

Optimisation of Reservoir Operations Using Genetic Algorithms

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Abstract— This paper deals with the application of Genetic Algorithms (GA) for optimisation of multiobjective reservoir operations. The GA technique is used to evolve efficient pattern for water releases for maximizing annual power production and irrigation demands. Constraints include the release for power and turbine capacity, irrigation demand, storage continuity equation and reservoir storage restrictions. Penalty function approach is used to convert constrained problem into an unconstrained one. A generic genetic algorithm model for the optimization of reservoir systems has been developed that is easily transportable to any reservoir system. This generality is a distinct practical advantage of the genetic algorithm approach. Also model was run with existing GA models. For fixing GA parameters the model is run for various values of population, generations, cross over and mutation probabilities. Comparison of the genetic algorithms results with those produced by linear programming is also presented. Results obtained by GA are compared with Linear Programming solution and found to be reasonably close. GA is found to be an effective optimization tool for multiobjective reservoir planning and the results obtained can be utilized for efficient planning of any reservoir system.

Keywords—Genetic Algorithm(GA); optimisation; reservoir operations;

I. INTRODUCTION

Water is the vital resource to support all the forms of life. It is essential for all the important activities like food production, industries like energy, irrigation, production and manufacturing. The supply of water available for our use is limited by the nature. Most cities meet their needs for water by withdrawing it from the nearest river, lake or reservoir. Reservoirs are artificial lake that is used to store a large supply of water for irrigation, power production, drinking purpose, flood control, recreation purpose etc. Optimisation of reservoir operations has been a major area of study in water resources systems. For the optimisation of the reservoir operations, a set of rules for determining the quantities of water to be stored and to be released under various conditions are formulated. Optimization models are useful tools to identify reservoir operations, but there are some computational presumptions in these models that restrict their efficiency and flexibility. Most of these models are not able to represent the complex physical, hydrological, and operational characteristics of the system

adequately. Moreover, the objective functions or the form of the operating rules must often be defined under assumptions which further constrain the utility of the models. In the direct search approach, optimization of operating policies is accomplished directly by finding optimal parameters of the policy using system simulation results (Oliveira and Loucks 1994). A direct search model can theoretically optimize any kind of objective function and operating policy which can be used in the simulation models. All the behavioural patterns of inflow sequences can take part in the optimized policy since the objective function is directly represented by simulated operating results [j9].

To obtain optimal operating rules, a large number of optimization and simulation models have been developed and applied over the past two decades. Genetic Algorithm is a robust search and optimization technique for solving complex reservoir operations optimisation problems. A large number of works has been reported on the application of GA for various complex reservoir problems.

The idea with GA is to use this power of evolution to solve optimization problems. The father of the original Genetic Algorithm was John Holland who invented it in the early 1970's. Genetic Algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination operators to these structures as to preserve critical information. Genetic algorithms are often viewed as function optimizer, although the ranges of problems to which genetic algorithms have been applied are quite broad.

It is better than conventional Algorithms in that it is more robust. Unlike older systems, they do not break easily even if the inputs changed slightly, or in the presence of reasonable noise. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, a genetic algorithm may offer significant benefits over more typical search of optimization techniques.

II. LITERATURE REVIEW

GAs have lot of application in reservoir systems optimisation. Esat and Hall (1994) applied a GA to the four-reservoir problem. The objective was to maximize the benefits

III. METHODOLOGY

from power generation and irrigation water supply subject to constraints on storages and releases from the reservoirs. The paper by Esat and Hall showed the significant potential of GAs in water resources systems optimisation and clearly demonstrated the advantages of GAs over standard Dynamic Programming (DP) techniques in terms of computational requirements. Fahmy et al. (1994) also applied a GA to a reservoir system, and compared performance of the GA approach with that of dynamic programming. A comparative study on the applicability and computational difficulties of conventional models is presented by Mujumdar and Narulkar (1993). A major characteristic of any reservoir is that it is operated in a Multi-Objective framework. Shie-Yui et al. (2004) applied a Multiple Objective GA to the Chaliyar river basin system in India to maximise the Irrigation and Hydropower. Jothiprakash and Ganesan (2006) developed a GA model for operating policies for Pechiparai reservoir in India.

