APPLICATION OF GENETIC ALGORITHMS FOR OPTIMAL RESERVOIR OPERATION

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ABSTRACT

Genetic Algorithms (GAs) application in the field of water resources engineering is of recent origin. Genetic Algorithms is one of the tools, which handles nonlinear optimization problems in an efficient manner. Optimal reservoir operation of reservoir for hydropower production involves constrained nonlinear optimization. The constrained problem is converted into unconstrained problem by using penalty function method. Genetic algorithm was then used to optimize the reservoir operation for hydropower production. This apporach was used to develop optimal operating policy for Hirakud reservoir, a multipurpose project on river Mahanadi, India (geographical location of the dam: Latitude 21^0 $32'$ N, Longitude 83^0 52' E). Hydropower production from the system is maximized with other demands as constraints. Various steps involved in deriving the optimal operating policy for the reservoir using GA are discussed in the paper. For fixing the GA parameters viz. Crossover probability and mutation probability, the model is run for different values of crossover and mutation probabilities. For a crossover probability of 0.800 and a mutation probability 0.006, the model was found to perform well. After fixing the GA parameters the model is run for various dependable levels of inflows. The operating policy thus obtained can be used for optimal operation of the reservoir. Results from the model and possible extensions were discussed.

KEYWORDS

Reservoir operation, Genetic Algorithms, Hydropower

INTRODUCTION

Application of genetic algorithms (GAs) in the field of water resources engineering is of recent origin. Genetic Algorithms provided solutions as good as those obtained by other traditional methods like Linear Programming, Non Linear programming and Dynamic Programming. For more complicated problems, particularly discontinuous or highly nonlinear and nonconvex type, genetic algorithm proved to be computationally superior to gradient based methods. McKinney and Lin (1994) applied GAs in the Management of Ground Water models. Simpson et al, (1994, 1996) used the GAs in optimization of pipe network and the results obtained compared well with those obtained by other methods. Savic and Walters (1997) developed a computer model called GANET for least cost design of water distribution networks. Reddy (1997) developed a nonlinear optimization model based on genetic algorithms for land grading design of irregular fields. Oliveira and Loucks (1997) derived multireservoir operating rules using real-valued vectors containing information needed to define both system release and individual reservoir storage volume targets as functions of total storage in each of the multiple within-year periods. In this paper genetic algorithms were applied to determine the optimal reservoir releases for hydropower generation from a multipurpose reservoir.

GENETIC ALGORITHMS

Genetic Algorithms (GAs) are based on the theory given by Darwin that fittest of the fit will survive. They belong to a family of combinatorial optimization methods that search for solutions of complex problems using an analogy between optimization and natural selection. They use a random search procedure inspired by biological evolution, cross breeding trial designs and allowing only the 'Fittest' designs to survive and propagate to successive generations. GAs handle nonlinear optimization problems in an efficient manner and they differ from other traditional methods in number of ways (Goldberg, 1989) like (i) GA's work with a coding of parameter sets and not with parameters themselves, thus allowing one to use a wide variety of parameters as decision variables, (ii) GA's use objective function or fitness information only in contrast to traditional methods which rely on existence and continuity of derivatives or other auxiliary information.

Working Principle of GAs

Any nonlinear optimization problem without constraints is solved using Genetic Algorithms involving basically three tasks viz., Coding, Fitness evaluation and Genetic operation. First of all decision variables are identified from the given optimization problem. These decision variables are coded into some string like structures. For coding the decision variables binary coding is used. This coded string is called Chromosome. The length of chromosome depends on the desired accuracy of the solution. It is not necessary to code all the decision variables in equal substring length.

Generally, the fitness function is first derived from objective function and is used in successive genetic operations. Genetic operators require that the fitness function should be nonnegative. If the problem is of maximization, the fitness function is taken as directly proportional to the objective function. The fitness function value of a string is known as the string's fitness.

Once the fitness of each string is evaluated, the population is operated by three common operators for creating new population of points. They are Reproduction, Crossover and Mutation. Reproduction selects good strings in a population and forms a mating pool. In this paper Roulette wheel simulation is used for the selection of good strings. In cross over operator, two strings are picked from the mating pool at random and some portions of the strings are exchanged between the strings. A single point cross over operation is performed by randomly choosing a crossing site along the string and by exchanging all bits on the right side of the crossing site. The mutation operator changes 1 to 0 and 0 to 1 with a small mutation probability, p_m, within the string. Mutation creates points in the neighborhood of the current point, which helps in local search around the current solution. It is also used to maintain diversity in the population.

The newly created population using the above operators is further evaluated and tested for termination. If the termination criterion is not met the population is iteratively operated by the above three mentioned GA operators and evaluated. This process is continued until termination criterion is met. One cycle of these operations and the subsequent evaluation procedure is known as a generation.

