Comparison between Harmony Search algorithm, Genetic Algorithm and Particle Swarm Optimization in economic power dispatch

การเปรียบเทียบระหว่างอัลกอริธึมการค้นหาแบบฮาร์โมนี อัลกอริธึมแบบพันธุกรรม และอัลกอริธึมการค้นหาค่าเหมาะสมที่สุดแบบฝูงอนุภาค สำหรับการจัดการกำลังไฟฟ้าในเชิงเศรษฐศาสตร์

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ABSTRACT

This paper presents a solution to economic power dispatch problem using Harmony Search (HS) algorithm. The method is applied to IEEE 118-bus power system having 54 generating units. The problem is also solved by Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques. Results have shown that Harmony Search algorithm gives minimum cost of production of real power and minimum power loss in the system. Moreover, cost of real power generation in dollar per hour per megawatt output of each generator is calculated to identify the least to most expensive generator in the system.

บทคัดย่อ

ในบทความนี้ได้นำเสนอ วิธีการแก้ปัญหาการจัดการกำลังไฟฟ้าในเชิงเศรษฐศาสตร์ โดยใช้อัลกอริธึมการค้นหาแบบฮาร์โมนี (harmony search, HS) ประยุกต์กับระบบกำลังไฟฟ้า IEEE 118-bus ที่มีหน่วยกำลังผลิต 54 หน่วย นอกจากนี้ยังใช้เทคนิควิธีอัลกอริธึมแบบพันธุกรรม (genetic algorithm, GA) และอัลกอริธึมการค้นหาค่าเหมาะสมที่สุดแบบฝูงอนุภาค (particle swarm optimization, PSO) สำหรับการแก้ปัญหานี้อีกด้วย จากผลการทดสอบพบว่า อัลกอริธึมการค้นหาแบบฮาร์โมนีให้ผลเฉลยของค่าใช้จ่ายในการผลิตกำลังไฟฟ้าจริงต่ำที่สุด และยังให้ผลเฉลยของกำลังไฟฟ้าสูญเสียในระบบต่ำที่สุดอีกด้วย เมื่อเทียบกับเทคนิควิธีการค้นหาแบบอื่นๆ นอกจากนี้ ในบทความยังได้แสดงการคำนวณค่าใช้จ่ายการผลิตกำลังไฟฟ้าจริงในหน่วยดอลลาร์/เมกกะวัตต์ ในหนึ่งชั่วโมงของแต่ละเครื่องกำเนิดกำลังไฟฟ้า เพื่อระบุค่าใช้จ่ายของเครื่องกำเนิดกำลังไฟฟ้าจากน้อยที่สุดไปมากที่สุด

Key Words: Economic power dispatch, Harmony search algorithm, Optimization.

คำสำคัญ: การจัดการกำลังไฟฟ้าในเชิงเศรษฐศาสตร์ อัลกอริธึมการค้นหาแบบฮาร์โมนี หาค่าเหมาะสมที่สุด

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Introduction

The factors influencing power generation at minimum cost are operating efficiencies of generators, fuel cost, and transmission losses. The most efficient generator in the system does not guarantee minimum cost as may be located in an area where fuel cost is high. Also, if the plant is located far from the load center, transmission losses may be considerably higher and hence the plant may be overly uneconomical. Hence the problem is to determine the generation of different plants such that the total operating cost is minimum (Sayah et al, 2010). The operating cost plays an important role in the economic scheduling. This problem becomes more complicated when there is imbalance in the system in such a way that there is a need to bring in some generators in case of overload or shut down some generators due to a trip of a major load so as restore balance in the system. In this situation a system engineer has the task to decide which generator to bring in or shut down while satisfying system and generators' constraints.

The unit commitment problem is defined mathematically as a nonlinear, non-convex, large scaled, mixed integer combinatorial optimization problem, often involving a wide spectrum of equality and inequality constraints. The optimal solution to such a complex combinatorial optimization problem can be obtained only by global search technique (Garg et al, 2008).

