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Application of Multi objective Genetic Algorithm to Multipurpose Reservoir

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Abstract*: During last two decades, water resources planning and management profession has seen a dramatic increase in the development and application of various types of evolutionary algorithms (EAs). In the present study, Multi-objective Genetic Algorithm(MOGA) has been used to optimize the operation of existing multipurpose reservoir in India, and also to derive reservoir operating rules for optimal reservoir operations. The fitness functions used in the model are minimization of irrigation deficits and maximization of hydropower generation. These two are conflicting objectives, as one tries to minimize the irrigation deficits, requiring more water to be released to satisfy irrigation demands and the other tries to maximize hydropower production, which requires higher level of storage to be maintained in the reservoir to produce more power. The decision variables are monthly releases from the reservoir for irrigation and initial storages in reservoir at beginning of the month. The constraints considered for this optimization are reservoir capacity and bounds for decision variables. In weighted sum approach weights are given to objective function depending up on the priority of the objective function. Function is to be minimized. By this approach the multi-objective optimization problem is converted into single objective optimization problem. Results show that, even during the low flow condition, the present GA model if applied to the Ukai reservoir in Gujarat State, India, can satisfy downstream irrigation demand. Hence based on the present case study it can be concluded that GA model has the capability to perform efficiently, if applied in real world operation of the reservoir.

*Keywords***: Evolutionary algorithms (EA), Multi-objective Genetic Algorithm (MOGA), weighted sum, fitness function***

I. INTRODUCTION

This document is a template. In reservoir operation problems, to achieve the best possible performance of the system, decisions need to be taken on releases and storages over a period of time considering the variations in inflows and demands. In the past, various researchers applied different kinds of mathematical programming techniques like linear programming, dynamic programming, nonlinear programming (NLP), etc. to solve such reservoir operation problems. But as far as reservoir operation is concerned, no standard algorithm is available, as each problem has its own individual physical and operational characteristics. In case of multipurpose reservoir operation, the goals are more complex than for single purpose reservoir operation and often involve various problems such as insufficient inflows and larger demands. In order to achieve the best possible performance of such a reservoir system, a model should be formulated as close to reality as possible. In this process, the model is expected to solve problems having nonlinearities and non-convexities in their domain. In spite of development of many conventional techniques for optimization, each of these techniques has its own limitations. To overcome those limitations, recently metaheuristic techniques are being used for optimization. By using these techniques, the given problem can be represented more realistically. These also provide ease in handling the nonlinear and nonconvex relationships of the formulated model. An approach to stopping criteria for multi–objective optimization evolutionary algorithms: The MGBM Criterion is discussed by Ashish Ghosh et.al. in the international journal of computing and information sciences. In this paper some important papers of evolutionary algorithms are reviewed and systematic comparison has been made. Its importance in single and multi-objective optimization has also been emphasized. Some possible further research problems are also expressed in detail [1].

Multi-objective Evolutionary Algorithms: Analyzing the State-of-the-Art is discussed by David A. Van Veldhuizen et.al in the journal of Evolutionary computation. It is discussed in the paper that solving optimization problems with multiple (often conflicting) objectives is, generally, a very difficult goal. Evolutionary algorithms (EAs) were initially extended and applied during the mid-eighties in an attempt to stochastically solve problems of this generic class. [2]

An efficient constraint handling methodology for multi-objective evolutionary algorithms is discussed by Mauricio Granada Echeverri et.al. In the paper a new approach for solving constraint optimization problems (COP) based on the philosophy of lexicographical goal programming. A two-phase methodology for solving COP using a multi-objective strategy is used [3]. Comparison of two multi-objective optimization techniques with and within genetic algorithms is discussed by Shapour Azar et.al in the Proceedings of the 1999 ASME Design Engineering Technical Conference. In the paper it is mentioned that engineering decision making involving multiple competing objectives relies on choosing a design solution from an optimal set of solutions. [4] A study on the convergence of Multi-objective Evolutionary Algorithms is discussed by Tushar Goel et.al. It is discussed in the paper that high computational cost has been a major impediment to the widespread use of evolutionary algorithms in industry [5].

