Literature Review on Application of Artificial Neural Network (Ann) In Operation of Reservoirs

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ABSTRACT

Population explosion, urbanisation and industrialisation increased the water demands for various purposes other than irrigation demands like domestic requirements, industrial demands, hydropower and recreation etc. Reservoirs, the most important elements of a complex water resources system are constructed for spatial and temporal redistribution of water resources. Once the structural facilities like dams, barrages and distribution network etc. are constructed, the benefits that could be available / gained depends to a large extent, upon how well these facilities are operated and managed. System analysis like simulation and optimisation has proved to be a potential tool in the planning, operation and management of the available resources. In recent years, artificial intelligence techniques like Artificial Neural Networks (ANN) have arisen as an alternative to overcome some of the limitations of traditional Guide curve methods. Artificial Neural Networks (ANN) is black box models that are used to forecasting and estimating purposes in so many different areas of the science and engineering. A study will be carried out to develop an ANN model for reservoir operation and assess the application potential of ANN in attaining the reservoir operation objectives compared with the conventional rule curves. In this paper, an attempt is made to present the literature review on applications of ANN in the field of water resources engineering with special mention to reservoir operation. This literature review may not be exhaustive but it glimpses the Artificial Neural Network's (ANN) contribution in the field of modelling reservoir operation.

KEY WORDS: *Artificial Neural Network, Guide curves (Rule curves), optimisation, reservoir operation, System analysis.*

I. INTRODUCTION

Reservoir operation is an important element in water resources planning and management. It consists of several parameters like inflow, storage, evaporation and demands that define the operation strategies for giving a sequence of releases to meet a large number of demands from stake-holders with different objectives, such as irrigation, water supply, hydro power etc. Applying simulation and optimisation techniques for reservoir operation is not a new idea. Various techniques have been applied in an attempt to improve the efficiency of reservoir (s) operation. This technique includes Linear Programming (LP); Non liner Programming (NLP); Dynamic Programming (DP); Stochastic Dynamic Programming (SDP). In recent years Heuristic Programming such as Genetic Algorithms (GP), Fuzzy logic and Artificial Neural Networks (ANN) are emerging as an alternative to conventional techniques.

Hydraulic constraints are defined by the reservoirs continuity equation,

$S(t+1) = S(t) + I(t) - R(t) – E(t)$, $t = 1,2……….T$

Where, $S(t+1)$ is storage at time step t+1.,

$S(t)$ is storage at time step t; $I(t)$ is the reservoir net inflow at time step t (including reservoir inflow and precipitation) ; $R(t)$ is the reservoir out flow at time step t and $E(t)$ is the reservoir evaporation at time step t. T is the total number of time steps in the considered period.Constraint on out flow/releases defined by maximum and minimum permissible reservoir releases:

$R_{min} \leq R(t) \leq R_{max}$ $t = 1,2,……….T$

Constraints on storages defined by maximum and minimum permissible reservoir storages

$S_{min} \leq S(t) \leq S_{max}$ $t = 1,2…………..T$

Constraints on elevations defined by maximum and minimum permissible water level at specified sites/reservoirs;

$h_{min} \leq h(t) \leq h_{max}$ $t = 1,2,…….T.$

In general, a multi-objective reservoir operation problem can be formulated as follows
Maximise / Minimise F (x) = [F1 (x), F2 (x) ……….Fn(x)]
Subject to
qi (x) $\leq$ 0 I = 1,2,……….m
Where Fj (x) , j = 1,2,…….N are the objective functions, X is a vector of decision variables, qi (x) are constraints that define the feasible solutions.

