed HEBMO optimization technique is feasible for solving other optimization problems with considerable alteration and modification, on the fitness and control variables. Results obtained from the study could be beneficial to the utilities in performing their offline remedial action and economic planning.

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