Reservoir Operation using Combined Genetic Algorithm & Dynamic Programming for Ukai Reservoir Project

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Abstract

Operation of reservoirs, often for conflicting purposes, is a difficult task. The uncertainty associated with reservoir operations is further increased due to the on-going hydrological impacts of climate change. Therefore, various artificial intelligence techniques such as genetic algorithms, ant-colony optimization, fuzzy logic and mathematical optimization methods such as Linear programming, Dynamic Programming are increasingly being employed to solve multi-reservoir operation problems. For doing optimization, objective function is formulated which is subjected to various constraints. Constraints include continuity equation, reservoir storage constraints, release constraint and overflow constraint. Monthly data for the study are used of year 2007 to 2011. Genetic algorithm is based on Darwin's theory of Survival of the fittest. GA reduces the difference between releases and demand and returns the value of the fitness function / Objective function. In 2007, using Genetic Algorithm the generation of power can be increased 9.22% through optimal releases. There is 7.14% increase in optimal reservoir release. Further include the study of to optimize the monthly releases from the reservoir i.e. to minimize the sum of the squared difference between monthly release of water from the reservoir and downstream demands for Ukai Reservoir Project. DP is a quantitative technique which converts one big/large problem having many decision variables into a sequence of problem each with a small number of decision variables. DP reduces the difference between releases and demand and returns the value of the Objective function. After that the difference between actual releases and optimal releases i.e. Maximum Absolute Error is calculated for a month of July, August, September and October for each year. Also for evaluation of models developed by using dynamic programming the Root Mean Square Error and Correlation coefficient is calculated for all models. And also net additional available water for every year is also carried out.
Keyword- Dynamic Programming, Genetic Algorithm, Reservoir Operation, Ukai Reservoir

I. INTRODUCTION

A dam is a barrier built across a watercourse for impounding water. By erecting dams, humans can obstruct and control the flow of water in a basin. A reservoir is an artificial lake, usually the result of a dam, where water is collected and stored in quantity for various uses.

Main purposes of reservoir are irrigation, Irrigation, Water supply, Hydroelectric Power Generation, Flood Control, Navigation, Recreation, Development of fish & wild life Soil Conservation.

Hydroelectric power plants do not use up resources to create electricity nor do they pollute the air, land, or water, as other power plants may. Water, when it is falling by the force of gravity, can be used to turn turbines and generators that produce electricity.

Reservoir can be used to retain high rainfall events to prevent or reduce downstream flooding and then releases the stored water to fulfill the various demands for irrigation and other use for the social and economic development of the related area.

II. RESERVOIR OPERATION

The problem in reservoir operation is typically to determine the operating policy, which is a specification of how much water is to be released each period, depending on the state of the system in that period, to best attain a specified objective or goal.

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit.

Hydropower projects are operated primarily with the goal of maximizing the value of energy generated, while meeting constraints on upstream water supply and regulatory constraints on downstream releases.

The flow in the river changes seasonally and from year to year, due to temporal and spatial variation in precipitation. Thus, the water available abundantly during the monsoon season becomes scarce during the non-monsoon season, when it is most needed. The traditional method followed commonly for meeting the needs of water while the scarce period is a construction of a storage reservoir on the river course. The excess water during the monsoon season is stored in such reservoirs for eventual use in a lean period. Construction of storages will also help in control of flood, as well as generation of electricity power. Without proper regulation schedules, the reservoir may not meet the full objective for which it was planned and may also pose a danger to the structure itself.

III. OBJECTIVES OF THE STUDY

- To use genetic algorithm, its mechanism and its applications for optimization of releasing water for maximization of hydropower generation for the Ukai reservoir project,
- To analyze the reservoir operation optimization model for Ukai reservoir project.
- Understand the terminologies, Identify the methods, Formulation of model, Solution of dynamic programming problems used in dynamic programming.

