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A Novel Approach for Solving Unit Commitment Problem using Evolutionary Programming Method with Cooling – Banking Constraints

KEYWORDS Unit Commitment Problem, Evolutionary Programming, Cooling-Banking Constraints, Hydro-Thermal Scheduling, Dynamic Programming

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ABSTRACT *This paper presents a novel approach for solving Unit Commitment Problem (UCP) using Evolutionary Programming Method (EPM) with Cooling – Banking Constraints. The objective of this paper 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. An initial population of parent solutions is generated at random. Here the parents are obtained from a pre-defined set of solutions i.e. each and every solution is adjusted to meet the requirements. Then, random recommitment is carried out with respect to the unit's minimum down times. The best population is selected by Evolutionary Strategy (ES). The numerical results are shown comparing the cost solutions and computation time obtained by using the EPM with cooling and banking constraints with conventional methods like Dynamic Programming (DP).*

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.

Research endeavors, therefore, have been focused on; efficient, near-optimal UC algorithms, which can be applied to large-scale, power systems and have reasonable storage and computation time requirements. A survey of existing literature on the problem reveals that various numerical optimization techniques have been employed to approach the complicated unit commitment problem. More specifically, these are the Dynamic Programming method (DP), the Lagrangian relaxation method (LR), the Simulated Annealing method (SA), the Tabu Search (TS), the Genetic Algorithm (GA), the Artificial Neural Network (ANN), the Evolutionary Programming (EP) and so on. The major limitations of the numerical techniques are the problem dimensions, large computational time and complexity in programming.

The DP method [1], [8] is flexible but the disadvantage is the "curse of dimensionality", which results it may leads to more mathematical complexity and increase in computation time if the constraints are taken in to consideration. The LR approach [2-3], to solve the short-term UC Problems was found that it provides faster solution but it will fail to obtaining solution feasibility and solution quality problems and becomes complex if the number of units increased. SA [6], is a powerful, general-purpose stochastic optimization technique, which can theoretically converge asymptotically to a global optimum solution with probability one. But it will take much time to reach the near-global minimum. The TS [5] is an iterative improvement procedure that starts from some initial feasible solution and attempts to determine a better solution in the manner of a greatest – decent algorithm. However, TS is characterized by an ability to escape local optima by using a short-term memory of recent solutions. GA [3] and [6], is a general-purpose stochastic and parallel search method based on the mechanics of natural selection and natural genetics. It is a search method to have potential of obtaining near-global minimum. And it has the capability to obtain the accurate results within short time and the constraints are included easily. The GA has the advantages of good convergent property and a significant speedup over traditional methods and can obtain high quality solutions. The "Curse of dimensionality" is surmounted, and the computational burden is almost linear with the problem scale.

Evolutionary programming [7] and [9] simulates evolution as a phenotypic process, which emphasizes the behavioral link between parents and offspring, rather than their generic link, as in genetic algorithms. Evolutionary programming starts with an initial population of abstracted organisms, each of which is called a species (some literature use the term "individual" to mean the same thing). They are evolved over many generations, using mutation as the only search operator. In each generation, each species is evaluated using a fitness function. Tournament selection is then applied, and the best half of the population is copied to the next generation. Hence, local search and hybrid combinations of different methods have been proposed to obtain a robust optimization method. EP has the advantages of good convergent property and significant speedup over traditional methods. A power system consisting of 4 hydro generating units and a thermal system with seven generating units has been considered as a case study. Finally these results are compared with the conventional method.

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 [8] 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 (1a).

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

where,

A_i, B_i, C_i - The Cost Function parameters of unit i (Rs/hr, Rs/MWhr, Rs/MW2hr).