II. THEORITICAL BACKGROUND

An Artificial Neural Network (ANN) is a massively parallel-distributed-information-processing system that has certain performance characteristics resembling biological neural network of human brain. In application of ANN to reservoir operation, preparation of train and test data is the first step. Initial storage, inflow forms input data whereas optimal release of reservoir forms output layer of ANN model. Dynamic programming model will be used for optimum operation policy of a reservoir and then simulation model presents the optimum monthly release of the reservoir over a considerable long period. Out of these data some represents train data and some represents test data of ANN model. Finally the structure of an ANN model will be constructed defining 1) the number of hidden layers and neurons in each layer, 2) selection of transformation function's type. Lastly supposing the method for acquiring optimum weight of the nodes, the final network will be implemented by trial and error. Performance of a network is usually evaluated by some parameters such as 1) RMSE (root mean square error); 2) R-(correlation coefficient); 3) e- (relative error). All these parameters should be evaluated for both training and testing sets.

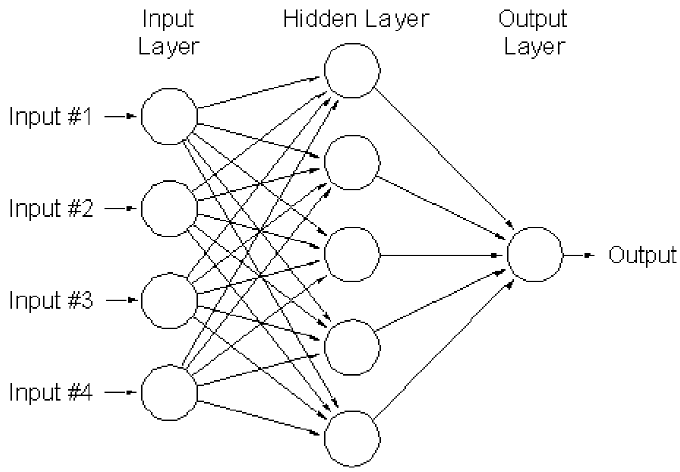
A typical Artificial Neural Network is shown below.

Input-1 Initial Storage

Input-2 Inflow

Input-3 Evaporation

Input-4 Reservations etc.



Output -- Optimum Release

III. HISTORY

Development of ANN has an interesting history. Major events / achievements in ANN history are presented here to appreciate how contributions to the field have led to its development over the years. The year 1943 is often considered the initial year in the development of ANN systems; when W.S. McCulloch and W. Pitts proposed a theory of information processing based on networks of binary processing elements, called 'neurons'. The network differs from a traditional computer in that the steps of the program are not executed sequentially, but in parallel with 'neurons'. This model laid the foundation for future development. In 1949, Donald Hebb first proposed a learning scheme for updating neuron's connections that we now refer to as the Hebbian learning rule. The works of McCulloch and Hebb are on the neural science aspects of neural networks. Minsky in 1954 built & tested the first neurocomputer. Neuron like element called perceptron was developed / invented by Frank Rosenblatt in 1958. It was a trainable machine of learning to classify certain patterns by modifying connections to the threshold elements. The idea caught the imagination of engineers and scientist and laid the groundwork for the basic machine learning algorithms that we still use today. In 1960, Bernard Widrow & Marcian Hoff founded the first neural network company, the minister corporation. The monograph on learning machines by Nils Nilsson in 1965 summarized many of the developments of that time. This book also formulates inherent limitations of learning machines with modifiable connections.

The study of learning in networks of threshold elements and of the mathematical theory of neural networks was pursued by Sun Ichi Amari (1972,1977), Fukushima and Miyaka (1980). Associative memory research has been pursued by, among others, Tuevo Kohonen in Finland (1977, 1982, 1984, and 1988) and James Anderson (1977), Kohonen (1982), Stephen Grossberg and Gail Carpenter (1974, 1982). Hopfield's work in 1982 & 1984 is considered a breakthrough in neural network research. The Hopfield network is directly related to electronic circuits, and therefore is easy for VLSI implementations. The publication by McClelland and Rumelhart opened a new era for the once underestimated computing potential of layered networks. The PDP group published their book Parallel Distributed Processing in 1986. Many research achievements were included. There are numerous publications on neural networks. The International Neural Network Society (INNS) holds annual conferences & publishes its proceedings. The journal Neural Networks was founded by INNS. Many special issues can be found in periodicals under the names IEEE & ACM. Most important articles that establish the foundation of neural networks can be found in two books edited by Anderson & Ressenfield. The list of applications that can be solved by neural networks has expanded from small test size example to large practical tasks. Very large scale integrated neural network chips have been fabricated. Educational offering have been established to explore the artificial neural network science. Although ANN has had interesting history, the field is steel in its early stages of development.

