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A REVIEW ON APPLICATION OF NEURAL NETWORKS AND FUZZY LOGIC TO SOLVE HYDROTHERMAL SCHEDULING PROBLEM

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Electrical power system is highly complicated having hydro and thermal mix with large number of machines. To reduce power production cost, hydro and thermal resources are mixed. Hydrothermal scheduling is the optimal coordination of hydro and thermal plants to meet the system load demand at minimum possible operational cost while satisfying the system constraints. Hydrothermal scheduling is dynamic, large scale, non-linear and non-convex optimization problem. The classical techniques have failed in solving such problem. Artificial Intelligence Tools based techniques are used now a day to solve this complex optimization problem because of their no requirements on the nature of the problem. The aim of this research paper is to provide a comprehensive survey of literature related to both Artificial Neural Network (ANN) and Fuzzy Logic (FL) as effective optimization algorithms for the hydrothermal scheduling problem. The outcomes along with the merits and demerits of individual techniques are also discussed.

Keywords : Hydrothermal, Non-convex, Multi Objective Fuzzy Logic, Neural networks, Supervised learning

1. Introduction

Hydrothermal scheduling (HTS) is a highly dynamic, large scale, non-linear, non-convex constrained optimization problem, making it difficult to find global optimum solution using mathematical and enumerative techniques. The major goal of hydrothermal scheduling is to minimize the total operational cost while satisfying the various constraints on hydraulic and thermal system network. The power production cost of hydroelectric plants is quite small. Thus, this problem aims to minimize the fuel cost of thermal plants only. All hydraulic and thermal constraints like generation limits of hydro and thermal units, load balance, water discharge, starting and ending storage volume of water and spillage discharge rate are taken into account. Hydrothermal scheduling is optimal use of hydro and thermal resources during a scheduling period. Now-a-days, due to environmental consideration, minimization of emission level is also taken as an objective. It has become almost compulsory for electric utilities to reduce the emission levels below certain limit. One of the complications in the above considerations is that the cost and emission functions are of conflicting nature. In other words, minimizing pollution increases cost and vice versa.

Earlier, several mathematical optimization techniques like Gradient Search Method, Dynamic Programming (DP) [1], Network Flow Programming (NFP) [2], Decomposition Approach (DA) [3] etc. were applied to solve the hydrothermal scheduling problems but because of certain flaws, such as drastic growth of computational requirement, insecure convergence characteristics and requirement of linearity and convexity of objective function makes them non-suitable for such problem. Nowadays, AI tools based techniques like Genetic algorithm (GA) [4], Evolutionary programming (EP) [5], Ant Colony Search Algorithm (ACSA) [6], Bacterial Forging Algorithm (BFA) [7] etc. have performed efficiently in solving the hydrothermal scheduling problem because of their global search regions and no restrictions i.e. continuity, differentiability, convexity etc. on requirement of objective function. These heuristic methods do not always guarantee the globally optimal solution, they provide a reasonable solution (near global optimal) in a short processing time.

This paper presents the comprehensive review on the application of Neural Networks and Fuzzy logic bases techniques to solve the hydrothermal scheduling problems. The outcomes alongwith both strengths and weaknesses of individual algorithms are also discussed. The rest of the paper is organized as: In Section 2, mathematical formulation of HTS problem is presented. Section 3 classifies the different optimization techniques applied to solve the HTS problem. In section 4, the detailed review of neural networks and fuzzy logic based techniques to solve the HTS problem are presented.

2. Mathematical Formulation

Mathematically, the Short-term HTS optimization problem can be formulated, in general, as follows :

Minimize :

$$F(P_{sit}) = \sum_{t=1}^{T} \sum_{i=1}^{N_s} [f_{it}\ (P_{sit})] \quad (1)$$

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Where F (P_{sit}) is the total fuel cost, T is the total number of time intervals for the scheduling horizon, Ns is the total number of thermal generating units, P_{sit} is the power generation of ith thermal generating unit at time t and $f_{it}(P_{sit})$ is the fuel cost function and can be defined as :

$$f_{it}(P_{sit}) = a_{si} + b_{si}P_{sit} + c_{si}P_{sit}^2 \quad (2)$$

Where a_{si}, b_{si}, c_{si} are fuel cost coefficients of the ith thermal generating unit. The effect of valve-point effect loading may be considered by adding a sinusoidal function to the above described quadratic cost function. Hence, the above function is revised in (3) as follows :

$$f_{it}(P_{sit}) = a_{si} + b_{si}P_{sit} + c_{si}P_{sit}^2 + (e_{si}\sin\{f_{si} \times (P_{si}^{min} - p_{sit})\}) \quad (3)$$

Where $f_{it}(P_{sit})$ is the fuel cost function of thermal units including the valve-point loading effect and e_{si}, f_{si} are fuel cost coefficients of the ith thermal generating unit reflecting the valve-point effect.

