A HYBRID EVOLUTIONARY PROGRAMMING – SIMULATED ANNEALING METHOD FOR HYDRO-THERMAL SCHEDULING WITH COOLING – BANKING CONSTRAINTS

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ABSTRACT

This Paper proposes a new hybrid algorithm for solving the Unit Commitment problem in Hydrothermal Power System using a hybrid Evolutionary Programming – Simulated Annealing method with cooling-banking constraints. The main objective of this project is to find the generation scheduling by committing the generating units such that the total operating cost can be minimized by satisfying both the forecasted load demand and various operating constraints of the generating units. Simulated Annealing (SA) is a powerful optimization procedure that has been successfully applied to a number of combinatorial optimization problems. It avoids entrapment at local optimum by maintaining a short term memory of recently obtained solutions. Numerical results are shown comparing the cost solutions and computation time obtained by using the proposed hybrid method than conventional methods like Dynamic Programming, Lagrangian Relaxation.

Key words: Evolutionary Programming, Simulated Annealing, Unit Commitment, Dynamic Programming, Lagrangian Relaxation.

I. INTRODUCTION

The short-term optimization problem is how to schedule generation to minimize the total fuel cost or to maximize the total profit over a study period of typically a day, subject to a large number of constraints that must be satisfied. The daily load pattern for a given system may exhibit large differences between minimum and maximum demand. Therefore enough reliable power generation to meet the peak load demand must therefore be synchronized prior to the actual occurrence of the load. Thus it is clear that it is not proper and economical to run all the units available all the time. Since the load varies continuously with time, the optimum condition of units may alter during any period.

For instance the availability of fuel in precise, load forecast variable costs affected by the loading of generator units and the losses caused by reactive flows are some of the unpredictable issues. There are other problems of inconsistency that affect the overall economic operation of the electric power station. In order to reach a feasible solution for Unit Commitment Problem (UCP), different considerations must be considered.

Research endeavors have been focused on developing efficient algorithms that can be applied to large power systems and have less memory and computation time requirements. A number of numerical optimization techniques have been employed to solve the complicated UCP. The different categories being used to solve UCP include Classical methods like the Dynamic Programming (DP), the Lagrangian Relaxation (LR), the Simulated Annealing Method (SAM), and the Evolutionary Programming (EP). The major limitations of the numerical techniques are inability to handle problem dimensions, large computation time, more memory space and complexity in programming.

The proposed two-stage method [1] has smaller computational requirements than that of the Simulated Annealing algorithm. The optimal generation from hydro and thermal resources is computed simultaneously in the two stage algorithm; there is no need for assuming constant operation of some reservoirs as in the Simulated Annealing method. No discretization of state and control variables is needed in the proposed method. The required storage as well as computing time in the proposed method is reduced as compared to those in the successive-approximations algorithm. The proposed LR-DP method [2] is efficiently and effectively implemented to solve the UC problem. The proposed LR total production costs over the scheduled time horizon are less than conventional methods especially for the larger number of generating units. The augmented Lagrangian approach [3] presented in this paper accommodates further for pumped-storage units and line flow limitations and concurrently can produce accurate scheduling results. The approach produces feasible schedules and requires no iteration with economic dispatch algorithms. The LR approach [4] to solve the short-term UC Problems was found that it provides faster solution but it will fail to obtain solution feasibility and solution quality problems and becomes complex if the number of units increased. The results revealed that the proposed method [5] is very effective in reaching an optimal generation schedule.

SAM [6-9] is a powerful, general-purpose stochastic optimization technique, which can theoretically converge asymptotically to a global optimum solution with probability one. It has the special characteristic of escaping the local optima by employing a flexible memory system. SAM utilizes a short term memory of recent solutions to lead the algorithm to a different direction away from the local optimum region to obtain better solutions that are near to global optimum.