A Cumulative Evidential Stopping Criterion for Multi-objective Optimization Evolutionary Algorithms is discussed by Luis Martí, et.al. In this work a novel and efficient algorithm independent stopping criterion, called the MGBM criterion, suitable for Multi-objective Optimization Evolutionary Algorithms (MOEAs) is presented[6].Examining the relationship between algorithm stopping criteria and performance using elitist genetic algorithm is discussed by Jin-Lee Kim. A major disadvantage of using a genetic algorithm for solving a complex problem is that it requires a relatively large amount of computational time to search for the solution space before the solution is finally attained in the paper [7]. On the disruption level of polynomial mutation for evolutionary multi-objective optimization algorithms is studied by Mohammad Hadman. This paper looks at two variants of polynomial mutation used in various evolutionary optimization algorithms for mutli-objective problems [8]. Self-adaptive mechanism for multi-objective evolutionary algorithms is reported by Fanchao Zeng. In the paper it is discussed that evolutionary algorithms can efficiently solve multi-objective optimization problems (MOPs) by obtaining diverse and near-optimal solution sets. However, the performance of multi-objective evolutionary algorithms (MOEAs) is often limited by the suitability of their corresponding parameter settings with respect to different optimization problems [9].

II. STUDY AREA

The reservoir chosen for the application of the GA model is the Ukai reservoir in Tapi river basin. Gujarat has around 21 large dams, among 541 Indian Dams. Ukai Dam near Surat is one of the major projects including Sardar Sarovar Dam. Ukai reservoir is the multipurpose reservoir situated in the Ukai village of Surat district on Tapti River, is the largest reservoir in Gujarat. It is also known as Vallabh Sagar. It is located between longitudes 73°32'25"-78°36'30"E and latitudes 20°5'0"-22°52'30"N. Ukai dam was constructed in 1971, the dam is meant for irrigation, power generation and flood control. The site is located 94 km from Surat.

III.MATHEMATICAL MODEL DEVELOPMENT BY USING WEIGHTED SUM APPROACH

The two objectives considered in the model are minimization of irrigation deficits and maximization of hydropower generation. These two are conflicting objectives, as one tries to minimize the irrigation deficits, requiring more water to be released to satisfy irrigation demands and the other tries to maximize hydropower production, which requires higher level of storage to be maintained in the reservoir to produce more power. The two competing objectives of the system are expressed as,

A. Minimize Sum Of Squared Deficits For Irrigation Annually

$$SQDV = \sum_{t=1}^{12}\left(D_{l,t} - R_{l,t}\right)^2 + \sum_{t=1}^{12}\left(D_{KS,t} - R_{KS,t}\right)^2 \quad (3.1)$$

B. Minimize Sum Of Squared Deficits For Irrigation Annually

where SQDV is sum of squared deviations of irrigation demand and releases;

$$E = \sum_{t=1}^{12} p\left(R_{l,t}H_{l,t} + R_{KS,t}H_{KS,t}\right) \quad (3.2)$$

where E is the total energy produced in Kwh(106);

p is power production coefficient;

Hl,t, HKS,t are the net heads available to left bank and Kakarapar power generation system respectively in meters during period t.

This model is subjected to following constraints:

Storage continuity

$$S_{t+1} = S_t + I_t - (R_{1,t} + R_{2,t} + R_{3,t} + E_t + O_t) \quad \text{for all t = 1,2,………,12} \quad (3.3)$$

where S_t = active reservoir storage at the beginning of period t in Mm3

I_t = inflow to the reservoir during period t in Mm3

E_t = evaporation losses during period t in Mm3 (a non-linear function of initial and final storages of period t)

O_t = overflow from reservoir in Mm3

Storage limits

$S_{\min} \le S_f \le S_{\max}$ for all t = 1,2,………..,12 (3.4)

where $S_{\min}$ and $S_{\max}$ are the minimum and maximum active storages of the reservoir.

