Improved Harmony Search for Economic Power Dispatch

V. Ravikumar Pandi,
Department of Electrical Engineering,
IIT, New Delhi, India – 110016
E-mail: ravikumarpandi@gmail.com.

B. K. Panigrahi,
Department of Electrical Engineering,
IIT, New Delhi, India – 110016
E-mail: bkpanigrahi@ee.iitd.ac.in.

Manas Kumar Mallick,
Department of Electrical Engineering,
ITER, SOA University,
Bhubaneswar, India
Email: manasmallick.iter@gmail.com

Ajith Abraham,
Scientific Network for Innovation and Research Excellence
Machine Intelligence Research Labs, USA
Email: ajithabraham@ieee.org

Swagatam Das,
Department of Electronics & Telecommunication Engineering,
Jadavpur University, Kolkata, India.
E-mail: swagatamdas19@yahoo.co.in.

***Abstract*-- This paper presents a novel optimization approach using Improved Harmony Search (IHS) algorithm to solve economic power dispatch problem. The proposed methodology easily takes care of different equality and inequality constraints of the power dispatch problem to find the optimal solution. To show its efficiency, the proposed algorithm is applied to single area and multi area system of four area having 16 units with and without Prohibited Operating Zones (POZ). The results are compared with other existing relevant approaches. The result obtained by the proposed method confirmed that the robustness and efficiency of the algorithms over other reported methods.**

Keywords-Harmony search algorithm, Multi area Economic dispatch, prohibited operating zones.

I. INTRODUCTION

Among most of the power system optimization problems, economic load dispatch (ELD) problem lies at the kernel [1]. The problem of dividing the total load demand among the online generators economically and also satisfying the various constraints is called economic load dispatch (ELD). In the past decades, many optimization algorithms are tried with different kinds of constraints [2, 3]. The ELD is also extended to multi area system, where all the areas are connected through tie lines [4]. In the multi area system by looking the overall economic operation of the system, the dispatching of the load is performed. Direct search method is used to solve Taiwan power system having three areas [5]. The solution of Multi area economic load dispatch using evolutionary programming technique is given in [6]. The MAED having the generators with multiple fuel options is used in [7] and dispatch is done using evolutionary programming technique.

Evolutionary methods have becomes more popular to solve any mathematical functions in the past decades. The natural selection and meta heuristic methods are useful for finding the global optimum solution, since they all are maintaining population of solutions to the considered problem. Harmony Search algorithm (HS) has been developed by Geem et al. [8]. It imitates the improvisation process of musicians to find the perfect state of harmony. This HS algorithm has been successfully applied to various mathematical optimization problems [9-13] in the application field of civil and mechanical engineering.

This paper solves the single area as well as multi area economic load dispatch problem using improved harmony search algorithm. The control parameter *distance bandwidth (bw)* in classical harmony search has been tuned depending on the variance of the current population to have a better explorative power in improved harmony search algorithm. A more detailed description relating to theoretical and an implementation aspect of the proposed approach are provided in later sections. This paper considers single area six unit system and the four area system having 16 generators. The multi area economic dispatch problem is then extended to have prohibited operating zones in some of the generators. In general, whole of the unit operating range is not always available for load allocation due to physical operation limitation such as faults in the machines and associated auxiliaries. The results obtained are compared with those of other promising methods. The methodology proves to be a robust optimization technique for solving single and multi area problem.

Rest of the paper is arranged as follows. Problem description is given in Section 2 followed by a gentle introduction of Harmony Search in Section 3. Experimental results are provided in Section 4 and some conclusions are also given in Section 5.

II. PROBLEM DESCRIPTION

In a power system, the unit commitment problem has various sub-problems varying from linear programming problems to complex non-linear problems. The concerned problem is one of the different non-linear programming sub-problems of unit commitment. The problem formulation is written in general for multi area system and can be made for single area system by considering the number of areas as one. The objective of the ELD problem is about minimizing the total fuel cost of thermal generating units for a specific period of operation.

