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Irrigation Operating Policies Using Genetic Algorithm- Ukai Reservoir as a Case Study

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Abstract— In reservoir operation, appropriate methodology for deriving reservoir operating rules should be selected and operating rules should then be formulated. In the present study, Genetic Algorithm (GA) 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 function used is minimization of irrigation deficit i.e minimize sum of squared deviation of releases from demands of irrigation. 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. 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— Genetic algorithm, Optimization, Ukai, reservoir, irrigation

I. INTRODUCTION

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. An extensive review of these techniques can be found in Loucks et al. (1981), Yakowitz (1982), Yeh (1985), and Wurbs (1993). But as far as reservoir operation is concerned, no standard algorithm is available, as each problem has its own individual physical and operational characteristics (Yeh 1985). 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. Genetic Algorithms (GAs) (Goldberg 1989) and Particle Swarm Optimization (PSO) (Eberhart and Kennedy 1995) are some of the techniques in this category. These evolutionary algorithms search from a population of points, so there is a greater possibility to cover the whole search space and reaching the global optimum. GA is one of the population-based search techniques, which works on the concept of “survival of the fittest” (Goldberg 1989). In the field of water resources, in earlier studies, few applications of the GA technique to derive reservoir operating policies have been reported (Oliveira and Loucks 1997; Wardlaw and Sharif 1999) and they illustrated the utility of evolutionary techniques for reservoir operation problems. Use of Genetic Algorithm (GA) in determining the optimal reservoir operation policies, is receiving significant attention from water resources engineers. Many traditional numerical methods are available to facilitate the formation of reservoir operating policies. Yeh (1985) in state of art review on reservoir management and operation models discussed in details the usefulness of various models for reservoir operations. In spite of extensive research in reservoir optimization, researchers are still in search of new optimizing techniques, which can derive more efficient reservoir operating policy for reservoir operation. GA is one such optimizing technique which it is robust and is considered in this study for deriving multipurpose reservoir operating policies.

One of the advantages of GA is that it identifies alternative near optimal solutions. Oliveira and Loucks (1997) reported that GA can be used to identify effective operation policies. Sharif and Wardlaw (1999) used GA in water resource development and compared it with dynamic programming; they concluded that both results were comparable. Ahmed et al. (2005) developed a GA model for deriving the optimal operating policy and compared its performance with that of stochastic dynamic programming (SDP) for a multipurpose reservoir. The objective function of both GA and SDP was to minimize the squared deviation of irrigation release. Sensitivity analysis was carried out for mutation and cross over. They found that GA model releases nearer to the required demand and concluded that GA is advantageous over SDP in deriving the optimal operating polices. Janga Reddy and Nagesh Kumar(2005) developed Multi-objective Evolutionary Algorithm to derive a set of optimal operation policies for a multipurpose reservoir system and concluded that the results obtained using the proposed evolutionary algorithm was able to offer many better alternative policies for the reservoir operation, giving flexibility to choose the best out of them. Jotiprakash et.al (2006) developed a GA model for deriving the optimal operating policy for a multi-purpose reservoir. In the present paper, a GA model has been used for optimum reservoir operation. The objective of this study is to minimize the squared deviation of monthly irrigation demand deficit. The decision variables used are the release for irrigation demand from the reservoir through Ukai left bank canal and Ukai right bank canal. The constraints used for this optimization are mass balance equation, reservoir capacity, and the bounds for decision variables.

II. STUDY AREA

An easy way to comply with IJRASET paper formatting requirements is to use this document as a template and simply type your text into it. 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. Figure 1 shows ukai reservoir system and table I shows salient features of Ukai reservoir system.

The data available is for 36 years from 1975 to 2010. Figure 2 shows the plot of years against reservoir inflow in MCM and the trend line drawn show a constant reduction in annual inflow, demanding better water planning. Table II shows historical data.