Its [10] performance compares favorably with constructive DP which is known to be faster than standard LP. It can be used for a rapid approximate optimal scheduling for large scale complex system with multiple cascaded and pumped storage. Results [11] show that with quadratic thermal cost and without prohibited discharge zones, all EP-based algorithms converge faster during initial stages while Fast Evolutionary Programming and Classical Evolutionary Programming slow down in the latter stages compared to Improved Fast EP. Improved Fast EP performs the best amongst the three in solving this problem in terms of execution time, minimum cost, and mean cost.

The solution speed can be thus further improved. There is no obvious limitation on the size of the problem that must be addressed, for its data structure is such that the search space is reduced to a minimum; No relaxation of constraints is required; instead, populations of feasible solutions are produced at each generation and throughout the evolution process; Multiple near optimal solutions to the problem involving multiple constraints and conflicting objectives can be obtained in a reasonable time with the use of heuristics; It works only with feasible solutions generated based on heuristics, thus avoiding the computational burden entailed by the Genetic Algorithm methods which first generate all feasible solutions and then purge the infeasible ones [12].

Hence, in this paper, an attempt has been made to couple EP with SAM (EPSAM) with cooling-banking constraints for meeting these requirements of the UCP, which gives the better solution than the individual EP and SA methods with reasonable time. The validity and effectiveness of the proposed integrated algorithm has been tested with an IEEE test system consisting of 4 hydro generating units and 10 thermal generating units has been considered as case study. And the test results are compared with the results obtained from other methods.

II. PROBLEM FORMULATION

The main objective of UCP is to determine the on/off status of the generating units in a power system by meeting the load demand at a minimum operating cost in addition to satisfying the constraints [13] of the generating units. The problem formulation includes the quadratic cost characteristics, startup cost of thermal power system and operating constraints of thermal and hydro generating units. The power generation cost for thermal power system is given in Equation 1 (a).

$$F_{s,\,it}(P_{s,\,it}) = A_i + B_i P_{s,\,it} + C_i P_{s,\,it}^2 \text{ (Rs/hr)} \qquad 1\text{ (a)}$$

where,

A_i, B_i, C_i - The Cost Function parameters of unit i (Rs/hr, Rs/MWhr, Rs/MW^{2}hr).

$F_{s,\,it}(P_{s,\,it})$ - The generation cost of unit i at time t (Rs/hr).

$P_{s,\,it}$ - The output power from unit i at time t (MW).

The overall objective function (9) of UCP that is to be minimized is given in Equation 1 (b)

$$F_T = \sum_{t=1}^{T} \sum_{i=1}^{N} (F_{it}(P_{it})\, U_{it} + S_i V_{it}) \text{ (Rs/hr)} \qquad 1\text{ (b)}$$

where,

U_{it} – Unit i status at hour t

V_{it} – Unit i start up/ shut down status at time t

F_T – Total operating cost over the schedule horizon (Rs/hr)

S_{it} – Startup cost of unit i at time t (Rs)

A. Constraints

Load Power balance constraint

The real power generated by thermal and hydro generating units must be sufficient enough to meet the load demand and must satisfy the equation

$$\sum_{i=1}^{N} P_{s,\,it} + \sum_{j=1}^{M} P_{h,\,it} = P_{D,i} + P_{L,\,i} \quad 1 \le t \le T \qquad [2]$$

Spinning Reserve constraint

Spinning reserve is the total amount of generation available from all units synchronized on the system minus the present load plus the losses being supplied. The reserve is usually expressed as a percentage of forecasted load demand. Spinning reserve is necessary to prevent drop in system frequency and also to meet the loss of most heavily loaded unit in the power system.

$$\sum_{i=1}^{N} P_{max,\,i}\, U_{it} \ge (P_{D,\,i} + R_t) \quad 1 \le t \le T \qquad [3]$$

Thermal constraints

A thermal unit undergoes gradual temperature changes and this increases the time period required to bring the unit online. This time restriction imposes various constraints on generating unit. Some of the constraints are minimum up/down time constraint and crew constraints.

