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Fixed Head Short Term Hydro Thermal Scheduling using Improved Particle Swarm Optimization

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ABSTRACT

Complications of optimization problem associated with Fixed Head Short Term Hydrothermal Scheduling (STHTS) are not only greatly obscure but also enclose numerous constraints. Generally non-linear, non-convex and clustered search space is connected with STHTS problem. Number of techniques, from simplex to complex, have already been used and implemented by research scholars in order to solve STHTS and management related problems. A very powerful and robust technique is necessary to efficiently optimize STHTS problem. With this objective, Improved Particle Swarm Optimization technique implemented here to comparatively better optimize STHTS problem.

1. Introduction

Major chunk of electrical power generated worldwide is due to hydro and thermal resources. Since hydro and thermal power plants have their own merits/demerits, their combination may be used to achieve the objective of reducing power generation cost. Use of effective scheduling techniques for this purpose is an area of active research.

Short Term Hydrothermal coordination is a complex problem where the main objective is the minimization of the net cost of electricity with the coordinated operation of both hydro and thermal power plants.

Hydrothermal Scheduling has become one of the main concerns in power generation systems that determine the optimal usage of hydro and thermal resources while scheduling under a specific set of constraints. Efficient scheduling of existing resources plays a crucial role in bringing down the cost of power generation. STHTS is of paramount importance, particularly where the hydro sources are scarce and high cost of thermal generation has to be relied on to meet the power demands. Hydro system is more complex to tackle due to stochastic nature of availability and limited energy storage capability of reservoirs. Effective hydro-resource allocation, in conjunction with thermal resources, is necessary as it can lead to significant savings in fuel and associated costs. [1]. Hence the optimum scheduling of hydrothermal power plant has a key role to play in modern power systems.

As the scheduling of hydrothermal power plant is a highly complex problem, a robust as well as flexible algorithm is required to solve this problem efficiently.

Many researchers have worked on the optimal scheduling of STHTS problem to minimize the operation cost while satisfying the consumer demand as well as other constraints of hydrothermal power plants [2]. Previously, the researchers used base load procedure, best point loading and incremental cost criterion to arrive at a near-optimal solution to this problem. However, these techniques require more time to arrive at the solution, more memory size to store the values and have an additional drawback of dimensionality complications. The issues mentioned were later resolved by using Deterministic, Classical Deterministic and Heuristic methods [3-20].

The other most famous example of dimensionality reduction is “Principal Components Analysis” (CPA) [21] and Fisher's discriminant analysis (FDA) [22]. In these technique searches for directions in the data that have largest variance and subsequently project the data onto it. In this way, we obtain a lower dimensional representation of the data that removes some of the “noisy” directions. There are many difficult issues with how many directions one needs to choose. PCA perform dimensionality reduction while preserving as much of the variance in the high dimensional space as possible [21]. FDA perform dimensionality reduction while preserving as much of the class discriminatory information as possible [22].

Presently, heuristic methods have gained popularity due to their versatility, flexibility and robustness. In Bacterial foraging algorithm (BFA), a new technique, a unit step length constant parameter is used which may shows good result for small optimization problem but shows poor performance in complex large scale problems [23, 24]. So to overcome these issues a run-length parameter introduced in Modified Bacterial Foraging Algorithm (MBFA) which is key factor to controlling the local and global minima. In MBFA a decreasing dynamic function is utilized to perform swim walk instead of constant step [28, 29]. Particle Swarm optimization (PSO) is becoming increasingly popular due to its versatility and robustness to find the global minimum optimal value [25, 26]. In this manuscript, IPSO is implemented on three STHTS problems picked from [27, 28, and 29] and the comparison of IPSO, PSO and MBFA is given.

The paper is organized such that Section 2 presents the mathematical modelling of the STHTS problem, Section 3 presents the algorithm used along with its details. Section 4 gives a comparison of IPSO, PSO and MBFA techniques and the conclusions are presented in Section 5.

2. Mathematical Modeling

In mathematical modeling the objective function of thermal power plant is defined in 2.1. Then hydraulic model of hydro plant is defined in 2.2. At the end constraints of both and hydro thermal power plant are defined in 2.3.

