 ICCES, vol.4, no.1, pp.31-39, 2007

Fuzzy Logic Model on Operation and Control of Hydro-Power Dams in Malaysia

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Summary

The aim of this paper is to develop a fuzzy logic model for deriving optimal operational rules at the macro level for better performance and control of hydro-power generation. System modeling based on conventional mathematical tools is not well suited for dealing with ill-defined and uncertain systems. By contrast, a fuzzy inference system employing "*if-then*" rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses. In fuzzy logic, diagnosis is based on imprecise data. For instance, when the demand is 'very high' i.e. in linguistic term, then its value is important in assisting with the diagnosis. But fuzzy logic can work with this kind of data too. Systems like this are too complex to be modeled using classical discrete mathematics. The model uses the methodology for expressing operational rules of hydro-power generation in linguistic terms instead of mathematical equations. The model will be validated using the data from Chenderoh dam in state of Perak in West Malaysia.

keywords: water power engineering; operation policy of dam; fuzzy logic; heuristic approach.

Introduction

Reservoirs are built usually to serve multiple purposes for example irrigation, municipal and industrial water supply, hydro-power and flood control. Fuzzy system is an alternative to traditional notions of set membership and logic that has its origins in ancient Greek philosophy, and applications at the leading edge of Artificial Intelligence. Yet, despite its long-standing origins, it is a relatively new field, and as such leaves much room for development. Optimal operation of reservoir has been an active area of research for many years. Various techniques have been developed and adopted for reservoir operation incorporating the uncertainty due to stochastic nature of inflows and demands. The fuzzy logic based modeling of a reservoir operation is a simple approach, which operates on an 'if-then' principle, where 'if is a vector of fuzzy explanatory variables or premises such as the present reservoir pool elevation, the inflow, the demand, and time of the year. The 'then' is a fuzzy consequence such as release from the reservoir. Hence fuzzy sets provides translation of linguistic descriptors into usable numerical values. Fuzzy logic has been used in a number of water resources applications but generally as a refinement to conventional optimization techniques in which the usual 'crisp' objective and some or all of the constraints are replaced by the fuzzy constraints. Many systems are too complex to be modeled using classical discrete mathematics.

The main objectives of this study are i) To understand the fuzzy logic and how fuzzy rule base system can be applied in derivation of rules for reservoir operation for hydro power generation. ii) To derive optimal reservoir operation rules at the macro level for better performance and control of the system Russel and Campbell (1996) stated that the difference that the expert knowledge for framing the Fuzzy rules can be derived from an explicit stochastic model. A steady state policy derived from a Stochastic Dynamic Programming (SDP) model provides this knowledge base. The methodology for building the fuzzy rule based model is independent of the stochastic model, and any other expert knowledge may also be used in its place.

Suharyanto and Goulter (1996) used fuzzy set theory in consideration of storage non-specificity in stochastic dynamic programming for reservoir operation. They approach to assessing the implications of the actual storage occurring at any point within the storage class interval and the influence of storage intervals or classes adjacent to the storage interval in which the actual storage falls through application of fuzzy set and its associated concept of membership functions. The proposed approach is demonstrated by application to the Fairbairn reservoir in Emerald, Central Queensland, Australia. They described an approach on fuzzy set theory where in operating rules are generated with explicit recognition of storage volume non-specificity in the discrete Stochastic Dynamic Programming (SPD). Umamahesh and Chandramouli (1996) used fuzzy dynamic programming model for optimal operation of a multipurpose reservoir, to derive the 10 daily operating policy for Hirakud dam in the State of Orissa in India. The main demands of the Hirakud project as irrigation, hydropower generation and flood control are considered as fuzzy variables. The reservoir operation during monsoon is complicated due to conflicting objectives like flood control, irrigation, power generation and conservation at the end of the period. The non-monsoon operation is relatively simple. Hence reservoir operation only for monsoon period is considered in their study and the entire non-monsoon season is lumped as one time period. Hasebe and Nagayama (2002) used the neural network and fuzzy systems for dam control of a multipurpose dam with drainage area relatively smaller compared with dam capacity. A comparison is made between reservoir operations using the fuzzy and neural network systems and actual one by operator, using examples of floods during flood and non-flood seasons.

Methodology

Fuzzy logic starts with the concept of a fuzzy set. A *fuzzy set* is a set without a crisp or clearly defined boundary. It can contain elements with only a partial degree of membership. The fuzzy inference process known as Mamdani's fuzzy inference method is used in this study. It's the most commonly seen fuzzy methodology. All output membership functions are singleton spikes, and the implication and aggregation methods are fixed and can not be edited. The implication method is simply multiplication, and the aggregation operator just includes all of the singletons.