(a) Minimum Up time

If the units are already running there will be a minimum time before which the units cannot be turned OFF and the constraint is given in [4].

$$T_{on,\,i} \ge T_{up,\,i} \qquad [4]$$

(b) Minimum Down time

If the units are already OFF there will be a minimum time before which they cannot be turned ON and the constraint is given in [5].

$$T_{off,\,i} \ge T_{down,\,i} \qquad [5]$$

Must Run units

Some units in the power system are given must run status in order to provide voltage support for the network.

Unit Capacity limits

The power generated by the thermal unit must lie within the maximum and minimum power capacity of the unit.

$$P_{s,\,i}^{min} \le P_{s,\,i} \le P_{s,\,i}^{max} \qquad [6]$$

B. Hydro constraints

Hydro Plant generation limits

The power generated by the hydro units must be within the maximum and minimum power capacity of the unit (1).

$$P_{h,i}^{min} \le P_{h,i} \le P_{h,i}^{max} \qquad [7]$$

Hydraulic network constraints

Physical limitations on reservoir storage volumes and discharge rates.

$$V_{h,i}^{min} \le V_{h,i} \le V_{h,i}^{max} \qquad [8]$$

$$Q_{h,i}^{min} \le Q_{h,i} \le Q_{h,i}^{max} \qquad [9]$$

The initial volume and the final volume that is to be retained at the end of scheduling period.

$$V_{h,it}^{t=0} = V_{h,i}^{begin} \qquad [10]$$

$$V_{h,it}^{t=T} = V_{h,i}^{end} \qquad [11]$$

The Continuity equation for hydro reservoir network is given in [12].

$$V_h(i,t) = V_h(i,t-1) + I_h(i,t) - S_h(i,t) - \sum_{m=1}^{Ru} [Q_h(m, t-\Gamma(i,m)) + S_h(m, t-\Gamma(i,m))] \qquad [12]$$

Hydro plant unit power generation characteristics

The hydro power generated is related to the reservoir characteristics as well as water discharge rates. Hydro power output is a function of the volume of the reservoir and discharge rate. The equation representing the hydro power generation characteristics is given in [13].

$$P_h(i,t) = C_{1,\,i} V_h(i,t)^2 + C_{2,\,i} Q_h(i,t)^2 + C_{3,i} [V_h(i,t)\, Q_h(i,t)]\, C_{4,i} V_h(i,t) + C_{5,i} Q_h(i,t) + C_{6,i} \qquad [13]$$

III. EPSAM FOR HYDRO-THERMAL UCP

The proposed integrated algorithm combines EP and SA techniques to solve the UCP problem. The EP technique, hold the main responsibility of finding the optimal point and SA assists EP to converge towards the optimum point quickly. The search is basically done with EP, but additionally the SA is used to escape the search path from local optimum point. The algorithm for the proposed method is as follows: -

1. Commit all the M hydro units and considering discharge rates ($Q_h(i,t)$) between the limits, calculate the volumes ($V_h(i,t)$) of the reservoirs from 1 to M.

$$V_h(i,t) = V_h(i,t-1) + I_h(i,t) - Q_h(i,t) - S_h(i,t) + \sum_{m=1}^{Ru} [Q_h(m, t-\tau(i,m) + S_h(m,t-\zeta(i,m))] \quad [14]$$

2. Calculate the power produced by each hydro unit ($P_h(i,t)$) from the values of discharge rates and volumes.

$$P_h(i,t) = C_{1,i}V_h(i,t)^2 + C_{2,i}Q_h(i,t)^2 + C_{3,i}(V_h(i,t) * Q_h(i,t)) + C_{4,i}V_h(i,t) + C_{5,i}Q_h(i,t) + C_{6,i} \quad [15]$$

3. Sum up all the hydro powers for each period and subtract the total hydro power from the power demand for each period.

4. Find the remaining load demand to be met with thermal power such that

$$\sum_{i\in Rs} P_s(i,t) + \sum_{i=Rh} P_h(i,t) = PD(t) + PL(t) \quad [16]$$

5. Obtain the power (P_{dt}) to be produced by thermal unit,

$$PD_t = PD - PD_h \quad [17]$$

and for the thermal system Unit Commitment is performed as below.