A study by Mohammad Noori et.al (2013) conducted on the topic ‘Genetic Algorithm model for optimal operation of a multi-reservoir’ is the inspiring paper behind this study. In this paper a GA model of multi-objective water resource system in Ghezal Ozan watershed for hydropower generation and flood control is developed. Janga Reddy and Nagesh Kumar (2000) developed a comparable model of GA on the topic ‘multiobjective differential evolution with application to reservoir system optimisation’. They focused on water resource systems which are characterized by multiple objectives. Sharif and Wardlaw (1990) developed a GA model for optimisation of a multi-reservoir system in Indonesia by considering different scenarios. Several alternative formulations of a genetic algorithm for reservoir systems are evaluated using the four-reservoir, deterministic, finite-horizon problem. Based on the literatures it can be concluded that Genetic Algorithm can be used for water resources optimisation problems.

The primary objective of this paper to explore the potential of alternative GA formulations in application to a reservoir system, and to develop a self created GA model in Matlab. This paper significantly extends the work by Nagesh Kumar et.al (2000) and leads to proposal for water release for the power production of a new study area. The problem addressed here differs from that considered by Nagesh Kumar and Janga Reddy (2000), who were concerned with the reservoir operations for optimal hydropower generations for different levels of inflows. GAs may be set up in many ways, but as yet there is little guidance in the literature on the type of formulation most appropriate for reservoir systems. Little detail was given by Nagesh Kumar and Janga Reddy on their GA formulation, although it appears that they did not consider every time step of the problem in the same way as considered here. In this paper several different approaches to GA formulation are considered, along with cross over probability, mutation probability, selection and encoding techniques. The object has been to present GAs as a practical tool in reservoir system evaluation, and to examine the potential of different GA formulations for multi- objective reservoir problems.

A. Objective of the study

The objective for optimisation problem adopted is to maximize the hydropower generated from the reservoir release for power (RP) with the other demands from the reservoir as constraints. If RP is expressed in million cubic meter (Mm³) per month and head causing flow, h in meters, then power produced P in kilowatt hour for a 30 day month is given by $P=2725 RP h$. The objective is to maximize total hydropower production in a year. As can be seen this objective involves non linear optimisation. For the demonstration of applicability of GAs for optimisation problem a courser time interval of one month is chosen which can be further reduced to weekly or daily.

Thus the objective for hydropower optimisation is, Maximize

$$Z = \sum_{t=0}^{12} P_t \tag{1}$$

Where P is the power generated in each month and t is the time period. The objective function is subjected to the following constraints.

Release 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 firm power.

$$RP_t \leq TC \quad \forall t = 1,2, \dots \dots \tag{2}$$

$$RP_t \geq FP_t \quad \forall t = 1,2, \dots \dots \tag{3}$$

Irrigation demand constraints

The release for irrigation should be greater than or equal to the minimum irrigation demand to sustain crops and also at the sometime this should not exceed the maximum irrigation demand to produce the targeted yield.

$$RI_t \geq ID_{MIN} \quad \forall t = 1,2, \dots \dots \tag{4}$$

$$RI_t \leq ID_{MAX} \quad \forall t = 1,2, \dots \dots \tag{5}$$

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 release for power, release for irrigation, overflows, reservoir storage, inflows and the losses through the reservoir during the period t for all months expressed in volume units.

$$S_{t+1} = S_t + Q_t - RP_t - RI_t - OVR_t - Ae_t \tag{6}$$

Where S_t is storage at the beginning of the period t, Q_t is inflow during the period t, OVR_t is the overflow for the period t (if any), A reservoir water surface area corresponding to the dead storage volume, e_t is evaporation rate for that period in depth units.