2.1 Constraints

2.1.1 Active Power Balance

The total power generated must balance the power demand plus losses, at each time interval over the entire scheduling period.

$$\sum_{i=1}^{N_s} P_{sit} + \sum_{j=1}^{N_h} P_{hjt} - P_{D_t} - P_{L_t} = 0 \quad (4)$$

Where P_{hjt} is the power generation of jth hydro generating unit at time t, P_{D_t} is power demand at time t and P_{L_t} is total transmission loss at the corresponding time. The hydropower generation is a function of water discharge rate and reservoir storage volume, which can be described in (5) as follows:

$$P_{hjt} = C_{1j}V_{hjt}^2 + C_{2j}Q_{hjt}^2 + C_{3j}V_{hjt}Q_{hjt} + C_{4j}V_{hjt} + C_{5j}Q_{hjt} + C_{6j} \quad (5)$$

where C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j} are power generation coefficients of jth hydro generating unit, V_{hjt} is the storage volume of jth reservoir at time t and Q_{hjt} is water discharge rate of jth reservoir at time t. The power losses in transmission network are shown in (6):

$$P_{Lt} = \sum_{i=1}^{N_s+N_h} P_{si}B_{ij}P_{hj} + \sum_{i=1}^{N_s+N_h} B_{0i} + B_{00} \quad (6)$$

Where Bij, B_{0i} and B_{00} are the B-coefficients.

2.1.2 Power Generation Limits

$$P_{si}^{min} \le P_{sit} \le P_{si}^{max} \quad (7)$$

$$P_{hj}^{min} \le P_{hjt} \le P_{hj}^{max} \quad (8)$$

Where P_{si}^{min} and P_{si}^{max} are the minimum and maximum power generation by ith thermal generating unit, P_{hj}^{min} and P_{hj}^{max} are the minimum and maximum power generation by the jth hydro generating unit respectively.

2.1.3 Dynamic Water Balance

$$P_{Lt} = V_{hj,t-1} + I_{hjt} - Q_{hjt} + S_{hjt} + \sum_{m=1}^{R_{uj}}(Q_{hm,t-\tau_{mj}} + S_{hm,t-\tau_{mj}}) \quad (9)$$

Where I_{hjt} is natural inflow of jth hydro reservoir at time t, S_{hjt} is spillage discharge rate of jth hydro generating unit at time t, τ_{mj} is the water transport delay from reservoir m to j and R_{uj} is the number of upstream hydro generating plants immediately above the jth reservoir. If this constraint is ignored then the problem becomes fixed head. Above equation is for a reservoir on same steam. The water balance equation for reservoirs on different streams is:

$$V_{hjt} = V_{hj,t-1} + I_{hjt} - Q_{hjt} - S_{hjt} - R_{hjt} \quad (10)$$

Where R_{uj} is water loss in jth reservoir.

2.1.4 Reservoir Storage Volume Limit

$$V_{hj}^{min} \le V_{hjt} \le V_{hj}^{max} \quad (11)$$

Where $V_{hj}^{min}, V_{hj}^{max}$ are the minimum and maximum storage volumes of jth reservoir.

2.1.5 Water Discharge Rate Limits

$$Q_{hj}^{min} \le Q_{hjt} \le Q_{hj}^{max} \quad (12)$$

Where $Q_{hj}^{min}, Q_{hj}^{max}$ are the minimum and maximum water discharge rates of the jth reservoir respectively.

2.1.6 Bi-objective Problem

In bi-objective problem emission scheduling is included. The pollution function is:

$$E(P_{sit}) = \sum_{t=1}^{T}\sum_{i=1}^{N_s} [\alpha_{si} + B_{si}P_{sit} + \gamma_{si}P_{sit}^2\eta_{si}\exp(\delta_{si}P_{sit})] \quad (13)$$

Here E (P_{sit}) is the total amount of emission and $\alpha_{si}, \beta_{si}, \gamma_{si}$, and δ_{si} are the emission coefficients of the ith unit. In bi-objective problem, there are two objectives. A price penalty factor approach is used to combine the two as done below:

$$TC = F(P_{sit}) + h_t \times E(P_{sit}) \quad (14)$$

Where h_t, the price penalty factor and TC is the total operational cost.