Genetic Algorithms for constrained problems:

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

$$F_i = f(x) + \in \sum_{j=1}^{k} \delta_j (\phi_j)^2 \qquad (1)$$

where F_i is fitness value, $f(x)$ is objective function value, k is total numbers of constraints, $\in$ is -1 for maximization and +1 for minimization, δ_j is penalty co-efficient and ϕ_j is amount of violation. Once the problem is converted into unconstrained problem, the rest of the procedure remains the same.

DESCRIPTION OF THE CASE STUDY AREA

The Hirakud dam is a multipurpose project built across river Mahanadi in Orissa State, India. The geographical location of this dam is Latitude 21^0 32' N, Longitude 83^0 52' E. Hirakud dam was conceived primarily for flood control in Mahanadi delta with the other purposes of the dam being irrigation and hydropower. The catchment area of the reservoir upto the dam site is 83,400 sq. km. The active storage capacity of the reservoir is 5,375 million m^3 with the gross storage capacity being 7,189 million m^3. Total installed capacity for power generation is 307.5 MW. Area of irrigation during the first crop season, *Kharif*, is 1,556.5 sq.km. and during the second crop season, *Rabi*, is 1,084 sq.km.

HYDROPOWER OPTIMIZATION FORMULATION

The objective for optimization problem adopted is to maximize the hydropower generated from the reservoir releases for power (*RP*) with the other demands from the reservoir as constraints. If *RP* is expressed in million cubic meters (M m^3) per month and head causing the flow, h in meters, then power produced *P* in kilowatt hours for a 30 day month is given by $P = 2725\, RP\, h$. The objective is to maximize total hydropower produced in a year. As can be seen this objective involves nonlinear optimization. For the demonstration of applicability of GAs for the optimization problem a courser time interval of one month is chosen which can be further reduced to weekly or daily. Thus the objective for hydropower optimization is

$$Maximize \qquad Z = \sum_{t=1}^{12} P_t \qquad (2)$$

This objective function is subject to the following constraints.

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.

$$RP_t \leq TC \qquad \forall \quad t = 1,2, \ldots\ldots\ldots\ldots 12 \qquad (3)$$

$$RP_t \geq FP_t \qquad \forall \quad t = 1,2, \ldots\ldots\ldots\ldots 12 \qquad (4)$$

where RP_t is release for power in the period t, TC is turbine capacity and FP_t is firm power for the period t.

Irrigation Demand Constraints

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

$$RI_t \geq ID_{MIN_t} \qquad \forall \quad t = 1,2, \ldots\ldots\ldots\ldots 12 \qquad (5)$$

$$RI_t \leq ID_{MAX_t} \qquad \forall \quad t = 1,2, \ldots\ldots\ldots\ldots 12 \qquad (6)$$

where RI_t is release for irrigation in the period t, ID_{MIN_t} is the minimum irrigation demand to sustain the crops and ID_{MAX_t} is the maximum irrigation demand to produce the targeted yield for the period t.

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.

$$(1 + a_t)S_{t+1} = (1 - a_t)S_t + Q_t - RI_t - RP_t - OVF_t - A_o e_t \qquad (7)$$

where S_t is storage at the beginning of the period t, Q_t is inflow during the period t, OVF_t is overflow for the period t (if any), A_o reservoir water surface area corresponding to the dead storage volume, e_t is evaporation rate for that period in depth units, $a_t = 0.5 \; A_a e_t$ and Aa is the reservoir water spread area per unit volume of active storage.

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.

$$S_t \leq S_{\max} \qquad \forall \quad t = 1,2, \ldots\ldots\ldots\ldots 12 \qquad (8)$$

The above optimization model (Equations 3 through 8) is solved using genetic algorithms as explained in the following steps.

1. **Identification of decision variable:** Here the decision variable is, release for power in each month. So there are twelve decision variables.
2. **Fixation of upper and lower bound:** For fixing the upper and lower bound of the decision variable, the two constraints given in eqs. 3 and 4 are considered. The lower bound, is the firm power and the upper bound is the capacity of the turbines.

3. **Fixation of binary string length:** Based on the difference between the upper and lower bound of the decision variables the length of the binary string is fixed.
4. **Coding of string:** Binary coding of the string is done by generating random numbers.
5. **Decoding of decision variable:** The coded string is decoded by using linear mapping rule.
6. **Calculation of effective head:** Effective head for hydropower generation is calculated using storage continuity equation and elevation-storage relation.
7. **Calculation of fitness:** The values of the decision variable and the effective head are substituted into fitness function to evaluate fitness of each string.
8. **G A operations:** All the three steps involved in GA operation viz., Reproduction, Crossover and Mutation are performed on the strings.

Step 6 to 8 are repeated until termination criterion is met.

Lower and upper bounds for the decision variable and the string length for each month are given in Table 1. Average inflows into the reservoir and the average irrigation demands are presented in Table 2. Most of the inflows to the reservoir occur during monsoon months ie., July to October.