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.

$$S_t \leq S_{MAX} \quad \forall t = 1, 2, \dots \dots \dots \quad (7)$$

The above optimisation model is solved using genetic algorithms.

B. Study area

As the objective is to optimise the reservoir operations, the reservoir selected should have different kind of operations to perform, in short, the reservoir should be a multipurpose reservoir. Based on the objective and accessibility, Peechi Dam is selected as the study area. The Peechi dam is a multipurpose project built across the river Manali in Thrissur district, and is endowed with an immense catchment area that stretches across an expanse of nearly 3200 acres. The project is intended for irrigating 17555 Ha land in Mukundapuram, Thalappally, Thrissur and Chavakkad Taluk, through the left and right bank main canals. In addition to this, drinking water is supplied to Thrissur Corporation and eight nearby Panchayats from this reservoir. Peechi dam, which is 23 km from Thrissur lies between longitude 76°21'27.45"E and latitude 10°31'20.03"N. It is the main irrigation project of the city, now burgeoned into a popular picnic spot, which offers boating facilities at the reservoir. The hydropower generation started very recently in 2013. The turbine capacity is 1270 KW.

C. Data Collection

The required data are collected. Head causing flow in each month of year 2013, turbine capacity and firm power of each month are collected. From these data, flow corresponding to each firm power is calculated and tabulated as lower limit; similarly flow corresponding to turbine capacity is tabulated as upper bound of variable. For this study, the irrigation demand and drinking water demand also considered. Overflows, reservoir storage, inflows and evaporation losses of the reservoir for all months in volume are collected.

TABLE 1. HEAD DATA, UPPER BOUND AND LOWER BOUND DATA

MONTH t	HEAD h (M)	FIRM POWER (KWH)	MAX. CAPACITY OF TURBINE (KWH)	LOWER BOUND FLOW CORRESPONDING TO FP (MCM)	UPPER BOUND FLOW CORRESPONDING TO TC (MCM)
JAN	19.46	3583	300000	0.067567	5.65733521
FEB	18	8646	300000	0.176269	6.11620795
MAR	13.94	4522	300000	0.119042	7.89754255
APR	11.72	2000	300000	0.062623	9.39349344
MAY	10.17	2000	300000	0.072168	10.8251468
JUN	10.74	2000	300000	0.068338	10.2506279
JUL	25.75	4051	300000	0.057732	4.2754075
AUG	26.01	1890	300000	0.026666	4.23266986
SEPT	26.08	5203	300000	0.073212	4.22130917
OCT	26.06	9580	300000	0.134904	4.22454885
NOV	25.98	4559	300000	0.064397	4.23755747
DEC	24.6	10010	300000	0.149325	4.47527411

TABLE 2. DATA FOR STORAGE CONTINUITY EQUATION

Month	Q (Inflow) MCM	OVF (Over flow) MCM	RI (Release for irrigation) MCM	RD (Release for Drinking) MCM	Ae (Evaporation loss) MCM	S (Max. Storage) MCM
JAN	4	0	6	1.57	0.021	110.9
FEB	7	0	9	1.41	0.018	110.9
MAR	14	0	16	1.57	0.011	110.9
APR	5	0	4	1.52	0.01	110.9
MAY	3	0	1	1.57	0.003	110.9
JUN	1	3	0	1.52	0.001	110.9
JUL	65	4	0	1.57	0.01	110.9
AUG	2	8	0	1.57	0.015	110.9
SEPT	0	9	0	1.52	0.007	110.9
OCT	0	7	0	1.57	0.029	110.9
NOV	1	6	11	1.52	0.028	110.9
DEC	11	0	19	1.57	0.055	110.9

D. Genetic programming

Genetic programming typically starts with a population of randomly generated computer programme composed of the available programmatic ingredients. Genetic programming iteratively transforms a population of computer programme into a new generation of the population by applying analogies of naturally occurring genetic operations. These operations are applied to individual(s) selected from the population. The individuals are probabilistically selected to participate in the genetic operations based on their fitness. The iterative transformation of the population is executed inside the main generational loop of the run of genetic programming.