Problem formulation

The economic dispatch problem can be defined as finding the optimal combination of power outputs that minimizes the total operating cost while satisfying the given constraints (Garg et al, 2008). The sum of the power outputs must equal the total load demand and the power output of an individual unit must be within its respective operating limits. Additionally, primary constraint groups, i.e. fuel consumption constraints, and secondary constraint group, i.e. energy constraints, must be met. Cost of production of the real power can generally be stated as [3],

$$C_i = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \tag{1}$$

The economic dispatching problem is:

$$\text{Min } C_t = \sum_{i=1}^{n} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \tag{2}$$

Subject to:

$$\sum_{i=1}^{n} P_{Gi} = P_D + P_L \tag{3}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \qquad i = 1, \ldots, Ng$$

Harmony Search Algorithm

Harmony search method mimics a jazz improvisation process by musicians in order to seek a fantastic state of harmony (Ratniyomchai et al, 2010).

Harmony Search Steps (Mahdavi et al, 2007)

i. Initialize the problem and algorithm parameters.
ii. Initialize the harmony memory.
iii. Improvise a new harmony memory.
iv. Update the harmony memory.
v. Check the stopping criterion.

Optimization procedure of Harmony Search (Belmadani et al, 2011)

i. Initialize the problem and algorithm parameters.

The optimization problem is specified as follows:

$$\min\{f(x)|x \in X\} \tag{4}$$

Subject to $g(x) \geq 0$

$h(x) = 0$

Where:

f(*x*) is the objective function

g(*x*) is the inequality constraint function

h(*x*) is the equality constraint function

x is the set of each decision variable

x_i and **X** is the set of the possible range of values for each decision variable

i.e. $x_{\min} \leq X \leq x_{\max}$

The HS algorithm parameters are also specified in these steps:

Step 1: The Harmony Memory Size (HMS), or the number of solution vectors in the harmony memory.

Step 2: Harmony Memory Considering Rate (HMCR).

Step 3: Pitch Adjusting Rate (PAR).

Step 4: Number of decision variables (*N*)

Step 5: The Number of Improvisations (NI), or stopping criterion.

Harmony memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. This HM is similar to the genetic pool in the GA. Here, HMCR and PAR are parameters that are used to improve the solution vector. Both are defined in Step 3.

ii. Initialize the harmony memory

In Step 2, the HM matrix is filled with as many randomly generated solution vectors as the HMS

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{5}$$

iii. Improvise a new harmony

A new harmony vector, $x^j = (x_1^j, x_2^j, \ldots, x_N^j)$, is generated based on three rules:

1. Memory consideration
2. Pitch adjustment
3. Random selection.

Thereby generating a new harmony called 'improvisation'. In the memory consideration, the value of the first decision variable x_1^i for the new vector is chosen from any value in the specified HM range $(x_1^1 - x_1^{HMS})$. Values of the other decision variables $(x_2^j, x_3^j, \ldots, x_N^j)$ are chosen in the same manner. The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while (1 — HMCR) is the rate of randomly selecting one value from the possible range of values.

$$x_i^j \leftarrow \begin{cases} x_i^1 \in \{x_i^1, x_i^2, \cdots, x_i^{HMS}\}, probability = HMCR \\ x_i^j \in X_i, probability = (1 - HMCR) \end{cases} \tag{6}$$

For example, a HMCR of 0.85 indicates that the HS algorithm will choose the decision variable value from historically stored values in the HM with the 85% probability or from the entire possible range with the 100–

85% probability. Every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusted. This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

$$x_i^j \leftarrow \begin{cases} \text{yes with probabilit y PAR} \\ \text{No with probablity } (1 - PAR) \end{cases} \quad (7)$$

The value of (1 — PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i^j is Yes, x_i^j is replaced as follows:

$$x_i^j \leftarrow x_i^j \pm rand\ (\ )*bw \quad (8)$$

Where bw is an arbitrary distance bandwidth, *r* and ( ) is a random number between 0 and 1. In Step 3, HM consideration, pitch adjustment or random selection is applied to each variable of the new harmony vector in turn.

iv. Update harmony memory

If the new harmony vector, $x^j = \left(x_1^j, x_2^j, \ldots, x_N^j\right)$ is better than the worst harmony in the HM', judged in terms of the objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

v. Check stopping criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated.