IV. APPLICATION IN WATER RESOURCES ENGINEERING

Neural network is a computational method inspired by studies of brain and nerves systems in biological organism. Neural network models are aimed to mimic the function of human brain. Since the early 1990's there has been a rapidly growing interest among engineers & scientist to apply ANN in diverse field of water resources engineering like forecasting of stream flows, river stage, rainfall, water table fluctuations , ground water modelling, water quality modelling, water management, reservoir operation and so on. Since inflow prediction is the most important and deciding factor in reservoir operation, important events/studies related to application of ANN in inflow prediction are described in the following paragraphs.

French et al (1992) developed three layered neural networks to forecast rainfall intensity fields in space and time. After training with input patterns, the neural network was used to forecast rainfall using the current fields as input. They showed that ANN was capable of learning the complex relationship describing the space-time evolution of rainfall. Ranjithan et al (1993) used neural network based screening approach for ground water reclamation.Smith and Eli (1995) used ANN to model rainfall-runoff process. They used a 5x5 grid cell synthetic watershed to generate runoff from stochastically generated rainfall patterns. They used a back propagation algorithm for training to predict the peak discharge and the time of peak resulting from single rainfall pattern. Muller (1996) and Babovic & Larsen (1998) reported many applications of decision support and management systems, geographic information systems and neural networks. Hsu et al (1999) used ANN for the estimation of physical variables from multichannel remotely sensed imageries for rainfall estimation.Dawson & Wilby (1998) used artificial neural network approach to rainfall runoff modelling. They used multilayered feed forward network structure to model the flood forecasting system and back propagation algorithm for training the network combinations. Mair and Dandy (1999) used feed forward ANN to forecast the salinity in the river. They concluded that any impact different learning rules have on training speed is masked by the effect of epoch size and the number of hidden nodes required for optimal model performance.

Raman and Sunilkumar (1995) used ANN for the synthesis of inflows to reservoirs. Real observations were used to train and test the feed forward networks. Feed forward structure was used to model the ANN and back propagation algorithm to train the ANN. They remarked that the neural network provides a very good fit with the data. Thirumaliah and Deo (1998) used ANN in real time forecasting of water levels at a given site continuously throughout the year based on the same levels at some upstream gauging station and or using the stage time history recorded at the same site.

They concluded that the continuous forecasting of a river stage in real time sense was possible through the use of ANN. Young et al (1997) developed ANN model to simulate fluctuations in mid span water table depths and drain out flows as influenced by daily rainfall and potential evapotranspiration rates. They concluded that it is highly desirable in ANN modelling to have a training data set that include both general and extreme conditions otherwise the model performance may not be very satisfactory. Zealand, Burn and Simonovic (1999) used the ANN to forecast the short-term stream flow. They explored the possibility of using ANN over the conventional methods for the forecasting of the flood. From the results they concluded that ANN approach might provide a superior alternative to the time series approach for developing input-output simulation and forecasting models in situations that do not require modelling of the internal structure of the water shed. Jurgen Garbrecht (2006) compared three alternative ANN designs for monthly rainfall-runoff simulation. The performance of three ANN designs that account differently, for the effects of seasonal rainfall and runoff variation were estimated for monthly rainfall runoff simulation. For the three ANN designs tested, a regression of simulated versus measured runoff displayed a slope slightly under 1 and positive intercept, pointing to a tendency of the ANN to under predict high values and over predicts low values. Rajib Maity & D Nagesh