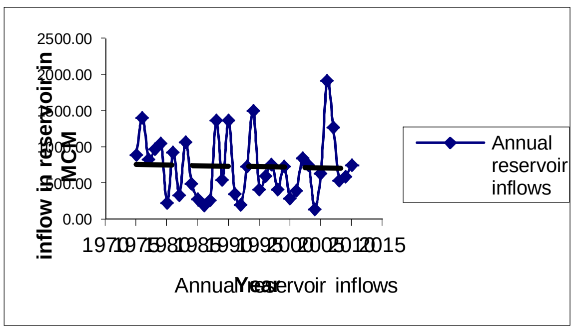

Fig.1Annual reservoir inflows

Table I Statistical analysis of historical Inflow data

SN	Months	Average inflows (MCM)	Standard deviation	Skew ness
1	June	503.21	501.25	1.24
2	July	1757.67	1458.89	2.09
3	August	3456.17	2638.26	2.05
4	September	2351.00	2101.01	1.40
5	October	520.44	640.01	2.57
6	November	93.20	156.73	3.51
7	December	56.71	159.02	4.69
8	January	4.66	9.43	2.25
9	February	1.48	3.04	1.88
10	March	0.74	1.91	2.51
11	April	0.26	1.47	5.71
12	May	0.37	1.60	5.03

III. MODEL DEVELOPMENT

In the present study, the fitness function of the GA model is minimization of irrigation deficit i.e Minimize sum of squared deviation of releases from demands of irrigation

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

Where, SQDV is the sum of squared deviations of irrigation releases from demands, $D_{l,t}$
And $D_{Rb,t}$ are the irrigation demands for the left bank and right bank canal command areas respectively in period t in Mm^3; $R_{l,t}$ and $R_{r,t}$ are the releases in to the left and right bank canals respectively in period t in Mm^3.
This model is subjected to following constraints:

a. Storage continuity

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

Where S_t = active reservoir storage at the beginning of period t in Mm^3

I_t = inflow to the reservoir during period t in Mm^3

E_t = the evaporation losses during period t in Mm^3 (a non-linear function of initial and final storages of period t)

O_t = overflow from reservoir in Mm^3

b. Storage limits

$$S_{\min} \le S_f \le S_{\max} \quad \text{for all t = 1,2,………..,12} \quad (3)$$

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

c. Canal capacity limits

$$R_{l,t} \le C_{1,\max}\ R_{l,t} \le C_{1,\max}, \quad \text{for all t = 1,2,………..,12} \quad (4)$$

Where $C_{1,\max}$ is the maximum canal carrying capacity of the Ukai left bank canal.

d. Irrigation demands

$$Dl_{\min,t} \le R_{l,t} \le Dl_{\max,t} \quad \text{for all t = 1,2,………..,12} \quad (5)$$

$$Dr_{\min,t} \le R_{r,t} \le Dr_{\max,t} \quad \text{for all t = 1,2,………..,12} \quad (6)$$

Where $Dl_{\min,t}$ and $Dl_{\max,t}$ are minimum and maximum irrigation demands for left canal respectively, $Dr_{\min,t}$ and $Dr_{\max,t}$ are minimum and maximum irrigation demands for Karkapar right canal and Karkapar left bank canal respectively in time t.

e. Overflow constraint

$$O_t = S_{t+1} - 7414.29 \quad \text{for all t = 1,2,………..,12} \quad (7)$$

Where s_{t+1} = storage at the end of the month Mm^3. 7414.29 is gross storage of reservoir.

f. Steady state storage constraint

$$S13 = S1 \quad (8)$$

This constraint is required to bring the steady state condition for the reservoir storage, i.e., storage at the end of a year is equal to the initial storage at the beginning of that year.

IV. MODEL APPLICATION AND DISCUSSION

For the selection of the optimal size of the different parameters such as size population, optimal probabilities of crossover, a thorough sensitivity analysis is carried out. In GA one of the important parameter is population size, obtaining optimum population is very important. In water resources applications, its values ranges from 64 to 300 and even up to 1000. A larger population helps to maintain greater diversity but, it involves considerable computational cost when the full model is being used to generate performance predictions. To find optimum population size in present study different population size has been considered. Population size is increased up to certain population size. Second important parameter affecting GA performance is the probability of cross over. Its effect on the system performance is studied by varying the probability of crossover from 0.6 to 0.9 with an increment of 0.01 and adopting the obtained optimal population of 100. Figure 3 shows variation of objective function with crossover probability.

