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OPTIMAL RESERVOIR OPERATION FOR HYDROPOWER GENERATION USING GENETIC ALGORITHMS FOR UKAI RESERVOIR PROJECT

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Abstract
Operation of reservoirs, often for conflicting purposes, is a difficult task. The solution to the problem is difficult because of the large number of variables involved, the non-linearity of system dynamics, the stochastic nature of future inflows, and other uncertainties of the system. 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, and fuzzy logic are increasingly being employed to solve multi-reservoir operation problems. Here the Genetic Algorithm technique is used for reservoir operation of Ukai Reservoir for hydropower generation. 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. Three models are developed. In this study, there are three models are developed from 2007. Genetic algorithm is a robust search technique to solve problems which needs optimization. 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. The releases to be made from the reservoir are also obtained. The releases obtained from all these models are compared with the actual releases made from the reservoir. The models are also compared based on their fitness values. 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. For average data of three year, using Genetic Algorithm the generation of power can be increased to 7.49% through optimal releases. There is 5.30% variation between existing and optimal reservoir release. In 2009, the generation of power can be increased to 5.15% through optimal releases. There is 4.90 % variation between existing and optimal reservoir release.

Keywords- *Reservoir Operation, Genetic Algorithm, Optimization, Hydropower Generation, Ukai Reservoir*

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. The major function of reservoirs is to smooth out the variability of surface water flow through control and regulation and make water available in case of necessity.

Water may flow out of a reservoir through various outlets such as derivations (to draw water for irrigation or other consumption), spillways (for flood protection) and penstocks (to produce electricity). Also, there may be water losses due to evaporation and seepage into the ground. 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 is a form of energy and it is a renewable resources. 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. Hydroelectric power comes from flowing water from mountain streams and clear lakes. Water, when it is falling by the force of gravity, can be used to turn turbines and generators that produce electricity.

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. Application of optimisation techniques to reservoir operation has become a major focus of water resources planning and management. Additional uncertainty in reservoir operations is introduced due to global climate change as well as economic activities in the river basin. Due to changes of hydro-meteorological conditions and shifting goals of water requirements from one region to the other, each reservoir has a different set of operation rules.

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. Performance of a hydropower reservoir in supplying water demands might only affect local users downstream of the reservoir, but the power generation has regional effects on the power network.

OBJECTIVES OF THE STUDY

To use genetic algorithm, its mechanism and its applications,
To use the genetic algorithm optimization tool and optimization of releasing water for hydropower generation for the Ukai reservoir project,
To use genetic algorithm for maximization of hydropower generation,
To analyze the reservoir operation optimization model for Ukai reservoir project.

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.

Genetic algorithms rely on a population of candidate solutions. The population size, which is usually a user-specified parameter, is one of the important factors affecting the scalability and performance of genetic algorithms. For example, small population sizes might lead to premature convergence and yield substandard solutions. On the other hand, large population sizes lead to unnecessary expenditure of valuable computational time. Once the problem is encoded in a chromosomal manner and a fitness measure for discriminating good solutions from bad ones has been chosen, 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. The main idea of selection is to prefer better solutions to worse ones, and many selection procedures have been proposed to accomplish this idea, including roulette-wheel selection, stochastic universal selection, ranking selection and tournament selection, some of which are described in the next section.
4. **Recombination:** Recombination combines parts of two or more parental solutions to create new, possibly better solutions (i.e. offspring). There are many ways of accomplishing this (some of which are discussed in the next section), and competent performance depends on a properly designed recombination mechanism. 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.

STUDY AREA

Ukai Dam, constructed across the Tapti River, is the largest reservoir in Gujarat. It is also known as Vallabh Sagar. Constructed in 1971, the dam is meant for irrigation, power generation and flood control. It is located between 21°15′ N latitude and 73°35′ E longitude and 105 km from Surat. The year of commencement of construction work of Ukai reservoir is 1964.The Ukai head works were completed in the year 1972 after a construction period of seven years.