TABLE 1. Lower, upper bound and string length for the decision variable

Month	Decision Variable	Lower bound	Upper bound	String length
January	RP_1	616.50	2000	10
February	RP_2	370.00	2000	15
March	RP_3	370.00	2000	15
April	RP_4	245.00	2000	15
May	RP_5	370.00	2000	15
June	RP_6	370.00	2000	15
July	RP_7	615.00	2000	10
August	RP_8	1233.00	2000	10
September	RP_9	1110.00	2000	10
October	RP_{10}	615.00	2000	10
November	RP_{11}	615.00	2000	10
December	RP_{12}	615.00	2000	10

TABLE 2. Average inflows and Irrigation Demands for different months

Month	Inflows M.cu.m.	Irrigation Demand M.cu.m
January	397.026	229.831
February	178.785	268.671
March	33.291	323.046
April	46.854	313.428
May	6.165	57.334
June	431.550	107.518
July	4,151.511	249.683
August	18,377.865	243.271
September	5,611.383	265.588
October	1,392.057	295.304
November	626.364	45.005
December	556.083	117.135

RESULTS AND CONCLUSIONS

For fixing the GA parameters viz. crossover probability and mutation probability, the model is run for different values of crossover and mutation probabilities. Two values for crossover probability, 0.80 & 0.85 and three values for mutation probability, 0.005, 0.006 & 0.007 are chosen. Results obtained are compared in terms of total hydropower produced, fitness and number of generations (Ashok, 1999). From these comparisons it is concluded that for crossover probability 0.800 and mutation probability 0.006, the hydropower produced is maximum and the solution converged at moderate number of generations. For values of mutation probability other than 0.006 the solution converges very rapidly which is not desirable. So the GA parameters are fixed as crossover probability of 0.800 and mutation probability of 0.006 for the case study made.

Once the GA parameters are fixed the model is run for four different levels of inflows viz., 40% & 20% below average inflows, average inflows and 20% above average inflows. Optimized monthly releases for hydropower (in million cubic meters, M.cu.m) are shown for different levels in Figure1.

From these results, reservoir can be operated for optimal hydropower generation for different expected levels of inflows into the reservoir after meeting the other demands from the reservoir. Efforts are on to develop operating policy for much smaller time intervals.

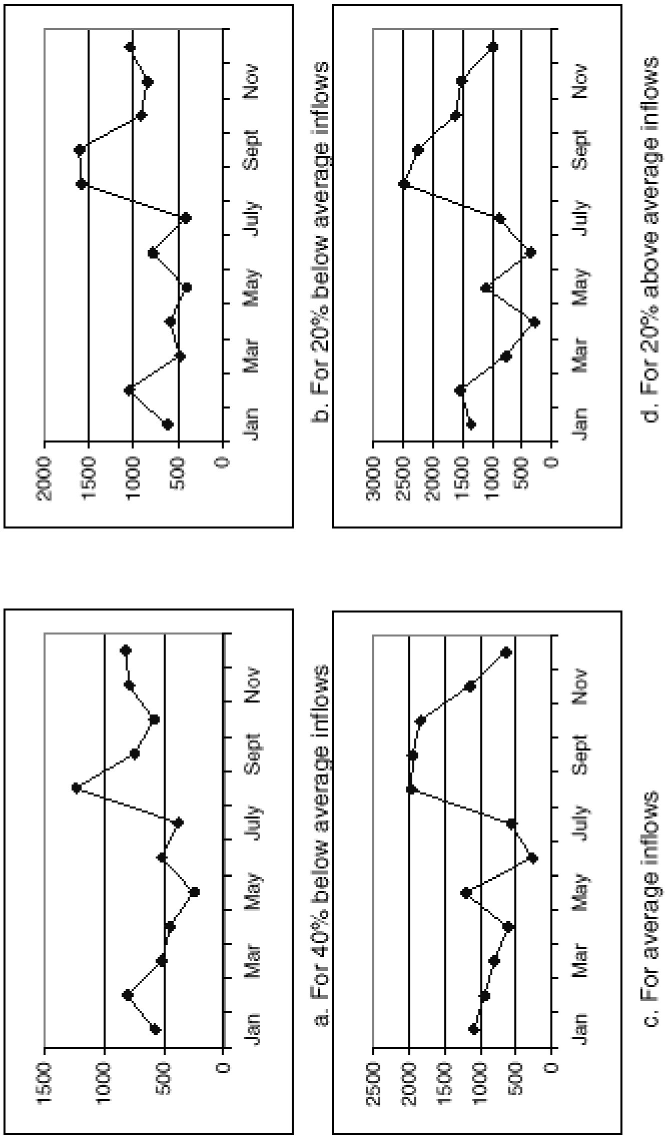

Figure 1. Optimum Monthly Releases (M.cu.m) for Hydropower for Various Inflow Levels

From this study it can be concluded that Genetic Algorithms have very strong potential for application in water resources optimization. In this paper GAs were successfully applied for optimal hydropower generation from a multipurpose reservoir and is demonstrated through a case study of an existing multipurpose reservoir in Orissa state, India.

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