Canal capacity limits

$R_{l,t} \le C_{l,\max}$ for all t = 1,2,………..,12 (3.5)

$R_{KS,t} \le C_{KS,\max}$, for all t = 1,2,………..,12 (3.6)

where $C_{l,\max}$ is the maximum canal carrying capacity of the Ukai left bank canal and $C_{KS,\max}$ is maximum canal carrying capacity of Kakarapar irrigation scheme ($10^6 m^3$/month).

Irrigation demands

$Dl_{\min,t} \le R_{l,t} \le Dl_{\max,t}$ for all t = 1,2,………..,12 (3.7)

$D_{KS\min,t} \le R_{KS,t} \le D_{KS\max,t}$ for all t = 1,2,………..,12 (3.8)

where $Dl_{\min,t}$ and $Dl_{\max,t}$ are minimum and maximum irrigation demands for left canal respectively, $D_{KS\min,t}$ and $D_{KS\max,t}$ are minimum and maximum irrigation demands for Kakrapar irrigation system respectively in time t.

Overflow constraint

$O_t = S_{t+1} - S_{\max}$ for all t = 1,2,………..,12 (3.9)

where S_{t+1} = storage at the end of the month Mm3. S max = 7414.29 is gross storage of reservoir.

Maximum power production limits

$pR_{i,t}H_{i,t} \le E_{l,\max}$ for all t = 1,2,……………………….,12 (3.10)

$pR_{KS,t}H_{KS,t} \le E_{KS,\max}$ for all t = 1,2,……………………….,12 (3.11)

where $E_{l,\max}$, $E_{KS,\max}$ are the maximum amounts of power that can be produced (turbine capacity) by left bank canal Kakrapar power generation system.

The reservoir is mainly meant for irrigation, and so priority is given to irrigation. After meeting the irrigation demands, power production is to be maximized. To handle these multiple objectives, in this study a weighted approach is adopted. By giving a larger weight to irrigation and a smaller weight to hydropower generation, it is possible to satisfy the prescribed priorities. In this model a normalized squared deficit is used for irrigation(instead of simpler squared deficits) with the aim to evenly distribute the deficits throughout the season in the case of occurrence of deficits, by giving equal priority to larger and smaller magnitudes of demands of kakrapar system and left bank canals, respectively. To bring both the objectives into same units, the hydropower objective is non dimensional zed. So the final fitness function for the model is as follows

$$E = \sum_{t=1}^{12} p\left(R_{l,t}H_{l,t} + R_{KS,t}H_{KS,t}\right) \quad (3.2)$$

where E is the total energy produced in Kwh(106);

p is power production coefficient;

Hl,t, HKS,t are the net heads available to left bank and Kakarapar power generation system respectively in meters during period t.

This model is subjected to following constraints:

Storage continuity

$S_{t+1} = S_t + I_t - (R_{1,t} + R_{2,t} + R_{3,t} + E_t + O_t)$ for all t = 1,2,………,12 (3.3) where S_t = active reservoir storage at the beginning of period t in Mm3

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O_t = overflow from reservoir in Mm3

Storage limits

$S_{\min} \le S_f \le S_{\max}$ for all t = 1,2,………..,12 (3.4)

where $S_{\min}$ and $S_{\max}$ are the minimum and maximum active storages of the reservoir.

Canal capacity limits

$R_{l,t} \le C_{l,\max}$ for all t = 1,2,………..,12 (3.5)

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where $Dl_{\min,t}$ and $Dl_{\max,t}$ are minimum and maximum irrigation demands for left canal respectively, $D_{KS\min,t}$ and $D_{KS\max,t}$ are minimum and maximum irrigation demands for Kakrapar irrigation system respectively in time t.

Overflow constraint

$O_t = S_{t+1} - S_{\max}$ for all t = 1,2,………..,12 (3.9)

where S_{t+1} = storage at the end of the month Mm3. S max = 7414.29 is gross storage of reservoir.

