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Development of Fuzzy Rule Based (FRB) Model to Simulate Power Generation in a Cascade Hydropower System

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***Abstract**: The aim of this paper is to correlate the auxiliary power generation from an irrigation reservoir with the power generation of its upstream hydro power project in a cascade reservoir system. System considered for the study is the Pamba Basin- Kakkad Hydro Power Project and Maniyar Reservoir of Pamba Irrigation Project of Kerala State. In a water year from the 1st June to 31st May, irrigation period spans for seven months from November to May in the Irrigation Project. As the water release of the upstream Hydro Electric Plant exceeds the irrigation demand, even during the peak irrigating months of January and February, it is hypothesized that there is surplus inflow for power production. A water year is divided to two Seasons namely Irrigation and Non-Irrigation seasons and rules are developed for both, based on the data of upstream Generation and Irrigation demand. A Fuzzy Rule model to simulate power generation using the surplus water is evolved and the outputs are compared with the real time data. In the Fuzzy Rule Based (FRB) model, the inputs considered are the Generation in units of the upstream Kakkad Hydro Electric Project, the Runoff of the catchment and the Irrigation Release. Spill from the barrage and the Power Generation in the downstream Carborandum Universal Madras India Ltd.'s - Small Hydro Electric Project (CUMI-SHEP) are considered as the outputs. The results obtained shows that the power generation from the FRB model are almost matching with the real time data.*

***Index Terms**: Cascade system, Membership function, Fuzzy rule, Mamdani fuzzy inference method, MATLAB*

I. INTRODUCTION

As reservoirs contribute major water storage system, their optimal operation is of utmost importance for water resource management. Multipurpose reservoir operation involves interactions and trade-offs between purposes, which are sometimes complementary but often competitive or conflicting. Due to the frequent variation of inflows and multipurpose demands, the task of allocation of available water becomes very complicated. With the growing pressure on available resources, the problem of conservation and allocation has assumed importance in recent days. The application of mathematical tools to reservoir management is of most importance in water resources engineering . The modification of existing operating rules or evolving operation rules in case it is absent, is very important to meet the changing demands on the basis of public needs and objectives. An operation schedule is a set of rules for deciding how much quantity of water with respect to time can be made available for each purpose, under various conditions for meeting the Conflicting and complementary demands.

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A. *Fuzzy logic approach in civil engineering*

Civil Engineering is basically different in the sense that the available theories never totally fit the actual design problem. This is because of the fact that each project is unique and needs special attention and way thinking. So some basic 'thumb rules' could not be avoided especially at the preliminary design level. Moreover, these engineering problems are constraint satisfaction problems. The designer has a range of tolerance and uncertainties to deal with and make optimum decisions. Because of these complexities and uncertainties, civil engineers have an affinity towards fuzzy concepts. Yeh (1985) observed there is a considerable progress in research relating to reservoir operation, but it is very slow in finding its way into practice. The reservoir operators are often uncomfortable with the sophisticated optimisation techniques used in the mathematical models. The fuzzy logic approach, which is more flexible, may provide a promising alternative to the methods used for reservoir operation modelling [1]. Mynepally, Anjaneya Prasad, S.Mohan, (2005) demonstrated a fuzzy rule based model with a case of two serial reservoirs Nizamsagar & Sriramsagar on river Godavari. Results shows that any reservoir problem is usually site specific in nature and The Fuzzy Inference System utilizes the knowledge of reservoir managers and avoids complex optimization procedure hence more acceptable [2]. Umadevi P.P., James E.J., Jagathambal P (2014) developed decision support models using a fuzzy logic with different combination of inputs for developing rules for the operation of Aliyar reservoir in South India. The study concluded that Fuzzy logic can be effectively applied for evolving reservoir operation rules and Computational challenges can be overcome[3] . Sahil Sanjeev Salvi [2017] developed an optimal reservoir operation model using fuzzy Inference System (FIS).

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It is reported that fuzzy logic model based on MATLAB is very useful for the estimation of irrigation water release corresponding to the maximum level of satisfaction and more comfortable for operators [4].

The application of fuzzy sets theory can provide a feasible solution to handle situations when problems with objectives are difficult to define due to imprecision. Out of the two types of Fuzzy Inference System namely Mamdani type and Sugeno type, the Mamdani fuzzy inference method has been adopted as it depicts the output more realistically.