2.1 Objective Function

The objective function of the problem is minimizing the fuel cost of the thermal power plant as given below [30].

$$Minimize\, F = \sum_{t=1}^{T}\sum_{i=1}^{No}\left[x_{oi}P_{oit}^{2} + y_{oi}P_{oit} + z_{oi} \right] \tag{1}$$

x_{oi}, y_{oi} and z_{oi} are cost coefficients of thermal power plant, P_{oit} is the output power of thermal unit during t, T is the index of the time interval and N_o is the index of thermal plants.

2.2 Hydraulic Model

Glimn-Kirchmayer describes water discharge model for fixed head as following [27, 28]:

$$q_{jt} = K\phi\left(P_{hjt}\right) \tag{2}$$

where q_j is water discharge, t is time index, K is constant of proportionality and φ can be defined as:

$$\phi\left(P_{hjt}\right) = m_0 + m_1 P_{hjt} + m_2 P_{hjt}^{2} \tag{3}$$

where m_0, m_1 and m_2 are hydraulic model coefficients. The discharge rate q_{jk} model is following [27, 28] :

$$q_{jt} = a_j P_{hjt}^{2} + b_j P_{hjt} + c_j \tag{4}$$

a, b, c are discharge rate coefficients and P_{hjt} is the output of hydro unit during t.

2.3 Constraints

The objective of optimal scheduling is to minimize the operational costs while satisfying all hydrothermal constraints [31, 32].

The main purpose of a reliable power system is fulfilling the consumers demand while taking into consideration the transmission and other losses of the system.

$$\sum_{i=1}^{No} P_{oit} + \sum_{j=1}^{Nh} P_{hjt} = P_{Dt} + P_{Lt} \qquad t \in T \tag{5}$$

P_{DT} and P_{LT} are consumer demand and Transmission losses respectively.

Both hydro and thermal power plants have specific power generation capabilities. They should be operated within their lower and upper bounds.

In case of hydro power plant the discharge rate q_{jk} of whole interval should be equal to Volume of available water V_j.

$$\int_{0}^{T} q_{jt}\, dt = V_j \tag{6}$$

3. Particle Swarm Optimization (PSO)

R. Eberhart and J. Kennedy [25] introduced Particle Swarm Optimization, a non-derivative, technique that later became a part of artificial intelligence. The technique produced estimated solutions to impossible and unusual numeric minimization and maximization problems. The idea of the technique is based on social behavior of individuals interacting with each other as well as with their surroundings i.e. bird flocking and/or fish schooling. The process of this technique follows natural scenario of group communication to share their knowledge while searching a common piece of food placed in an area. Although every individual does not know food site but on the basis of social behavior they all can easily pinpoint how far-away their food is. To track down the food site each bird adopts effective and best strategy by following the bird nearest to food.

PSO is a multiple interacting intelligent parallel search technique in which individual member of inhabitants is recognized as a particle and the whole population is known as a swarm due to jagged movement of individuals in search space.

The PSO has been already implemented on STHTS problem with different improvements. Wang and

Zhang [33] introduced the refined form of PSO in which he divided the particles into many cluster. It shows good results but in this method required greater memory size.

Umayal and Kamaraj [34] proposed an application to sort out the multi-objective optimization problem of short-term optimal generation schedule. Using this method net cost was minimized but some of the constraints violate in it and this algorithm was just implemented on simple HTS systems. The size of the system was not large.

C. Samudi et al. [35] presented an improved form of PSO. In this method he took reservoir volume as a particle. It shows good results.

S. Liu and J. Wang [36] presented a modified form of PSO. An inertia weight technique was used. But the issue of this technique was that it could not handle the constraints so penalty coefficient multiplied with net cost.

G. Sreenivasn et al. [37] proposed an approach of particle swarm optimization. The thermal units were mathematically replaced by an equivalent unit. The system model incorporated the generated load power balance equations and net water discharge equation. In the algorithm constraints on the operational limits and on the reservoir volume were considered. The numerical findings showed that the algorithm was better than generic algorithm. It produced better solution quality and good convergence characteristics.

W. Ying et al. [38] proposed a new form of PSO. In this algorithm values of two PSO parameters was changed. A new scheme was presented to tackle the different constraints. The algorithm was tested on four hydro units and an equal thermal unit. The results showed that the new scheme produced better results. It was robust and accurate in comparison with the other methods.