The dam comprises a 4,927 m long earth-cum-masonry dam and bed rock is basalt. The dam is located at about 29 km upstream of the Kakrapar weir. The earth dam is 80.77 meter high above the lowest foundation level, while the masonry dam is 68.68 meter high above the lowest foundation. The storage extends irrigation facilities to an area of 1,522 sq. km under the Ukai left bank canal and Ukai right bank canal system besides firming up irrigation in an area of 2,275 sq. km under the command of pick up weir at Kakrapar. Thus, the total irrigation facilities provided are for 3,797 sq. km under Ukai and Kakrapar. Ukai reservoir has FRL up to 105.15 m and HFL up to 106.99 m. It has gross storage capacity of 8511 mcm, live storage capacity of 7369 mcm and dead storage capacity of 1142 mcm. There are 22 radial gates of 15.545 x 14.783 m size each. The length of the Ogee spillway is 425.195 m. The area under submergence due to the construction of reservoir (at FRL) is 601.30 sq. km, out of which 303 sq. km is in agricultural land, 223 sq. km is forest land and the remaining 75.30 sq. km is wasteland. Villages affected by submergence are 170. In Ukai dam, 5.5 km^3 of water is stored against the gates. This amounts to nearly 78% of the live storage.

The total catchment area of the Ukai reservoir is 62,225 sq. km, which lies in the Deccan plateau. Its catchment is located between longitudes 73°32'25" to 78°36'30"E and latitudes 20°5'0" to 22°52'30" N. The catchment of the dam covers large areas of 12 districts of Maharashtra, Madhya Pradesh, and Gujarat. The districts that lie in the catchment include Betul, Hoshangabad, Khandwa and Khargaon of Madhya Pradesh; Akola, Amravati, Buldhana, Dhule, Jalgaon and Nasik of Maharashtra and Surat and Bharuch of Gujarat state.

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.

At Ukai the the hydropower plant is a type of underground, river bed power house. Hydraulic head is 57 m to 34 m. The size of 4 no.s of penstock is 7.01 m Dia. The annual energy of Ukai hydropower is 670 x 106 KWH. Initially, the Ukai dam toe hydropower station with an installed capacity of 300 MW was planned as a peaking station and it was to be operated only for 8 to 10 hours in a day. In the initial years, with no upstream utilization in Maharashtra, the project was expected to generate about 990 MU annually. This was expected to reduce to 745 MU after 30 years and further to 587 MU after 60 years of operation, due to upstream development leading to reduced inflows to the reservoir. The actual performance of power house indicates that the stipulated generation of 900 MU was exceeded in 12 out of 25 years, the maximum annual generation reaching 1,233 MU in the year 1977-78.

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.

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.

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

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

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.

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.

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

Where,
S_{t+1} = Storage in the reservoir at the time period t, MCM.
$\mathbf{I}_t$ = 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

.

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.

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

RESULTS AND ANALYSIS

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.

Three models are developed here as described below using Genetic Algorithms:

1) Model of Year 2007,
2) Model of average data of 3 year (2007-2009)
3) Model of average data of 5 year (2007-2011)

1) **Model of Year 2007**

Table 1: Obtained Releases for Model of Year 2007

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 2: Actual and Optimal Power Generation

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

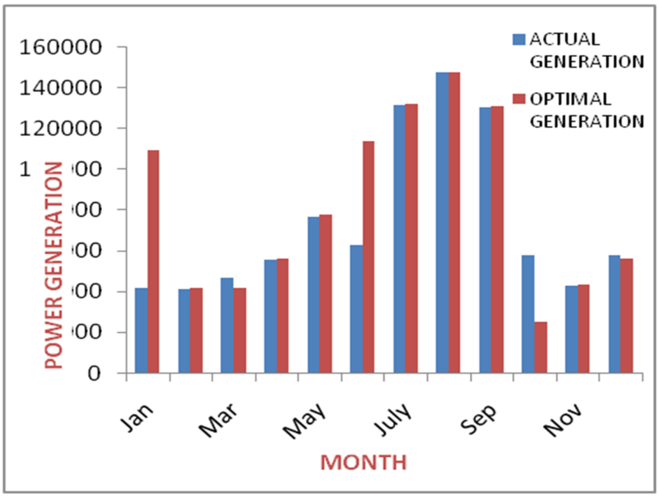

Fig. 1 Actual and Optimal Power Generation in year 2007.