Pseudo Code of the Harmony Search (Garg et al, 2008).

```
Begin
    Objective $f(x), x = (x_1, x_2, \ldots, x_d)^T$
    Generate initial harmonics (real number arrays)
    Define pitch adjusting rate $(r_{pa})$
    Define harmony memory accepting rate $(r_{accept})$
    while ( $t$ < Maximum number of iterations)
        Generate new harmonics by accepting best harmonics
        Adjust pitch to get new harmonics (solutions)
        if $(rand > r_{accept})$, choose an existing harmonic randomly
        elseif $(rand > r_{pa})$, adjust the pitch randomly within limits
        else generate new harmonics via randomization
        endif
        Accept the new harmonics (solutions) if bette
    endwhile
    Find the current best solutions
end
```

Optimal dispatch for IEEE 118-bus power system

Harmony search algorithm was used to solve the cost minimization problem for IEEE-118 bus power system (Motor.ece.iit.edu/data/JEAS_IEEE118) to show the validity and effectiveness of the proposed algorithm. The system consists of 54 generating units. The objective was to find total minimum cost of real power generation, total power loss in the system, optimal power generation of each generator, minimum generation cost of each generator in \$/h and minimum generation cost of each generator in \$/h/MW while satisfying system constraints and generator limits. The cost functions of the units were given as follows:

$$
\begin{aligned}
c_1 &= 31.67 + 26.2438P_{G1} + 0.069663P_{G1}^2 \\
&\vdots \\
c_{54} &= 58.81 + 22.9423P_{G54} + 0.00977P_{G54}^2
\end{aligned} \tag{9}
$$

$$
\text{Min}\, C = \sum_{i=1}^{54} c_i \qquad i = 1,\ldots,54 \tag{10}
$$

Subject to:

$$
\begin{gathered}
05 \le 30 \\
\vdots \\
25 \le 50
\end{gathered} \tag{11}
$$

$$
\sum_{i=1}^{54} P_{Gi} = 3773.1 + P_L \tag{12}
$$

Where transmission line losses P_L were computed using an approximate loss formula [9] as,

$$
P_L = \sum_{i=1}^{Ng} B_{ii} P_i^2 \tag{13}
$$

Loss coefficients B_{ii} were assumed. From (13) we have total power loss as:

$$
\begin{aligned}
P_L &= 0.000183P_{G1}^2 + 0.000284P_{G2}^2 + \ldots \\
&\quad + 0.000139P_{G54}^2
\end{aligned} \tag{14}
$$

The problem was also solved by Genetic Algorithm and Particles Optimization techniques. Power generation costs for all generators were also calculated. Results are shown on Table 1 below.

Table 1 Generators' numbers (G. No.), Bus numbers (B. No.), output power of each generator in MW, cost of power generation in \$/h and cost per megawatt output in one hour for each generator in \$/h/MW.