Fuzzy Operation Model

The methodology of Mandani fuzzy inference system (Mandani & Asilian, 1975) used for modeling of operation of Power Generation from Chenderoh dam situated Perak River. Chenderoh Reservoir, located on the Perak River, Peninsular Malaysia (5^o01' 40^o56' N and 100^o55' 01^o00' E), is the oldest reservoir in Malaysia, being commissioned for hydroelectric generation in 1930 and approximately 52km at downstream of Kenering Hydro Electric Power Station and approximately 34km by road, north of the town of Kuala Kangsar in Perak in west Malaysia. Three newer reservoirs, namely the Kenering, Bersia and Temenggor, are located upstream, thus modifying the flow and water level regime of the Chenderoh Reservoir.

It is a single purpose irrigation reservoir which has been in operation since June 1930 and is one of the oldest hydro stations in South East Asia. The dam is of the Hollow Amberson type founded on granite. The overall length of the dam is 390m including 209m of spillway and 30.5m free opening for the sector gate. The Figure 1 shows the location of Chenderoh Dam with the mapping on the North and East Coast of Malaysia. The reservoir serves a command area in a drought prone region in which water shortage occurs. There is a good scope for implementing scientific operating policies in this case study. The fuzzy logic model presented in this article, on the other hand, is mathematically simple and provides implemental, near optimal operating policies. Since the model is not mathematically complex the technology transfer is expected to be more effective.

The fuzzy logic tool box available with the MATLAB package, version 4.2c, is used for developing the model (MATLAB, 1995). The inputs to the fuzzy system are period, storage. The output are the release and power generation. For the inputs and output operations the logical and implication operators are taken as (with conventional Fuzzy notation),

And Method = 'Min';

Or Method = 'Max';

Imp Method = 'Min':

Defuzz Method = 'Centroid'.

Where the 'And' and 'Or' method corresponds to the conjunction (min) arid disjunction (max) operation of classical logic. The implication method 'Min' produces a clipped output fuzzy set and the defuzzification method 'Centroid' is used. The Figure 2 shows the fuzzy inference system created for chenderoh dam.

The ranges for membership functions for reservoir storage, inflow and release

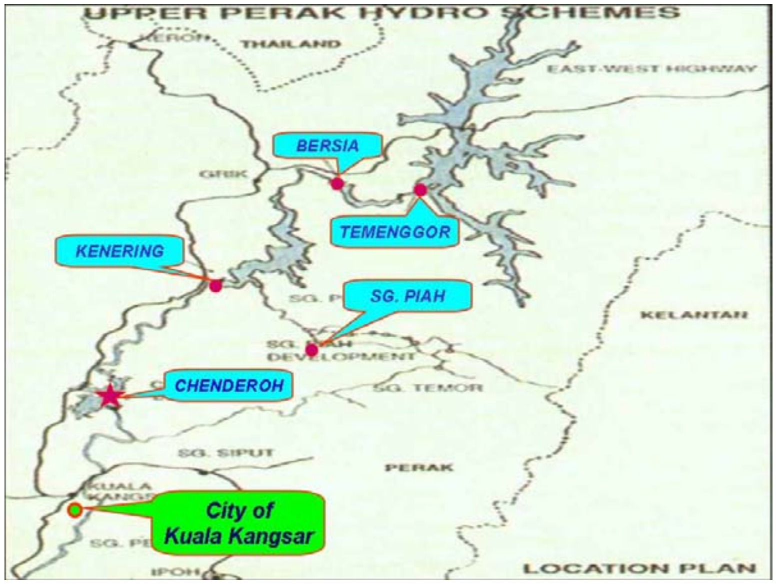

Figure 1: Location of Chenderoh dam

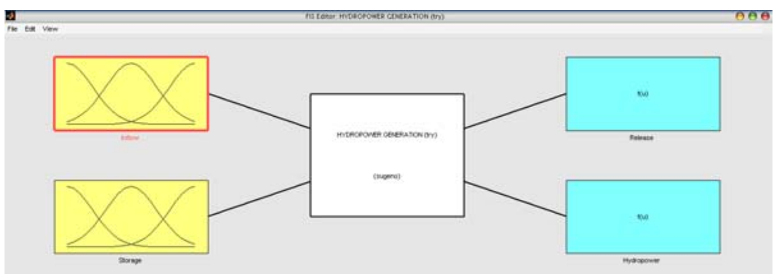

Figure 2: Fuzzy Inference System

are fixed, keeping in view the computational considerations. The fuzzy model was developed based on daily data of the year 2005. The 36 ten-day periods in a year arc divided into three distinct groups for the purpose of discretisation: Periods 1 to 12 (January to April), periods 13 to 24 (May to August), and periods 25-36 (September to December). All periods in a group will thus have the same Membership functions (MF) for inflow, storage, output of hydropower and release.

