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Optimal Generation Scheduling of Cascaded Hydroelectric System using Natural Exponential Inertia Weight PSO

Nand Kishore [1*], Amita Mahor [2]

[1*] corresponding author,M.Tech. Power Electronics Student, Department of Electrical & Electronics Engineering, NIIST Bhopal,Email: nkmeena83@gmail.com

[2] Professor & Head, Department of Electrical & Electronics Engineering, NIIST Bhopal, Email: amitamahor@yahoo.co.in

Abstract- Generation scheduling is a most important task in the operation and planning of power system. It can be on real term, short term, medium term, and long term basis as per the scheduled horizon. Scheduling of purely hydroelectric system differ from the thermal scheduling and hydrothermal scheduling problems in two aspects firstly fuel cost for the thermal part of the system can no longer be used in the objective function. Secondly water availability in seasonal reservoirs is the necessary part of such system. Many researchers suggested different solution algorithms of optimization for each type of problem and claimed better solution. This paper presents a Natural Exponential Inertia Weight Particle Swarm Optimization (NEIW_PSO) approach to determine the optimal generation schedule of hydro power plants of cascaded hydroelectric test system.

Index Terms: Particle Swarm Optimization, Natural Exponential Inertia Weight PSO, short term generation scheduling.

1. Introduction

The biggest share of electricity in all countries is produced by power plants driven by water, fossil fuels and nuclear resources. Worldwide there is a shortage of power and to fulfill the demand it is required that the existing generation installed capacity should enhance. To fulfill this gap of power generation and demand, generation utilities are facing issues like depletion of available power generation resources fossil fuels, continuous increase in its prices and environmental aspects. Considering above it become must that utilization of available hydro resources should be optimum. Connection of Hydro power plants in cascaded fashion is a step in this direction, where the water discharge from upstream hydro power plants increase the water level of reservoir at downstream. Various conventional [1] [2] and non-conventional methods [3], [4], [5], [6] are suggested in literature to solve such problems. Amongst all Particle swarm optimization technique [7] is the most popular algorithm due to its fast dynamic convergence and quality solution. Here NEIW_PSO has been used to determine the hourly optimal generation schedule of hydro power plants of cascaded hydro electric test system [8] for the time horizon of 24 hours.

2. Problem formulation

Short term hydroelectric power generation scheduling problem of cascaded hydro electric system can be stated to find out the water discharges through each hydro power plants of cascaded system satisfying all physical and operational constraints. These are in form of demand supply balance, flow balance or continuity equation, bounds on reservoir storage, bound on water release or discharge, limits on spillage, and coupling constraints that put a boundary condition on the initial and final reservoir level.

Hydro scheduling problems requires an optimization problem formulation. During formulation, water travelling time from upstream power plant to immediate downstream plant is considered of constant value in spite of varying discharges. In present work hydro plant problem has been formulated without considering natural inflows, irrigation requirement and evaporation losses.

2.1 Objective function

An objective function expresses the main aim of the model which is either to be minimized or maximized. It is expressed in terms of design variables and other problem parameters. In present hydroelectric scheduling problem, the goal is to minimize the deviation between load demand including transmission losses and generation through hydroelectric power plants as given below:

$$E = \text{Min} \sum_{t=1}^{T} E_t \quad (1)$$

Where E^t is the deviation between load demand and generated power at time t and calculated as below:

$$E^t = \text{Min}\,(1/2) \times [(P_D^{\,t} - \sum_{j=1}^{n} P_j^t)^2] \quad (2)$$

Where P^t_D and P^t_j represented load demand, power generated through jth hydro power plants of hydroelectric system at time t respectively.

2.2 Constraints

The optimal value of the objective function as given in eq. (1) is computed subjected to constraints of two kinds of equality constraints and inequality constraints or simple variable bounds as given below. The decision is discretized into 1 h period.