Process of Particle Swarm Optimization (PSO) technique involves following steps:

Step I: Input parameters of the system then randomly initialize the population within the limits of hydro and thermal power units. Particles are hydro and thermal generation power. Select 10 particles for each interval for each machine and also initialize the velocities in the limit of v_{max} and v_{min}. Velocity is the movement of particles towards optimum cost.

Step II: Calculate the fitness value of each particle through objective function defined in equation (1) and (2). The obtained fitness value of a particle depicts the proximity among current position of that particle and its solution. The fitness value is the cost of the system.

Step III: Using the fitness values obtained, find out the P_{best} of each particle which is the position of each particle giving best fitness value. P_{best} of each particle is updated iteratively.

Step IV: The best position encountered by entire swarm G_{best} is found in each interval. G_{best} of each interval is also updated iteratively.

Then calculate the velocity of each particle with the help of following formula:

$$v_{ij}^{t+1} = \omega v_{ij}^{t} + c_1 r_{1j}^{t}\left[P_{best,i}^{t} - x_{ij}^{t}\right] + c_2 r_{2j}^{t}\left[G_{best} - x_{ij}^{t}\right] \quad (7)$$

where v_{ij} is velocity vector, P_{best} is personal best of each particle and G_{best} is global best of entire swarm, c_1 and c_2 are cognitive and social parameters respectively, ω the inertial weight and r_1 & r_2 are random numbers.

Step V: After calculating velocity component of each particle, update the position of particle by following eq.

$$x_{ij}^{t+1} = x_{ij}^{t} + v_{ij}^{t+1} \quad (8)$$

where x_{ij} is the position of each particle (power of machine). x_{ij}^{t+1} show the updated values of power generation by each machine. On the basis of these updated velocities and position values, calculate the fitness value again and again.

Step VI: The entire process continues until or unless all particle's P_{best} equal to G_{best} and/or algorithm meets its maximum number of iterations. The flow chart of this algorithm is shown in Figure 1.

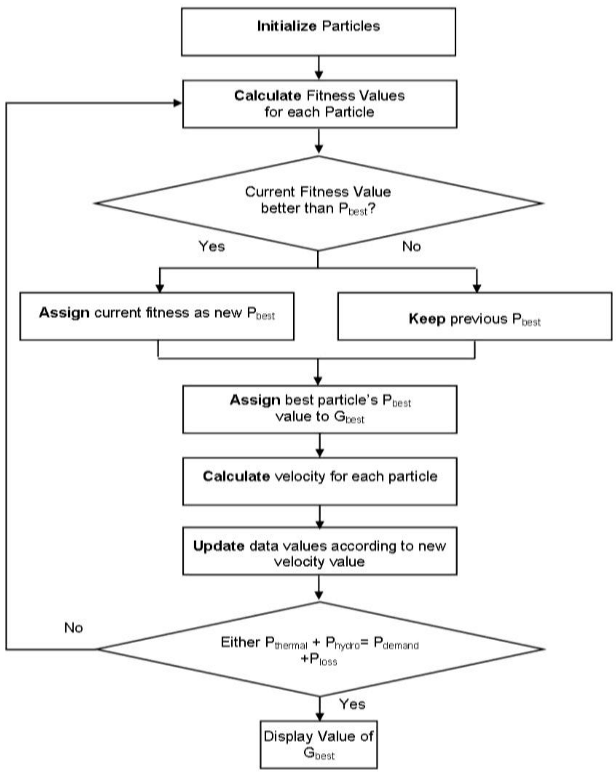

Fig. 1: IPSO's flow chart

Pseudo Code of IPSO for STHTS

Input: (Popsize, max_{it}, *i*, ω, t, r_1, r_2 etc.); Output: Global Best
Initialize the population at *t=0*and *i=0*;
FOR p = 1, ………, popsize
Set Position vector
x_i^t = Randomly initialize the position of each particle in between $x_{\min}$ & $x_{\max}$;
Set Velocity vector
v_i^t = Randomly initialize the velocity of each particle in between $v_{\min}$ & $v_{\max}$;
Set P_{best}= x_i^0
Set G_{best}= Best particle's position
END
WHILE $i \le max_{it}$ OR $P_{best} \ne G_{best}$
a. Calculate fitness value using equation (1) & (2);
b. Update particle's best positions;
(Personal Best position)
FOR p = 1, ………, popsize
If Fitness value <P_{best}
Set current fitness value as new P_{best}
Else Keep previous P_{best}
End
END
(Global Best position)
Identify G_{best}
If P_{best}<G_{best}
Set P_{best} as new G_{best}
Else Keep previous G_{best}
End
c. Update parameters;
Cognitive = c_1
= average of particle's velocity in that interval
Social = c_2
=average of particle's position in that interval
d. Update particle's velocity;
FOR p = 1, ………, popsize
Calculate particle's velocity using equation