978-0-7695-3745-0/09 $25.00 © 2009 IEEE
DOI 10.1109/HIS.2009.294

The objective function corresponding to the production cost can be approximated to be a quadratic function of the active power outputs from the generating units. Symbolically, it is represented as

$$\text{Minimize} \quad F_t^{\cos t} = \sum_{j=1}^{M} \sum_{i=1}^{N_G} f_{ij}(P_{ij}) + TC \tag{1}$$

where the fuel cost function of the generating units is given by

$$f_{ij}(P_{ij}) = a_{ij}P_{ij}^2 + b_{ij}P_{ij} + c_{ij} \tag{2}$$

$$TC = \sum_{j=1}^{M-1} \sum_{k=j+1}^{M} f_{jk} PT_{jk} \tag{3}$$

where a_{ij}, b_{ij} and c_{ij} are the fuel cost coefficients of i^{th} unit, in the j^{th} area. P_{ij} is the real power output (MW) of i^{th} generator of the j^{th} area corresponding to time period t. N_G is the number of online generating units to be dispatched in area j and M is the number of areas in the considered system. The single area ELD is implemented by assuming the value of M=1. TC is the cost for tie line flow which is considered only in multi area system. NT is the number of tie lines. PT_{jk} and f_{jk} are the tie line power flow and cost coefficients from area j to area k.

This ELD problem is subjected to a variety of constraints depending upon assumptions and practical implications. These include power balance constraints to take into account the energy balance, generator constraints, tie line limit constraints and prohibited operating zones. These constraints are discussed as under.

1) Area Power Balance Constraints or Demand Constraints: This constraint is based on the principle of equilibrium between total area generation and total area load demand (P_{Dj}) along with imports and exports of power from neighboring areas. That is,

$$\sum_{i=1}^{NG} P_{ij} = PD_j + \sum_{k,k\neq j} PT_{jk} \qquad j = 1,2,..., M \tag{4}$$

The power balance constraint for the single area system can be described as,

$$\sum_{i=1}^{NG} P_{ij} = PD_j + P_{loss} \tag{5}$$

2) The Generator Constraints: The output power of each generating unit has a lower and upper bound so that it lies in between these bounds. This constraint is represented by a pair of inequality constraints as follows.

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max} \tag{6}$$

where, P_{ij}^{min} and P_{ij}^{max} are lower and upper bounds for power outputs of the i^{th} generating unit in j^{th} area.

3) Prohibited Operating Zone: The generating units may have certain ranges where operation is restricted on the grounds of physical limitations of machine components or instability e.g. due to steam valve or vibration in shaft bearings. Consequently, discontinuities are produced in cost curves corresponding to the prohibited operating zones. So, there is a quest to avoid operation in these zones in order to economize the production. Symbolically, for a generating unit i,

$$P_{ij} \le \breve{P}^{pz} \text{ and } P_{ij} \ge \hat{P}^{pz} \tag{7}$$

where $\breve{P}^{pz}$ and $\hat{P}^{pz}$ are the lower and upper are limits of a given prohibited zone for generating unit *i* in area *j*.

4) Tie Line constraints: The tie line power flow from area j to area k should not exceed the thermal limits of the line,

$$PT_{jk}^{\min} \le PT_{jk} \le PT_{jk}^{\max} \tag{8}$$

Where PT_{jk}^{max} and PT_{jk}^{min} are the maximum and minimum tie line transmission limits.

