Optimal load dispatch solution of power system using enhanced harmony search algorithm

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ABSTRACT. *The key object of electric power generation is to deliver required energy to the consumer by optimum economic operation. Power system is a large interconnected system and usage of power also increasing drastically with modernization and the cost of production of electric energy will increase with rapid growth of transmission and distribution infrastructure as losses for new transmission and distribution occurs. So there is a need for optimizing generation of power at different locations of power system. This leads to minimization of cost of input thermal generating units meeting the load demand and transmission losses. This is a challenging task called Economic Dispatch (ED) which includes non-linear quadratic function and valve point loadings, and requires complex solving. Literature exhibits those convex cost functions of steam thermal generating units when included with valve point loadings leads to non-convexity resulting in non-convex problem. Perfect modeling of ED for steam thermal generating units is possible with valve point loadings. Solving non-convex problem by conventional methods is a difficult issue as sudden changes and discontinuities are possible in incremental cost function. Improved Harmony Search (EHS) algorithm has been introduced in this work to resolve the ED problem. The proposed method is applied to thirteen-unit test system at 2-different load demands and the results also presented.*

RÉSUMÉ. *L'objectif principal de la production d'énergie électrique est de fournir au consommateur l'énergie requise par un fonctionnement économique optimal. Le système électrique est un grand système interconnecté et l'utilisation de l'énergie augmente considérablement avec la modernisation et le coût de production de l'énergie électrique augmentera avec la croissance rapide de l'infrastructure de transport et de distribution, entraînant des pertes pour la nouvelle transmission et distribution. Il est donc nécessaire d'optimiser la production d'électricité à différents endroits du système d'alimentation. Ceci conduit à une minimisation du coût des unités de production thermique d'entrée répondant à la demande de charge et aux pertes de transmission. C'est une tâche complexe appelée Economic Dispatch (ED), qui inclut des charges quadratiques non linéaires et des chargements de points* *de vanne, et qui nécessite une résolution complexe. La littérature présente ces fonctions de coût convexes des unités de génération thermiques à vapeur lorsqu'elles sont incluses avec des chargements de points de vanne conduisant à une non-convexité entraînant un problème non convexe. Une modélisation parfaite de l'ED pour les unités génératrices thermiques à vapeur est possible avec les chargements de points de vannes. La résolution du problème non convexe par des méthodes conventionnelles est une question difficile car des changements soudains et des discontinuités sont possibles dans la fonction de coût incrémentiel. Un algorithme amélioré de recherche de l'harmonie(EHS) a été introduit dans cet article pour résoudre le problème de l'ED. La méthode proposée est appliquée à un système d'essai de treize unités avec deux demandes de charge différentes et les résultats sont également présentés.*

KEYWORDS: *non convex, economic load dispatch, harmony search algorithm (HS), enhanced harmony search algorithm (EHS), valve point loading.*

MOTS-CLÉS: *non convexe, répartition économique de la charge, algorithme de recherche de l'harmonie (HS), algorithme amélioré de recherche de l'harmonie(EHS), chargements de points de vannes.*

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1. Introduction

Operation of power system network at low price is the most precious factor and this can be achieved effectively by distributing the true power demand from available source of generation properly. Running of the system with effective economic point view termed as ED problems. The ED Problem have association to solve 2-dissimmer obstacles (Wood & Wollenberg, 1996). Here the pre dispatch obstacle is the first one that is how to meet the requirement of the load by selecting the available unit out of other units optimally for required time and online ED is second obstacle that means to decrease the generation cost how to select the one unit from parallel running units for minute to minute requirements. The effective work of ED problem is by satisfying the load demand requirement produce the real power with low price. So the production cost always depending on the load demand at particular time (Rad & Amjady, 2010).

Due to large interconnection of electrical power system, the power demand is huge and that will continuous hike in the cost of energy, so we must diminishes the operating cost of plant by minimizing the fuel consumption for a particular load. ED is one of the aspects of Optimal Power Flow (OPF) has to decrease overall input generating costs of generating units, objective function and total generation must maintain load demand and transmission line losses, equality constraints (Walters & Sheble, 1993). Traditionally ED is solved by Lagrangian approaches, Lambda-iteration approach, Newton methods, linear programming and quadratic programming and Gradient approaches (Mahor *et al.,* 2009). For higher test systems above mentioned approaches solve the ED problem with lower efficiency.

