

Short Term Hydrothermal Scheduling Using Particle Swarm Optimization

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Abstract: Operation of a system having both hydro and thermal plants is a challenging problem as hydro plants have negligible operating cost, but are required to operate under constraints of water available for hydro generation in a given period of time. The problem of minimizing the operating cost of a hydrothermal system can be viewed as one of minimizing the fuel cost of thermal plants under constraints of water availability for hydro generation over a given period of operation. Earlier, a wide variety of optimization techniques have been applied to solve the Hydrothermal scheduling problems such as dynamic programming, gradient search but these methods have drawbacks such as large computation time, algorithm complexity. The work done in this work presents solution to short-term hydrothermal scheduling problem. The solution approach is based on Particle Swarm Optimization (PSO) under matlab software.

Index Terms - genetic algorithm, Particle Swarm Optimization, short-term hydrothermal, control constraints, long-range scheduling

I. INTRODUCTION

In present set-up, optimum scheduling of hydrothermal plants is important because of its economical aspect in interconnected power system operation. The hydrothermal scheduling problem is directed to minimize the operating cost of thermal plants as the operating cost of hydro plants is negligible. Thus, the problem of minimizing the operational cost of a hydrothermal system is to minimize the fuel cost of thermal plants subjected to various equality and inequality constraints offered by the operation of hydrothermal plants and power system network. Limited energy storing capacity of water reservoirs and having the stochastic nature of availability of water makes the solution more difficult for hydrothermal systems compared to pure thermal systems [1]. Hydroelectric plants also meet purposes other than power generation including flood control and irrigation purpose [2]. Most of the hydro-systems are having different characteristics mainly due to differences in availability of water, control constraints, non-uniform water flow, number of hydro stations and their locations etc. The problem is different when the plants are located on the same stream or on a different stream, a "bird" in the search space. We call it "particle". All of particles have fitness values, which are evaluated by the fitness function to be optimized,

To minimize overall cost of system available hydro resources has to be utilized fully. The hydrothermal problem includes long range problem and short range problem.

The Long-range hydro scheduling problem involves the long range forecasting of water availability and the scheduling of water releases. Typical long-range scheduling goes anywhere from one week to one year or several years. Long range scheduling involves optimizing policy in the context of unknowns such as loads, hydraulic inflows and unit availabilities. These unknowns are treated statistically and long-range scheduling involves optimization of statistical variables. This problem is classified as: multi-storage hydroelectric systems cascaded hydroelectric systems, multi-chain hydroelectric systems.

The Short-range hydro scheduling problem involves one day to one week or hour-by-hour scheduling of all generations on a system to achieve minimum production cost for the given time period. A set of starting conditions is given to get the optimized schedule with the minimum cost which is desired. The amount of water to be utilized for short-range scheduling problem is known from the solution of long-range scheduling problem. This problem is classified as: fixed head hydrothermal scheduling and variable head hydrothermal scheduling. Several methods for solving the problem of short-term hydrothermal scheduling have been proposed. The classical methods of solving the scheduling problem are not suitable when the system size increases. Further the computational requirements also increase with the classical methods. Therefore, various evolutionary techniques such as particle swarm optimization (PSO) [3] [4] [5], constriction factor based particle swarm optimization technique (CFPSO) [6], evolutionary programming (EP) [7], genetic algorithm (GA) [8] [9], differential evolution [10] [11] are used for hydrothermal scheduling.

II. PARTICLE SWARM OPTIMIZATION

PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know how far the food is in each iteration. So what's the best strategy to find the food? The effective one is to follow the bird, which is nearest to the food. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is

- Solution.
- In general, the inertia weight w is set according to

and have velocities, which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global standing called g-best. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called p-best. After finding the two best values, the particle updates its velocity and positions with following equation 1 and 2

$$V_{i(u+1)} = C_1 * W * V_{i(u)} * rand() * (pbest_i - P_{i(u)}) + C_2 * rand() * (gbest_i - P_{i(u)}) \quad (1)$$

$$P_{i(u+1)} = P_{i(u)} + V_{i(u+1)} \quad (2)$$

In the above equations,

The term $rand() * (pbest_i - P_{i(u)})$ is called particle memory influence

The term $rand() * (gbest_i - P_{i(u)})$ is called swarm influence.