II. FUZZY OPERATION MODEL

In modelling reservoir operation with fuzzy logic, the following consecutive steps are planned with the aid of MATLAB package.

1)Fuzzification of inputs, 2) Formulation of fuzzy rule set, 3) Application of a fuzzy operator, 4) Implication, 5) Aggregation, 6) Defuzzification

III. SYSTEM DESCRIPTION

Pamba basin system of Kerala State, India has been selected for the study. The reservoir of Pamba Irrigation Project is impounded by Maniyar Barrage constructed across the river Kakkad, a tributary to the Holy river Pamba, Kerala State. The reservoir caters to the irrigation needs of 21135ha of command area in Pathanamthitta and Alappuzha districts. The project was commissioned in the year 1979.The reservoir gets a perennial inflow from the tail race of Ullumkal-shep, which in turn gets inflow from the upstream Kakkad powerhouse of Kerala State Electricity Board. Sabarigiri, the top most power house of KSEB, draws water from Pamba Basin consisting of a number of reservoirs and after power generation its tail race water gets collected and is conveyed to the Kakkad powerhouse through penstocks. The reservoir has a catchment area of 280 km^2, which is partially impounded by barrages. The schematic diagram of the Pamba Irrigation Project is shown in Fig.1

The details of the cascade system are given in Table I.

I: Details of the cascade system

Sl. no.	Name of project	Installed capacity (MW)	Average water Use / unit generation (m^3)	Additional Catchment area(km^2)
1	KSEB-Kakkkad, Seethatode-HEP	50	3.25	28.75
2	Pamba Irrigation Project-Maniyar	Irrigation purpose.	-	280.00
3	CUMI-Maniyar-SHEP	12	30.00	-

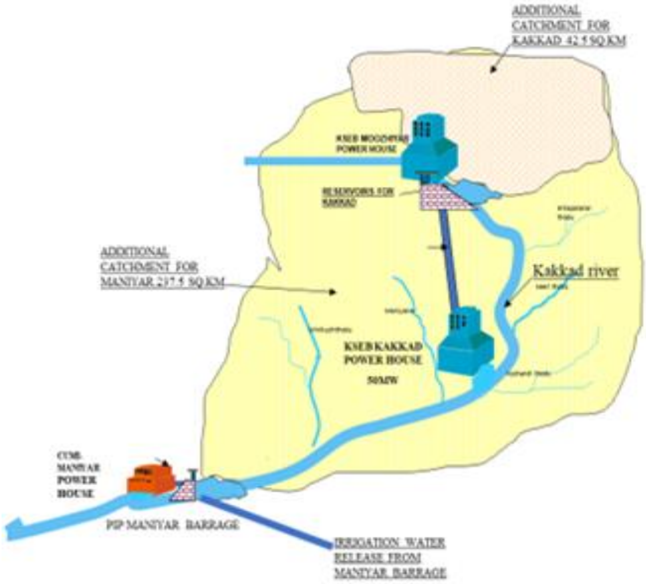

Fig.1: Diagram of water source to Pamba Irrigation Project, Maniyar Reservoir, Kerala State.

IV. FORMULATION OF MODEL

Maniyar Barrage, built across the river Kakkad for irrigation purpose, forms the Pamba Irrigation Project reservoir and diverts water to the canal system. The storage of the barrage is very limited and it is only an interim storage. The tailrace inflow to the reservoir varies as it depends on the State's power demand, but it is perennial. Runoff to the reservoir is intermittent as it depends on seasonal rains. In the present study, a water year is divided to Two seasons and Two distinct set of rules are formulated. A month is divided to 3, 10 day periods and this results in 36 periods in a water year. The excess or shortage of days if any, is adjusted with the 3rd period of the month.

Season No.- 1- Irrigation (dry) season:- The irrigation demand starts in the month of November and ends by May, but during this period the inflow is less as it is contributed by the upstream tailrace alone. The priority is to be given to irrigation supply and the surplus if any, may be used for power generation during this period. Out of the two demands namely, irrigation demand and power generation, irrigation demand is to be satisfied to its maximum degree during **Season-1** and power generation is to be planned to avoid spill/wastage of water during the sane period.

The Inputs given to the model are:

- Kakkad generation
  (ranges from 0-100 lakhs units)
- Irrigation water release
  (ranges from 0-55 Mcm)

The Outputs obtained from the model are:

- Power generation
  (ranges from 0-25 lakhs units)
- spillage from the reservoir
  (ranges from 0-50 Mcm)

Membership functions are traced to 'low', 'medium', 'high' for input and output as given in table II.