$$v_{ij}^{t+1} = \omega v_{ij}^t + c_1 r_{1j}^t \left[P_{best,i}^t - x_{ij}^t \right] + c_2 r_{2j}^t \left[G_{best} - x_{ij}^t \right]$$

END
e. Evolve to new particle's position;
FOR p = 1, ………, popsize
Calculate particle's position using equation

$$x_{ij}^{t+1} = x_{ij}^t + v_{ij}^{t+1}$$

END
f. Set *i = i + 1*
END
Global Best = G_{best}

Interval = Time span for a Demand
Popsize = Population/Swarm size = 10* No. of intervals
max_{it} = Maximum number of iteration = 20
ω = Inertial Weight = $(x_{max}-x_{min})/max_{it}$
x_{max} & x_{min} = Generation upper (P_{max}) and lower (P_{min}) limits
t = Time
r_1& r_2 = Random Numbers between (0, 1)

$c_1 = \sum_i^T v_{ij} \Big/ No.of\ Particles$

$c_2 = \sum_i^T x_{ij} \Big/ No.of\ Particles$

4. Improved Particle Swarm Optimization

In PSO the most important part is the selection of parameters. Parameters selection increases the convergence rate of the algorithm and also helps to decrease the chances of premature convergence before the global minima. In ordinary PSO the value of cognitive and social parameters is taking as a constant (c_1=c_2=2.5) [39].

So in the improved particle swarm optimization algorithm we update the value of cognitive and social parameters in each iteration. By doing this the rate of convergence of PSO increased and premature convergence decreases. In IPSO the cognitive parameter is selected by taking the average of particle's velocities for that interval and social parameter is selected by taking the average of particle's positions for that interval. It shows better results and good convergence rate as discussed in Section 5. The box show the Pseudo code [40] and parameters' values used in Improved Particle Swarm Optimization (IPSO) technique.

5. Simulation Results

The three test cases adopted from literature and PSO and IPSO algorithm have been implemented in MATLAB®. In all test cases 30 independent runs were conducted. In ordinary PSO the value of c_1 and c_2 are 2.5 [39]. The results and cost comparisons made with [28, 29] and simple PSO [39] has been explained as follows:

5.1 Test Case I

Test case I consists of one thermal and two hydro units [26]. Cost function of thermal unit is following:

$$F_1(P_3(t)) = 0.01P_3^2(t) + 3.0P_3(t) + 15\$/h$$

Hydro unit I and Hydro unit II functions are following:

$$q_1(t) = 0.00005P_1^2(t) + 0.03P_1(t) + 0.2M.ft^3/h$$

$$q_2(t) = 0.0001P_2^2(t) + 0.06P_2(t) + 0.4M.ft^3/h$$

Volumes of both hydro units are 25.0 M.ft^3 and 35.0 M.ft^3 respectively.

The transmission loss coefficients are :

$$B = 10^{-3}\begin{bmatrix} 0.0 & 0.0 & 0.0 \\ 0.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 0.5 \end{bmatrix}$$

$$B_0 = \begin{bmatrix} 0.0 \\ 0.0 \\ 0.0 \end{bmatrix}$$

$$B_{00} = 0.0$$

The schedule of hourly demand of a day is listed in Table 1. IPSO implemented on the Test Case I. The optimum generated powers are tabulated in Table 2 with Discharge rate of both hydro units.