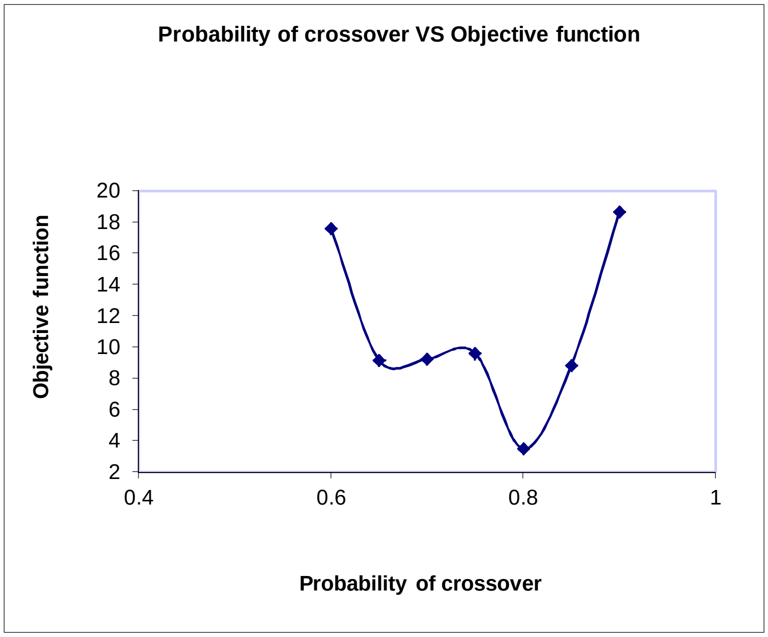

Fig.2 Probability of crossover Vs Objective function

A comparative plot of actual demand and GA model release for an average inflow shown in Fig.6 shows that the demand is almost satisfied with the releases obtained through GA model for Ukai left bank canal and Ukai downstream. To derive rule curve the results obtained are plotted in Fig. 4 and Fig 5.The parameters used in applying GA to reservoir operation model were those selected after a thorough sensitivity analysis by varying each of the parameters. A population size of 100 and crossover probability of 0.8 are chosen to run the model.

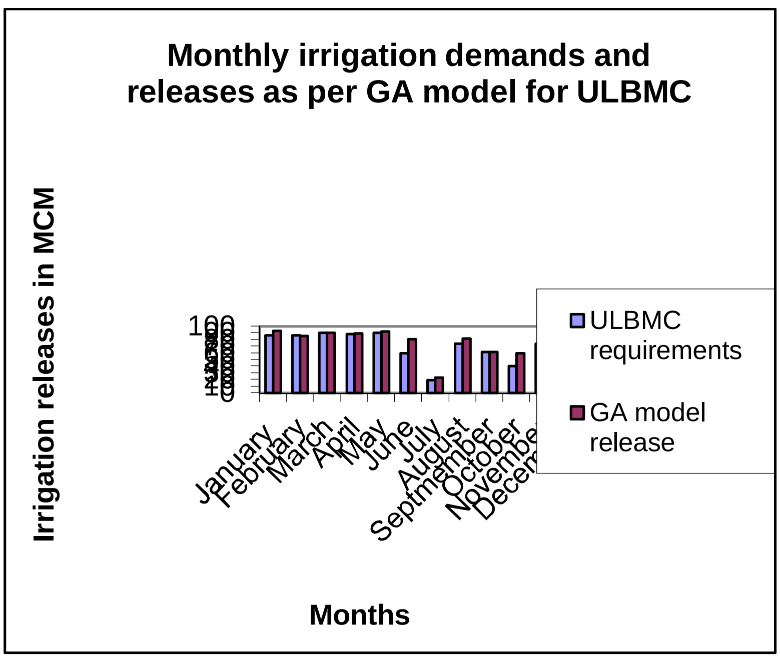

Fig. 3 Monthly irrigation demand and releases as per GA model for ULBMC

Table 2 – Summarized results

Month	Evap. Loss (MCM)	Inflow (MCM)	Overflow (MCM)	ULBMC releases as per model (MCM)	D/S releases as per model (MCM)	Storage at the end of month (MCM)	Overflow (MCM)
June	16.48	503.21	0.00	80..91	272.96	1452.3	--
July	50.39	1757.67	0.00	22.81	103.61	2904.5	--
Aug	22.26	3456.17	0.00	81.81	407.4	5847.9	289.71
Sept	37.58	2351.00	289.71	61.67	394.24	7704.0	336.11
Oct	28.52	520.44	336.11	59..33	385.55	7750.4	--
Nov	21.24	93.20	0.00	84.14	404.25	7335.5	--
Dec	24.97	56.71	0.00	86.99	368.77	6911.5	--
Jan	35.65	4.66	0.00	93.02	366.9	6420.6	--
Feb	46.33	1.48	0.00	85.19	361.35	5929.2	--
Mar	39.44	0.74	0.00	90.04	352.57	5447.9	--
Apr	35.96	0.26	0.00	89.61	363.13	4959.5	--
May	65.72	0.37	0.00	91.99	413.77	4388.4	--