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II: Membership functions during Season 1

	Input		Output	
	Kakkad -HEP Power generation (lakh units)	Irrigation water release (Mcm)	CUMI-SHEP Power generation (lakh units)	spillage of the reservoir (Mcm)
Low (L)	0-35	0-6	0-8.5	0-16
Medium (M)	25-65	4-11	6-16	14-31
High (H)	60-100	9-15	14-25	28-50

III: fuzzy rules for Season 1

Rule No.	Input		Output	
	Tailrace Inflow	Irrigation	Power generation	Spillage
1	H	H	L	L
2	H	M	M	L
3	H	L	M	L
4	M	H	L	L
5	M	M	L	L
6	M	L	M	L
7	L	H	L	L
8	L	M	L	L
9	L	L	L	L

The generalised fuzzy rules for Season 1 are shown in Fig.2

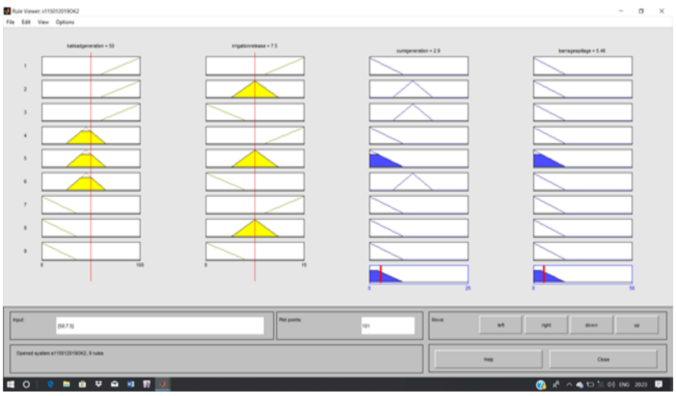

Fig. 2: Generalised fuzzy rules for Season 1

The surface generated using fuzzy rules for season 1 is shown in Fig.3

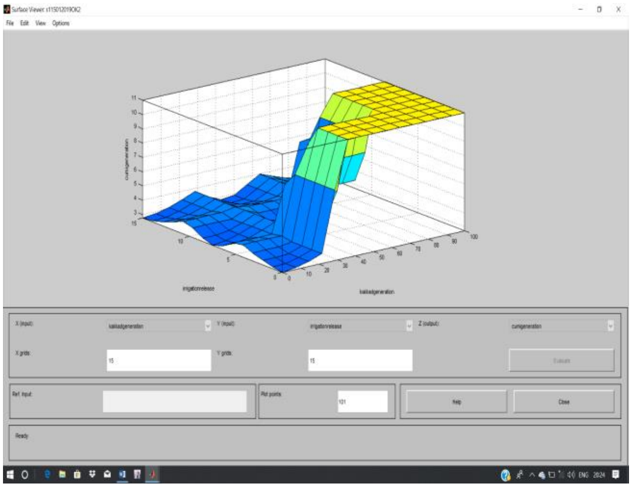

Fig. 3: Generated Surface generated using fuzzy rules for Season 1

Season no. 2 - Non-irrigation (rainy) period:- The inflow to the reservoir is contributed by both the runoff and the tailrace and there is no irrigation requirement during this period. Thus the whole inflow can be used for power generation and there is occasional spill of water due to excessive rains. During **Season-2** , maximum power is to be generated in order to avoid spill/wastage as far as possible.

The Inputs to the model are:

- tailrace Inflow
  (ranges from 0-100 lakhs units)
- Runoff inflow
  (ranges from 0-55 Mcm)

The Outputs obtained from the model are:

- Power generation
  (ranges from 0-25 lakhs units)
- spill from the reservoir
  (ranges from 0-50 Mcm)

Knowing the tail race and runoff ('low,' 'medium' and 'high'), the appropriate fuzzy rule is invoked. The fuzzy operation model yields a single crisp value for power generation and spilling. The input and output were considered based on the membership functions as 'Low', 'Medium', and 'High' as given in Table IV.