2.2.1 Equality constraints

2.2.1.1 Water balance equation

Naturally occurring reservoirs are not standard geometric shapes. Generation associated discharge varies with time and there are environmental and weather factors which also contribute directly to change in water level. A reservoir thus has a number of independent inflows and outflows. This water continuity equation relates the previous interval water storage in reservoirs with current storage including delay in water transportation between successive reservoirs water continuity has been expressed as:

$$X_j^{t+1} = X_j^t + Yjt + Uup^{\,t-\delta} + S_{up}^{\,t-\delta} - U_j^t - S_j^t - IR_j^t - EL_j^t \quad (3)$$

For these cases average hourly evaporation loss, irrigation requirement & natural inflows in reservoirs of each plant of cascaded system is assumed zero. Hence the above eq. (3) can be rewrite as given below.

$$X_j^{t+1} = X_j^t + Uup^{\,t-\delta} + S_{up}^{\,t-\delta} - U_j^t - S_j^t \quad (4)$$

As hydro power plants are connected in cascaded mode hence the water release from upstream hydro power plants will reach to its immediate downstream plant with appropriate time delay. The delay time between the successive reservoirs of the Cascaded Hydro-electric System have been mentioned in Table 1.

Table 1

Water travel time between consecutive hydro electric power plant of test system

Name of plant	Travel time	Name of plant	Travel time	Name of plant	Travel time
P1	62 hrs	P2	4 hrs	P3	3 hrs
P4	17 hrs	P5	0 hrs	-	-

2.2.2 Inequality Constraints

Reservoir storage, turbine discharges rates, spillages and power generation limit should be in minimum and maximum bound due to the physical limitation of the dam and turbine. Reservoir storage before scheduled horizon and at the end of the horizon should be taken from midterm planning.

2.2.2.1 Reservoir storage bounds

Hydro electric plants are the multipurpose projects. Hence the min and max reservoir volume should be as per the Indian standard guidelines IS 7323:1994 of reservoir operation. In hydro power plants volume of water stored in reservoir up-to Full Reservoir Level (FRL) is called the gross storage and is considered as maximum bound on reservoir storage. Generally in hydro power plants the volume of water available between the Minimum Draw down Level (MDDL) and Full Reservoir Level (FRL) which is also called the live storage capacity has been used for power generation. Hence in present work the minimum bound of reservoir storage are the difference of gross storage and live storage of the concerned power plants.

$$X_j^{min} \le X_j^t \le X_j^{max} \quad (5)$$

2.2.2.2 Water Discharge Bounds

This is a minimum and maximum bound on the release of the hydro power plant through turbine.

$$U_j^{min} \le U_j^t \le U_j^{max} \quad (6)$$

2.2.2.3 Power Generation Bounds

Power generated through hydro power plants should be minimum and maximum bounds.

$$P_j^{min} \le P_j^t \le P_j^{max} \quad (7)$$

2.2.2.4 Spillage

Spillage from the reservoir is allowed only when to be released from reservoir exceeds the maximum discharge limits. Water spilled from reservoir j during time t can be calculated as follows:

$$S_j^t = Q_j^t - U_j^{max} \text{ if } Q_j^t > U_j^{max} \quad (8)$$

$$= 0 \qquad \text{otherwise}$$

2.2.2.5 Initial & end reservoir storage volumes

Terminal reservoir volumes are generally set through midterm scheduling process. This constraints implies the total quantity of utilized water for short term scheduling should be within limit so that the user of the reservoir should not be penalized. In present research work it has been assumed that all five reservoirs are filled up-to FRL hence gross storage has been considered as beginning or initial storage in reservoir at the starting of scheduled horizon. Live storage capacity at that time considered as available water for generation for scheduled horizon i.e. the water storage at the end of scheduled horizon of 24 hrs has been calculated as given below:

$$X_j^0 = X_j^{begin} \qquad X_j^t = X_j^{end}$$

$$X_j^0 = X_j^{begin} = X_j^{max}$$

$$X_j^{oneday} = (X_j^{max} - X_j^{min})/365$$

$$X_j^{end} = X_j^0 - X_j^{oneday}$$

3. Overview of Particle swarm optimization

Particle swarm optimization is a population based stochastic search algorithm which is the most recent developments in the category combinatorial meta-heuristic optimization. It was first introduced by Kennedy and eberhart in 1995 [9] as new heuristic method. The original objective of their research was to graphically model to the social behavior of bird flocks and fish schools. But this original version can only handle the non-linear continuous optimization problems. Further; the advancement in this PSO algorithm can explore the global optimal solution of complex problems of engineering and sciences. Amongst various version of PSO, most familiar version was proposed by Shi and Eberhart [10].the key attractive feature of PSO is its simplicity as it involves only two model eq.(1) and eq.(2).In PSO, the co-ordinates of each particle represent a possible solution called particle associated with position and velocity vector. At each iteration particle moves towards an optimum solution through its present velocity and their individual best solution obtained by themselves and global best solution obtained by all particles. In a physical dimensional search space, the position and velocity of the particle I are represented as the vector of

$X_i = [x_{i1}, x_{i2}, \ldots\ldots x_{id}]$ and $v_i = [V_{i1}, v_{i2}, \ldots\ldots V_{id}]$in the PSO algorithm.

Let $P\_best(i) = [X_{i1pbest}, x_{i2pbest} \ldots\ldots X_{idpbest}]$ and

$G\_best = [X_{1gbest}, X_{2gbest} \ldots\ldots X_{ngbest}]$ be the best position of particle I and global best position respectively. The modified velocity and position of each particle can be calculated using the current velocity and distance from P-best (i) and G_best as shown fig 1.

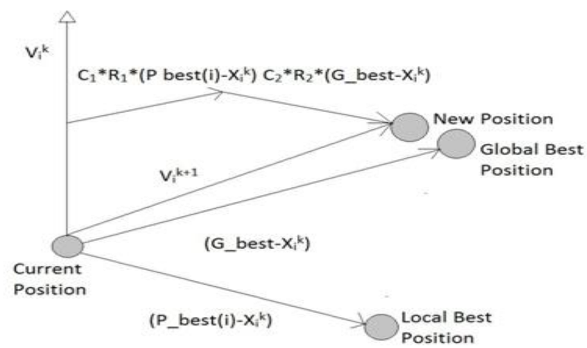


Fig.1 IIustration of PSO (9)

Mathematically velocity and position of the particle have been updated as given below: (10)

(11)

$$V_i^{k+1} = K\{V_i^k \times \omega + C_1 \times R_1 \times (P\_best(i) - X_i^k) + C_2 \times R_2 \times (G\text{-}best - X_i^k)\} \quad (12) \quad (13)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (14)$$

$$K = 2/\text{abs}\{2 - C - \sqrt{(C^2 - 4*C)}\} \quad (15)$$

Where $C = C_1 + C_2$

In this velocity updating process, the value of the parameter such as inertia weight ω, cognitive rate C1, social rate C2, random function between 0 to 1 {R1 and R2},constriction factor K should be determined in advance. The inertia weight ω is linearly decreasing as the inertia proceeds and obtained as:

$$\omega = \omega_{max} - \{(\omega_{max} - \omega_{min})\, iter\} / iter\_max \quad (16)$$

The key attractive feature of PSO is its simplicity as it is involves only tow eq.(13) and eq.(14)the first part of eq. (13) represent the previous velocity, which provides the necessary momentum for particle to roam across the search space. The second part knows as "cognitive "component represent the personal thinking of each particle. Cognitive component encourages the particle moves toward their own best positions found so far .The third part is known as the "social" component, which represent the collaborative effect of the particle, in finding the global optimal solution. The social component always pulls the particle towards global best t particle so far.

4. Description of cascaded Hydroelectric test System

In order to verify the feasibility and effectiveness of the proposed method, a test system taken from ref. [11] is used. The system consists of a multi-chain cascade of five hydro power plants. The scheduling period is one day of 24 hrs with one hour time intervals. The test hydro system configuration is shown in fig. (2).This hydraulic test system having huge hydraulic coupling amongst plant 2, 3 & 4 as the maximum tail race level of plant 2 will act as full reservoir level of plant 3 and so on.