6. An initial population of "parent" solutions S_k, k=1,2,3…,M (where M is the number of parents), is generated at random.

7. The objective function value associated with each solution S_k is calculated by economically dispatching the hourly load to the operating units and by computing the total fuel and start-up/shut-down costs, i.e.,

$$TC(S_k) = TFC(S_k) + TSUC(S_k) + TSDC(S_k) \quad [18]$$

8. An offspring S_k' is created from each parent by adding a Gaussian random variable $N(0, \sigma^2_k)$ to the elements a_{ijk} of parent S_k:

$$a'_{ijk} = a_{ijk} + N(0, \sigma_k^2) \quad [19]$$

$$\sigma_k = \beta_i * \frac{TC(S_k) * p_i}{TC_{\min}} \quad [20]$$

Here, the value of β_i is chosen in such a manner that product $\beta_i \, x \, p_i$ should guarantee a minimum variance. Normally constant scaling factor is used in conventional EP. In this non-linear scaling factor is used for better convergence. For the first 40% of the total number of generations (N1) the decrement in scaling factor 'g1' is calculated as

$$g1 = \frac{(\beta_{\max} - \beta_{mid})}{N1} \quad [21]$$

For the remaining 60% of the total number of generations (N2) the decrement in is calculated as 'g2' as

$$g2 = \frac{(\beta_{mid} - \beta_{\min})}{N2} \quad [22]$$

9. Each feasible offspring S_k' is evaluated according to 7.

10. For each feasible candidate, parent or offspring, a value W_k is assigned.

$$W_k = \sum_{\zeta=1}^{c} W_\zeta \quad [23]$$

$$W_\zeta = \begin{cases} 1, \text{ if } TC(S_k) < TC(S_r) \\ 0, \text{ otherwise}; \end{cases} \quad [24]$$

where $r = [2Mu + 1]$, *r not equal to* k, $[x]$ denotes the greatest integer less than or equal to x, c is the number of competitions, and u is a uniform random number ranging over $[0,1]$. Here, c is set at *1/10* of the population.