Regarding to past data the power generated in 2007 is 893389 MW. After developed model using Genetic Algorithm, power is maximized 893389 MW to 975771.24 MW through optimal releases.

2) Model of Average Data of Three Years

Table 3: Obtained Releases for Average data of Three Years

MONTH	ACTUAL RELEASE for HYDRO in MCM	OPTIMAL RELEASE for HYDRO in MCM
Jan	314.79	646.68
Feb	322.53	820.67
Mar	369.91	388.87
April	455.52	961.69
May	682.80	487.52
June	635.67	489.86
July	1128.43	1149.51
Aug	1149.51	589.58
Sep	959.34	894.86
Oct	444.42	345.86
Nov	364.52	370.69
Dec	323.56	384.33

Table 4: Actual and Optimal Power Generation

MONTH	ACTUAL GENERATION	OBTAINED GENERATION
Jan	41552	85359.96
Feb	41090	104553.04
Mar	46917	49321.77
April	55688	117569.05
May	76941	54935.59
June	62990	88673.72
July	131667	101097.35
Aug	147727	75768.73
Sep	130317	156149.68
Oct	57757	26233.81
Nov	42705	31712.43
Dec	58038	68938.51

Regarding to past data the power generated in 2007 is 893389 MW. After developed model using Genetic Algorithm, power is maximized 893389 MW to 960313.65 MW through optimal releases.

3) Model of Average Data of Five Years

Table 5: Obtained Releases for Model of Average Data of 5 Years

MONTH	ACTUAL RELEASE for HYDRO in MCM	OPTIMAL RELEASE for HYDRO in MCM
JAN	314.79	386.75
FEB	322.53	677.81
MAR	369.91	377.12
APRIL	455.52	424.68
MAY	682.80	904.81
JUNE	635.67	803.2
JULY	1128.43	953.36
AUG	1149.51	957.92
SEP	959.34	1149.51
OCT	444.42	242.44
NOV	364.52	263.48
DEC	323.56	360.52

Table 6: Actual and Optimal Power Generation

MONTH	ACTUAL GENERATION	OBTAINED GENERATION
Jan	41552	51049.92
Feb	41090	86452.73
Mar	46917	47831.47
April	55688	51918.21
May	76941	101957.40
June	62990	79690.92
July	131667	111239.29
Aug	147727	123205.23
Sep	130317	156149.68
Oct	57757	36607.60
Nov	42705	31867.75
Dec	58038	64667.63

Regarding to past data the power generated in 2007 is 893389 MW. After developed model using Genetic Algorithm, power is maximized 893389 MW to 942637.86 MW through optimal releases.

CONCLUSIONS

In the present study, GA based models are developed for the reservoir operation of Ukai Reservoir Project. The main objective was to maximize power generation through optimal releases. The releases obtained in the study are the optimal releases. Various models were developed and the following conclusions are observed.

Conclusions of five yearly models are as follows:

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 powncrease in optimal reservoir release.

Model of average data of 3 year:
In 2007, generated power was 803389 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 7.49%. It is 960313.65 MW generated through optimal releases.
There is 5.30% increase in optimal reservoir release.

Model of average data of 5 year:
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 5.15%. It is 942637.86 MW generated through optimal releases.
There is 4.90% increase in optimal reservoir release.

RECOMONDATIONS

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%.

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