Kumar (2006) used ANN approach for stream flow forecasting in India. ANN approach is shown to be a useful tool to capture the unknown relationship between stream flow and large scale circulation phenomena. Dogan E at all (2009) studied daily inflow forecasting using ANN. Taesoon Kim at all (2009) successfully used ANN for inflow forecasting of reservoir Hwacheon in South Korea. They concluded that ANN is useful to forecast inflow of reservoir especially for the real time operation since it can be used in case of input data missing. El Shafie A at all (2009) studied radial basis Neural network model and upstream monitoring stations measurements in enhancing inflow forecasting model at Aswan High Dam. El Shafie at all (2011) used ANN technique for rainfall forecasting to Alexandra. Recently Doan (2012) used ANN for reservoir inflow forecasting for Missouri river basin. Ozlem Terzi & Sadik Onal (2012) studied application of ANN and multiple linear regression to forecast monthly river inflow in Turkey. The performance of the models suggested that the flow could be forecasted easily from available data using ANN. A Sarkar & R Kumar (2012) successfully used the ANN approach to examine its applicability to model the event based rainfall-runoff process. The result demonstrated that ANN model are able to provide a good representation of an event based R-R process.

V. APPLICATION IN RESERVOIR OPERATION

Many studies are reported in the literature on the application of ANN in the field of water resources were in the field of stream flow and rainfall forecasting. Few studies have been concentrated on reservoir operation. In most of the studies, feed forward structure and the back propagation algorithm have been used to design and train the ANN models respectively. Important studies/papers related to the reservoir operation studies using ANN are briefly described in the following paragraphs. Saad et al(1994) described a disaggregation procedure by training an ANN. After training, this network gave the storage level of each reservoir of a system when supplied with the value of an aggregate storage level. The training set was obtained by solving the deterministic operation problem of a large number of equally likely flow sequences. They used back propagation algorithm and the minimisation of quadratic error was computed by gradient method. The aggregate storage level was determined by SDP algorithm in which all hydroelectric reservoirs were aggregated to form one equivalent reservoir. He presented a comparison with principle component analysis disaggregation technique with ANN based technique.

Jain, Das and Shrivastava(1999) used artificial neural network for reservoir inflow prediction and the operation for upper Indravati Multipurpose Project, Orissa. They developed two ANN to model the reservoir inflows and to map the operation policy. Feed forward structure was used in ANN model. They found that ANN was suitable to predict high flows. The optimal releases were derived using nonlinear regression by relating inflow, storage and demand. They concluded that ANN was a powerful tool for input output mapping and can be used effectively for reservoir inflow forecasting & operation.Raman and Chandramouli (1996) used artificial neural networks for deriving better operating policy for the Aliyer dam in Tamil Nadu. They used feed forward back propagation algorithm. They derived the operating policies using three models; dynamic programming model, stochastic dynamic programming model and standard operating policy. General operating policies were derived using neural network model from the DP model. The results of ANN with dynamic programming algorithm provided better performance than the other models. Chandramouli et al (2002) developed a dynamic programming based neural network model for analysing the water sharing between two reservoirs in a multi reservoir system catering for irrigation. They found that the DPN model gives very good performance compared to other models considered. Cancelliere et all (2002) used artificial neural networks for deriving irrigation reservoir operating rules and found that operating rules based on an optimization with constraints resembling real system operation criteria lead to a good performance both in natural and in drought period, reducing maximum deficits and water spills. Oscar Dollins and Eduardo Varas (2004) presented a paper which depicts a decision support procedure that integrates continuous simulation, ANN and optimisation to produce decision rules in water shed management for multipurpose complex water resources system. the methodology was applied to the San Juan river basin, Argentina. Result shows conclusively the usefulness of simulation in the study of alternatives of water resources system with multiple use and the feasibility of ANN to encapsulate the behaviour of simulation model.