IV. GENETIC ALGORITHMS

Charles Darwin stated the theory of natural evolution in the origin of species. Over several generations, biological organisms evolve based on the principle of natural selection “survival of the fittest” to reach certain remarkable tasks. Genetic algorithms are based on this Darwin’s theory. In the computer science field of artificial intelligence, a genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover.
We can start to evolve solutions to the search problem using the following steps:

1) Initialization: The initial population of candidate solutions is usually generated randomly across the search space. However, domain-specific knowledge or other information can be easily incorporated.
2) Evaluation: Once the population is initialized or an offspring population is created, the fitness values of the candidate solutions are evaluated.
3) Selection: Selection allocates more copies of those solutions with higher fitness values and thus imposes the survival-of-the-fittest mechanism on the candidate solutions.
4) Recombination: Recombination combines parts of two or more parental solutions to create new, possibly better solutions (i.e. offspring). The offspring under recombination will not be identical to any particular parent and will instead combine parental traits in a novel manner (Goldberg, 2002).
5) Mutation: While recombination operates on two or more parental chromosomes, mutation locally but randomly modifies a solution. Again, there are many variations of mutation, but it usually involves one or more changes being made to an individual’s trait or traits. In other words, mutation performs a random walk in the vicinity of a candidate solution.
6) Replacement: The offspring population created by selection, recombination, and mutation replaces the original parental population. Many replacement techniques such as elitist replacement, generation-wise replacement and steady-state replacement methods are used in GAs.

Repeat steps 2–6 until a terminating condition is met.

V. DYNAMIC PROGRAMMING

Dynamic programming is originated by Richard E Bellman and GB Dantzing in early 1950‘s. It is a quantitative technique which converts one big/large problem having many decision variables into a sequence of problem each with small number of decisions variables. Thus, a big problem which is difficult to solve can be converted into a series of a small problems, which can be easily solved it attempts to optimize multi-stage decision variables and uses the word ‘programming’ in the mathematical sense of selection of optimal allocation of resources. Also, the word ‘dynamic’ is used to indicate that the decisions are taken at a number of stages like daily, weekly etc. Stage – When a large problem is developed into various sub-problems in a sequence, these are the stages of the original problem. It is in fact, each point where the decision must be made, for example, in salesman allocation, a stage may represent a group of cities, in the case of replacement problem, and each year may represent a stage. State – Specific information is describing the problem at different stages with the help of variables. The variables linking two stages are called the state variables. In the salesman allocation problem replacement problem, the state is the beginning with a new machine. Principle of Optimality - Bellman’s principle of optimally sates “An optimal policy (a sequence of decision) has the property that whatever the initial state and decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision”. According to this principle, a wrong decision (non-optimal) taken at one stage does not mean that optimum decisions for the remaining stages cannot be taken. Forward and Backward Recursive approach – It is a type of computation Forward or Backward depending upon whether we proceed from stage 1 to n i.e. S1 → S2 S3 → Sn or from stage Sn to S1 i.e. Sn → Sn-1 → Sn-2 → S1

VI. STUDY AREA

The area selected for the present study is the catchment area of the Ukai dam, which is located across Tapi River near Ukai village of Fort Songadh taluka in Surat district. Its catchment is located between longitudes 73º32'25" to 78º36'3" E and latitudes 20º5'0" to 22º52'30" N. The dam is located at about 29 km upstream of the Kakrapar weir. The total catchment area of the Ukai reservoir is 62,225 sq. km, which lies in the Deccan plateau. The catchment of the dam covers large areas of 12 districts of Maharashtra, Madhya Pradesh and Gujarat. The command area of 66,168 Ha is spread over the districts of Surat, Tapi, Navsari and Valsad. The 75% dependable yield of Tapi River at Ukai dam site is 11,350 MCM. Out of this, the share of Gujarat is 3,947 MCM or 38.4%. This water is utilized to:

- Provide irrigation in 152,000 ha in the command of Ukai Left Bank and Right Bank canals,
- Firm up irrigation in 227,500 ha in the command of Kakrapar canals, and
- Generate hydropower up to 300 MW for 8 – 10 hours a day to meet the peak demands.