3. Optimization Tools

Optimization is to find the perfect solution of real world problems within certain constraints. In optimization, inputs are variables and outputs are fitness function or cost. The process of optimization is cost function or a fitness function. Mainly there are three major optimization techniques. a) Calculus based technique, requiring the function to be differentiable but sometimes real life problems are non-differentiable. Also this method requires the starting point, direction of search and step length. The method searches from point to point, therefore, can get trapped into the region of local optimum. b) Enumerative method searches the function from point to point and gets slow as the size of search space enlarges. c) Random methods have found increased popularity as they overcome the deficiencies of calculus based and enumerative methods. Among them are heuristic methods based on natural evolution. Among these heuristic methods are fuzzy logic and neural networks. Different techniques are:

A. Calculus Based Methods:
   1. Indirect Method
   2. Direct Method
B. Random Methods:
   1. Simulated Annealing
   2. Evolutionary Algorithm (Heuristic Methods)
C. Enumerative Methods:
   1. Dynamic programming

References at [46-48] are the review papers published on the same subject HTS but for other techniques like PSO, Evolutionary Algorithms and Lagrange Relaxation, Interior Point and Dynamic Programming methods.

4. Artificial Intelligence

Computational Intelligence (CI) methods, that give a global optimum or nearly so, such as Artificial Neural Network (ANN) and fuzzy logic, etc. have emerged in recent years in power systems applications as useful tools. These methods are also known as Artificial Intelligence (AI) Tools in several works. AI Tools are powerful approach that can deal with the high non-linearity of practical systems.

4.1 Neural Networks

An Artificial Neural Network (ANN) is an information processing engine that is based on the biological nervous systems, such as the brain, processing information. ANNs is composed of a large number of interconnected processing elements (neurons) working in union to solve the specific problems. ANNs, like humans, learn by example. The starting point of ANN application was the training algorithm proposed and demonstrated, by Hebb in 1949. During the training phase, the neurons are subjected to a set of finite examples called training sets, and the neurons then adjust their weights according to certain learning rule. Very little computation is carried out at the site of individual node (neuron).

ANNs are very useful in solving the nonlinear problems. ANN does not require any prior knowledge of system. ANNs have massive parallelism. ANN is fast and robust with learning ability and adaptation to the data.

The term generation means the ability of the neural network producing “reasonable” results for inputs encountered during the training process. Despite the advantages, some disadvantages of the ANN are, their huge dimensionality, selection of the optimum configuration, choice of training methodology, lack of explanation capabilities and the fact that results are always generated even if the input data are unreasonable. Another drawback is that once an ANN is trained to do certain task, it is difficult to use it for other tasks without retraining. Based on the architecture, ANN model may be single-layer ANN, which includes perception model (suggested by Rosenblot, in 1959) and ADALINE (suggested by Widrow& Hoff in 1960). ANN model can be further classified as Feed forward NN and Feed Backward NN based on neuron interactions. Most of implementations are based on feed forward multi-layer networks. Learning of ANN may be Supervised Learning, Unsupervised Learning, and Reinforcement Learning. Based on neuron structure, ANN model may be classified as multilayer perception model, Boltzmann machine, Cauchy machine, Kohonen self-organizing maps, bidirectional associative memories, Adaptive Resonance Theory-I (ART-1), Adaptive Resonance Theory-2 (ART-2), counter propagation ANN. Some other special ANN models are parallel self-hierarchical NN, recurrent NN, radial basis function NN, knowledge based NN, hybrid NN, wavelet NN, cellular NN, quantum NN, dynamic NN, etc.