III. Overview Of Improved Harmony search

Harmony search is a new meta-heuristic optimization algorithm which imitates the music improvisation process applied by musicians. Each musician improvises the pitches of his/her instrument to obtain a better state of harmony. The goal of the process is to reach a perfect state of harmony. Here the control parameter called bandwidth is adaptively changed by variance of population. The different steps of the IHS algorithm are described below:

Step 1: The 1^{st} step is to specify the problem and initialize the parameter values. The optimization problem is defined as minimize (or maximize) $f(\mathbf{x})$ such that ${}_L x_i \le x_i \le {}_U x_i$, where $f(\mathbf{x})$ is the objective function, $\mathbf{x}$ is a solution vector consisting of *N* decision variables (x_i) and ${}_L x_i$ and ${}_U x_i$ are the lower and upper bounds of each decision variable, respectively. The parameters of the HS algorithm i.e. the harmony memory size (HMS), or the number of solution vectors in the harmony memory; harmony memory considering rate ($HMCR$); pitch adjusting rate (PAR); and the number of improvisations (NI) or stopping criterion are also specified in this step.

Step 2: The 2^{nd} step is to initialize the Harmony Memory. The initial harmony memory is generated from a uniform distribution in the ranges $[{}_L x_i, {}_U x_i]$, where $1 \le i \le N$. This is done as follows:

$x_i^j = {}_L x_i + r \times ({}_U x_i - {}_L x_i)$, where $j = 1,2,3....,HMS$ and $r \sim U(0,1)$

Step 3: The third step is known as the 'improvisation' step. Generating a new harmony is called 'improvisation'. The New Harmony vector $\mathbf{x}' = (x_1', x_2', x_3', x_4',..., x_N')$ is generated using the following rules: memory consideration, pitch adjustment, and random selection. The procedure works as follows:

Pseudo-code of improvisation in HS

bw=variance(*x*) /* Adaptive bw calculation */

for each $i \in [1, N]$ **do**

if $U(0,1) \le HMCR$ **then** /*memory consideration*/

begin

$x_i^{/} = x_i^{j}$, where $j \sim U(1,2,\ldots,HMS)$.

if $U(0,1) \le PAR$ **then** /* Pitch adjustment */

begin

$x_i^{/} = x_i^{/} + r \times bw(i)$ **,** where $r \sim U(0,1)$ and $bw(i)$ is the arbitrary distance bandwidth parameter.

else /* random selection */

$x_i^{j} = {}_L x_i + r \cdot ({}_U x_i - {}_L x_i)$

endif

done

Step 4: In this step the harmony memory is updated.

The generated harmony vector $\mathbf{x}^{/} = (x_1^{/}, x_2^{/}, x_3^{/}, x_4^{/}, \ldots, x_N^{/})$ replaces the worst harmony in the HM (harmony memory), only if its fitness (measured in terms of the objective function) is better than the worst harmony.

***Step 5**:* The stopping criterion (generally the number of iterations) is checked. If it is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated.

Table 1
Simulation results of single area six unit system

Generator Power Output (MW)	PSO [3]	GA [3]	IHS
P_{G1}	447.4970	474.8066	446.9850
P_{G2}	173.3221	178.6363	173.9859
P_{G3}	263.4745	262.2089	258.9769
P_{G4}	139.0594	134.2826	144.5362
P_{G5}	165.4761	151.9039	164.5465
P_{G6}	87.1280	74.1812	86.3574
Total Power Generation (MW)	1276.01	1276.03	1275.3879
Minimum Cost ($/hr)	**15450**	**15459**	**15444.302**
Ploss (MW)	12.9584	13.0217	12.3918
Mean Cost ($/hr)	15454	15469	15449.865
Standard Deviation of Cost ($/hr)	-	-	4.5312