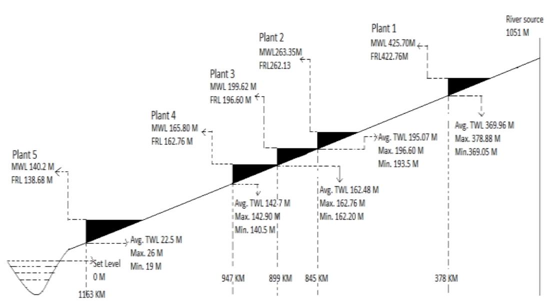


Fig.2 Hydraulic coupling of hydro power plants of test system

5. Generation Scheduling Using of Natural Exponential Inertia Weight PSO

In PSO particles movement is governed by its previous own velocity and two acceleration components i.e. cognitive component & social component. Usually implementation of PSO needs predefine parameters inertia weight ω, cognitive rate C1, social rate C2, constriction factor K, maximum velocity V_{max}, swarm size, topology and random number generation techniques. Proper selection and control of these parameters is necessary to get the good quality solution from PSO. Many researchers has proposed modification in PSO to improve its performance by adopt change in any of above parameters. Natural Exponential Inertia Weight PSO NEIW_PSO method is one of the variants proposed by [12] where Inertia weight exponentially decreases as given in eq. (17).In present work NEIW_PSO has been used to determine the hourly optimal generation schedule of power plants of cascaded test system for the time horizon of 24 hrs. Details steps of implementation are given below:

$$\omega = \omega\ max - \{(\omega\ max - \omega\ min).e^{-[t/(MAXITER)/4]2} \qquad (17)$$

Step 1: Initialize position of discharge particle between U_j^{min} & U_j^{max} for population size PS.
Step 2: Initialize velocity of discharge particle between $-V_j^{max}$ to $+V_j^{max}$, where V_j^{max} calculated is given

$$V_j^{max} = (U_j^{max} - U_j^{min})/10$$

Step 3: Initialize dependent discharge matrix.
Step 4: Inialize the p_best (i) and G_best.
Step 5: Set iteration count = 0.
Step 6: Calculate the dependent reservoir storage X_j^t.
Step 7:Check whether X_j^t is within limit X_j^{min} ,X_j^{max}.

- If $X_j^t < X_j^{min}$ then set $X_j^t = X_j^{min}$
- If $X_j^t > X_j^{max}$ then set $X_j^t = X_j^{max}$
- If $X_j^{min} \le X_j^t \le X_j^{max}$ then set $X_j^t = X_j^t$

Step 8: Evaluate the fitness function as given below:

$$F(X_j^t,U_j^t) = 1/[1+\min(1/2)\times P_1^t - \sum_{j=1}^{5} P_j^t)^2] \qquad (19)$$

Step 9: Is fitness value is greater than G_best(i)?

- If yes,set it as new P_best(i) then go to next step.
- Else go to next step.

Step 10: Is fitness value is greater than G_best?

- If yes,set it as new G_best than go to next step.
- Else go to next step.

Step 11: check whether stopping criteria max iteration (iter_max) reached?

- If yes than go to step 19.
- Else go to next step.

Step 12: Update inertia weight using eq. (17)
Step 13: Update velocity of discharge particle using eq.(13).
Step 14: Check whether V_j^t is within limit V_j^{min},V_j^{max}

- If $V_j^t < V_j^{min}$ then set $V_j^t = V_j^{min}$
- If $V_j^t > V_j^{max}$ then set $V_j^t = V_j^{max}$
- If $V_j^{min} \le V_j^t \le V_j^{max}$ then set $V_j^t = V_j^t$

Step 15: Update position of discharge particles using eq.(14).
Step 16: Check whether U_j^t is with in limit U_j^{min},U_j^{max}.

- If $U_j^t < U_j^{min}$ then set $U_j^t = U_j^{min}$
- If $U_j^t > U_j^{max}$ then set $U_j^t = U_j^{max}$
- If $U_j^{min} \le U_j^t \le U_j^{max}$ then set $U_j^t = U_j^t$

Step 17: Update dependent discharge matrix considering hydraulic coupling.
Step 18: Check for stopping criteria.