$V_{i(u)}$ Which is the velocity of i th particle at iteration 'u' must lie in the range $V_{min} \leq V_{i(u)} \leq V_{max}$

- The parameter V_{max} determines the resolution, or fitness, with which regions are to be searched between the present position and the target position
- If V_{max} is too high, particles may fly past good solutions. If V_{min} is too small, particles may not explore sufficiently beyond local solutions.
- In many experiences with PSO, V_{max} was often set at 10-20% of the dynamic range on each dimension.
- The constants C_1 and C_2 pull each particle towards pbest and gbest positions.
- Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, target regions.
- The acceleration constants C_1 and C_2 are often set to be 2.0 according to past experiences
- Suitable selection of inertia weight ' ω ' provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal

$$Q = \begin{bmatrix} Q_{1,1} & \cdots & Q_{1,k+j} \\ \vdots & \ddots & \vdots \\ Q_{N,1} & \cdots & Q_{N,k+j} \end{bmatrix} \quad (11)$$

STEP 2: Handling water availability constrain:

the following equation,

$$W = W_{max} - \left[\frac{W_{max} - W_{min}}{ITER_{max}} \right] * ITER \quad (3)$$

Where W is the inertia weighting factor

W_{max} Maximum value of weighting factor

W_{min} Minimum value of weighting factor

$ITER_{max}$ Maximum number of iterations

$ITER$ Current number of iteration

III. PROBLEM FORMULATION

1. Function:-

The objective of solving STHTS problem is to minimize the cost of the fuel of the thermal generation which is a function of output power of seven gas turbines over a day period as described in equation.(4)

$$F = \min \left[\sum_{t=1}^{24} \sum_{i=1}^7 F_i [P_{gi}^t] \right] \quad (4)$$

$$F_i [P_{gi}^t] = a_1 + b_1 \cdot P_{gi} + c_1 \cdot P_{gi}^2 \quad (5)$$

where a_1, b_1, c_1 Are the coefficients of gas turbines

2. Constrains:

The function which is described in equation 4 subjected to different constrains which are:

2.1 Equality constrains:

- Real power balance:

$$\sum_{i=1}^7 P_{gi}^t + \sum_{j=1}^{10} P_{hj}^t + P_{loss} [P_{gi}^t, P_{hk}^t] = P_D^t \quad (6)$$

$$P_{loss} [P_{gi}^t, P_{hk}^t] = B_{11} * [P_{gi}^t]^2 + 2 * B_{12} * [P_{gi}^t] * [P_{hk}^t] + B_{22} * [P_{hk}^t]^2 \quad (7)$$

Where B_{11}, B_{12}, B_{22} are transmission losses coefficients

- Reservoir end volume :

$$Q_{TOT} = \sum_{j=1}^{24} \sum_{k=1}^{10} [Q_{jk} (P_{Hjk})] = 179828019.79 \text{ m}^3 \quad (8)$$

2.2 Inequality constrains:

- Output power of the gas turbines

$$20 \leq P_g \leq 37 \quad (9)$$

- Output power of the hydro turbines

$$0 \leq P_h \leq 125 \quad (10)$$

IV. Implementation of PSO for STHTS

To implement PSO for STHTS problem there are various steps which can be summarized below:

1. Handling of constrains:

The STHTS problem is subjected to different constrains which are discharge, water availability, output hydro power limits, thermal output power limits and power balance considering transmission losses constrains so that in the following steps these constrains are handled one by one.

STEP1: Handling discharge constrain:

A random N populations of hydro turbines discharge considering discharge limits for K hydro turbines and load factor during J intervals and as shown below.

Where is the figure

satisfy equation 13 and the inequality constrain 9 then the iterations continue until max iteration is reached and the best generation cost during these iteration is determined

According to equation 11 the total discharge is calculated for each population and readjusted so that it satisfies equation 8.

STEP 3: Handling hydro output power constrain:

According to the previous step the hydro output power of hydro turbines during J intervals is calculated as shown in equation 8 which should satisfy equation 10.

$$PH = \begin{bmatrix} PH_{1,1} & \dots & PH_{1,k*J} \\ \vdots & \ddots & \vdots \\ PH_{N,1} & \dots & PH_{N,k*J} \end{bmatrix} \quad (12)$$

STEP 4: Implementation of the best hydro schedule:

In this step best population of hydro output power is implemented from equation 10 which described in equation 13

$$PH_{best} = [PH_{best,1} \dots PH_{best,J*K}] \quad (13)$$

STEP 5: Implementation of total thermal output power considering power balance constrain:

By rearranging equation 6 and 7

$$P_{th}^t + P_h^t + B_{11} * [P_{th}^t]^2 + 2 * B_{12} * [P_{th}^t] * P_{hk}^t + B_{22} * [P_{hk}^t]^2 = P_D^t \quad (14)$$

This can be arranged as:

$$B_{11} * [P_{th}^t]^2 + [1 + 2 * B_{12} * P_{hk}^t] * [P_{th}^t] + [B_{22} * [P_{hk}^t]^2 + P_h^t - P_D^t] = 0 \quad (15)$$

Using general rule of quadratic equation:

$$P_{th}^t = \frac{-[1 + 2 * B_{12} * P_{hk}^t] \pm \sqrt{[1 + 2 * B_{12} * P_{hk}^t]^2 - 4 * B_{11} * [B_{22} * [P_{hk}^t]^2 + P_h^t - P_D^t]}}{2 * B_{11}} \quad (16)$$

Using equation 16 the total thermal output power is calculated during each interval as shown in equation 17.

$$P_{th} = [P_{th,best,1} \dots P_{th,best,J}] \quad (17)$$

STEP 6: Implementation of thermal output power for each thermal unit:

For each J interval from J=1 up to J=24 a random thermal scheduling of M population for output power is formulated as shown in equation 18 so that it represent each element in matrix described in equation 17 it satisfy equations 6 and 7.

$$P_{th[m,7]} = \begin{bmatrix} P_{g[1,1]} & \dots & P_{g[1,7]} \\ \vdots & \ddots & \vdots \\ P_{g[m,1]} & \dots & P_{g[m,7]} \end{bmatrix} \quad (18)$$

2. Implementation of PSO for STHTS problem:

According to equation 18 the objective function 4 evaluated for each M population and the minimum generation cost through M populations is determined which is set to be F_{gbest} or the best generation cost and its position through $M = 1: M_{max}$ is set to be i_{gbest} or the best population and it's individual thermal generation is set to be p_{best} or the best particles then by using equations 1 and 2 a particle swarm optimization initiated for the gas turbine units and the steam turbine unit is float so that it should

and its corresponding best generation scheduling.

The above steps are repeated for equation 18 so that its result described in equation 16 and the total generation cost for each visible unit commitment is calculated using equation 19.

$$F = \begin{bmatrix} F_{best(1,1)} & \dots & F_{best(1,J)} \\ \vdots & \ddots & \vdots \\ F_{best(7,1)} & \dots & F_{best(7,J)} \end{bmatrix} \quad (19)$$

The best generation cost is determined from equation 20 using equation 19 and handling the startup and shutdown costs the corresponding thermal output power for each gas turbine and also the corresponding hydro output power and the losses during 24 hour period are determined.

$$F_{Tbest} = \min \begin{bmatrix} F_{best(1)} \\ \vdots \\ F_{best(J)} \end{bmatrix} \quad (20)$$

System description

V. RESULTS AND DISCUSSION

1. Program Execution:

During program iterations the minimum generation cost is recorded and compared with the previous minimum then if it is less than it will be registered as a best cost and the iteration continued until it is reach the max number of iteration. So that the best generation cost at the end of program execution is 51,615 \$

2. Output Hydro Power:

The hydro output power of the best schedule is shown and compared with the actual schedule in table 1 and fig 1 so that the PSO schedule has more output power during most of scheduling period while the same hydro resources are used while the thermal power is minimized as shown in figure 2.

Table 1: output power

HOUR	HYDRO		THERMAL	
	PSO	ACT	PSO	ACT
00:00	465.4	440	17.7	63
01:00	433.9	411	15.0	56
02:00	420.5	397	13.9	56
03:00	417.0	392	13.6	56
04:00	395.0	366	11.8	56
05:00	413.7	385	13.3	58
06:00	426.8	494	14.4	65
07:00	496.3	474	13.5	65
08:00	544.0	528	16.2	65
09:00	609.4	605	15.0	65
10:00	659.4	661	17.3	65
11:00	650.6	587	16.9	129
12:00	663.9	608	17.4	124
13:00	657.7	605	17.1	120
14:00	676.2	629	18.0	118
15:00	708.8	662	19.5	122
16:00	691.3	639	18.8	124
17:00	670.0	612	17.7	126
18:00	674.4	617	17.9	126
19:00	805.9	765	19.1	132
20:00	849.5	822	20.8	129
21:00	830.9	810	20.2	119
22:00	761.9	755	17.6	94
23:00	648.9	627	16.8	89



Fig 1: Hydro output power

3. Total thermal output power:

Figure 2 clearly can be read with figure 1 so that due to best use water resources the hydro power maximized while the thermal power minimizes which reflect directly on the operation cost.