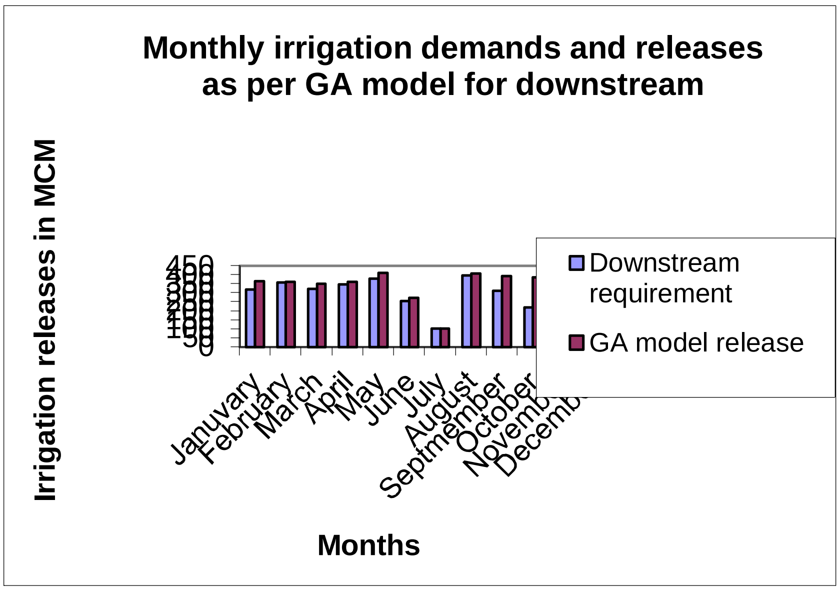

Fig. 4 Monthly irrigation demand and releases as per GA model for downstream

The operating rule curve obtained for Ukai Reservoir is shown in Fig. 7. This rule curves show the final storage to be maintained in the reservoir in each month starting from July under inflows.

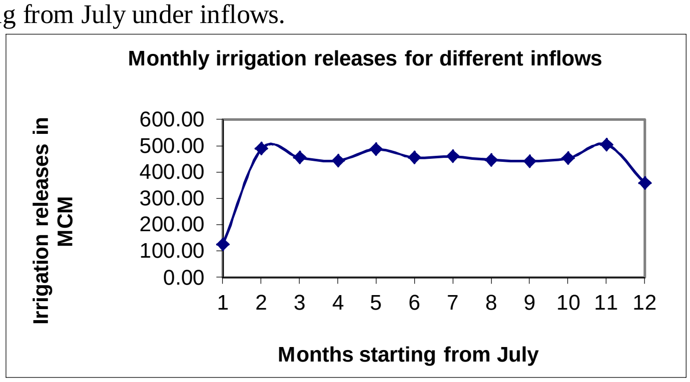

Fig 5. Monthly irrigation releases at different Inflows

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It is observed that storage is maximum at the start of October i.e. when monsoon has reaches its peak and consequently reduces to minimum in June to receive the next monsoon inflow, reduce flood damages and reduce water losses from the system. In the table II summarized results are shown.

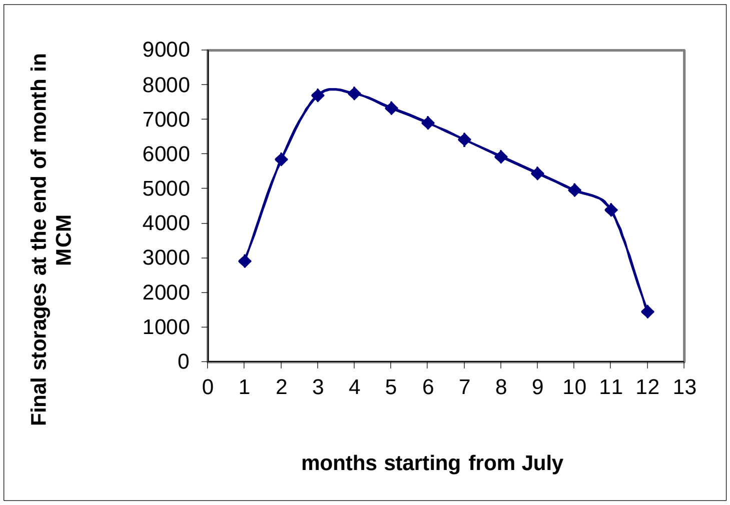

Fig 6. Monthly reservoir storages at different Inflows

V. CONCLUSIONS

The GA approach is applied to Ukai reservoir system to derive operating policies for the multipurpose reservoir systems with single objective. The sensitivity analysis of GA model applied to this particular reservoir suggests optimal size of population to be used 100 and probability of crossover of 0.80, to find optimal releases for Ukai reservoir. The model resulted in an irrigation releases nearly equal to irrigation demand. Minimum storages are observed in start of monsoon i.e. at the end of water year and maximum storage is observed when the monsoon reaches to its peak. These types of rule curves are expected to be useful in real life implementation of reservoir operation.