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

$P_{s,t}$ - 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 (1b)

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(Rs/hr) (1b) $$F_T = \sum_{t=1}^{T} \sum_{i=1}^{N} (F_i (P_i) U_i + S_i V_i)$$

Where,

U_t – Unit i status at hour t

V_t – Unit i start up/ shut down status at time t

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

S_t – Startup cost of unit i at time t (Rs)

A. Thermal Constraints

1. 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

$$1 \leq t \leq T \quad \sum_{i=1}^{N} P_{s,t} + \sum_{j=1}^{M} P_{h,t} = P_{D,i} + P_{L,i} \tag{2}$$

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.

$$1 \leq t \leq T \quad \sum_{i=1}^{N} P_{\max,i} U_{t} \geq (P_{D,i} + R_t) \tag{3}$$

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.

i. 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).

$$T_{on,i} \geq T_{up,i} \tag{4}$$

ii. 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).

$$T_{off,i} \geq T_{down,i} \tag{5}$$

4. Must Run units

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

5. Unit Capacity limits

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

$$P_{s,i}^{\min} \leq P_{s,i} \leq P_{s,i}^{\max} \tag{6}$$

B. Hydro constraints

1. Hydro Plant generation limits

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

$$P_{h,i}^{\min} \leq P_{h,i} \leq P_{h,i}^{\max} \tag{7}$$

2. Hydraulic network constraints

Physical limitations on reservoir storage volumes and discharge rates.

$$V_{h,i}^{\min} \leq V_{h,i} \leq V_{h,i}^{\max} \tag{8}$$

$$Q_{h,i}^{\min} \leq Q_{h,i} \leq Q_{h,i}^{\max} \tag{9}$$

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

$$V_{h,t}^{t=0} = V_{h,i}^{begin} \tag{10}$$

$$V_{h,t}^{t=T} = V_{h,i}^{end} \tag{11}$$

The Continuity equation for hydro reservoir network is given in (12).

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

3. 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).

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

III. EVOLUTIONARY PROGRAMMING

A. Introduction

EP is a mutation-based evolutionary algorithm [7] and [9] applied to discrete search spaces. David Fogel (Fogel 1988) extended the initial work of his father Larry Fogel (Fogel, 1962) for applications involving real-parameter optimization problems. Real-parameter EP is similar in principle to evolution strategy (ES), in that normally distributed mutations are performed in both algorithms. Both algorithms encode mutation strength (or variance of the normal distribution) for each decision variable and a self-adapting rule is used to update the mutation strengths. Several variants of EP have been suggested (Fogel, 1992).

A. Evolutionary Strategies

For the case of Evolutionary strategies [9] D. B. Fogel remarks "evolution can be categorized by several levels of hierarchy: the gene, the chromosome, the individual, the species, and the ecosystem." Thus, while Genetic Algorithms stress models of genetic operators, Evolutionary Strategies emphasize mutational transformation that maintains behavioral linkage between each parent and its offspring at the level of the individual. Evolutionary Strategies are a joint development of Bienert, Rechenberg, and Schwefel. The first applications were experimental and addressed some optimization problems in hydrodynamics.

B. EP Based Approach to Hydro Thermal UCP

1. Initialize Np random parent vectors for discharge.
2. Calculate the volume and hence power for each parent vectors for each period.
3. Check for volume limits and power limits.
4. Calculate the Thermal Power to be generated by subtracting the total Hydro power from the load demands for various periods.
5. Using Composite Thermal plant characteristics, cost of production of Thermal power is calculated.
6. From Np parent vectors Np off springs are created using Mutation
7. Repeat steps 2 to 5 for Np off springs.
8. From 2Np vectors first Np vectors giving minimum cost of Thermal production are chosen and they are initialized as parent vectors for next iteration.
9. If the given Number of iterations is over, the remaining load demand is calculated and Thermal units are committed to meet the demand.

C. Evolutionary Programming for UCP

The Flowchart for UCP using EP is shown in Figure 1.