Table 2
Simulation results of 4 area system with demand = 1250MW

Generator Power Output (MW)		NFP [4]	IFEP [6]	IHS
Area1	$\mathbf{P_{G1}}$	150.00	149.998	149.9997
	$\mathbf{P_{G2}}$	100.00	99.986	99.9985
	$\mathbf{P_{G3}}$	66.97	68.270	66.1206
	$\mathbf{P_{G4}}$	100.00	99.940	99.9964
Area2	$\mathbf{P_{G5}}$	56.97	56.349	56.9908
	$\mathbf{P_{G6}}$	96.25	96.753	96.2944
	$\mathbf{P_{G7}}$	41.87	41.264	41.6731
	$\mathbf{P_{G8}}$	72.52	72.586	72.459
Area3	$\mathbf{P_{G9}}$	50.00	50.003	50.0009
	$\mathbf{P_{G10}}$	36.27	35.985	36.4301
	$\mathbf{P_{G11}}$	38.49	38.012	37.647
	$\mathbf{P_{G12}}$	37.32	37.426	38.1545
Area4	$\mathbf{P_{G13}}$	150.00	149.998	149.9998
	$\mathbf{P_{G14}}$	100.00	99.964	99.9984
	$\mathbf{P_{G15}}$	57.05	57.601	57.7173
	$\mathbf{P_{G16}}$	96.27	95.874	96.5195
Tie Line Flows	$\mathbf{PT_{12}}$	0.00	0.094	0.004
	$\mathbf{PT_{13}}$	18.18	18.649	16.11
	$\mathbf{PT_{14}}$	0.00	0.00	0.00
	$\mathbf{PT_{21}}$	0.00	0.018	0.00
	$\mathbf{PT_{23}}$	69.73	69.997	71.658
	$\mathbf{PT_{24}}$	0.00	0.00	0.00
	$\mathbf{PT_{31}}$	0.00	0.00	0.00
	$\mathbf{PT_{32}}$	0.00	0.00	0.00
	$\mathbf{PT_{34}}$	0.00	0.00	0.00
	$\mathbf{PT_{41}}$	1.21	0.549	0.004
	$\mathbf{PT_{42}}$	2.11	2.951	4.236
	$\mathbf{PT_{43}}$	100.00	99.927	99.994
Total Power Generation (MW)		1249.980	1250.009	1250.000
Minimum Cost ($)		7337	7337.51	7337.275