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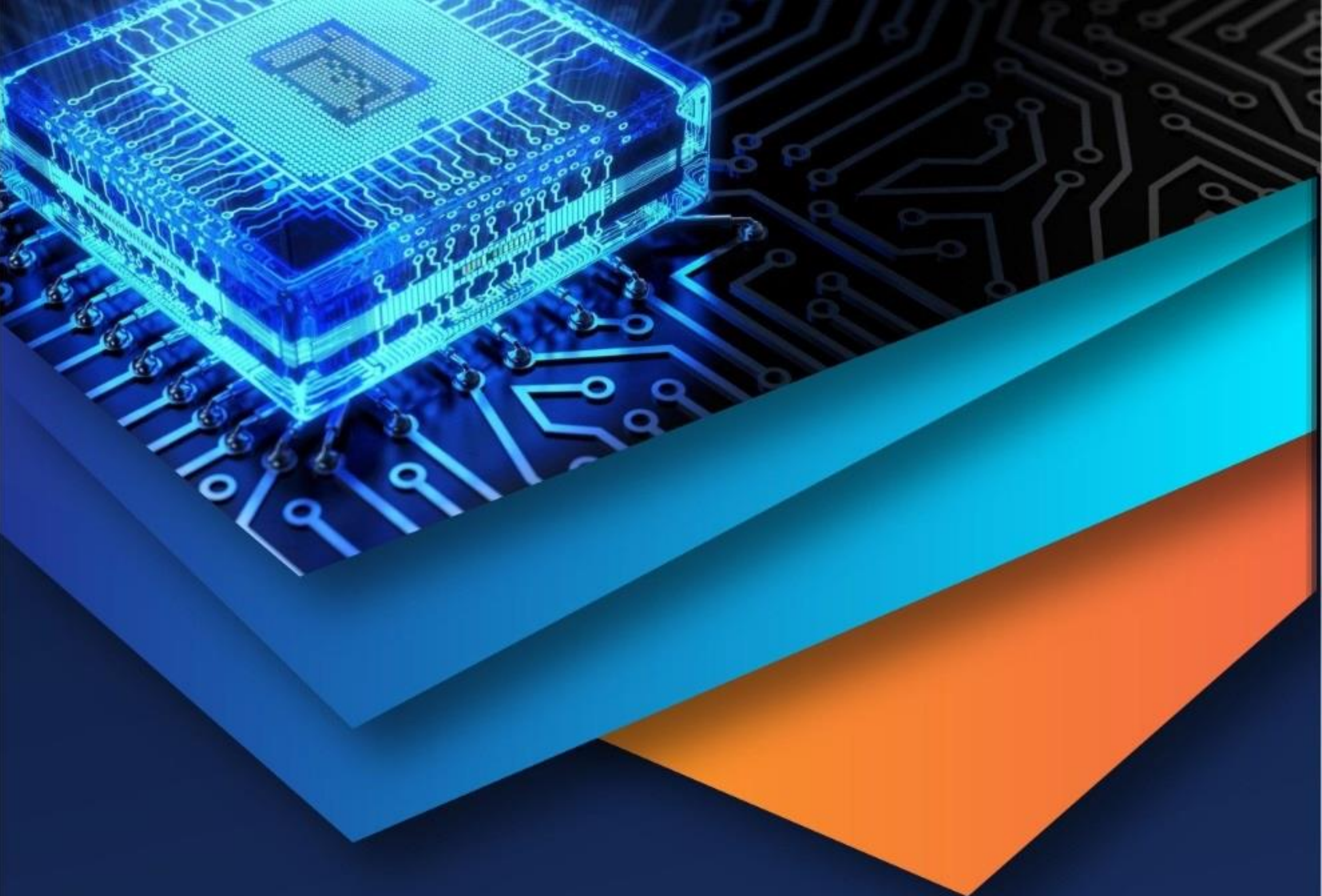

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