The generation cost of the power system can be minimized with proper economic load dispatch only. To make economic dispatch as a convex issue, generating units cost function taken in quartic form this can be solved using general existed methods. By one of the conventional method we can solve the ED without considering the transmission losses (Xia & Elaiw, 2010). Another traditional approach solved ED problem by bearing in mind network transmission losses (Li & Wang, 2013), and those approaches are unable to give the exact results due to approximation power balance equations. Hence for improved solution those can be united with an iterative to obtain precise result for convex problem.

ED problem cracking approaches can be divided into three assemblies. The first assembly comprises the approaches applied to ED problems in their unique versions. Rare samples are tabu search algorithm (TS) (Boonseng *et al.*, 2012), particle swarm optimization (PSO), differential evolution (DE) (Iba & Noman, 2008). The approaches of the second assembly are the modified kinds of the first assembly including modified tabu search (MTS) (Li *et al.*, 2002), improved PSO (IPSO) (Joong-Rin *et al.*, 2010), shuffled differential evolution (SDE) (Vaisakh & Srinivasa, 2013). Final assembly comprises of the mixture approaches as the grouping of approaches from the earlier groups mentioned above.

In this work, we recommend an advanced approach for cracking the ED problem by means of an Enhanced harmony search (EHS) algorithm. An ED problem constructed on a 13-unit test system (Chattopadhyay *et al.*, 2003) through incremental fuel cost function captivating into account the valve-point loading effects is employed to validate the presentation of the EHS. The valve-point loading effects familiarize various minima in the solution space. Numerical outcomes gained with the projected EHS approach were compared with classical HS technique and other optimization outcomes stated in literature.

2. Economic load dispatch problem formulation

For newly added units in power station technical fellows got successes to enhance the output of the generating plant apparatus like boilers, generators and turbines without interruption while comparing with the older units. To decrease the cost of generation for any operating condition of power system we should know the contribution of each power station. generation of power can be done by thermal, nuclear, diesel etc. and each and every power station have their own characteristics and various cost of generations at any loads to minimize the operation cost of plant we should go with effective scheduling plants. Every generating plant cost characteristic is nonlinear (Xia *et al.*, 2013). So to achieve the minimum operating cost also a nonlinear problem and difficult.

2.1. Cost function

The major impact on total cost of generation due to useful power only. If we want to meet more true power then we should boost up the speed of prime mover of particular plant and that will hike the fuel cost. Reactive power generation can’t affect the total cost of generation because that can be controlled by field current. Hence any generating station is for production of true power only (Jeddi & Vahidinasab, 2014).

2.1.1. Operating cost of a generator

Fuel cost, labor cost and maintains all together gives the total operating cost of generation. Generally conventional fuel power plants having low out power value that can be increased by proper adjustment of the turbine inlet valve. For amount of incoming fuel the cost of generation of all factors are fixed. Depending on the opening and closing of the turbine valve the efficiency of turbine also changes so we have open or close the valve properly depends on requirement. Fig: 1 represents the total operation involved in generation.

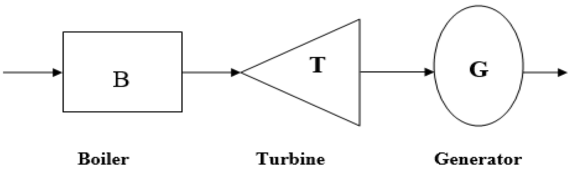

Figure 1. Thermal power generation cycle

The cost of fuel curve in true power generation has represented bellow (He *et al.*, 2015),

$$F_i(P_i) = a_i p_i^2 + b_i p_i + c_i \text{ Rs/hr} \tag{1}$$

Here,

$\boldsymbol{F_i(P_i)}$	Generator cost function i,
a_i, b_i, c_i	Generator cost coeffiecnt i
$\boldsymbol{P_i}$	Electrical output of generator i, MW
i	set for all generators

2.1.2. Equality constrains

To reduce Objective function, Total Input Fuel Cost, power constraint must be satisfied; where the power constraint is that overall power generation should maintain overall system demand and transmission line losses.

$$\sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \tag{2}$$

Here, P_D –overall system demand and P_L- Transmission line loss. In this work P_L is neglected.