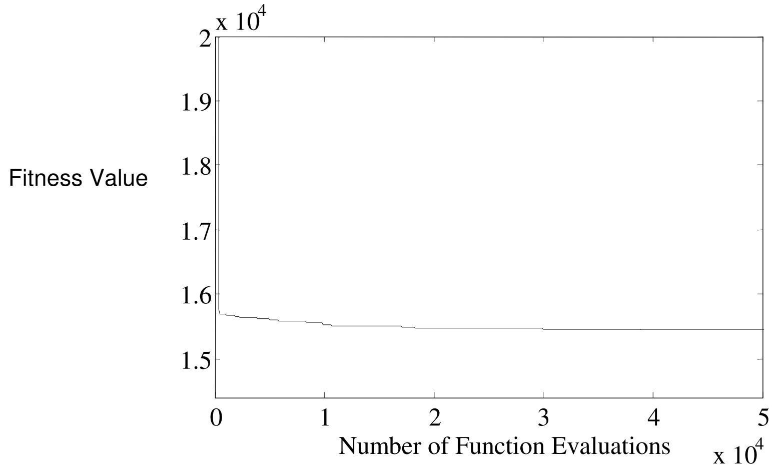

Figure 1. Convergence for six unit system

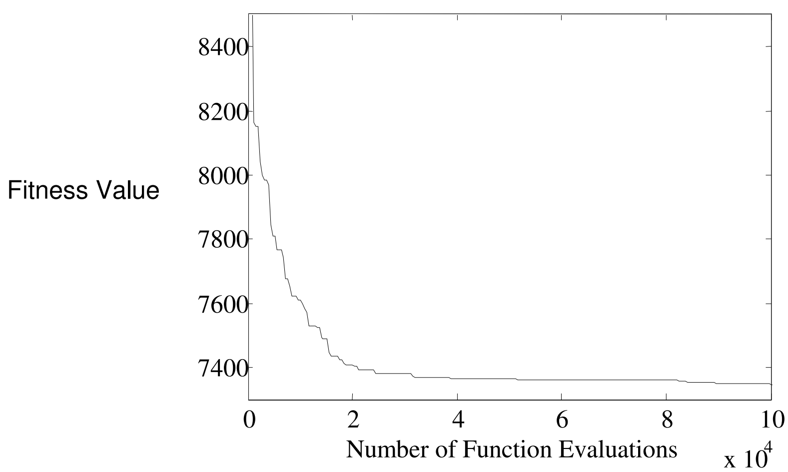

Figure 2. Convergence for four area system without POZ

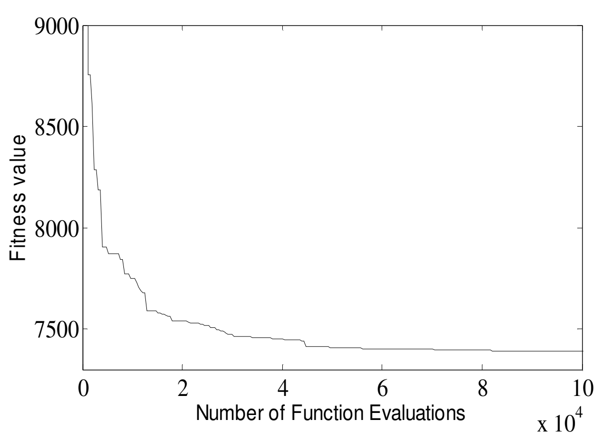

Figure 3. Convergence for four area system with POZ

IV. Experimental Results

The application of proposed method to power system has been tested for three different cases. In the first case we have considered single area six unit systems. In the second case the original system with four areas given in [4] is considered and in the third case the prohibited zones of operations is introduced in the previous data. The obtained results are compared with the Network Flow programming (NFP) [4] and improved fast evolutionary programming (IFEP) methods [6]. The parameters used for the simulation is as follows: HMCR=0.95 ;PAR= 0.9-0.4; HMS= 100; NI=1000;

Case1:

The single area six unit system is considered with the parameters of cost coefficients and loss coefficients are taken from [3]. The total load demand of the system is 1263 MW. The comparison of results for this test system is shown in table1. The convergence graph for this system is shown in figure 1.

Case2:

A multi area economic load dispatch having four areas along with tie line constraints is considered [4]. The total load demand of the system is 1250 MW. The obtained result is compared in table 2. The fitness function convergence characteristics is shown in figure 2.

Case 3:

The same data as used in case1 is considered here. But some of the generating units are also having the prohibited operating zones (POZ). The data for POZ is given in table 3. The result of MAED with prohibited operating zone is given in Table4. The convergence of algorithm is shown in figure 3.

Table 3
Data for Prohibited operating zones

Unit	No. of Zones	Zone1 (MW)	Zone2 (MW)
3	2	[30,45]	[60,78]
5	2	[55,80]	[120,140]
9	2	[55,80]	[120,140]
15	1	[45,80]	

Table 4
Simulation result of 4 area system with POZ

Power Generation							
$\mathbf{P_{G1}}$	149.9934	$\mathbf{P_{G5}}$	53.4804	$\mathbf{P_{G9}}$	50.0088	$\mathbf{P_{G13}}$	149.9875
$\mathbf{P_{G2}}$	99.8233	$\mathbf{P_{G6}}$	92.558	$\mathbf{P_{G10}}$	35.2368	$\mathbf{P_{G14}}$	99.986
$\mathbf{P_{G3}}$	57.3439	$\mathbf{P_{G7}}$	39.9196	$\mathbf{P_{G11}}$	39.0855	$\mathbf{P_{G15}}$	80.0025
$\mathbf{P_{G4}}$	98.8732	$\mathbf{P_{G8}}$	70.1969	$\mathbf{P_{G12}}$	36.082	$\mathbf{P_{G16}}$	97.4222
Tie Line Flows							
$\mathbf{PT_{12}}$	0.0308	$\mathbf{PT_{23}}$	63.012	$\mathbf{PT_{34}}$	0.000		
$\mathbf{PT_{13}}$	26.5806	$\mathbf{PT_{24}}$	0.000	$\mathbf{PT_{41}}$	20.5777		
$\mathbf{PT_{14}}$	0.000	$\mathbf{PT_{31}}$	0.000	$\mathbf{PT_{42}}$	6.8264		
$\mathbf{PT_{21}}$	0.000	$\mathbf{PT_{32}}$	0.000	$\mathbf{PT_{43}}$	99.994		
Total Power Generation (MW)							**1250.000**
Minimum Cost ($)							**7371.584**