Table 1: Hourly demand of test case I

Interval	Power demand	Interval	Power demand
12am-1am	30.0 MW	12 pm -1pm	60.0 MW
1am-2am	33.0 MW	1pm -2 pm	61.0 MW
2am-3am	35.0 MW	2pm-3pm	65.0 MW
3am-4am	38.0 MW	3pm-4pm	68.0 MW
4am-5am	40.0 MW	4pm-5pm	71.0 MW
5am-6am	45.0 MW	5pm-6pm	62.0 MW
6am-7am	50.0 MW	6pm-7pm	55.0 MW
7am-8am	59.0 MW	7pm-8pm	50.0 MW
8am-9am	61.0 MW	8pm-9pm	43.0 MW
9am-10am	58.0 MW	9pm-10pm	33.0 MW
10am-11am	56.0 MW	10pm-11pm	31.0 MW
11am-12pm	57.0 MW	11pm-12am	30.0 MW

The total optimum cost of Test Case I which is calculated by using proposed IPSO is 838.9229$. The graphical and tabulated comparison of MBFA [28], PSO [39] and IPSO costs are in Figure 2 and Table 3 along with average time of IPSO.

Table 2 : Power and discharge rate for test case I

Hour	Output power of units (MW)			Flow rate (M.ft^3/h)	
	Thermal unit	Hydro unit 1	Hydro unit 2	Hydro unit 1	Hydro unit 2
1	8.5102	14.0157	7.9352	0.6303	0.8825
2	8.1277	16.0117	9.3613	0.6932	0.9705
3	7.881	17.3484	10.318	0.7356	1.0298
4	7.5293	19.3286	11.736	0.7986	1.118
5	7.3042	20.6487	12.683	0.8408	1.1771
6	6.776	23.9331	15.044	0.9467	1.3253
7	6.2984	27.1848	17.388	1.0525	1.4735
8	5.5599	32.9726	21.574	1.2436	1.741
9	5.4364	34.0671	22.367	1.2801	1.7921
10	5.6408	32.2794	21.071	1.2205	1.7087
11	5.7873	31.0667	20.193	1.1803	1.6524
12	5.7109	31.6929	20.646	1.2011	1.6815
13	5.4859	33.6235	22.045	1.2653	1.7714
14	5.4359	34.0723	22.371	1.2803	1.7924
15	5.1695	36.6092	24.213	1.3653	1.9115
16	5.0275	38.0815	25.284	1.415	1.981
17	4.8591	39.9711	26.659	1.4791	2.0707
18	5.4132	34.2786	22.521	1.2872	1.802
19	5.8848	30.2862	19.628	1.1545	1.6163
20	6.2986	27.1834	17.387	1.0525	1.4735
21	6.9806	22.627	14.105	0.9045	1.2662
22	8.1269	16.0159	9.3643	0.6934	0.9707
23	8.3816	14.6772	8.4076	0.6511	0.9116
24	8.5133	13.9998	7.9239	0.6298	0.8818

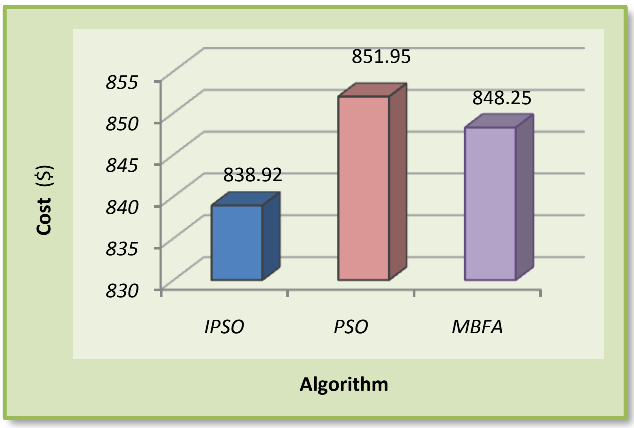

Fig. 2: Cost Comparisons

Table 3 : Operational costs comparisons of STHTS

	IPSO Dollar ($)	PSO [39] Dollar ($)	MBFA [28] Dollar ($)	IPSO average time
Fuel Cost	838.9229	851.9515	848.2512	11.9822 Secs