The graph between years and number of research papers taken from the databases of IEEE, Science Direct (Elsevier), and Springer is given below:

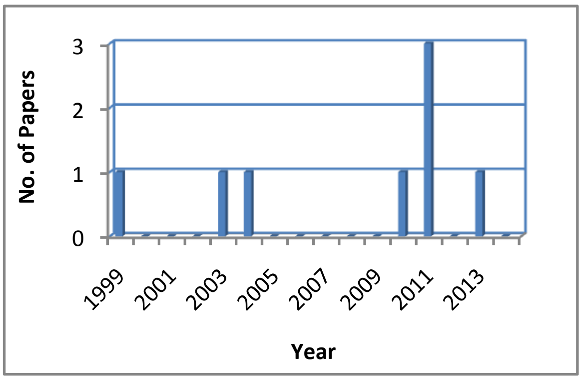

Figure 1. No. of papers published using NN to solve HTS problem.

Reference [8] presented a two-phase neural network based solution technique for short term hydrothermal scheduling. In this paper, solution of set of differential equations is obtained by transformation of augmented Lagrangian energy function. The cascaded hydroelectric plants and their dynamics are considered. The concurrent relationship among all the decision variables of this problem is taken in account in this proposed solution methodology, however setting of network parameters requires careful consideration. The proposed technique produces better results compared to Lagrangian method in terms of achieving optimality.

In reference [9], Hopfield neural networks for optimal scheduling of fixed head hydrothermal power systems are studied. The power dispatch from both thermal and fixed head hydro units is taken into consideration. The results obtained are compared with the results obtained by Newton's Method and found far better.

Reference [10] presented a novel approach of adaptive load frequency control of Nigerian hydrothermal system using unsupervised and supervised learning neural networks structure. Here predicted load disturbances of an interconnected power system are modeled by few clusters using unsupervised learning neural networks. Controller gains are obtained for corresponding load disturbances. Then supervised learning neural network process is deployed to learn the relationship between the cluster center and feedback gains. Simulation results revealed that different sets of feedback gains generated for each cluster center performed better than fixed feedback gain controllers.

Recurrent neural network solving a real large scale mid-term scheduling for power plants is studied [11]. Operational planning for generation is investigated for power production cost minimization. Two-phase optimization neural network which solves linear and quadratic programming problems is used. The networks use the set of solution obtained from differential equations that are in turn obtained from transformation of augmented Lagrangian function. Results obtained from this work reveal that the implemented methodology is robust even the starting point not a feasible initial solution.

V. Sharma, R. Naresh, Sushil and Deepika Yadav [12] proposed a high-performance feedback neural network optimizer based on a new idea of successive approximation for finding the hourly optimal release schedules of interconnected multi-reservoir power system is used to minimize the overall operational cost. This feedback neural network optimizer is compared with existing neural network optimizer and found that dual variables, penalty parameters or Lagrange multipliers are not required; also least number of state variables and better asymptotic stability is achieved. The proposed optimizer is evaluated on a nonlinear practical system of four cascaded reservoirs and a number of thermal reservoirs and quite promising results are obtained as compared to conventional approaches.

In an article [13], automatic generation control of a three area hydrothermal system using reinforced learning neural network controller is studied. Multi-layer perception neural network (MLPNN) is compared with bacterial foraging (BF) optimized integral controller and found that MLPNN controller is superior to BF integral controller. A similar study was also done by authors in [14] implementing automatic generation control of hydrothermal system by employing hybrid genetic neural approach. In this paper, a three layer feed forward Neural Network (NN) is proposed for controller design based on back propagation algorithm (BPA). Area Control Error (ACE) is input to the neural network controller and the output of the controller is provided to the governor in each area. Genetic Algorithm (GA) has been incorporated into the neural network in order to obtain optimal values of weights and bias. The proposed controller is tested for a two area hydrothermal system. Simulation results show that the limitations of conventional controller can be overcome by including Hybrid Genetic-Neural concept.

The authors [15] proposed a Back Propagation Neural Network (BPNN) to overcome the disadvantages of Kirchmayer's model for the short term scheduling oh hydrothermal power systems. The inputs for the neural network are load demand and loss. The outputs are Thermal and Hydel power generations. The network is trained with Back Propagation Algorithm using Gradient Descent method. In the proposed method the output of each neuron can be determined using sigmoid activation function. The result shows the effectiveness of the proposed method compared to the conventional in terms of speed and accuracy.

4.2 Fuzzy Logic

The idea of fuzzy sets was introduced by Zadeh in 1965. Fuzzy sets use membership functions to map elements to the unit interval [0, 1]. The membership function always reflects the features and limitations of the studied system. Fuzzy sets have been applied to various power system areas such as operational planning, state estimation and load forecasting and economical scheduling problems. Figure 2 gives the statistics of research work done on the application of fuzzy logic to solve hydrothermal scheduling problems using the databases of IEEE, Science Direct (Elsevier) and Springer.