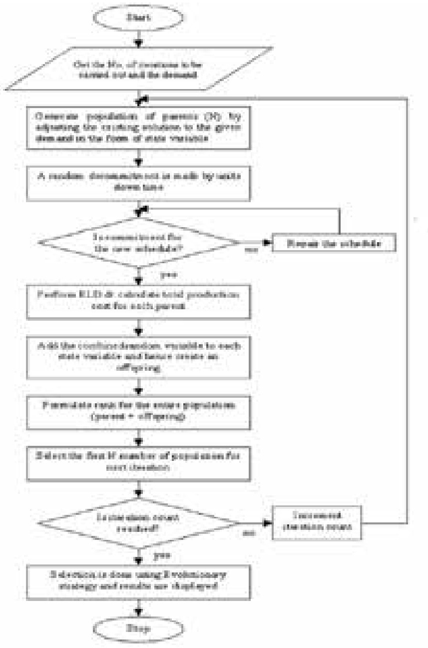


Figure 1. Flow Chart for UCP using EP

1. Initialize the parent vector p = [p1, p2, … pn], i = 1,2,… Np such that each element in the vector is determined by pj ~ random (pjmin, pjmax), j = 1,2,…N, with one generator as dependent generator.
2. Calculate the overall objective function if the UCP is given in equation (3) using the trail vector pi and find the minimum of FTi.
3. Create the offspring trail solution pi' using the following steps.

Calculate the standard deviation

$$\sigma j = \beta(F_{Tij} / \min(F_{T}))(P_{j\max} - P_{j\min})$$

Add a Gaussian random variable N (0, sj2) to all the state variable of pi, to get pi'.

4. Select the first Np individuals from the total 2Np individuals of both pi & pi' using the following steps for next iteration.
   a. Evaluate r = (2Np random (0,1) + 1)
   b. Evaluate each trail vector by Wpi=sum (Wx) Where x = 1,2,…Np, i = 1,2,…2Np such that Wx = 1 if FTij / (FTij+FTir) < random (0,1), otherwise, Wx = 0.
5. Sort the Wpi in descending order and the first Np individuals will survive and are transcribed along with their elements to form the basis of the next generation.
6. The above procedure is repeated from step (2) until a maximum number of generations Nm is reached.
7. Selection process is done using Evolutionary strategy.
8. For the units, which are in the off states, calculate the cost for both cooling and banking.
9. Compare the cooling and banking costs, if banking cost is lesser than cooling, bank the unit.
10. Print the optimum schedule.

IV. CASE STUDY

A power system consisting of 4 hydro generating units and a thermal system with seven generating units has been considered as a case study. A time of 6 periods, consisting of 4 hours each representing the 24 hours of a day is considered and the unit commitment problem is solved for these seven units power system. The required inputs for solving the UCP are briefed here. The total hourly load, the cost function parameters of each unit for thermal system, volume and discharge limits for hydro system, and hydro coefficients for hydro system are shown in Table I to Table IV.

TABLE I- TOTAL HOURLY LOAD

Period(j)	Load(MW)	Period(j)	Load(MW)
1	1249	**13**	908
2	1166	**14**	901
3	1184	**15**	896
4	1118	**16**	860
5	1165	**17**	843
6	1173	**18**	833
7	1152	**19**	855
8	1130	**20**	852
9	1015	**21**	849
10	1135	**22**	804
11	969	**23**	900
12	966	**24**	1210

TABLE II- COST FUNCTION PARAMETERS OF THERMAL SYSTEM

Units	Upper limit (Mw)	Lower Limit (Mw)	Running Cost			Start-Up Cost (Rs)
			A (Rs/MWh^2)	B (Rs/MWh)	C (Rs)	
1	60	15	750	70	0.255	34590
2	80	20	1250	75	0.198	41100
3	100	30	2000	70	0.198	57800
4	120	25	1600	70	0.191	32200
5	150	50	1450	75	0.106	39000
6	150	50	4950	65	0.0675	26270
7	200	75	4100	60	0.074	27200

TABLE III- VOLUME AND DISCHARGE LIMITS OF HYDRO SYSTEM

Plant No.	$V_{hj\min}$ (m^3)	$V_{hj\max}$ (m^3)	V_{ini} (m^3)	$V_{hj,end}$ (m^3)	$Q_{\min}$ (m^3/sec)	$Q_{\max}$ (m^3/sec)	$P_h$min (Mw)	$P_h$max (Mw)
1	0	200	100	100	0	30	0	500
2	0	200	100	100	0	30	0	500
3	0	350	150	150	0	40	0	500
4	0	350	150	150	0	40	0	500

TABLE IV- COEFFICIENTS FOR HYDRO SYSTEM

Plant No.	C1	C2	C3	C4	C5	C6
1	-0.0042	-0.42	0.03	0.9	10	50
2	-0.0040	-0.3	0.015	1.14	9.5	70
3	-0.0016	-0.125	0.014	0.55	5.5	40
4	-0.0030	-0.31	0.027	1.44	14	90

The cost convergence characteristics of EP for 10, 20 and 30 iterations are shown in Figures 2 to 4.