5.2 *Test Case II*

Test case II consists of three thermal units and one hydro unit [28]. Cost functions of thermal units are following :

$$F_1(P_1(t)) = 0.01P_1^2(t) + 0.1P_1(t) + 100\$/h$$

$$F_2(P_2(t)) = 0.02P_2^2(t) + 0.1P_2(t) + 120\$/h$$

$$F_3(P_3(t)) = 0.01P_3^2(t) + 0.2P_3(t) + 150\$/h$$

Thermal unit upper and lower limits are following:

$$50MW \le P_1 \le 200MW$$

$$40MW \le P_2 \le 170MW$$

$$30MW \le P_3 \le 215MW$$

Hydro unit function is following:

$$q_1(t) = 0.06P_4^2(t) + 20.0P_4(t) + 140.0m^3/h$$

The limits of the hydro and thermal units are following:

$$10MW \le P_4 \le 100MW$$

The transmission loss coefficients are:

$$B = 10^{-3}\begin{bmatrix} 0.50 & 0.05 & 0.20 & 0.03 \\ 0.05 & 0.04 & 0.18 & -0.11 \\ 0.20 & 0.18 & 0.50 & -0.12 \\ 0.03 & -0.11 & -0.12 & 0.23 \end{bmatrix} MW^{-1}$$

$$B_0 = \begin{bmatrix} 0.0 \\ 0.0 \\ 0.0 \end{bmatrix}$$

$$B_{00} = 0.0$$

The Volume of hydro unit is 25000.0m^3. The schedule of hourly demand of a day is listed in Table 4.

Table 4: Demand of test case II

Interval	Power Demand	Interval	Power Demand
12am-1am	175.0 MW	12 pm -1pm	565.0 MW
1am-2am	190.0 MW	1pm -2 pm	540.0 MW
2am-3am	220.0 MW	2pm-3pm	500.0 MW
3am-4am	280.0 MW	3pm-4pm	450.0 MW
4am-5am	320.0 MW	4pm-5pm	71.0 MW
5am-6am	360.0 MW	5pm-6pm	425.0 MW
6am-7am	390.0 MW	6pm-7pm	400.0 MW
7am-8am	410.0 MW	7pm-8pm	375.0 MW
8am-9am	440.0 MW	8pm-9pm	340.0 MW
9am-10am	475.0 MW	9pm-10pm	300.0 MW
10am-11am	525.0 MW	10pm-11pm	250.0 MW
11am-12pm	550.0 MW	11pm-12am	200.0 MW

IPSO implemented on the Test Case II. The optimum generated powers are tabulated in Table 5 with Discharge rate of hydro unit.

Table 5 : Power and discharge rate for test case II

Hour	Output Power of all Units (MW)				Flow rate (m^3/h)
	Thermal plant 1	Thermal plant 2	Thermal plant 3	Hydro	
1	66.2199	40	64.6765	10.0496	347.05
2	76.4631	40	70.6307	10.0496	347.05
3	91.3804	45.5961	83.0208	10.0496	347.05
4	118.948	59.4408	109.7248	10.0496	347.05
5	140.42	70.0859	124.7465	10.0496	347.05
6	153.677	77.3254	138.5873	17.7555	514.025
7	165.135	82.5319	143.4195	29.7944	789.15
8	171.91	85.8606	149.9024	38.0615	988.15
9	181.742	91.1859	157.9274	49.7316	1283.025
10	191.17	95.51	166.4084	64.7121	1685.5
11	200	111.777	178.4316	85.7267	2295.475
12	200	125.596	185.5388	96.73	2636
13	200	166.027	157.6221	100.0086	2740.275
14	200	130.23	171.0749	93.0004	2518.95
15	200	105.413	169.9423	75.6294	1995.775
16	186.585	93.0776	159.2703	54.3723	1404.825
17	179.417	89.2809	148.0566	43.6681	1127.775
18	171.609	85.5063	147.0763	33.7014	882.175
19	168.231	84.8462	133.8841	23.8083	650.175
20	156.155	77.7572	128.9902	10.9667	366.55
21	131.969	65.7855	113.2068	10.0401	346.85
22	109.998	55.1111	90.1824	10.0401	346.85
23	86.7263	43.2325	69.5479	10.0401	346.85
24	75.7221	40	62.3011	10.0401	346.85

The total optimum cost of Test Case II which is calculated by using proposed IPSO is 24081.5999$. The graphical and tabulated comparison of MBFA [28], PSO [39] and IPSO costs are in Table 6 and Figure 3 along with average time of IPSO.