VII. METHODOLOGY

Based on the releases for hydropower generation the objective function and constraints are to be evaluated for optimization of reservoir operation using Genetic Algorithms. The objective for optimization problem adopted is to maximize the hydropower generated from the reservoir releases for power (P) with the other demands from the reservoir as constraints. If P is expressed in million cubic meters (MCM) per month and head causing the flow, h in meters, then power produced P in MW hours for a 30 day month is given by P = R x h. The objective is to maximize total hydropower produced in a year.
Thus the objective for hydropower optimization is

$$\text{Maximize } Z = \sum_{t=1}^{12} Pt$$

This objective function is subject to the following constraints.

A. Releases for Power and Turbine Capacity Constraints

The releases into turbines for hydropower production should be less than or equal to the flow corresponding to the maximum capacity of the turbine. Also the power production in each month should be greater than or equal to the firm power.

$$RP_t \leq TC \qquad t = 1,2 ,.....12 \quad ....(1)$$
$$RP_t \geq FP \qquad t = 1,2 ,.....12 \quad ....(2)$$

Where RPt is release for power in the period t, TC is turbine capacity and t FP is firm power for the period t. The lower bound is the firm power and the upper bound is the capacity of the turbines.

B. Reservoir Storage Continuity Constraints

If the evaporation losses are expressed as a function of storage, storage continuity equation is given by (Loucks et al., 1984) this constraint involves releases for power, releases for irrigation, overflows, reservoir storage, inflows and the losses through the reservoir during the period t for all months expressed in volume units.

$$S_{t+1} = S_t + I_t - Q_t - R_t - Ovf_t - E_t \qquad .....(3)$$

Where,
S_{t+1} = Storage in the reservoir at the time period t, MCM.
I_t = Inflow into the reservoir during time period t, MCM.
Q_t = Outflow from the reservoir during time period t, MCM.
Ovf_t = Overflow from the reservoir during time period t, MCM.
E_t = Evaporation loss from the reservoir during time period t, MCM.
Values of inflow, outflow and evaporation are available. The inflow is added to the storage in the reservoir and outflow and evaporation are deduction from the storage.

C. Reservoir Storage – Capacity Constraints

The live storage in the reservoir during the period t should be less than or equal to the maximum active storage capacity (S_{max}) of the reservoir.

$$S_t \leq Smax \quad t = 1,2 ,.............12 \quad .....(4)$$

In Dynamic Programming the problem is solved by recursive equation approach.

In recursive equation approach there is two types one is backward recursive approach and forward recursive approach. Here we use forward recursive approach.

Here in this problem month is considered as a time period t. The problem was divided in to four stages.

1) Stage 1 is for a month of October.

For that stage the objective function is

Z= Minimize ∑ (Dt - Rt)2

Where

Dt=Demand from the reservoir for month October

Rt= release from the reservoir for month October

Now we are going from October to September that is in backward direction.

2) Stage 2 is for a month of September.

For this stage backward recursive equation is used which is shown below.

Z= Minimize ∑[(Dt - Rt)2 +ft+1n-1(St+1)]

Now for stage 3 and stage 4 that is for a month august and July we obtain the optimal release by using the above backward recursive equation.

BY using this backward recursive approach we get the optimal releases for every month.

After that Root Mean Square Error and Correlation Coefficient is found for all optimal releases of the all five model. And also a difference between actual releases and optimal releases are found for every month i.e. Maximum Absolute Error And also Net Additional Available water is also carried for all models.

VIII. RESULTS AND ANALYSIS

The Optimal Releases for model I for year 2007 is shown in The Table 1 and Demand, Actual Releases and Optimal Releases are compared and plotted in Fig.1

Year	*Month*	*Demand MCM*	*Actual Releases MCM*	*Optimal releases MCM*
2007	*July*	*2508.09*	*3135.12*	*2912.65*
	August	*1336.84*	*2912.65*	*1696.92*
	September	*1720.84*	*1696.92*	*1696.92*
	October	*505.79*	*499.46*	*727.93*

Table 1: Optimal Releases of Model I

Table 2 shows the difference between actual release and optimal release that is Net Deference for every month.