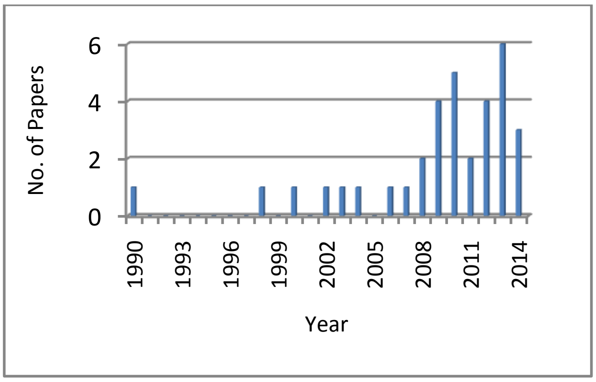

Figure 2. No. of papers published using fuzzy logic to solve HTS problem.

Research paper [16] uses fuzzy logic for operation rules of large hydrothermal power systems. This paper presents a method to fit Optimal Operation Rules for the coupled operation of Hydroelectric Power Plants (HPPs) using fuzzy logic. These rules establish a relationship between the state of each reservoir and the aggregated state of the whole hydroelectric system on an optimal operation context. The rules fitted using this method are used by a simulator and the results are compared with the results achieved by others fitting methods and by other kinds of rules. The test system is the Brazilian South East System. The proposed method has the great advantage of being totally automatic and presents a high performance in the simulations.

In reference [17], Fuzzy decision making is applied in multi-objective long-term scheduling of hydrothermal system. Uncertainties like power production cost data, Nitrogen emission, system load demand and water inflows are taken into consideration. It is a tri-objective problem in which fuel cost, nitrogen emission and load demand are minimized. Stochastic models are converted into deterministic models by a specific technique. Decomposition approach is applied to reduce the complexity of the problem. The efficiency of method is checked on 3-hydro and 4-thermal plants.

Reference [18], proposes fuzzy logic to solve a short-range fixed-head hydrothermal problem with five objectives namely cost, NO_x, emission, SO_2 emission, CO_2 emission and variance of generation mismatch. The objectives are contradicting and it is hard to find a compromise between them. Weighting method establishes a trade-off between them and fuzzy logic helps to choose the weighting pattern and the point of operation that minimizes all the objectives. More accurate analysis and taken into account the randomness in decision variables can further improve results.

M. Basu [19] uses an interactive fuzzy satisfying method based on evolutionary programming technique for multi-objective short-term hydrothermal scheduling taking into account cost and emission as dual objectives. This multi objective problem is converted into a mini-max problem that can be solved by evolutionary programming technique. A multi-reservoir cascaded hydroelectric system with water discharge rate, net head and power generation and water transport delay is considered. The results show improvement in attaining optimality. A similar solution approach was also used by authors in [20] employing fuzzy satisfying method based on evolutionary programming to solve multi-objective generation scheduling problem of hydrothermal power system. The obtained results are compared with the interactive fuzzy satisfying method based on simulated annealing approach.

J. Nanda [21] proposed an automatic generation control (AGC) of interconnected hydrothermal system in the continuous discrete mode using conventional integral and fuzzy logic controllers (FLC). Conventional integral controller and fuzzy logic controllers are compared considering small step disturbances using triangular membership functions. Simulation results reveal that application of FLC in both areas (thermal and hydel) with small step perturbation provides better dynamic response than with conventional controller. The authors [28] proposes an automatic generation control of two-area interconnected thyristor controlled phase shifter based HT system in continuous mode using fuzzy logic controller under open market scenario. The PI controller is compared with fuzzy logic controller for different load variations and step load perturbations. It is found that FLC is far superior to PI controller under system dynamics. The authors [36] also designed a fuzzy logic and artificial neural network based intelligent controller and implemented it for AGC in multi area interconnected hydrothermal problem. This designed controller worked like a time fluctuating PID controller. In reference [31], the authors studied the automatic generation control of unequal multi-area hydrothermal system by using genetic algorithm optimized fuzzy logic based integral-double derivative controller (FIDD). The obtained results is compared with Integral, proportional integral (PI), proportional integral derivative (PID) controller and integral- double derivative (IDD) controllers and it has been found that FIDD is the best one and it is highly robust at nominal 50 % loading conditions. Similarly the authors in [37] proposed a novel Bacterial Foraging (BF) optimized fuzzy integral–double derivative to improve the dynamic response of AGC of multi area hydrothermal system. The nominal 50% loading of FIDD controller was found quite vigorous for wide loading range the performance of proposed FIDD was found quite satisfactory as compared to PID and IDD.