The storage, inflow, output of hydropower and the release were assigned the triangular membership functions. The salient membership function for the input inflow and output power are shown in Figure 3 and Figure 4 respectively. It may be noted that the range of inflows for various membership functions for period 22 is the same as that for any other period between periods 1 to 36. The methodology was applied to Chenderoh reservoirs on Sungai Perak River System in Kuala Kangsar, Perak. These are single purpose dams with live storage capacities of 900 Mm^3 and 450 Mm^3 respectively. The daily inflows, storages, hydropower output and releases for a period of 12 month were collected for the present study.

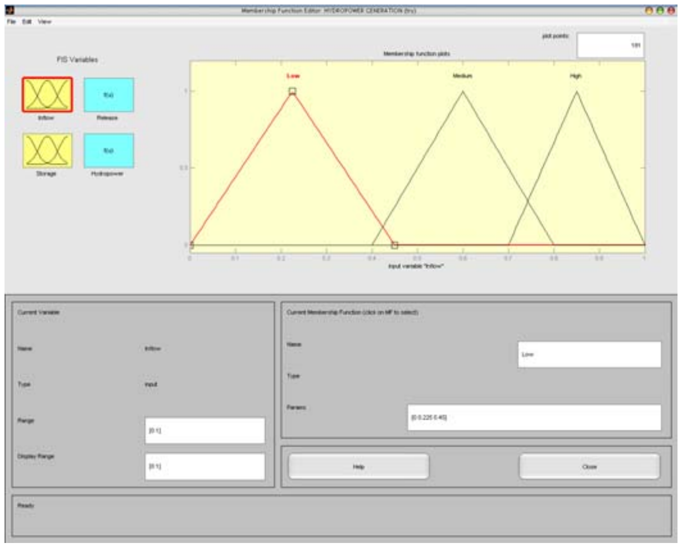

Figure 3: Membership function for inflow

Figure 4: Membership function for hydropower

Result And Discussion

The Fuzzy model formulated in the previous section is used to develop the optimal operating policy of the Chenderoh reservoir for Hydro Power Generation.The

Table 1: Results from fuzzy model for operation of dam for hydro-power generation (showing normalise values)

Period	**Period in 10 daily unit**	**Inflow (Mm3)**	**Storage (Mm3)**	**Release (Mm3)**	**Hydro-power (MW)**
1	January 1-10	0.775	0.120	0.540	0.812
2	January 11-20	0.818	0.681	0.714	0.925
3	January 21-31	0.738	0.810	0.667	0.782
4	February 1-10	0.680	0.109	0.683	0.706
5	February 11-20	0.908	0.816	0.834	0.839
6	February 21-28	1.000	0.343	0.871	0.874
7	March 1-10	0.509	0.989	0.489	0.545
8	March 11-20	0.481	0.198	0.512	0.519
9	March 21-31	0.450	0.090	0.496	0.526
10	April 1-10	0.633	1.000	0.611	0.546
11	April 11-20	0.469	1.000	0.453	0.522
12	April 21-30	0.627	0.463	0.716	0.658
13	May 1-10	0.472	0.890	0.429	0.522
14	May 11-20	0.473	0.559	0.352	0.543
15	May 21-31	0.444	0.820	0.387	0.489
16	June 1-10	0.452	0.703	0.366	0.491
17	June 11-20	0.436	0.099	0.445	0.475
18	June 21-30	0.450	0.132	0.464	0.495
19	July 1-10	0.439	0.703	0.354	0.481
20	July 11-20	0.434	0.483	0.297	0.494
21	July 21-31	0.472	0.889	0.429	0.525
22	August 1-10	0.547	0.780	0.476	0.608
23	August 11-20	0.409	0.715	0.327	0.449
24	August 21-31	0.385	0.360	0.458	0.416
25	September 1-10	0.381	0.220	0.440	0.439
26	September 11-20	0.470	0.890	0.428	0.509
27	September 21-30	0.445	1.000	0.430	0.771
28	October 1-10	0.597	0.506	0.646	0.647
29	October 11-20	0.770	1.000	0.744	0.829
30	October 21-31	0.745	0.556	0.615	0.804
31	November 1-10	0.641	0.813	0.575	0.737
32	November 11-20	0.783	0.440	0.861	0.835
33	November 21-30	0.671	0.549	0.681	0.784
34	December 1-10	0.705	0.012	0.680	0.779
35	December 11-20	0.865	0.500	0.954	0.883
36	December 21-31	0.946	0.360	1.000	1.000

model is generated synthetic sequences of reservoir release and hydropower output, which are used to develop the transitional probability matrices required by the Mandani model. The operation of the reservoir using the optimal operating policy derived from the model and the performance of the reservoir are evaluated using independent future data.