2.1.3. Inequality constrains

Generated output power of each unit should be within bounds, which is satisfied the inequality constrains given by (Modiri-Delshad *et al.*, 2016)

$$P_{min,\,i} \leq P_i \leq P_{max,\,i} \tag{3}$$

Here, $P_{min,\,i}$, $P_{max,\,i}$are the bounds of ith alternator.

3. Harmony search algorithm

Geem *et al.* (2001) suggested an effective harmony search meets-heuristic algorithm that was impressed by music process for a perfect state of harmony. Optimization technique and music in harmony both are similar and musician's improvisations are similar to local and global quest optimization methods. Harmony Search (HS) algorithm never asks about initial values and uses a stochastic random quest instead of gradient quest that is based on Harmony Memory Considering Rate (HMCR) and the Pitch Adjusting Rate (PAR).

HS algorithm, musical performances requires an effective state of harmony find from aesthetic estimation, as the optimization algorithms requires a perfect state find from objective function value. It has been effectively applied to different optimization problems in computation and engineering sectors.

The Optimization procedure of the HS algorithm has 1-5 steps, as bellow (Javadi *et al.*, 2012).

Step1. Frame the optimization problem, objective function with constraints and initialize the HS parameters.

Step 2. Harmony Memory (HM) is initialized.

Step 3. New Harmony from the HM is improved.

Step 4. Modernize the memory of harmony.

Step 5. Continue the loop of steps 3 and 4 until the total iterations are completed, stopping criterion.

3.1. Enhanced harmony search (EHS) algorithm

HS is effective one to give the best performance with in minimum time, but facing problems to local quest for data applications. To enhance the effectiveness of HS algorithm and knock out the defects lie with feasible values of Harmony Memory Considering Rate (HMCR) and the Pitch Adjusting Rate (PAR). Fesanghary *et al.* (2007) introduced an effective HS algorithm that uses variable PAR and Band Width (BW) in improvisation step and also introduced different in harmony search, termed as global apex harmony search and main data is dumped from swarm to obtain the effective results from HS. The EHS adopted in this work have similar steps like conventional HS without step 3, and in this PAR has been dynamically changed show bellow.

$$PAR = PAR_{\min} + \frac{PAR_{\max} - PAR_{\min}}{NI} * gn \tag{4}$$

where, PAR, Pitch Adjusting Rate for generation gn, PAR_{min} is the min. adjusting rate, PAR_{max} is the max. Adjusting rate, gn is the generation number and NI is the number of solving vector generation. In addition, bandwidth for generation is dynamically updated as follows (Javadi *et al.*, 2012).

$$bw = bw_{\max} e^{\left(\frac{\ln\left(\frac{bw_{\min}}{bw_{\max}} \right)}{NI} * gn \right)} \tag{5}$$

where,

bw is the generation bandwidth,

bw_{min} is the min. bandwidth and bw_{max} is the max. bandwidth

3.2. Application of harmony search algorithm to ED problem

After the initial development of HS algorithm in 2001, HS algorithm applications have been expanded in a huge range of obstacles. The scientific range is so broad, that one can conclude that Harmony Search Algorithm has generally accepted as a robust optimization technique (Coelhos & Mariani, 2009).

Step1. Initialize parameters.

Step2. Initialize the harmony memory.

Step3. Improvise a new harmony

Step4. Adaptive selection

Step5. Update harmony memory

Step6. Stopping criterion

3.3. Application of enhanced harmony search algorithm to ED problem

Although HSA has better capability in identifying the search space in sensible time it is not capable in finding local optimums in case of numerical issues. The drawbacks like fixed values of HMCR and fewer PAR values with large band widths may reduce the performance. Hence increase in iteration number may happen to find optimal solution. So 4 and 5 equations are utilized to change BW and PAR values.

4. Simulation results and discussions

The adopted algorithms HS, EHS were tested on 3- standard load dispatch problems consisting of 3-13 and 40-units and implemented by MATLAB 8.5 R2016b. Here selection of parameters in adopted method is somewhat difficult. Optimal parameter setting for the all test systems is given in Table I & Table II.