V. Conclusions

The paper has used improved harmony search algorithm to solve multi area economic dispatch problem. The practical generator constraint like prohibited operating zones are also considered in this study. The result obtained in this method is well comparable also proves the validity of the proposed method for solving this multi area economic load dispatch problem. In future, efforts will be made to incorporate more realistic constraints to the problem structure like reserve capacity and valve point loading effect in cost functions and also the practical large sized problems would be attempted by the proposed methodology.

VI. References

[1]. A.J. Wood and B.F. Wollenberg, Power Generation, Operation and Control, Wiley, New York, 1984.

[2]. S.O. Orero and M.R. Irving, "Economic dispatch of generators with prohibited operating zones: a genetic algorithm approach," *IEE Proceeding of Generation, Transmission and Distribution,* vol. 143, No. 6,pp. 529-534, November 1996.

[3]. Zwe-Lee Gaing, "Particle swarm optimization to solving the economic dispatch considering the generator constraints," *IEEE Trans. on Power Systems*, Vol. 18, No. 3, pp., 1187-1195, August 2003.

[4]. D. Streiffert, "Multi-Area economic dispatch with Tie Line constraints," *IEEE Trans. On Power Systems,* Vol. 10, No. 4, pp.1946-1951, November 1995.

[5]. C.L. Chen, and N.Chen, "Direct search method for solving economic dispatch problem considering transmission capacity constraints," *IEEE Trans. On Power Systems*, Vol. 16, No. 4, pp.764-769, November 2001.

[6]. T. Jayabarathi, K.Jayaprakash, D.N. Jeyakumar, and T. Raghunathan, "Evoluitonary programming techniques for different kinds of economic dispatch problems," *Electric Power System Research,* Vol 73, pp. 169-176, 2005.

[7]. P.S. Manoharan, P.S. Kannan, and V. Ramanathan, "A Novel EP approach for Multi-area economic dispatch with multiple fuel options," *Turk. Journal of Elect. Engineering,* Vol. 16, No. 2, pp.1-20, 2008.

[8]. Z.W. Geem, J.H. Kim, and G.V. Loganathan, "A new heuristic optimization algorithm: harmony search," *Simulation,* Vol. 76, No. 2, pp. 60-68, 2001.

[9]. S.L. Kang, and Z.W. Geem, "A new structural optimization method based on the harmony search algorithm," *Comput. Struct.* Vol. 82, No.9–10, pp. 781–798, 2004.

[10]. K. S. Lee, Z. W. Geem, "A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice," Comput. Methods Appl. Mech. Engg., Vol. 194, pp. 3902–3933, 2005.

[11]. M. Mahdavi, M. Fesanghary, E. Damangir, "An improved harmony search algorithm for solving optimization problems," Applied Mathematics and Computation, Vol. 188, pp. 1567–1579, 2007.

[12]. M.G.H. Omran, M. Mahdavi, "Global-best harmony search," Applied Mathematics and Computation,Vol. 198, pp. 643–656, 2008.

[13]. M. Fesanghary, M. Mahdavi, M. M,Jolandan, Y. Alizadeh, "Hybridizing harmony search algorithm with sequential quadratic programming for engineering optimization problems," Comput. Methods Appl. Mech. Engrg., Vol. 197, pp. 3080–3091, 2008.