- If iter<iter_max then increase iteration count by 1 & go to step 6.
- Else go to step 19.

Step 19: Last G_best position of particles is optimal solution.

6. Results and analysis

MATLAB programming to determine the optimal generation schedule of test system using NEIW_PSO has been done. Where PSO parameters C1= 2, C2=2 no. of iterations = 120 are adopted. Hourly load demand is mentioned in Table no. (2). Program has been run on MATLAB 7.0.1 version on a Dual core 2GB RAM Hard disk 320GB.The results for the short term optimal generation scheduling of hydro-electric test system using NEIW_PSO method have been obtained for different population size 5, 10, 15, 20 and 25 as mentioned in Table no. (3). for each population size 10 trails of individual hours are done and amongst all 10 trials best suitable results are considered. From results it has been observed that population size 5 is giving best possible solution.

Table (2)

Hourly Load Demand (MW)

Hour	Demand	Hour	Demand	Hour	Demand
1	1350	9	1900	17	1850
2	1300	10	1800	18	1900
3	1350	11	2000	19	1750
4	1300	12	1800	20	1700
5	1350	13	2000	21	1600
6	1400	14	2000	22	1500
7	1500	15	1900	23	1550
8	1600	16	1900	24	1900

Table (3)

Best value of objective function at different Population size

Population Size	Best objective function
5	1.45E-16
10	4.49E-14
15	3.37E-16
20	5.34E-16
25	3.08E-16

Optimum generation schedule of all five hydro power plants and its corresponding hourly discharge trajectories and reservoir storage trajectories are given in Fig. (3)- (5) respectively .

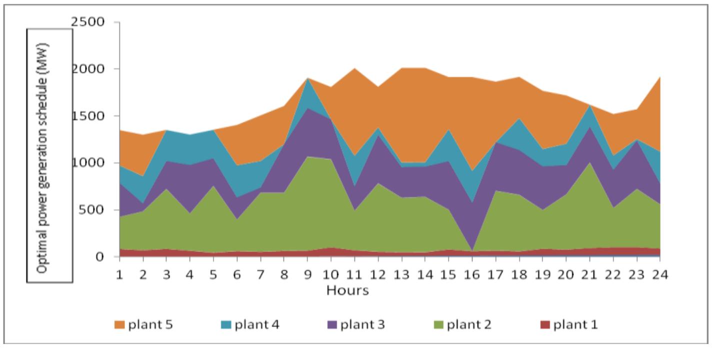
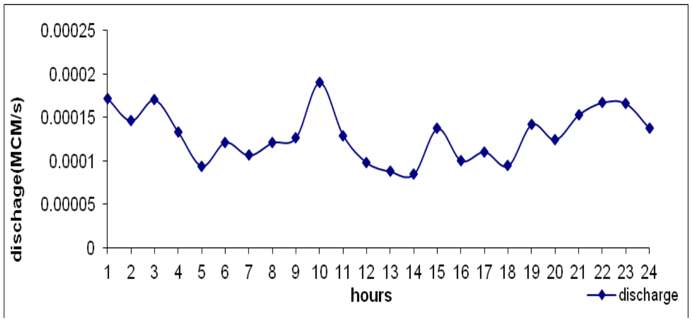


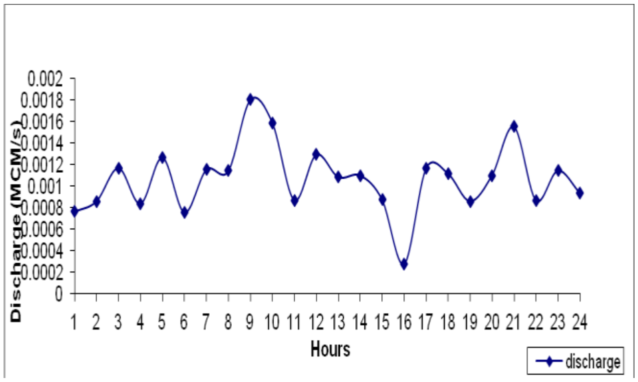
Fig. 3 Optimal power generation schedule of hydro power plants of test system