Maximum power production limits

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To bring both the objectives into same units, the hydropower objective is non dimensional zed. So the final fitness function for the model is as follows

C. Combined Objective Function

$$F_1 = \left[k_1 \sum_{t=1}^{n} \left(\frac{D_{l,t} - R_{l,t}}{D_{l,t}} \right)^2 + \left(\frac{D_{KS,t} - R_{KS,t}}{D_{KS,t}} \right)^2 + k_2 \sum_{t=1}^{n} \left(\frac{E_{l,\max} - P\left(Q_{l,t}, H_{l,t}\right)}{E_{l,\max}} \right) + \left(\frac{E_{KS\max} - P\left(Q_{KS,t}, H_{KS,t}\right)}{E_{KS\max}} \right) \right]$$

for t= 1,2,3,……,n. (3.12)

k1 & k2 are the weights given to objective function depending up on the priority of the objective function. F1 is to be minimized. By this approach the multi-objective optimization problem is converted into single objective optimization problem. This objective is subjected to the set of constraints as mentioned above (eq. 3.3 to eq. 3.11).

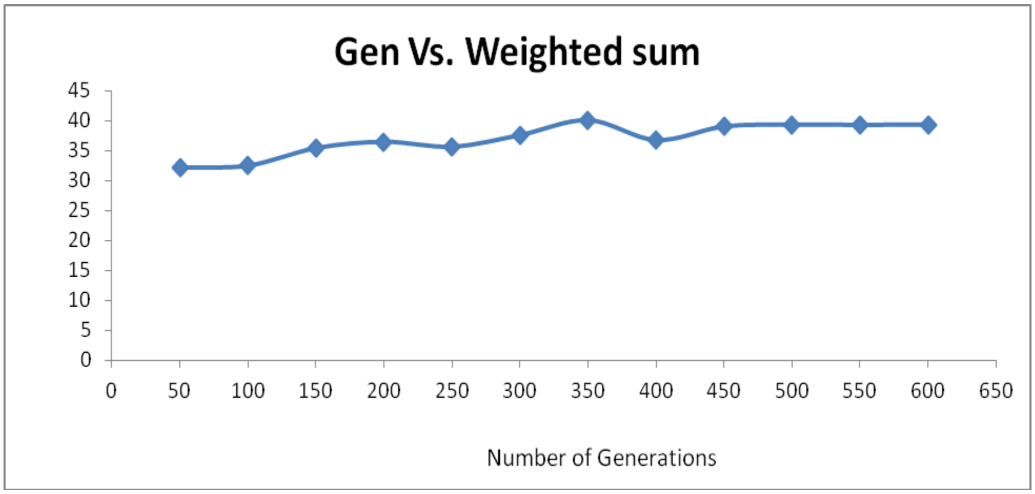
D. Model Application

Interactive computer program in MATLAB is developed for real coded genetic algorithms (RGA). In the present study RGA with penalty function approach is used for analysis to convert the constraint problem in to an unconstrained problem. The parameters considered in RGA are NP = 100 to 300 (generally 5 to 10 times the number of variables used in the problem), crossover probability Pc = 0.8 (normally in the range of 0.6 to 0.9) and mutation probability Pm = 0.042 which is (1/n) where n is number of variables. The distribution index for Simulated Binary Crossover (SBX) and mutation is fixed as 20 for single objective optimization problem and 20 respectively. Simulated binary crossover and polynomial mutation is used.

IV. SENSITIVITY ANALYSIS

The effect of varying parameter values on convergence to the optimal solution is investigated for the real coded genetic algorithm by carrying out sensitivity analysis.

In case of RGA, settings such as real coding with SBX crossover operator, polynomial mutation and proportionate selection which were employed in the original problem are used. The other parameters used in the analysis are population size (POP), crossover probability (Pc) from 0.6 to 0.90 in the interval of .05(8evels). To carry out the sensitivity analysis and to optimize the GA parameter initially a probability of crossover of 0.8 and mutation as 0.042 (1/n) n being number of variables, with a population size of 100 is assumed to estimate the system performance. For this combination the system performance is shown in the graph No. 3.1 for different generations. From this graph, it can be seen that the system performance is improved when the generations are increased to 100. It is also found that the system performance is improving up to a generation of 450 and is near about same thereafter. This optimum combination is decided by giving equal weightage to both objectives i.e 50% and 50% each.