		Power Output (MW)			Cost of Power Generation (\$/h)			Cost of Power Generation (\$/h/MW)		
G. No.	B. No.	HS	GA	PSO	HS	GA	PSO	HS	GA	PSO
1	4	6.14	6.71	27.57	195.3844	210.81	808.09	31.83	31.43	29.31
2	6	8.78	14.79	9.05	267.4113	435.19	274.86	30.46	29.42	30.37
3	8	5.28	7.98	28.29	172.2657	245.48	829.71	32.61	30.77	29.33
4	10	152.34	215.49	197.23	2222.5	3288.84	2971.62	14.59	15.26	15.07
5	12	102.77	113.28	104.08	1529.3	1707.25	1551.18	14.88	15.07	14.90
6	15	10.99	25.35	18.65	328.5699	741.67	545.46	29.89	29.26	29.24
7	18	25.44	29.71	88.50	471.7786	550.87	1687.55	18.54	18.54	19.07
8	19	7.25	28.89	5.06	225.5502	848.14	166.21	31.12	29.35	32.86
9	24	11.83	22.86	23.94	351.8583	667.99	699.79	29.75	29.22	29.23
10	25	103.80	233.93	157.87	1461.7	3616.68	2312.39	14.08	15.46	14.65
11	26	113.79	120.27	131.88	1296.1	1370.46	1504.12	11.39	11.39	11.41

Table 1 Generators' numbers (G. No.), Bus numbers (B. No.), output power of each generator in MW, cost of power generation in $/h and cost per megawatt output in one hour for each generator in $/h/MW. (Cont.)

		Power Output (MW)			Cost of Power Generation ($/h)			Cost of Power Generation ($/h/MW)		
G. No.	B. No.	HS	GA	PSO	HS	GA	PSO	HS	GA	PSO
12	27	9.87	29.85	19.38	297.4219	877.25	566.56	30.14	29.38	29.23
13	31	8.56	8.87	8.46	261.4378	270.01	258.77	30.54	30.43	30.58
14	32	33.60	67.32	61.39	623.4237	1267.71	1152.30	18.55	18.83	18.77
15	34	9.19	16.12	9.07	278.6899	472.96	275.54	30.33	29.33	30.37
16	36	26.77	64.65	78.86	496.3291	1215.67	1495.09	18.54	18.80	18.96
17	40	8.63	27.12	8.95	263.3972	794.59	272.00	30.51	29.30	30.41
18	42	11.27	16.64	20.70	336.4025	487.62	604.65	29.84	29.31	29.22
19	46	25.34	31.21	59.66	469.9630	578.85	1118.85	18.54	18.54	18.75
20	49	51.07	91.27	106.42	663.9263	1173.35	1367.38	13.00	12.86	12.85
21	54	71.81	65.49	101.10	924.9383	845.11	1297.39	12.88	12.90	12.83
22	55	25.12	34.34	44.00	465.8802	637.16	818.97	18.55	18.56	18.61
23	56	30.37	71.35	59.38	563.1865	1346.70	1113.45	18.54	18.88	18.75
24	59	56.83	134.63	100.88	808.4191	1907.99	1424.51	14.23	14.17	14.12
25	61	57.43	88.31	75.91	816.7058	1246.97	1073.16	14.22	14.12	14.14
26	62	34.12	52.30	44.84	633.1540	977.16	834.95	18.55	18.68	18.62
27	65	108.24	167.79	225.45	1090.9	1761.47	2482.53	10.08	10.50	11.01
28	66	117.13	161.58	223.26	1186.2	1688.06	2453.83	10.13	10.45	10.99
29	69	94.52	148.38	96.91	1322.1	2158.42	1357.90	13.99	14.55	14.01
30	70	32.48	42.91	79.36	625.1924	822.68	1591.39	19.25	19.17	20.05
31	72	16.62	29.71	12.90	486.9903	872.90	381.78	29.31	29.38	29.60
32	73	11.24	5.23	6.97	335.3457	170.95	218.05	29.85	32.66	31.27
33	74	7.82	16.76	6.21	314.3515	657.69	253.19	40.21	39.24	40.76
34	76	28.68	76.00	41.12	531.8396	1438.31	764.55	18.54	18.93	18.59
35	77	29.20	25.88	35.47	541.3874	479.83	658.39	18.54	18.54	18.56
36	80	155.30	169.98	233.70	2270.5	2511.61	3612.54	14.62	14.78	15.46
37	82	29.99	52.09	76.98	555.9949	973.19	1457.74	18.54	18.68	18.94
38	85	13.85	12.27	22.27	408.6082	364.23	650.54	29.49	29.68	29.22
39	87	119.34	141.11	164.45	1359.8	1610.99	1883.54	11.39	11.42	11.45
40	89	57.55	125.32	92.96	784.4369	1792.71	1298.75	13.63	14.30	13.97
41	90	8.29	10.39	12.09	332.5923	412.55	477.74	40.10	39.72	39.52
42	91	20.61	43.48	26.05	535.7232	1074.73	663.08	26.00	24.72	25.45
43	92	105.23	189.24	148.35	1483.3	2835.08	2157.98	14.10	14.98	14.55
44	99	100.38	239.90	130.72	1410.0	3724.40	1877.29	14.05	15.52	14.36
45	100	100.51	174.52	217.20	1411.90	2587.12	3319.03	14.05	14.82	15.28
46	103	9.67	11.25	15.14	384.9524	445.70	595.24	39.83	39.61	39.31
47	104	26.63	40.87	42.10	493.7461	759.92	783.12	18.54	18.59	18.60
48	105	25.10	50.28	73.58	465.5847	938.48	1390.65	18.55	18.67	18.90
49	107	8.01	14.91	14.80	321.6371	586.26	582.20	40.16	39.32	39.33
50	110	32.34	34.58	39.47	811.0194	863.85	979.62	25.08	24.98	24.82