Fig 2: Thermal output power

4. Unit commitment:

As shown in figure 3 the units committed and decommitted according to the required power from thermal plan so that as discussed before it was minimized then less number of thermal units are committed while in actual case all thermal units are on line during all scheduling period

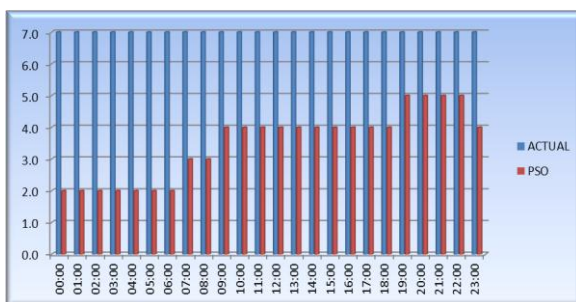


Fig 3: Unit commitment

5. Cost Comparison:

As shown in figure 4 the operational cost of the best schedule is 51,615\$ which represent 83.4 % from the actual cost in other words the best cost obtained is an actual operation cost up to hour 19:00 and the operation cost from 19:00 up to 23:00 is saving

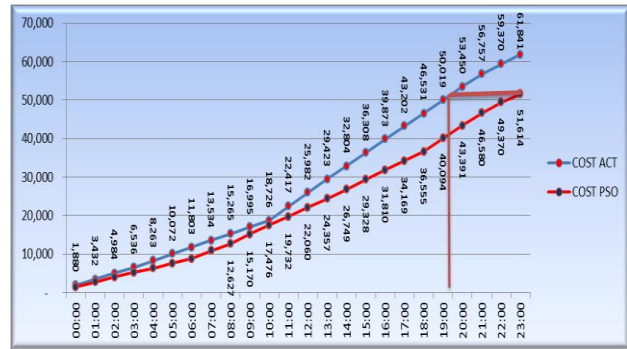


Fig 4: Cost comparison

6. Losses comparison:

Figure 5 indicate that the system loss slightly increase because the most of loads near the thermal plan (KHARTUOM load) as a result of that more power as discussed before will flow from the hydro plan which lead to increase the transmission line losses but as a final result the total operational cost of the system is minimized.



Fig 5: Losses comparison

VI. CONCLUSIONS

The particle swarm optimization algorithm has been applied to the short-term hydrothermal scheduling problem over the time horizon of 24 hours with one hour time interval. The presented algorithm determines the fuel cost of thermal generation for each time interval and give the optimum solution. So that the PSO algorithm has been applied to the Garri and Merwee power stations which containing seven gas turbine units and ten hydro units respectively and the following conclusions are drawn:

- With the same water volume used in short-term hydrothermal scheduling period on day (15/1/2015) and with handling the constrains the PSO algorithm give the best schedule which lead to minimize the operation cost by 14.5 %.
- The losses of system slightly increase because the most load near the thermal plant as a result of that the hydro plant participation increase.

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APPENDIX

MACHINE DATA

thermal machines $H(P)=a+b \cdot P+c \cdot P^2$ GJ/Hr	data	details
	plant name	GAR
	unit type	GAS
	p(min)	20
	p(max)	37
	ramp up(mw)	5
	ramp do (mw)	5
	min up time(min)	1440
	min do time (min)	720
	aux%	3
	cold start \$	500
	cold start T	20
	warm start\$	0
	warm start T	0
	hot start \$	0
	hot start T	0
	A	34.19
	B	7.66
	C	0.09914

FEUL DATA

No.	fuel name	fuel price Euro/Ton	heat content GJ/Ton
1	HFO	108	40
2	LPG	171	45.8
3	GASOIL	350	42.5
4	DIESEL	275	42.1
5	SPONJCOKE	42.9	47
6	LFO	108	40
7	HC	108	40
8	CRUDEOIL	108	40

BIOGRAPHIES

Dr.Mohammed Osman Hassan was born in Sudan in 1968; he received his Bachelor degree in Electrical Engineering, and his Master degree in Power System, in 1997,2003 from Sudan University of Science and Technology (SUST) –Sudan. And his PhD, in 2010, from Huazhong university of science and technology (HUST) - china. Currently, he is an Assistant Professor in Sudan University of Science and Technology. His main research interests are power system control, economic operation of power system, power system stability analysis, FACTS devices and application of AI in power systems.

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