The implementation steps of genetic programming are as follows:

1. Randomly create an initial population of the available functions.
2. Iteratively perform the following sub-steps on the population until the termination criterion is satisfied:
 - (a) Find out the fitness function by obtaining the objective function.
 - (b) Find out the penalty function of each individual and subtracted from objective function to get the actual fitness function of the problem

If the problem is constrained, it is converted into an unconstrained problem by using penalty function method. In this process, the solution falling outside the restricted solution region is considered at a high penalty. This penalty forces the solution to adjust itself in such a way that after some generations it will fall into the restricted solution space. In penalty function method, a penalty term, corresponding to the constraint violation, is added to the objective function.

$$Fi = f(x) + \epsilon \sum_{j=1}^k \delta_j (\varphi_j)^2 \quad (8)$$

Where Fi is fitness value, $f(x)$ is objective function value; k is total number of constraints, ϵ is -1 for maximization and $+1$ for minimization, δ_j is penalty coefficient and φ_j is amount

of constraint violation. That means if any constraint is violated, then some percentage (penalty coefficient) of the square of that violation is added to the objective function if the problem is minimisation. Hence the fitness function is modified. Once the problem is converted into an unconstrained problem, rest of the procedure remains the same.

- (c) Based on the fitness value, the chromosomes from the population is selected into mating pool
 - (d) Select two individual chromosomes from the mating pool to participate in the genetic operations
 - (e) Create new individual chromosomes for the population by applying the following genetic operations with specified probabilities:
 - *Reproduction*: Copy the selected individual program to the new population.
 - *Crossover*: Create new offspring program(s) for the new population by recombining randomly chosen parts from two selected programs.
 - *Mutation*: Create one new offspring program for the new population by randomly mutating a randomly chosen part of one selected program.
 - *Architecture-altering operations*: Choose an architecture-altering operation from the available repertoire of such operations and create one new offspring program for the new population by applying the chosen architecture-altering operation to one selected program.
3. After the termination criterion is satisfied, the single best program in the population produced during the run (the best-so-far individual) is harvested and designated as the result of the run. If the run is successful, the result may be a solution (or approximate solution) to the problem.

Genetic algorithms are carried out by two methods. By coding a self developed Genetic programme and by MATLAB Inbuilt GA Optimtool box. Validation of the results obtained using Linear Programming (LP).

IV. RESULT AND DISCUSSION

Self developed MATLAB code for implementing Genetic Algorithm provides full control on the genetic operations such as population, cross over and mutation, and also gives more freedom in developing constraints and penalty methods. In the programme coded, the user can specify the size of the population. Initial population is generated randomly. Real value coding is used. Fitness function is evaluated by penalty methods. Selection process is done by a self developed random selection method. One point crossover is carried out because it is easy to code in matlab and mutation probability is selected as 0.005 for the convenience in coding logic.

The result obtained by the created genetic programme is not always similar because of the difference in initial population, since the GA creates initial population randomly.

The size of population was selected by the user like 100, 300, 500, 600 etc. Solutions get converged randomly depending upon the size of initial population. The results generated were almost similar. And by doing several trials of about 50, the results are tabulated and corresponding objective function is calculated. Since the objective function is the maximum power generated, the chromosomes that possess larger value of objective function is selected as the optimum/the best solution to the given problem. Releases for power (RP) in 12 months in MCM are obtained. The optimum value of annual power production in the year 2013 is 3572200 kWh. The result obtained is shown below;

RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	RP9	RP10	RP11	RP12	POWER
5.84	6.24	6.18	9.13	10.76	8.53	4.63	4.85	4.25	4.13	4.7	4.26	3572206