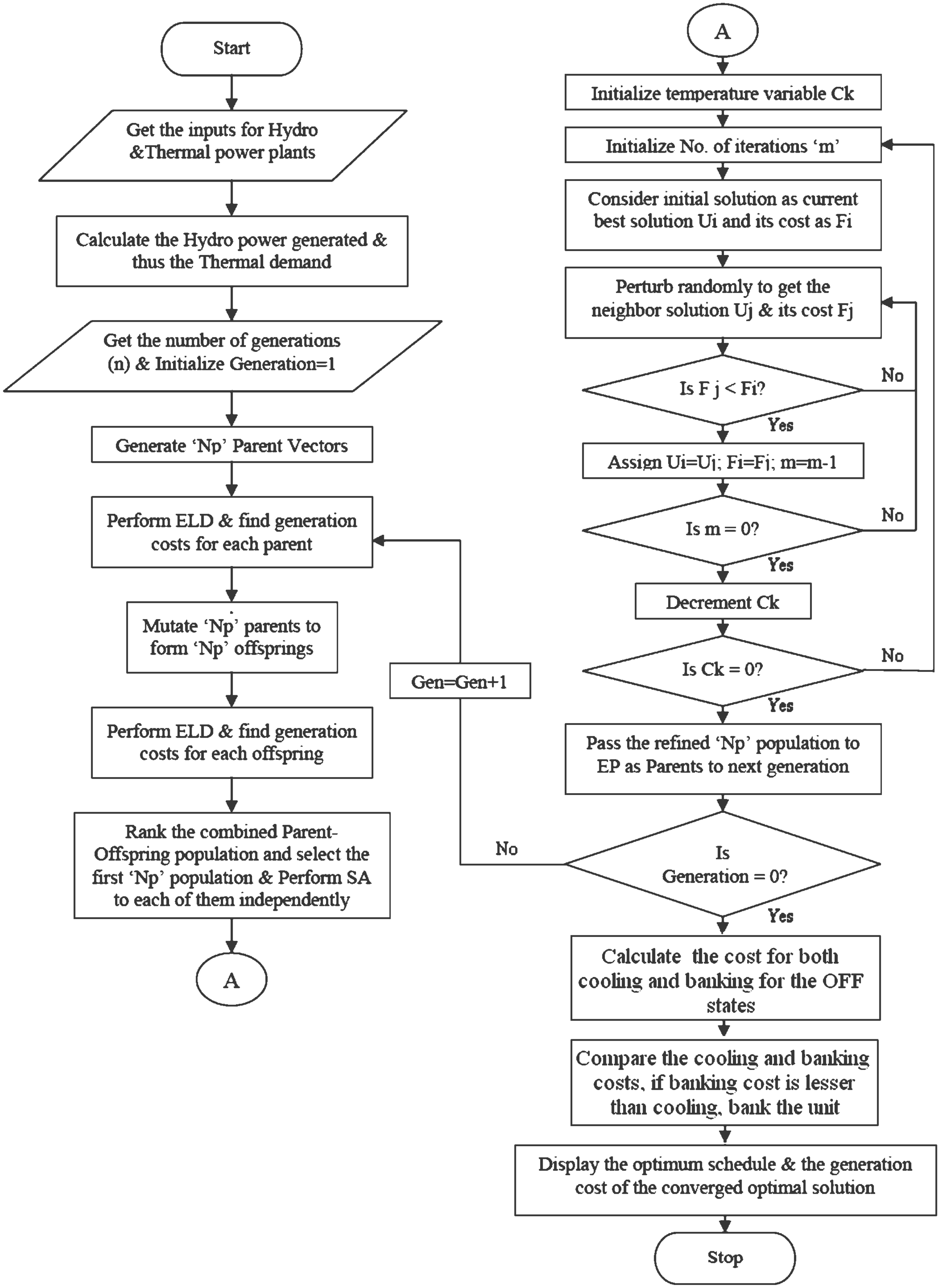

Fig. 1. EPSAM flowchart for Hydro-Thermal UCP

11. The feasible competitors are ranked in descending order of W_k. The first M solutions survive and are transcribed along with their elements to form the basis for Simulated Annealing Algorithm.

12. In Simulated Annealing Algorithm the temperature variable (C_p) is initially assigned to be relatively higher value.

13. The number of iteration 'n' to be performed for refining each individual solution is obtained and the process is done to every individual independently.

14. The initial solution is assigned as the current best solution 'Ui', the function to be checked is assumed to be minimum, in our case it is the cost 'Fi'.

15. Random perturbation is done to the current solution and the neighbouring solution 'Uj' is obtained whose feasibility is examined by checking to see if there is an uptime or downtime constraint.

16. Check if the cost Fj ≤ Fi, if less replace Uj and Fj as current solutions for Ui and Fi, if greater check if exp [(Fi-Fj)/Ck] ≥ U (0, 1), if satisfied, set Ui = Uj.

17. The iteration count 'n' is decremented and another neighbouring solution is generated. When the iteration count 'n' reaches zero, the temperature variable C_p is lowered to a new value.

18. The entire process terminates when sufficient iterations have occurred at the specified lowest temperature and this process is repeated to all the individual solution till all the Np solutions are refined.