Optimal power generation schedule of hydro power plants shows that the capacity factor of plant 5 is maximum i.e. 53.38% followed by plant 4(47.43%), plant 2 (44.14%), plant 1 (34.28%) and plant3 *(26.75%).*



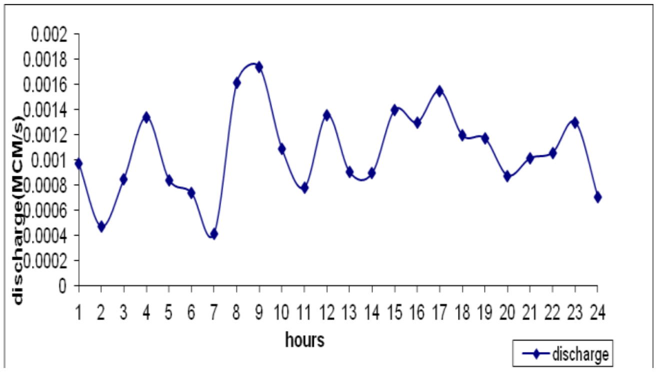
(a)

Plant 1

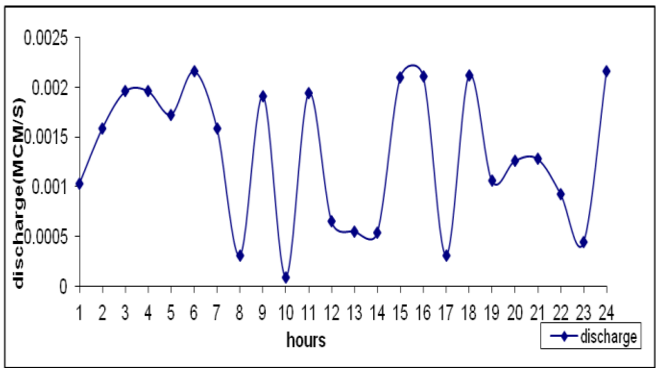


(b)