K. Singh et al. [40] discussed the design of a novel AGC controller based on fuzzy logic theory. The proposed knowledge based FLC comprised of two components, a database and fuzzy control base. The ideas related with a data base are applied to characterize fuzzy control rule and a fuzzy data management in a FLC. An improved dynamic responses of proposed FLC was obtained in overall closed loop system. Besides this, the proposed FLC gave better suppression of oscillations and improved peak over shoot damping compared to other controller performance under similar operating condition.

In reference [22], particle swarm optimization based interactive fuzzy satisfying method for bi-objective generation scheduling of fixed head hydro plants and thermal plants with non-smooth fuel cost and emission level functions is investigated. The bi-objective problem is transformed into a mini-max problem, which is then handled by the particle swarm optimization technique. The results obtained from the proposed method are compared to those found by interactive fuzzy satisfying method based on evolutionary programming technique. Same solution methodology was also applied by authors [23] to solve multi-objective short-term economic environmental load dispatch problem. In this approach multi-objective optimal problem can be transformed into a single objective optimal problem by means of minimizing the maximum difference between reference membership degree value and objective membership degree value. The simulation results show that the proposed approach is effective and feasible, avoids subjective randomness of confirming objective weight.

A fuzzy logic controller is investigated to control power flow in tie-line interconnecting two area hydrothermal system [24] considering non-linearities and boiler dynamics. The conventional proportional integral controller is compared with it and found that conventional controller does not produce adequate control and dynamic gain against load variations whereas fuzzy base does at different step load perturbations.

Reference [25] presents an adaptive Neuro-Fuzzy Inference System (NFIS) in parallel with a deterministic optimization model as a simpler and less complex alternative for the optimization of HTS problem. The performance of the proposed approach was compared to other policies, including stochastic dynamic programming (SDP), by simulation using historical inflow records of large Brazilian hydroelectric power plant. The results show similar performance of NFIS as is in case of SDP. The authors in [26] developed a energetic operation policy based on Takagi-Sugeno Fuzzy inference system. The fuzzy logic based energetic operation policy is compared with adopted operation policy in Brazilian system. It is found that the proposed policy is superior in achieving the optimum generation cost.

Research paper [27], proposes a fuzzy logic controller for load frequency control of 2-area interconnected hydrothermal system. The system is simulated by taking one percent load perturbation in either area. The fuzzy controller is matched with proportional integral controller and found that proposed controller gives better control even with the consideration of non-linearity's and boiler dynamics. The authors [29] also investigate load frequency control of a two-area hydrothermal system under deregulated environment. Fixed gain controllers for LFC are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions whereas control scheme based on an Adaptive Neuro-Fuzzy Inference System (ANFIS) performs brilliantly as it tracks the load change and gives better dynamic control.

Genetic algorithm and particle swarm optimization techniques are used to optimize the parameters of fuzzy logic controller (FLC) by S.K. Sinha, *et al.*, in [30] for better dynamic control of three area hydrothermal power system. It has been found that GA tuned and PSO tuned FLC give superior control over simple FLC.

Paper [32] discusses three operational policies for optimized use of hydel resources in Brazilian hydroelectric system. Policy based fuzzy inference system (PBFIS), policy based on polynomial and exponential functions and parallel policy are compared. It is found that PBFIS gives optimized use of resources and improves reliability of the system. For this same hydroelectric system, the authors [33] developed operation rules with great hydraulic participation. Fuzzy system with genetic algorithm tuned membership function was utilized to estimate the operating volume of reservoir. The proposed genetic-fuzzy operation rule was compared with Takagi-Sugeno based fuzzy operation rule, operation policy and operation policy obtained from exponential and polynomial functions and found that fuzzy operation policy is better than other three in terms of optimized use of hydel resources.