Table 1 shows the validation results from different 10 daily time periods.

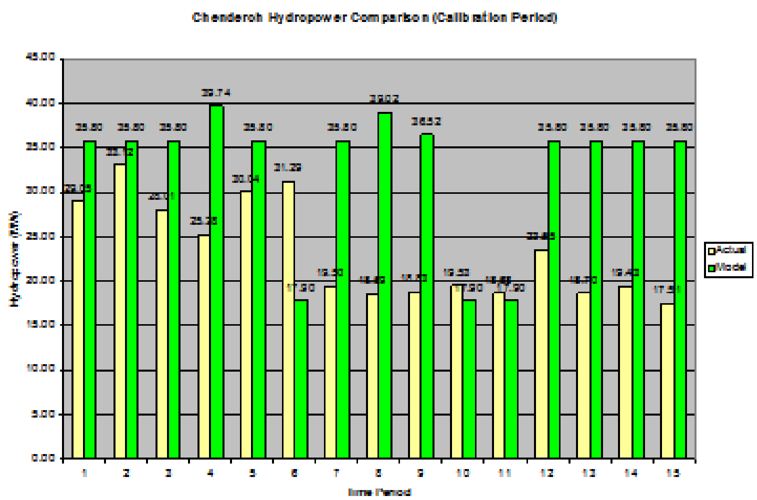

Figure 5: Hydropower Comparison Calibration Period

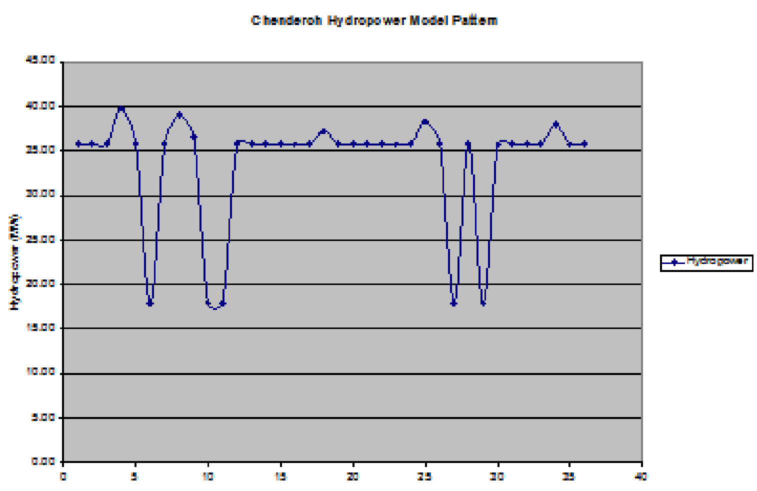

Figure 6: Hydropower Output Model Valued

It is understood the advantage of fuzzy rule based system is that it utilizes the knowledge of a reservoir operator and avoids complex optimization procedure hence it may be more acceptable to the reservoir managers. Since the input operators are in linguistic terms it is easy to adopt for operation control of dams. The performance of reservoir for Hydropower was evaluated with the developed model and compared with historical operation shown in Figure 5. A plot of the observed data and estimated values obtained from the selected model are given in Figure 6. The predictive accuracy of the fuzzy model is very reasonable. It was well understood that the data scarcity in modeling reservoir operation influence the estimation of proper release policies. But still from the very approximate data, the model is capable of generating reasonably accurate daily average values for Chenderoh reservoir.

The results are found to vary with actual values when compared with the value of fuzzy logic models. The results of this paper show that this method can be used in number of applications and it is not sensitive to the real input data. On the other hand they are sensitive to the relationship of one cost (or benefit) relative to the other. Hydro Power remains the most developed renewable resource worldwide but is now constrained due to societal and environmental barriers. This model can be offended or used to study the market potential resulting from detailed environmental, social and technical evaluations.

Acknowledgement

The authors acknowledge the research grant provided by the GOVERNMENT OF MALAYSIA, represented by Ministry of Science, Technology and Innovation (MOSTI) located in PUTRAJAYA for their support and publication of the paper that has resulted in this article. The authors also thank the Institute of Research Management and Consultancy (IPPP) for their fine co-ordination between the researchers and the MOSTI.

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