The MATLAB provides a Genetic Algorithm inbuilt tool box which gives a convenient method for doing GA very easily. A black box effect will be there, since what happened inside the GA Optimtool box is unknown to us. The GAtool box is provided with a certain filling ground, where we have to input the objective function, constraints, and upper bound etc. The tool itself provided the GA operation methods such as population, encoding, selection, crossover, mutation etc. Since GA is a heuristic search algorithm, in each GA operations, we are getting slightly different answers in each trial. Ten trials are carried out. The results obtained from MATLAB Optimtool box exhibits negligible variation. From a set of 10 optimum solutions, the best solution is taken as the optimum value for this problem. Hence the optimum value of annual power production is 3535000 kWh. The results shown below;

RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	RP9	RP10	RP11	RP12	POWER
5.62	6.07	7.80	9.29	10.61	9.79	4.26	4.22	4.12	4.14	4.14	4.25	3535000

Since Linear programming (LP) is very effective in solving constrained optimization problem especially in the area of water resource engineering, it can be taken as a validation tool for this optimisation. From linear programming, the optimum value of annual power production is 360000 kWh.

RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	RP9	RP10	RP11	RP12	POWER
5.65	6.11	7.89	9.39	10.82	10.25	4.27	4.23	4.22	4.22	4.23	4.47	3600000

The annual power obtained from the developed programme is 3572200 kWh and the annual power obtained from MATLAB GA Optimtool box is 3535000 kWh. These are very close values. The annual power given by linear programme is 3600000 kWh. Both the GA values are comparable with the result of linear programming and hence it is validated. The trend exhibited in the results from various methods is also similar.

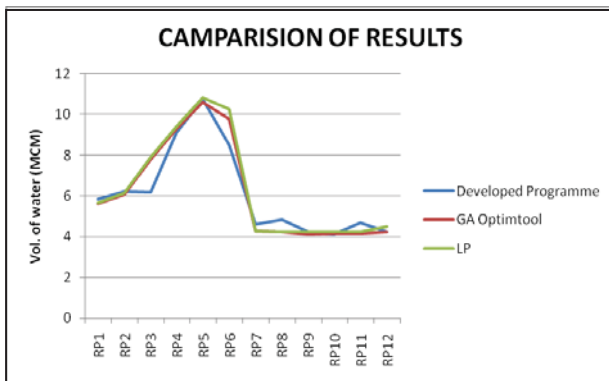


Figure 1 Comparison of results

Comparing with the actual scenario of Peechi dam in 2013, the annual power produced was 2800000 kWh. From the optimisation it is clearly identified that, the production of power can be maximised when the system follows this trend of reservoir release. Based on the results, it is observed that solutions obtained by both GA and LP are reasonably close proving that GA can be used for multiobjective reservoir operation optimisation problems with more confidence and it can be extended for larger problems.

V. CONCLUSION

In this study, a GA based model is developed for evolving an optimum multi-objective reservoir operation for Peechi Project, Kerala, India. The objective is to maximize annual power generated with the constraints such as release for power and turbine capacity, irrigation demand, storage continuity equation and reservoir storage restrictions. The results obtained from the GA model are compared with those obtained from Linear Programming model. Results show a very good comparability.

Based on the study, the following conclusions were made:

1. The maximum power generated by the developed programme is 3572200 kWh and by the Matlab inbuilt tool is 3535000 kWh. The Maximum hydropower by LP solution is 3600000 kWh.
2. It is observed that solutions obtained by both GAs and LP are reasonably close. Annual hydropower obtained by 'created genetic programme' and 'GA Optimtool' have deviated by 0.8% and 1.8% as compared to LP solution.
3. Genetic Algorithms is found to be an effective optimization tool for multi-objective reservoir operations and can be used for more complex systems involving non-linear optimization

Scope for future work

1. The solution obtained by GA for reservoir operations can be further refined for a number of factors such as penalty function values, mutation and crossover probabilities, generation and population.
2. Depending upon the constraints involved, the chosen penalty coefficient is observed to influence the pattern of convergence of the solution to a great extent. The inter dependability of constraints, penalty coefficient and the associated convergence criteria has a great scope for future research

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