Month	*ACTUAL RELEASE MCM*	*OPTIMAL RELEASE MCM*	*NET DEFERENE MCM*
JULY	*3135.12*	*2912.65*	*222.47*
AUG	*2912.65*	*1696.92*	*1215.73*
SEP	*1696.92*	*1696.92*	*0*
OCT	*499.46*	*727.93*	*-228.47*

Table 2: Net Deference for Model I

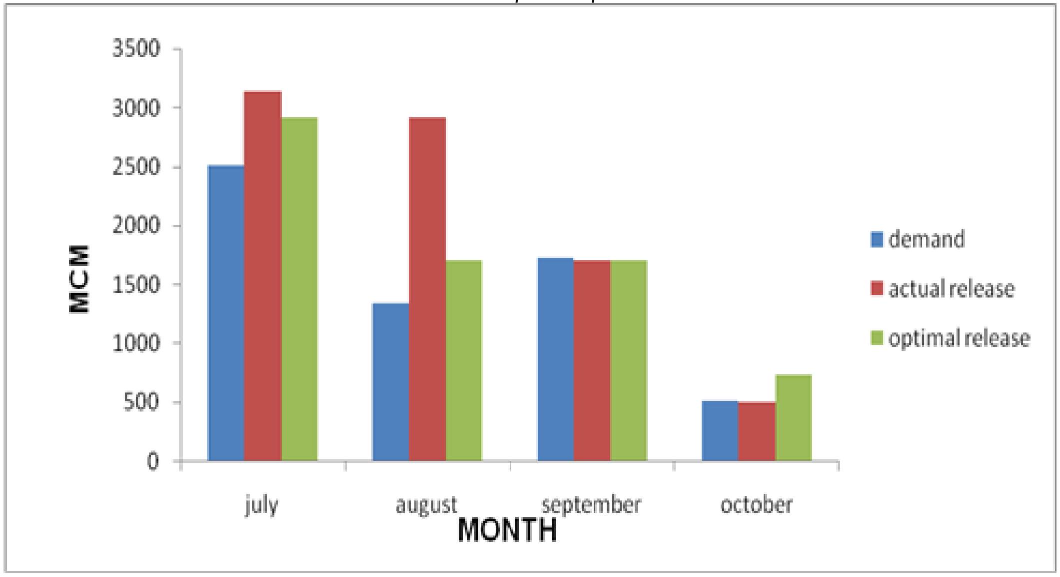

Fig. 1: Demand, Actual release and Optimal release of Model I

Fig.1 shows the monthly demand, actual releases and optimal releases for model I. Optimal releases are almost equal as demand of the respective month. Actual releases ranges from 499.46 to 3135.12 MCM whereas Optimal releases ranges from 727.93 to 2912.65 MCM. The drop of maximum release is of 222.47 MCM which is 10%. Optimal release in month of August is reduced from 2912.65 MCM to 1696.92 MCM against demand. Optimal release of October 727.93 MCM can satisfy 100% demand of 505.79 MCM by increasing the Actual release.

The optimal releases in month of July are the optimal releases in month of July are reduced from the actual releases made. The reduction done in releases is from 3135.12 MCM to 2912.65MCM which satisfies100% demand providing an excess of 404.56 MCM of water. This release can be considered as an appropriate release.

The optimal releases in month of September are 1696.92MCM which satisfies 58% of demand.

The optimal releases in month of October is 727.93 which satisfies100% demand providing an excess of 222.14 MCM of water. This release can be considered as an appropriate release.

Optimal releases for the hydropower generation from the reservoir are obtained using Genetic Algorithm. The different models are developed here to maximize hydropower generation by operating GAs operators. One of them is developed here as described below using Genetic Algorithms:

YEAR	*MONTH*	*ACTUAL RELEASE for HYDRO in MCM*	*OPTIMAL RELEASE for HYDRO in MCM*
2007	*JAN*	*314.79*	*830.19*
	FEB	*322.53*	*327.00*
	MAR	*369.91*	*327.06*
	APRIL	*455.52*	*460.12*
	MAY	*682.80*	*688.80*
	JUNE	*635.67*	*1149.51*
	JULY	*1128.43*	*1131.99*
	AUG	*1149.51*	*1149.51*
	SEP	*959.34*	*964.28*
	OCT	*444.42*	*148.28*
	NOV	*364.52*	*268.59*
	DEC	*323.56*	*216.66*