Graph 3.1 Generation convergence

Hence, the optimal generations has been taken as 450. With the optimal generations of 450, the system performance is estimated by varying population size and it is found that the system performance improved up to 250 and after that it is near about same. With 450 generations and 250 number of population the system performance is estimated by varying the probability of crossover from 0.6 to 0.95, with an increment of 0.05. The system performance for this sensitivity analysis of the probability of crossover is shown in graph. 3.2.

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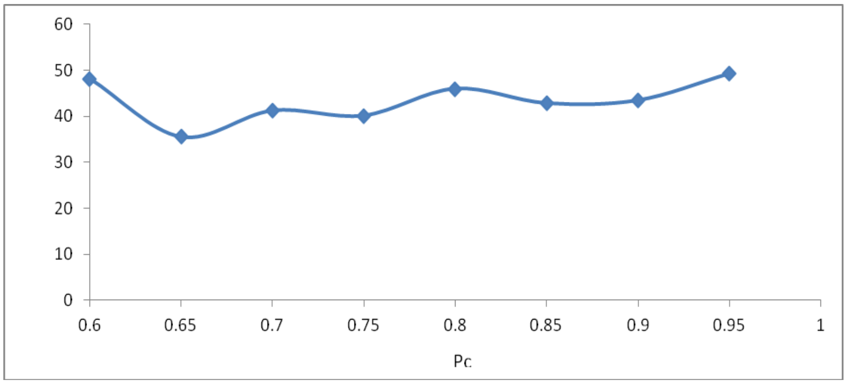


Graph 3.2 Probability of crossover

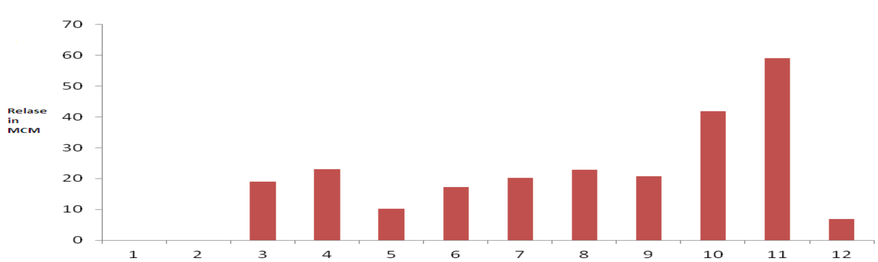
The optimal combination is generation of 450, population of 250 the optimal probability of crossover of 0.65. Hence the optimum policy according to this analysis is 250 number of population, 0.65 probability of crossover, 450number of generations, 0.042 mutation probability, distribution index for crossover and mutation is 2 and 100 respectively the optimal policy what is getting from the model is minimum irrigation deficit is 217086.3 $(MCM)^2$ annually and annual power generation is 342883877 (kWh)

V. RESULTS AND DISCUSSIONS

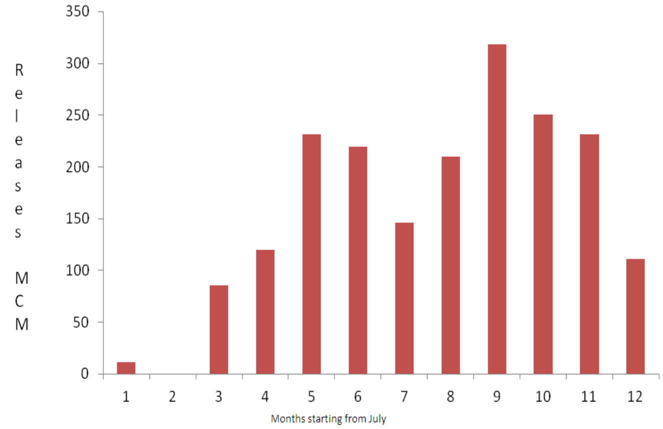
The same optimal combination is applied to the 10 different combinations for irrigation and power. the best weight combination is 95% irrigation and 5% power generation. According to optimal policy the releases are summarized in the table below.