Stochastic scheduling model for hydrothermal power systems based on fuzzy chance constrained programming, taking reservoir inflow and water level for a random variable is studied [34]. Reservoir water volume was formulated as a triangular fuzzy number. Fuzzy stochastic variables were used to represent the uncertainties incurred in optimization scheduling of hydrothermal power systems. A control function was introduced to coordinate the three objective functions, which includes coal consumption minimization, reservoir water level maximization and air pollutant emission minimization. A stochastic scheduling model of hydrothermal power systems can be converted into a determined form using fuzzy chance constrained programming and random chance constrained programming. A cascaded hydel system and coal fired plants was taken as a study example and obtained results proved the accuracy of model.

The authors [35] established a mathematical model for optimal unit commitment and active power dispatch of hydro-thermal power systems including cascaded hydropower Stations and derive an efficient algorithm for its equivalent integer linear programming. The power plants are decomposed into two classes by using the decomposition and coordination method for large-scale systems, and improve the method of Lagrangian multipliers for modifying hydro-thermal power plants, and finally combine the methods of fuzzy mathematics and operational research for solving economic scheduling problem of cascaded hydropower stations. In proposed method daily coal consumption rate decreases in considerable percent, and larger economic benefit can be obtained.

A.L. Rabelo et al. [38] proposed fuzzy based PSO system for hydrothermal operational planning. A fuzzy system was designed for each system. The membership function which is used to represents fuzzy system was adjusted by using PSO. Similarly in [39], the authors proposed a genetic based fuzzy system for hydrothermal operational planning. In this paper the rules for reservoir operation by using fuzzy genetic system. Simulation results demonstrate the effectiveness of the proposed scheme when used in energy operation of hydroelectric systems.

The authors [41] presented the Type-2 Fuzzy system to efficiently carry out the Load Frequency Control of hydrothermal power system. The salient advantage of the controller over conventional PI and Type-1 Fuzzy controller is that its action is very fast and it can efficiently handle system nonlinearities. Therefore, suitable under maximum overshoot and undershoot conditions. The simulation results reveal that under Hydro-thermal-thermal combination, the proposed controller gives a better dynamic performance and reduces the oscillations of frequency deviation and the tie line power.

The authors [42] proposed a fuzzy controller for frequency control of two area interconnected thermal-thermal and thermal hydro plant system. The settling time of PI controller is very large therefore causes deviation in frequency levels. It works at nominal operating condition but its performance over a wide range operating condition is not satisfactory. Fuzzy controller shows good result over the conventional controller especially in complex and nonlinearities associated system. In paper [43], the authors implemented both the conventional PI controller and Fuzzy Logic controller to study the load frequency control of interconnected power system. The performances of the controllers are simulated using Matlab/Simulink package and it has been noticed that for Fuzzy Logic Controller, the steady state error of frequencies and inadvertent interchange of tie-lines power are maintained in a given tolerance limitations.

In paper [44], variable structure fuzzy gain scheduling is proposed for solving the load frequency control problem of multisource multi area hydro thermal power system. The PI controller gains are tuned using Ziegler Nichols' (ZN) method and Genetic Algorithm (GA). In both the methods, the gain values of PI controllers are fixed for any system changes and it is not acceptable. This problem is overcome by scheduling the gain based on system changes using Fuzzy Logic. Matlab Simulink is used and better response is achieved while Fuzzy Gain Scheduling is implemented. On analyzing the controller based on performance indices, it is found that variable structure fuzzy gain scheduling controllers found to be the best controller for multi source multi area power system.

The paper [45] presents the implementation of load frequency control (LFC) of hydrothermal system under restructured scenario employing fuzzy controlled genetic algorithm (FCGA). The disadvantages posed by the conventional controllers are overcome by the concept of artificial intelligent techniques. The performance of integral controller and FCGA controller for a two area hydrothermal system under restructured scenario has been investigated and a simulation result shows the superior performance of the system using FCGA controller.

5. Conclusion

The current interest in using the Computation Intelligence (CI) for power system applications is increasing amongst the researchers and academicians. It is noticed that huge amount of research papers and articles are available in all the area of AI tools. The potential areas of CI application are also highlighted. New intelligent system technologies using digital signal processing techniques, expert systems, artificial intelligent and machine learning provide several unique advantages in solving the power system problems. The artificial intelligent systems are very close to natural search and can handle non-linear, dynamic, non-convex, discontinuous and non-differentiable function. These techniques are speedy and do not stuck in local optimum.

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