Table 1. Optimal parameter setting of HS, EHS for 3 and 13 units

Parameters	3- Units		13- Units	
	HS	EHS	HS	EHS
pop	30	30	130	130
HMCR	0.95	0.95	0.95	0.95
PAR	0.45	--	0.45	--
PAR_{min}	--	0.4	--	0.4
PAR_{max}	--	0.99	--	0.99
BW	0.01	0.01	0.01	0.01
BW_{min}	--	0.00005	--	0.00005
BW_{max}	--	0.05	--	0.05
iter	100	100	200	200

Table 2. Optimal parameter setting of HS, EHS for 13 and 40 units

Parameters	13- Units		40- Units	
	HS	EHS	HS	EHS
pop	130	130	400	400
HMCR	0.95	0.95	0.95	0.95
PAR	0.45	--	0.45	--
PAR_{min}	--	0.4	--	0.4
PAR_{max}	--	0.99	--	0.99
BW	0.01	0.01	0.01	0.01
BW_{min}	--	0.00005	--	0.00005
BW_{max}	--	0.05	--	0.05
iter	200	200	500	500

4.1. For three unit system

A system of 3-thermal generating units with the quadratic cost function has been considered in this test. All generating units collectively meet the total demand of 850MW. Global optimal solution for this three-unit test system is attained as 8194.356124$/hr (Xia *et al.*, 2013). The dispatch results using the proposed methods, HS, EHS are given Table 3. From Table 3, it is evident that the low cost gained by all the methods is same as the global solution. For this test system, hundred iteration (individual trails) have been made. Based on results obtained, the comparison of HS, EHS applied to thermal units are presented in Table III. The convergence criteria of HS, EHS methods for the three unit system are shown in Fig 2.

Table 3. Comparisons of simulation results for 3-unit system

Unit	Method	
	HS	EHS
G1	330.344330	443.285943
G2	399.090808	281.588517
G3	120.564862	125.125540
Minimum cost ($/h)	8194.368755	8194.356124
Total power (MW)	850	850

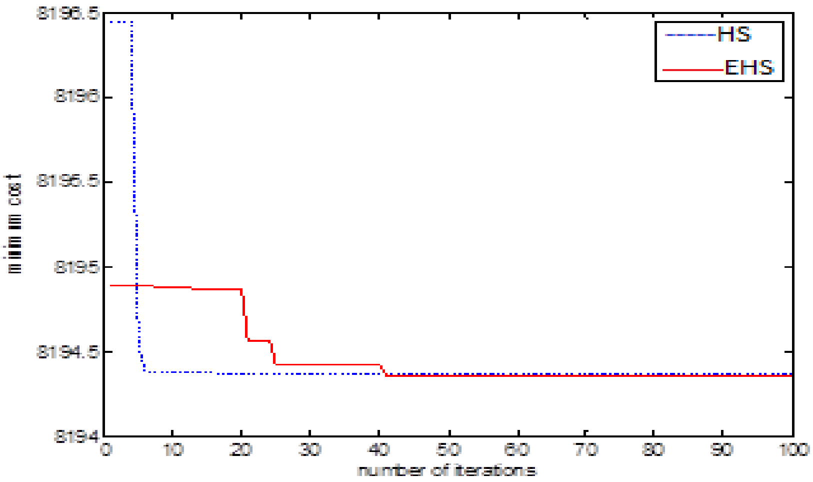

Figure 2. Convergence criterion for 3-unit system

4.2. For thirteen unit system

Here, the proposed methods are applied to the 13-generator unit test system that includes quadratic generator input cost functions. Two dissimilar power demands have been used to show the efficacy of adopted algorithms in obtaining optimum solutions. Two different case studies have been considered on this test system. At first a load demand of 1800MW is taken (Coelhos & Mariani, 2009) and later a load demand of 2520MW is considered.

Convergence criteria and the output power generations (MW) of HS and EHS methods applied to thirteen unit test system operating on a load demand of 1800MW is shown in Fig 3 and Table 4 respectively. From Table 4, it is clear that the low price gained from adopted approach is 17935.683284$/hr. Here we got the results by all the methods is same as the global solution.