Table 3.2 Release policy by GA model

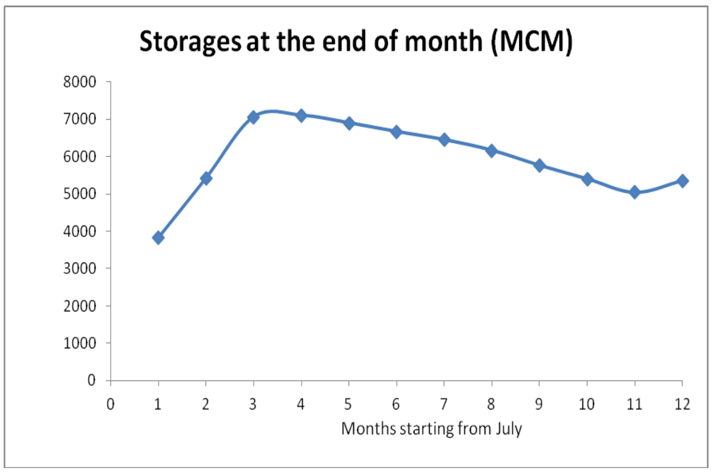
Month	ULBMC releases (MCM)	Kakrapar system releases (MCM)	Reservoir storage at the end of month (MCM)	Levels (m)	Overflow (MCM)
July	0.00	11.14	6961.955	(97.83)	3136.55
August	00.00	00.00	6784.24	(101.49)	1363.95
September	18.92	85.27	7614.61	(104.54)	556.43
October	22.99	119.97	7101.58	104.77	---
November	10.25	231.14	6898.52	104.50	---
December	17.26	219.52	6663.86	103.80	---
January	20.28	146.13	6448.28	103.46	---
February	22.93	209.62	6161.74	102.89	---
March	20.34	318.09	5759.96	102.32	---
April	41.77	250.77	5399.14	101.23	---
May	59.06	231.30	5036.40	100.76	---
June	6.88	111.47	5353.07	101.33	---



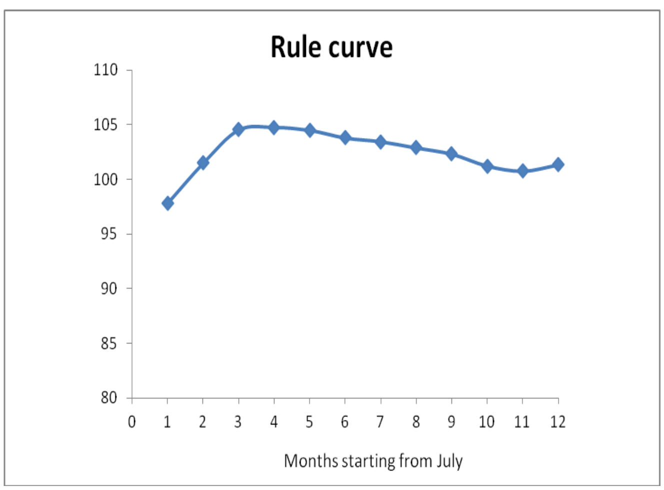
Graph 3.3 ULBMC releases by GA model (MCM)



Graph 3.4 Kakrapar system releases by GA model (MCM)



Graph 3.5 Storages at the end of month in reservoir (MCM)



Graph 3.6 Rule curve of reservoir

VI. CONCLUSIONS

The present scenario about Ukai Project was studied in accordance with irrigation, hydropower generation. The two objective functions are conflicting with each other and it is very difficult to handle these together. Although the scenario is true it has been tried to combine these two confecting objectives together by using weighted sum approach and optimal policy has been drawn for

Ukai reservoir. The tool used is MATLAB. Separate code is written in the MATLAB for simulated binary crossover and polynomial mutation. From the results the best weight combination is 95% irrigation and 5% power generation.

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