IV: Membership functions during Season 2

	Input		Output	
	Kakkad-HEP Power generation (lakh units)	Runoff (Mcm)	CUMI-SHEP Power generation (lakh units)	spillage of the reservoir (Mcm)
Low	0-35	0-6	0-8.5	0-16
Medium	25-65	4-11	6-16	14-31
High	60-100	9-15	14-25	28-50

The fuzzy rules for Season 2 are given in Table V

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V: fuzzy rules for Season 2

Rule No.	Input		Output	
	Tailrace inflow	Runoff Inflow	Power generation	Barrage Spill
1	H	H	H	M
2	H	M	H	L
3	H	L	M	L
4	M	H	H	L
5	M	M	M	L
6	M	L	M	L
7	L	H	M	L
8	L	M	M	L
9	L	L	L	L

The generalised fuzzy rules for Season 2 are shown in Fig.4

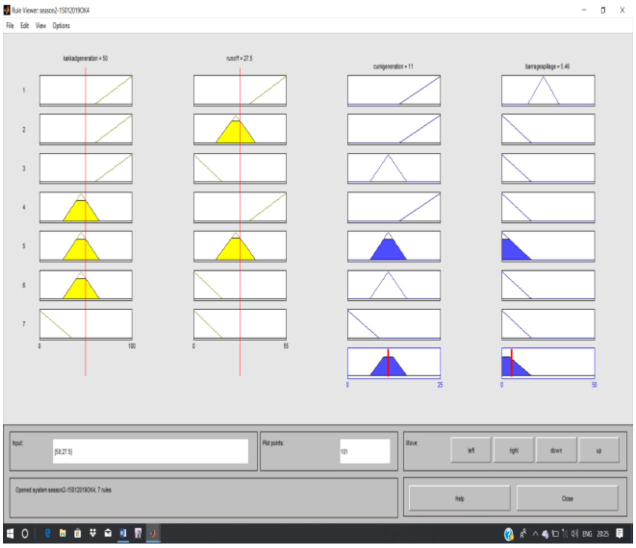

Fig. 4: Generalised fuzzy rules for Season 2

The surface generated using fuzzy rules for season 2 is shown in Fig.5

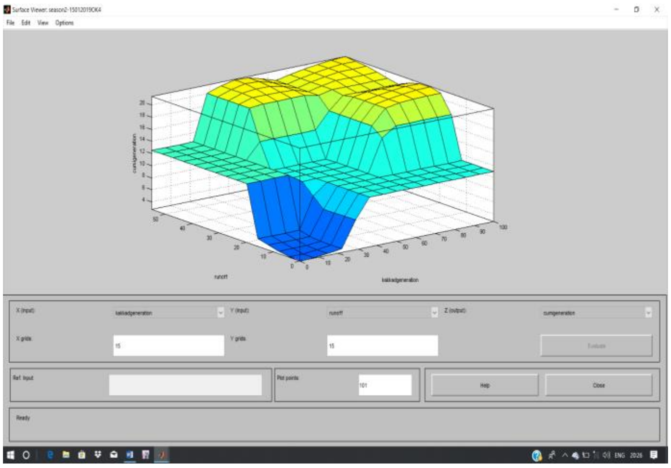

Fig. 5: Generated Surface generated using fuzzy rules for Season 2

II. RESULTS AND DISCUSSION

A water year is divided to 36, 10 day periods for the study with 03 periods per month as explained earlier. As the Season S1 extends for seven months from November to May, subsequently there are 21 periods occur in this Season. The rainy season S2, which spans for five months from June to October, consists of 15, 10 day periods. Data for five successive water years from 2009-10 to 2013-14 are taken for the present study and thus there are 21x5=105, 10 day periods of S1 and 15x5=75, 10 day periods of S2 for comparison. The Real and Fuzzy values of Secondary Generation at CUMI-SHEP are plotted against the 105 periods of S1 and 75 periods of S2 in two plots for the five water years and shown in Fig.6 & Fig.7 respectively. From the Fig. 6 & 7, it is observed that the trend matches with the real values. In the present study, Fuzzy Inference System model for power generation is developed and demonstrated over an existing Irrigation reservoir impounded by Maniyar Barrage of Pamba Irrigation Project, Kerala State. The fuzzy inference system tool box available with the MATLAB software was used for arriving at the model. The inputs are the 'Power Generation in units at the upstream HEP-Kakkad', 'Runoff 'and 'Irrigation release' on a 10 day period basis. The output is the 'Power Generation at the downstream CUMI-SHEP' and the 'Spillage at the Barrage'. 'And' method 'min', 'Or' method 'max' and 'centroid' method for defuzzification are resorted to for the inputs - output operations. The results obtained shows that the values of secondary power generation at CUMI-SHEP, from the FRB model are satisfying the real time data. As the storage of a reservoir impounded by a Barrage is very limited and highly fluctuating, that is not considered in the study.

