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Full Length Research Paper

The optimization model for long-term operation of hydrothermal power plants

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Coordinating the generation plan of hydrothermal power plants in a long-term period is extremely important in generation scheduling system of hydrothermal power plants. Regarding the importance of the issue, a method for optimizing the long-term operation of a combined system of hydroelectric and thermal power plants is presented in this research, in which the main system parameters, including water inlet to reservoirs of hydroelectric power plants and the energy demand of system are considered to be indefinite. The main difference of the present research from the other similar studies is its multi-purposefulness which takes not only the cost but also the flood control into account. The issue has been resolved with the help of NSGA-II and Noisy GA algorithms – two powerful algorithms in genetic algorithm –for Khouzestan utility system.

Key words: NSGA-II, noisy GA, hydrothermal power plant, indefinite scheduling, genetic algorithm, optimization.

INTRODUCTION

Appropriate scheduling plays an extremely important role in optimal operation of utility power systems consisting of thermal power plants and hydroelectric power plants with multipurpose reservoirs. This importance is due to the great savings resulted from appropriate coordination of power generation in thermal and hydroelectric power plants. Considering the low operational cost of hydroelectric power plants in contrary to thermal power plants, there is a greater tendency to use the former for meeting the existing demand. However, due to the limitation of water reserves in hydroelectric power plants reservoirs, satisfying the total demand during the operation period would not be possible. On the other hand, with growing demand, using thermal units which have higher generation cost becomes inevitable; therefore, the purpose of coordination of power generation in hydroelectric and thermal power plants is to make use of hydroelectric power plants in such a way that while satisfying the demand and the other limitations of the system, the use of thermal units having high Operating costs is minimized. Chao et al. (1990) have used 'decomposition-coordination method' for solving the long-term optimal scheduling for hydrothermal power systems with stochastic inflows. They developed a model composed of M hydroelectric and N thermal power plants. Then the hydroelectric and thermal sub-problems are solved by 'stochastic dynamic planning' and 'non-linear planning' respectively. The results of the sub-problems are input to the main problem which coordinates the results and this is done by updating Lagrangian multiplier. The reconstruction and updating process continues till an optimal situation is achieved. Escudero et al. (1996) solved long-term hydraulic generation system considering stochastic inflows to reservoirs using scenario analysis technique. The modeling of the system is linear. Stochastic is also applied to the model through creating different scenarios for inflows to reservoirs. Then through tracker model 1, the optimal result of stochastic problem is found. The developed model has been used in Iberdola system in Spain.

Ruey-Hsun (2000) proposed a short-term generation scheduling at Taiwan power system using neural network theory. In fact, with analogy of system equations with a

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Table 1. Summary of classical algorithm and genetic algorithm.

Classical algorithm	Genetic algorithm
Generates a single point at each iteration. The sequence of points approaches an optimal solution.	Generates a population of points at each iteration. The best point in the population approaches an optimal solution.
Selects the next point in the sequence by a deterministic computation.	Selects the next population by computation which uses random number generators.

Hopfield artificial network and solving them, the global optimum is achieved. Teegavarapu et al. (2000) used a nonlinear model with integer variables for real time scheduling of hydroelectric power system considering the hydraulic effect of reservoirs on each other. The proposed model has been used for scheduling Manitoba system. Mousavi et al. (2002) studied the operating policy of multi-reservoir systems using optimal control theory (OCT). The problem has two objectives: cost and water deficit. The problem is solved based on Pontryagin principle established by Lev Semenovich Pontryagin in 1962. Gonzalez et al. (1994) compared optimization and simulation models in a power system including hydrothermal power plants. He studied the effect of the optimization model assumptions on the accuracy of the optimal response and compared it with the response obtained from the simulations and concluded that it was accurate enough. Mohammad et al. (2001) have studied the application of simulation and optimization in stochastic scheduling. Using Monte Carlo simulation in a two-stage 'stochastic programming' with auxiliary variables, they showed that for considering the uncertainty, first, the value operator is not a reasonable expectation. Secondly, the problem's convergence at the real answer increases as the number of samples grows. Finally, 10 to 30 samples would suffice for most scientific problems. Most parameters are uncertain in the long-term planning and cannot be definitive because it is a big error in the model. In addition, low-cost hydropower production in comparison with thermal power plants, hydropower creates desire for more. Hydropower production is influenced by different goals for using the water tank. This point to the problem of optimizing long-term planning hydropower and thermal systems as one of the issues for researchers is considered noteworthy.

Many researchers have tried to solve this complicated problem in mathematical programming and using different techniques.

MATERIALS AND METHODS

The present research tries first to minimize the total cost of energy generation in a system combined from hydrothermal power plants and secondly to control the flood resulting from water inflows to reservoirs. The first step to that end is to define a target function and constraints which is the main part of the work. One of the objective functions is the cost function in which the total energy generation costs of hydrothermal power plants are defined as a cost function. The next objective function is the one for controlling the flood. This function should be identified clearly and its constraints must be defined as well. The second step is to provide the necessary data which could be real or artificial data. In the present research, we have used the real data. The next step is familiarization with algorithms and code writing.

Genetic algorithm

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. We can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms including problems in which the objective function is discontinuous, non-differentiable, stochastic or highly nonlinear. The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

i) Selection rules select the individuals called parents that contribute to the population at the next generation.
ii) Crossover rules combine two parents to form children for the next generation.
iii) Mutation rules apply random changes to individual parents to form children.

The genetic algorithm differs from a classical, derivative-based, optimization algorithm in two main ways as summarized in Table 1.