Table 3: Obtained Releases for Model of Year 2007

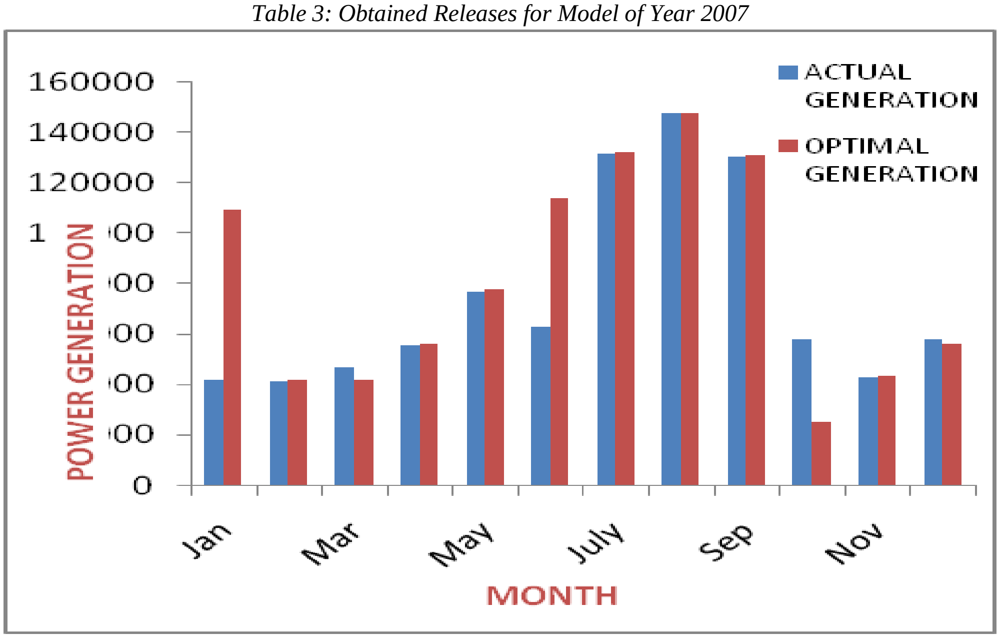

Fig. 2: Actual and Optimal Power Generation in year 2007

YEAR	MONTH	ACTUAL GENERATION	OBTAINED GENERATION
2007	Jan	41552	109582.80
	Feb	41090	41659.67
	Mar	46917	41482.18
	April	55688	56250.84
	May	76941	77616.58
	June	62990	113907.60
	July	131667	132082.10
	Aug	147727	147727.10
	Sep	130317	130988.00
	Oct	57757	24865.59
	Nov	42705	43362.07
	Dec	58038	56246.70

Table 4: Actual and Optimal Power Generation

IX. Conclusion

In the present study, GA and DP based models are developed for the reservoir operation of Ukai Reservoir Project. The main objective was to maximize power generation through optimal releases & to minimize sum of the squared difference between the monthly releases of water and downstream demand of reservoir. The releases obtained in the study are the optimal releases. Various models were developed and the following conclusions are observed.

A. Model of Year 2007

In 2007, generated power was 893389 MW. After develop the model using Genetic Algorithm and its various parameters like fitness scaling, selection, crossover, mutation the generation of power can be increased 9.22%. It is 975771.24 MW generated through optimal releases.

- In 2007 year there is 7.14% increase in optimal reservoir release.
- For year 2007 the value of Correlation Coefficient is 0.86and the value of RMSE is 34.78MCM.
- IN year 2007 Net Deference for month July is 222.47MCM. For month August is 1215.73MCM. For month September is 0MCM. For month October is -228.47MCM.
- The net additional available water in year 2007 is 1209.73MCM.

X. Recommendations

Implementing the optimization of reservoir Operation through Genetic Algorithms, the releases can be increased till 5.78%. Through these optimal releases, the power generation can be maximized till 7.28%.

Application of Dynamic Programming reduces the difference between the demand and release to a greater extent. In the present study it is found that the reduction in actual reservoir release corresponding to its Demand is occur up to 60%.

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