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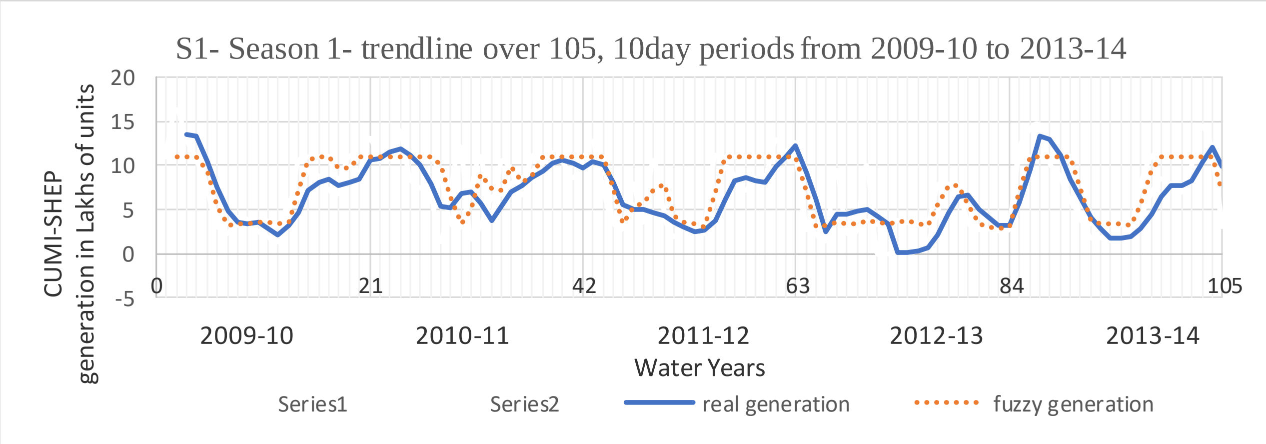

Fig.6: Comparison of Secondary Generation - Real and Fuzzy - during Irrigation Season-S1

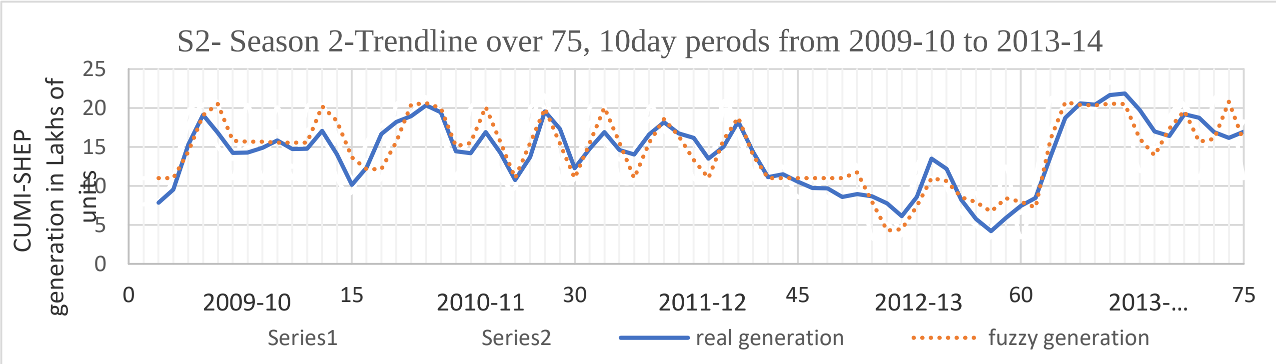

Fig.7: Comparison of Secondary Generation - Real and Fuzzy - during Non-Irrigation Season-S2

VI. CONCLUSIONS

Three Membership Functions 'Low', 'Medium', 'High' for input and output are applied in this study. The error decreases with the increase in number of Membership functions of Input and Output. But the increase in the number of Membership functions of input and output lead to dimensionality problem. The advantage of the fuzzy rule based reservoir model is that complex optimisation procedures are eliminated, expert opinion and linguistic statements such as 'low generation', 'high irrigation', 'medium runoff' etc., may be readily incorporated. As the results are quite sensitive to the Membership Functions and the Rules, it has to be carefully framed incorporating expert knowledge. The model was tested with the real time data and it was found that the performance of the FRB model was found to be satisfactory.

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