Table 1 Generators' numbers (G. No.), Bus numbers (B. No.), output power of each generator in MW, cost of power generation in $/h and cost per megawatt output in one hour for each generator in $/h/MW. (Cont.)

		Power Output (MW)			Cost of Power Generation ($/h)			Cost of Power Generation ($/h/MW)		
G. No.	B. No.	HS	GA	PSO	HS	GA	PSO	HS	GA	PSO
51	111	25.44	71.90	78.82	471.7158	1357.53	1494.34	18.54	18.88	18.96
52	112	26.87	66.80	40.31	498.2057	1257.58	749.29	18.54	18.83	18.59
53	113	33.00	35.57	44.22	612.2239	660.22	823.24	18.55	18.56	18.62
54	116	25.03	42.16	26.33	639.1768	1043.48	669.55	25.54	24.75	25.43

Harmony Search algorithm gave total generation cost in the system as 38111.14 $/h and total power loss of 34.48 MW while Genetic Algorithm had total cost of production of 63632 $/h and total power loss of 83.84MW and finally Particle Swarm Optimization technique gave these results; total generation cost in the system equal to 62670.72 $/h, total power loss in the system as 85.23 MW. Then, data in table 1 were rearranged based on the cost of generation in dollars per hour per megawatt output so as to make it easy to identify the most to least expensive generator in the system for the three methods as shown below:

Table 2 Generators' numbers (G. No.), Bus Numbers (B. No.), Power Output (P. Out.), Generation Cost (G. C.) of total power output for one hour in $/h and Generation Cost (G. C.) of one megawatt output in one hour in $/h/MW.