Table 4. Comparisons of simulation results for 13-unit system P_D=1800 MW

Unit	Method	
	HS	EHS
G1	623.150720	494.415492
G2	19.859718	126.920922
G3	195.827057	352.627500
G4	73.273771	73.556964
G5	171.449723	156.961100
G6	118.821822	68.377544
G7	75.778269	61.632842
G8	108.008892	121.345118
G9	99.879446	66.173336
G10	74.288292	68.534340
G11	87.001353	40.644621
G12	63.080884	100.643458
G13	89.580050	68.1 66764
Minimum Cost($/hr)	17935.418707	17935.683284
Total Power (MW)	1800	1800

Table 5. Comparisons of simulation results for 13-unit system P_D=2520 MW

Unit	Method	
	HS	EHS
G1	680.000000	680.000000
G2	277.380097	209.329820
G3	357.803149	314.965502
G4	101.803996	205.115220
G5	125.653425	203.759629
G6	161.343304	94.586705
G7	134.837412	118.625349
G8	151.287822	144.707589
G9	104.156086	105.136503
G10	117.409011	76.195748
G11	93.878199	133.645069
G12	115.492372	126.241200
G13	98.955126	107.691666
Minimum cost($/hr)	24062.989996	24062.580327
Total Power (MW)	2520	2520

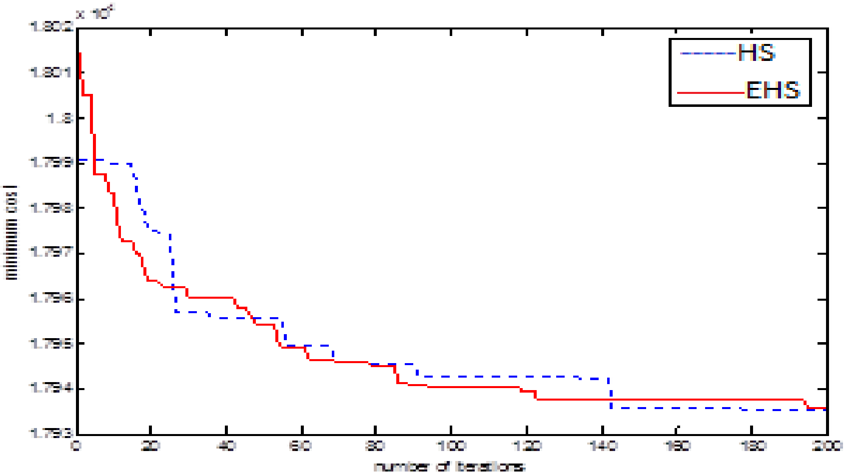

Figure 3. Convergence criterion for 13-unit system with P_D=1800 MW

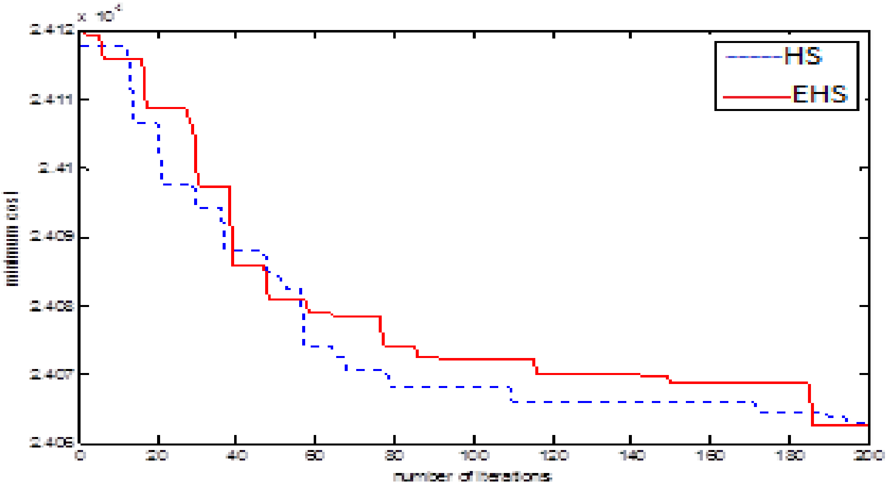

Figure 4. Convergence criterion for 13-unit system with P_D=2520MW

Table 5. shows that dispatch solutions HS, EHS methods to a load of 2520MW, Output gained from all methods, it is evident that the power balance constraint is compromised after sixth decimal also. Result obtained by proposed approach is compared with the HS, EHS as presented in Table 5. The least price gotten by the adopted approach is 24062.580327$/hr. This can be achieved by balancing the power constraints. Fig 4 shows illustrate the convergence criterion of proposed algorithms for the 13-unit system with a load demand of 2520 MW.