Ismail Kilnic and Kerem Cigizoglu (2005) focused on the estimation of three random variables crucial in reservoir management i.e. monthly inflow, monthly evaporation and monthly storage. Two different neural network methods, the radial basis functions and the feed forward back propagation are employed for this purpose.

It is shown that both methods provide quite satisfactory estimations reflected in performance evaluation criteria and in plots. Importance of the number of input layer elements can be seen easily from the output tables of the study. These results give us a good opinion about the future parameters of the reservoir. The types and number of the parameters in the input layer affects the resulting forecast very sensitively. Haddad and

Alimohammadi (2005) evaluated the performance of ANN model in extracting the optimum operation policy of reservoirs, as a tool for substituting of simulation models. Using a stochastic dynamic programming model, the discrete values of optimum releases for each month, which are a function of both monthly initial storage volumes and mean monthly releases in a 43 years historical period, are obtained by a simulation model using the SDP rules. These two parts of data were used in training and testing an ANN model and the results shown that ANNs are good substitutions to simulation models.

Farid Sharifi, Omid Haddad and Mahsoo Naderi (2005) derived operation rule of reservoir for a specific duration by dynamic programming. Output of this model was used as a set of train and test data for ANN. In each month by forecasting of inflow of reservoir in that period demand of that month and the reservoir level in the same period, input data of ANN model was available and the release of that month could fit the optimum value. Results had shown that ANN method for low inflow periods is more reliable. With the increase in number of periods of data, accuracy decreases. They concluded that 1) decreasing the number of forecasting periods and trying to retain the network with accurate data, 2) trying to provide a vast range of input data by producing various historical times a series with DP can enhance ANN model to be trained by every possible monthly release during operational period. Paulo Chaves & Fi John Chang (2008) proposed a intelligent reservoir operation system based on an evolving ANN. Evolving means the parameters of the ANN model are identified by the GA evolutionary optimisation technique. The results demonstrated that the developed ANN improved the operation performance of the reservoir when compared to its current operational strategies. The system was capable of successfully simultaneously handling various decision variables and provided reasonable and suitable decisions. Yi min Wang at all (2009) used simulation with radial basis function (RBF) neural network model for reservoir operation rules for the Yellow river upstream multi reservoir system. Amir Ali Moaven Shahid (2009) for deriving the optimal single reservoir operation, two dynamic programming based neural network were developed.

The paper presents the usefulness of the neural network in deriving general operating policy for a single reservoir system. The advantage of ANN model is due to the nonlinearity of the connection exist between all the input and output variables. El Shafie A at all (2011) used an integrated ANN & stochastic dynamic programming madel for optimising the operation policy of Aswan high dam. Sabah S Fayaed at all (2011) investigated the potentials of ANN model to establish relationship between elevation, area and capacity of a reservoir sq. Langat dam in Malaysia. Their study shown that ANN model show good capability to model hydrological process. Dr.Bithin Datta (2012) successfully studied the application of ANN in real time optimal operation of multireservoir system. T. S. Abdulkadir at all (2012) applied ANN technique to model the management of hydropower reservoirs along river Niger. They predicted the future storage values using ANN and formulated operating policies for Jebba and Kainji hydropower reservoirs. They concluded and recommended that forecasting using ANN is very versatile tool in reservoir management modelling.

VI. CONCLUSSION

Artificial neural networks technology is still very new and is developing quickly. The most likely applications of neural networks is to simulate physical systems that are best expressed by parallel networks involving classification, association and reasoning rather than sequential arithmetic computing. Water resources engineering especially prediction of inflows and the optimal operation of reservoirs is one of the most promising application of ANN. An attempt will be made to develop artificial neural network model for reservoir operations and assess the application potential of the Artificial Neural Network in attaining the reservoir operational objectives compared with the conventional rule curves. In this paper, an attempt is made to present the literature review on applications of ANN in the field of water resources engineering with special mention to reservoir operation. This literature review may not be exhaustive but it glimpses the Artificial Neural Network's (ANN) contribution in the field of modelling reservoir operation.

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