Harmony Search Algorithm					Genetic Algorithm					Particle Swarm Optimization				
G. No.	B. No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)	G. No.	Bus No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)	G. No.	Bus No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)
33	74	40.2	314.4	7.8	41	90	39.7	412.6	10.4	33	74	40.8	253.2	6.2
49	107	40.2	321.6	8.0	46	103	39.6	445.7	11.3	41	90	39.5	477.7	12.1
41	90	40.1	332.6	8.3	49	107	39.3	586.3	14.9	49	107	39.3	582.2	14.8
46	103	39.8	385.0	9.7	33	74	39.2	657.7	16.8	46	103	39.3	595.2	15.1
03	08	32.6	172.3	5.3	32	73	32.7	170.9	5.2	08	19	32.9	166.2	5.1
01	04	31.8	195.4	6.1	01	04	31.4	210.8	6.7	32	73	31.3	218.1	7.0
08	19	31.1	225.6	7.3	03	08	30.8	245.5	8.0	13	31	30.6	258.8	8.5
13	31	30.5	261.4	8.6	13	31	30.4	270.0	8.9	17	40	30.4	272.0	8.9
17	40	30.5	263.4	8.6	38	85	29.7	364.2	12.3	02	06	30.4	274.9	9.1
02	06	30.5	267.4	8.8	02	06	29.4	435.2	14.8	15	34	30.4	275.5	9.1
15	34	30.3	278.7	9.2	12	27	29.4	877.2	29.9	31	72	29.6	381.8	12.9
12	27	30.1	297.4	9.9	31	72	29.4	872.9	29.7	03	08	29.3	829.7	28.3
06	15	29.9	328.6	11.0	08	19	29.4	848.1	28.9	1	4	29.3	808.1	27.6
32	73	29.9	335.3	11.2	15	34	29.3	473.0	16.1	6	15	29.2	545.5	18.7

Table 2 Generators' numbers (G. No.), Bus Numbers (B. No.), Power Output (P. Out.), Generation Cost (G. C.) of total power output for one hour in $/h and Generation Cost (G. C.) of one megawatt output in one hour in $/h/MW. (Cont.)