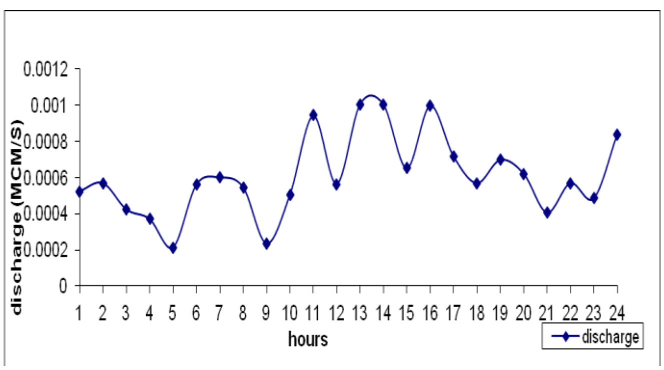
Plant 2



© Plant 3

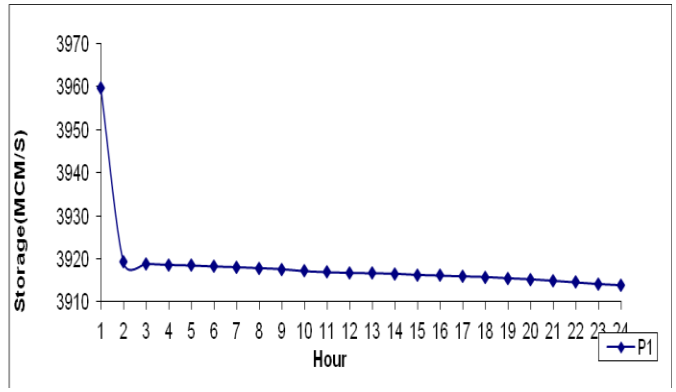


(d) Plant 4

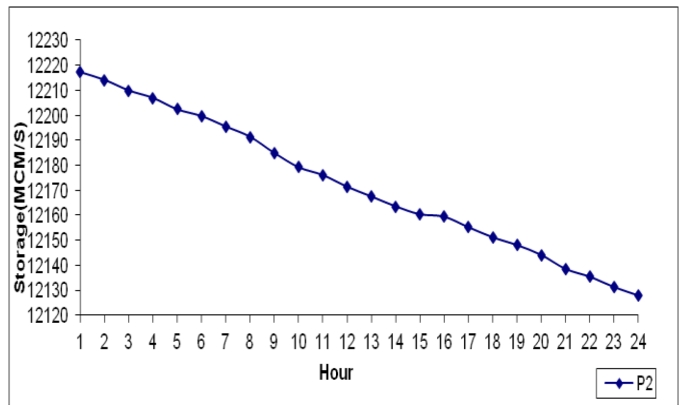


(e) Plant 5

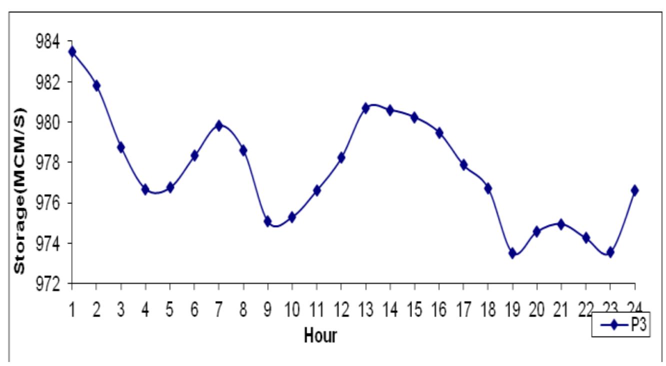
Fig. 4 (a)-(e) Discharge Trajectories of hydro power plants of test system



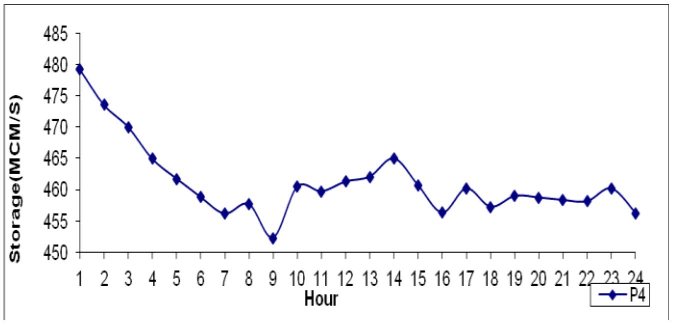
(a) Plant 1



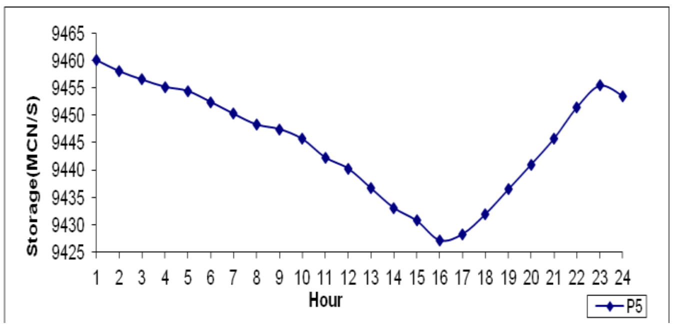
(b) Plant 2



© Plant 3



(d) Plant 4



(e) Plant 5

Fig.5 Reservoir storage trajectories of hydro power plants of test system

7. Conclusion

In optimal generation scheduling problem of hydro electric system, complexity introduced by the cascaded pattern. This problem becomes more complex when there is hydraulic coupling between hydro plants of cascade system. Modern heuristic optimization techniques especially PSO gained popularly to solve such problem due to its simplicity. The performance of PSO is governed by its parameters like inertia weight, acceleration coefficients and personal and global experience of the particles. Here in present work NEIW_PSO has been adopted to determine the optimal generation schedule of hydro power plants of the test system for the time horizon of 24hrs. The results are obtained for different population sizes i.e. 5,10,15,20 and 25. It has been observed that population size 5 is giving best suitable value of objective function (1.45E-16). Apart from this results also show that capacity factor of plant 5 of the test system is maximum for effective utilization of water resources.

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