19. The refined Np number of population is passed on to the EP part as the parents for next generation. And this process is repeated till the convergence in production cost is reached along with the optimum schedule having satisfied the constraints

20. For the units, which are in the off states, calculate the cost for both cooling and banking.

21. Compare the cooling and banking costs, if banking cost is lesser than cooling, bank the unit.

22. Print the optimum schedule.

The diagrammatic description of the proposed hybrid EPSAM algorithm is shown in Fig. I.

A. Termination Criterion of the algorithm

The algorithm can be terminated at any time if it satisfies certain conditions. There may be several possible conditions for termination of the algorithm. But the best conditions are selected by the quality of the solution obtained after termination. In this algorithm two possible conditions for termination have been applied. The algorithm will be terminated if the following conditions are satisfied:

1. Given maximum number of iterations have been performed (or)

2. The best operating cost obtained repeats successively for certain number of iterations.

IV. CASE STUDY

An IEEE test system consisting of 4 hydro generating units and 10 thermal generating units has been considered as a case study (12). A time period of 24 hours is considered and the unit commitment problem is solved for these 10 units power system. The required inputs for solving the UCP are tabulated below. The Cost convergence graph of EPSAM and hydro and thermal generations are shown in Figures 2 and 3. The operating cost comparison of EPSAM with EP, SAM, LR and DP is shown in Table 1.

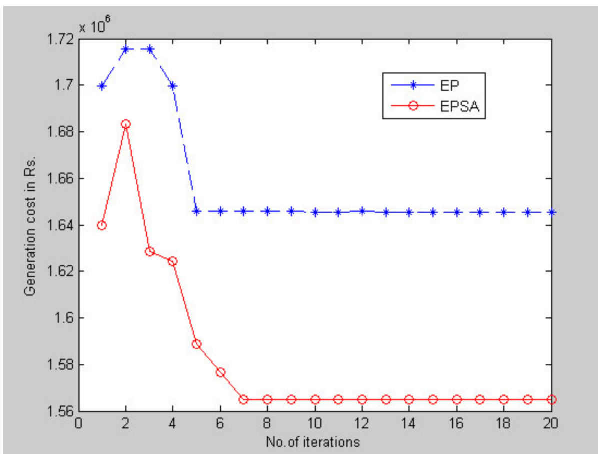

Fig. 2. Cost Convergence Characteristics for 20 Iterations

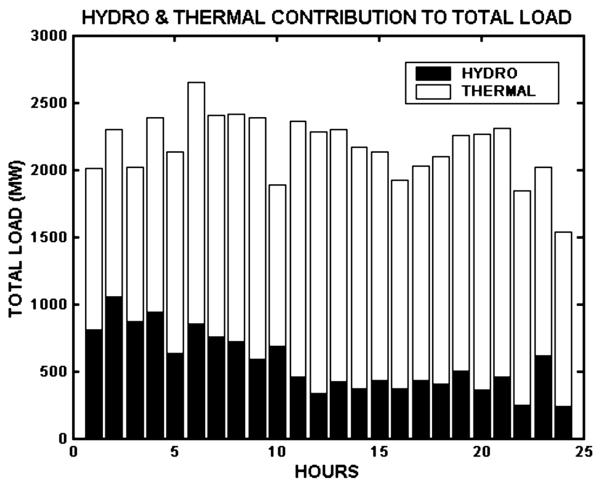

Fig. 3. Hydro & Thermal generations

Table 1
Production Cost for Different Techniques

System	Methods	Total Cost (p.u)	CPU Time Sec
10 Thermal+4 Hydro Systems	DP	1.00000	325
	LR	0.96481	279
	SA	0.95000	270
	EP	0.94902	224
	EPSA	0.92690	218
	EPSA(C&B)	0.92578	216

By analyzing the graphs between the cost and iterations, as iterations increased the cost will be reduced with the slight increase of computation time. From the results obtained, we observed that the EPSAM method with cooling-banking constraints approaches to near optimal solution.