Harmony Search Algorithm					Genetic Algorithm					Particle Swarm Optimization				
G. No.	B. No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)	G. No.	Bus No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)	G. No.	Bus No.	G. C. ($/h/MW)	G. C. ($/h)	P. Out. (MW)
18	42	29.8	336.4	11.3	18	42	29.3	487.6	16.6	9	24	29.2	699.8	23.9
09	24	29.7	351.9	11.8	17	40	29.3	794.6	27.1	12	27	29.2	566.6	19.4
38	85	29.5	408.6	13.8	06	15	29.3	741.7	25.4	18	42	29.2	604.7	20.7
31	72	29.3	487.0	16.6	09	24	29.2	668.0	22.9	38	85	29.2	650.5	22.3
42	91	26.0	535.7	20.6	50	110	25.0	863.9	34.6	42	91	25.5	663.1	26.1
54	116	25.5	639.2	25.0	54	116	24.8	1043.5	42.2	54	116	254	669.5	26.3
50	110	25.1	811.0	32.3	42	91	24.7	1074.7	43.5	50	110	24.8	979.6	39.5
30	70	19.3	625.2	32.5	30	70	19.2	822.7	42.9	30	70	20.1	1591.4	79.4
14	32	18.6	623.4	33.6	34	76	18.9	1438.3	76.0	7	18	19.1	1687.5	88.5
22	55	18.6	465.9	25.1	23	56	18.9	1346.7	71.3	16	36	19.0	1495.1	78.9
26	62	18.6	633.2	34.1	51	111	18.9	1357.5	71.9	51	111	19.0	1494.3	78.8
48	105	18.6	465.6	25.1	14	32	18.8	1267.7	67.3	37	82	18.9	1457.7	77.0
53	113	18.6	612.2	33.0	52	112	18.8	1257.6	66.8	48	105	18.9	1390.7	73.6
07	18	18.5	471.8	25.4	16	36	18.8	1215.7	64.6	14	32	18.8	1152.3	61.4
16	36	18.5	496.3	26.8	26	62	18.7	977.2	52.3	19	46	18.7	1118.8	59.7
19	46	18.5	470.0	25.3	37	82	18.7	973.2	52.1	23	56	18.7	1113.5	59.4
23	56	18.5	563.2	30.4	48	105	18.7	938.5	50.3	26	62	18.6	835.0	44.8
34	76	18.5	531.8	28.7	47	104	18.6	759.9	40.9	53	113	18.6	823.2	44.2
35	77	18.5	541.4	29.2	22	55	18.6	637.2	34.3	22	55	18.6	819.0	44.0
37	82	18.5	556.0	30.0	53	113	18.6	660.2	35.6	47	104	18.6	783.1	42.1
47	104	18.5	493.7	26.6	07	18	18.5	550.9	29.7	34	76	18.6	764.5	41.1
51	111	18.5	471.7	25.4	19	46	18.5	578.8	31.2	52	112	18.6	749.3	40.3
52	112	18.5	498.2	26.9	35	77	18.5	479.8	25.9	35	77	18.6	658.4	35.5
05	12	14.9	1529.3	102.8	44	99	15.5	3724.4	239.9	36	80	15.5	3612.5	233.7
36	80	14.6	2270.5	155.3	10	25	15.5	3616.7	233.9	45	10	15.3	3319.0	217.2
04	10	14.6	2222.5	152.3	04	10	15.3	3288.8	215.5	04	10	15.1	2971.6	197.2
24	59	14.2	808.4	56.8	05	12	15.1	1707.2	113.3	05	12	14.9	1551.2	104.1
25	61	14.2	816.7	57.4	43	92	15.0	2835.1	189.2	10	25	14.7	2312.4	157.9
43	92	14.1	1483.3	105.2	45	100	14.8	2587.1	174.5	43	92	14.6	2158.0	148.3
10	25	14.1	1461.7	103.8	36	80	14.8	2511.6	170.0	44	99	14.4	1877.3	130.7
44	99	14.1	1410.0	100.4	29	69	14.6	2158.4	148.4	25	61	14.1	1073.2	75.9
45	100	14.1	1411.9	100.5	40	89	14.3	1792.7	125.3	24	59	14.1	1424.5	100.9
29	69	14.0	1322.1	94.5	24	59	14.2	1908.0	134.6	29	69	14.0	1357.9	96.9
40	89	13.6	784.4	57.5	25	61	14.1	1247.0	88.3	40	89	14.0	1298.8	93.0
20	49	13.0	663.9	51.1	21	54	12.9	845.1	65.5	20	49	12.9	1367.4	106.4
21	54	12.9	924.9	71.8	20	49	12.9	1173.3	91.3	21	54	12.8	1297.4	101.1
11	26	11.4	1296.1	113.8	39	87	11.4	1611.0	141.1	39	87	11.5	1883.5	164.4
39	87	11.4	1359.8	119.3	11	26	11.4	1370.5	120.3	11	26	11.4	1504.1	131.9
28	66	10.1	1186.2	117.1	27	65	10.5	1761.5	167.8	27	65	11.0	2482.5	225.4
27	65	10.1	1090.9	108.2	28	66	10.4	1688.1	161.6	28	66	11.0	2453.8	223.3

Conclusion

This paper has shown that Harmony Search algorithm is the most efficient compared to Genetic Algorithm and Particle Swarm Optimization in economic power dispatch. Harmony Search has given minimum cost of production of real power and minimum power loss in the system. With it the total cost of production is 38111.14 $/h, GA (63632 $/h) and PSO (62670.72 $/h) and total power loss is 34.48 MW, which is less than half of that given by GA (83.84MW) and PSO (85.23 MW). In addition, this paper has calculated cost of generating one megawatt in one hour for each generator. This value can be used by power system engineers to compute for total generation cost of a generator for a number of hours it would run. In case of a contingency causing imbalance in the system between load and generation in such a way that there is a need to bring in or shut down some generators, it is easy to make a decision on the selection of generator(s) to switch on or off while taking care of system constraints. Table 2 result show that generator number 34 at bus number 74 and generator number 27 at bus number 65 are the most and least expensive to run respectively using Harmony Search, generator number 41 at bus number 90 and generator number 28 at bus number 66 are the most and least expensive to run respectively using Genetic Algorithm and generator number 33 at bus number 74 and generator number 28 at bus number 66 are the most and least expensive to run respectively using Particle Swarm Optimization.

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