Table 6: Operational costs comparisons of STHTS

	IPSO Dollar ($)	PSO [39] Dollar ($)	MBFA [28] Dollar ($)	IPSO average time
Fuel Cost	24,081.5999	24,132.6601	24,267	8.7002 Secs

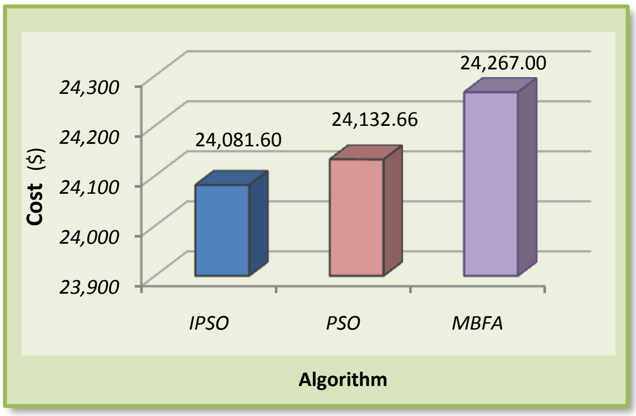

Fig. 3: Cost comparisons

4.1 Test Case III

Test case III having single unit of thermal and hydro plants [29]. Cost functions of thermal plant with its generating limits are following :

$$F_1(P_1(t)) = 0.00184P_1^2(t) + 9.2P_1(t) + 575$$

$$150.00MW \le P_1 \le 1500.00MW$$

Hydro unit function with its generating limit is following :

$$q_1(t) = 0.05(P_2 - 1000)^2(t) + 12.0(P_2(t) - 1000)$$
$$+\ 5300.0acre - ft/h$$

for $1000 \le P_2 \le 1100MW$

and

$$q_1(t) = 4.97P_2(t) + 330.0acre - ft/h$$

for $0 \le P_2 \le 1000MW$

The transmission losses are:

$$P_L = 0.00008P_1^2$$
$$V = 100{,}000acre - ft$$

The demand schedule of two intervals of a day is listed in Table 7.

Table 7 : Demand of test case II

Interval	Power demand
12am-12pm	1200.00 MW
12pm-12am	1500.00 MW

IPSO implemented on the Test Case III. The optimum generated powers are tabulated in Table 8 along with Discharge rate of hydro unit.

Table 8 : Power and discharge rate for test case III

Interval	Output Power of all Units (MW)		Flow rate (acre-ft/h)
	Thermal unit	Hydro unit	Hydro unit
1	557.9322	678.8442	3703.8556
2	694.6794	865.1029	4629.5614

The total optimum cost of Test Case III which is calculated by using proposed IPSO is 169,616$. The graphical and tabulated comparison of MBFA [29], PSO [39] and IPSO costs are in Table 9 and Figure 4 along with average time of IPSO.

Table 9 : Operational costs comparisons of STHTS

	IPSO Dollar ($)	PSO [39] Dollar ($)	MBFA [29] Dollar ($)	IPSO average time
Fuel Cost	169,616.1	169,641.7	169,630	2.0821 Secs

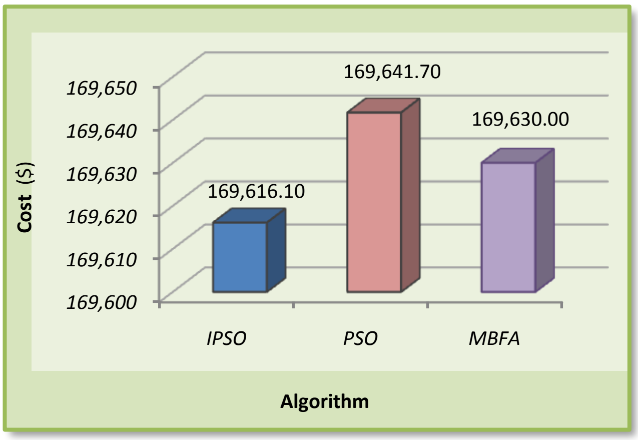

Fig. 4 : Cost comparisons

4. Conclusion

The paper presents the application of particle swarm optimization technique in solving fixed-head short-term hydrothermal scheduling problem. Near optimal solutions were obtained as an output of the process which depicts the robustness as well as the effectiveness of the algorithm. IPSO gives comparatively better results when compared with the results obtained by modified BFA.

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