V. CONCLUSION

This paper is concerned with obtaining a better efficient, fast and robust solution for unit commitment problem through EPSAM Technique with cooling-banking constraints. In EPSAM, the solution obtained through EP is fed as the initial solution to SAM. SAM is also used to verify certain constraints, which is time consuming when done by EP. The use of Gaussian distribution with non linear scaling factor in the process of mutation incorporated in the EP helps in reducing the computing time. On comparing the results attained by the different techniques the EPSAM with cooling-banking constraints obviously displays a satisfactory performance. Thus, the solution obtained through EPSAM is having better quality and in terms of economy and computation time.

NOMENCLATURE

E_c	:	Energy of the current configuration
E_{Config}	:	Energy of a given configuration
E_t	:	Energy of the trail configuration
F_{it} (P_{it})	:	Production cost of unit i at a time t (Rs/hr.)
F_T	:	Total operating cost over the scheduled horizon (Rs/Hr)
K	:	Constant
N	:	Number of available generating units
P_{Config}	:	Probability of a given configuration
PD_t	:	System peak demand at hour t (MW)
P_{it}	:	Output power from unit i at time t (MW)
P_{maxi}	:	Maximum generation limit of unit i (MW)
P_{mini}	:	Unit i minimum generation limit (MW)
R_t	:	Spinning reserve at time t (MW).
S_{it}	:	Start up cost of unit i at hour t (Rs).
S_{oi}	:	Unit i cold start – up cost (Rs).
T	:	Scheduled time horizon (24 hrs)
$Tdown_i$	:	Unit i minimum down time (Hr)
$Toff_i$	:	Duration for which unit i is continuously OFF (Hr)
Ton_i	:	Duration for which unit i is continuously ON (Hr)

$Tshut_i$	:	Instant of shut down of a unit i (Hr)
$Tstart_i$	:	Instant of start up of a unit i (Hr)
Tup_i	:	Unit i minimum up time (Hr)
U (0,1)	:	Uniform distribution with parameters 0&1
U_{it}	:	Unit i status at hour t = 1 (if unit is ON) = 0 (if unit is OFF)
UD (a, b)	:	Discrete uniform distribution with parameters a and b.
V_{it}	:	Unit i start up /shut down status at hour t = 1 if the unit is started at hour t and 0 otherwise.
F	:	Composite cost function
F_i	:	Fuel cost of i^{th} thermal unit in Rs/hr
P_s (i, t)	:	Generation of i^{th} thermal unit at time t in MW
P_h (i, t)	:	Generation of i^{th} hydro unit a time t in MW
V_h (i,,t)	:	Storage volume of i^{th} reservoir at time t in m^3
Q_h (i,,t)	:	Water discharge rate of i^{th} reservoir at time t in m^3
P_D (t)	:	Power demand at time t in MW
P_L (t)	:	Total Transmission line losses at time t in MW
S_h (i, t)	:	Spillage of i^{th} reservoir at time t in m^3
I_h (i, t)	:	Inflow rate of i^{th} reservoir at time t in m^3
H_i (t)	:	Net head of i^{th} reservoir at time t in m^3
α, β, γ	:	Thermal generation cost coefficients
$C_{i,1}$ to $C_{i,6}$	:	Hydro power generation coefficients
$\tau_{i,m}$	:	Water transport delay from reservoir % to i
R_u	:	Set of upstream units directly above i^{th} hydro unit
R_h / R_s	:	Set of Hydro/Thermal plants in the system
i,m	:	Reservoir index, index of reservoir upstream of the i^{th} reservoir
t,T	:	Time index, scheduling period
V,i^{begin}	:	Initial storage volume of i^{th} reservoir in m^3
V,i^{end}	:	Final storage volume of i^{th} reservoir in m^3
P_i	:	Output generation for unit i in MW
P_L	:	Total current system load in MW
PT_L	:	Total system transmission losses in MW
OBJ	:	Objective cost function
F_i	:	Cost function for unit i

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