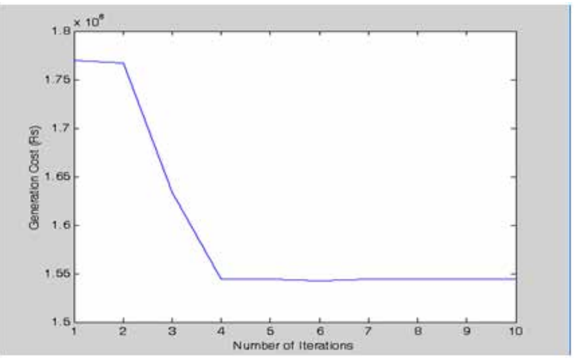


Figure 2. Cost Convergence Characteristics for 10 Iterations

Figure 3. Cost Convergence Characteristics for 20 Iterations

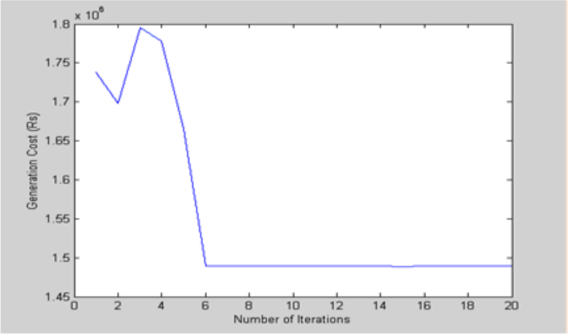
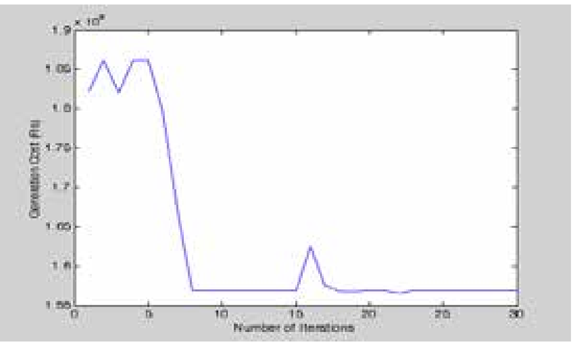


Figure 4. Cost Convergence Characteristics for 30 Iterations



By analyzing the graphs between the cost and iterations, as iterations increased the cost will be reduced with the slight increase of computation time. The cost comparison between the DP, EP and EP with cooling and banking constraints method are shown in the Table V. From the results obtained, we observed that the EP with cooling and banking constraints method approaches to near optimal solution.

TABLE V- COMPARISONS OF TOTAL PRODUCTION COST

Method	Total Production Cost
Dynamic Programming	Rs. 24,03,000
Evolutionary Programming	Rs. 16,33,900
Evolutionary Programming with Cooling- Banking	Rs. 16,11,560

V. CONCLUSION

This paper presents EP method to solve the unit commitment problem. In this method, the essential processes simulated in the procedure are mutation, competition, and selection. The mutation rate is computed as a function of the ratio of the total cost by the schedule of interest to the cost of the best schedule in the current population. Competition and selection are applied to select from among the parents and the offspring, the best solutions to form the basis of the subsequent generation. Then, a random recommitment is carried out with respect to the unit's minimum down times. And the selection process is done using Evolutionary Strategy. In comparison with the results produced by the referenced techniques (EP, DP) shown in Table V, the EP method obviously displays a satisfactory performance. It works only with feasible solutions generated based on heuristics, thus avoiding the computational burden entailed by the GA methods which first generate all feasible solutions and then purge the infeasible ones.

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