4.3. For forty unit system

Table 6. Simulation results of HS and EHS methods for 40-unit system

Unit	Method	
	HS	EHS
G1	113.999232	113.999014
G2	114.000000	114.000000
G3	120.000000	120.000000
G4	190.000000	190.000000
G5	97.000000	97.000000
G6	140.000000	140.000000
G7	300.000000	300.000000

G8	300.000000	300.000000
G9	300.000000	300.000000
G10	130.000000	130.000000
G11	94.000000	94.000000
G12	94.000000	94.000000
G13	125.000000	125.000000
G14	271.853430	270.842149
G15	265.890514	266.432925
G16	267.256825	267.726011
G17	500.000000	500.000000
G18	500.000000	500.000000
G19	550.000000	550.000000
G20	550.000000	550.000000
G21	550.000000	550.000000
G22	550.000000	550.000000
G23	550.000000	550.000000
G24	550.000000	550.000000
G25	550.000000	549.999900
G26	550.000000	550.000000
G27	10.000000	10.000000
G28	10.000000	10.000000
G29	10.000000	10.000000
G30	97.000000	97.000000
G31	190.000000	190.000000
G32	190.000000	190.000000
G33	190.000000	190.000000
G34	200.000000	200.000000
G35	200.000000	200.000000
G36	200.000000	200.000000
G37	110.000000	110.000000
G38	110.000000	110.000000

G39	110.000000	110.000000
G40	550.000000	550.000000
Minimum Cost ($/hr.)	119450.643035	118660.253435
Total Power (MW)	10500	10500

Here adopted methods are implanted to forty thermal units with the quadratic input fuel cost function. Here the load demand expected to be met by generating units is 10500 MW.

Result obtained by implemented approach with 100 trails, on the 40 thermal units (Li & Wang, 2013) test is given in Table 6. It can be cleared that the adopted approach achieved in obtaining believable result of 40-unit test system & has represented the importance to the other approaches for 40-unit systems. The final low cost gained by the adopted approach for 40- unit system is 119441.588684$/hr. Fig 5 shows illustrate the convergence criterion of proposed algorithms for the 40-unit system with a load demand of 10500 MW.

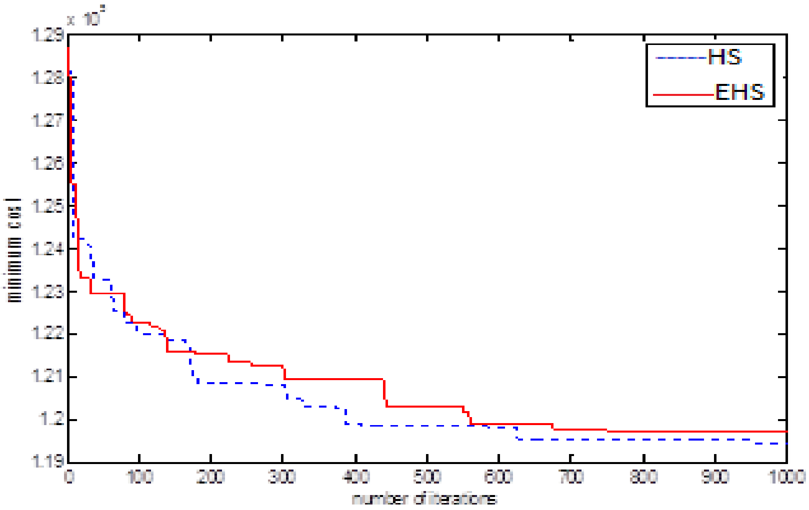

Figure 5. Convergence criterion for 40-unit system with P_D=10500 MW

5. Conclusion

In this work heuristic approach such as Harmony Search and Enhanced Harmony Search algorithms effectively implemented to solve power system ED problem. The usefulness, perfectness of the adopted algorithm tested on electrical network having three, thirteen and forty units. From three systems simulation results we overcome the problem with reduction in cost of generation. Adopted method highly increased the searching capability and perfectly handled the system constraints. The successful global optimizing performance on the validation data set shows the efficiency of the adopted approach and show that it can be used as a dependable tool for solving ED problem.

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