Problem formulation

The problem of optimal operation in a reservoir is formulated based on flood controlling and cost minimization. Figure 1 shows the schematic of a water dam system. In this system, the inputs are assumed as net flow and the effects of evaporation and penetration are not considered. In Figure 1, QI flows into the dam and the stored water (S) are allocated to agriculture, industry and drinking (totally showed as QA). SP, R, DRF and RF represent reservoir spillway, dam abandonment through outlets, river direction flow which is the consumption surplus of total output water and returned water from drinking, industrial and agricultural use plus river direction flow respectively which constitute the downstream water right. There is a minimum water right necessary for meeting environmental needs. Formulation of the aforementioned conceptual model in equation and inequalities form: problem constraints: cohesion equation in reservoir:

$$S_{T,i} + QI_{T,i} - R_{T,i} - SP_{T,i} = S_{T+1,i} \tag{1}$$

Where:

$S_{T,i}$ is water volume in reservoir i at the beginning of interval $T(MCM)$

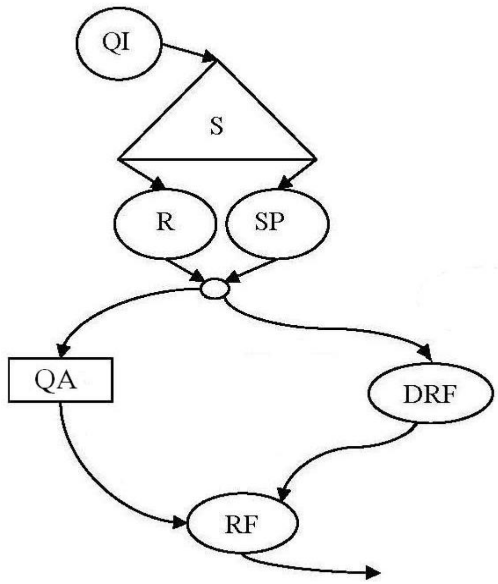

Figure 1. Schematic of a water dam system.

$QI_{T,i}$ is monthly inflow volume to reservoir i at interval $T(MCM)$

$R_{T,i}$ is abandonment volume from dam reservoir i through outlets at interval $T(MCM)$

$SP_{T,i}$ is spillway volume from dam reservoir i through outlets at interval $T(MCM)$

Reservoir capacity limitation and the favorable condition of reservoir at the beginning of the period:

$$k_d \leq s_{T,i} \leq k \tag{2}$$

$$s_{1,i} = s_{o,i} \tag{3}$$

Where:

$S_{o,i}$ is initial water volume in reservoir $T(MCM)$
k is effective volume of reservoirs,
kd is dead volume of reservoirs.

An inequality showing the maximum allocable water to different usage in each period:

$$QA_{T,i} \leq R_{T,i} + SP_{T,i} \tag{4}$$

Where:

$QA_{T,i}$ is water volume allocated to the agricultural, industrial and urban usage from reservoir i in month $T(MCM)$.

Equation of water allocation to different usage:

$$QA_{T,i} + SLQD_{T,i} = QD_{T,i} \tag{5}$$

Where:

$SLQD_{T,i}$ is violation in supplying water in reservoir i in period $T(MCM)$, $QD_{T,i}$ is water demand from reservoir i in month $T(MCM)$. Equation 6 shows returned water to river water system:

$$RTNF_{T,i} = Alfa \times QA_{T,i} \tag{6}$$

Where:

$RTNF_{T,i}$ is returned water from all usage locations to river system i in each period $T(MCM)$. $Alfa$ is returned water coefficient from usage location to surface water system in period $T(MCM)$. Equations 7 and 8 show the water flowing in river downstream:

$$DRF_{T,i} = R_{T,i} + SP_{T,i} - QA_{T,i} \tag{7}$$

$$RF_{T,i} = DRF_{T,i} + RTRNF_{T,i} \tag{8}$$

Where:

$DRF_{T,i}$ is river direction flow or surplus of total output water usage from reservoir i in period $T(MCM)$; $RFT_{T,i}$ is flowing water in downstream of reservoir i in period $T(MCM)$.

The inequalities showing the minimum water needed in downstream (for environmental water right) is Equation 9.

$$RF_{T,i} \geq EnvDem_i \tag{9}$$

Where:

$EnvDem_i$ is the environmental water right of river i (the minimum water necessary for meeting environmental needs).

Equation 10 shows the constraint of the energy balance equation:

$$\sum_{i=1}^{k} PH_{T,i} + \sum_{j=1}^{n} PT_{T,j} + PI_T - PX_T = DT_T \tag{10}$$

Where:

$PH_{T\,i}$ is energy generation of hydro power plant reservoir i in period $T(MCM)$, $PT_T\,j$ is energy generation of thermal power plant i in period $T(MCM)$, PT_T is energy input in period

$T(MCM)$, PX_T is energy output in period $T(MCM)$, DP_T is energy demand in period $T(MW)$.

Equations 11 and 12 show the constraints of command reservoir curve equation:

$$H_{T,i} = HMAX_{T,i} + SLUPR_{T,i} \tag{11}$$

$$H_{T,i} = HMIN_{T,i} - SLDOR_{T,i} \tag{12}$$

Where:

$H_{T,i}$ is water height in reservoir i in period T, $HMAX_{T,i}$ is upper limit curve of command reservoir i in period T, $HMIN_{T,i}$ is lower limit curve of command reservoir i in period T, $SLUPR_{T,i}$ is violation of upper limit curve of command reservoir i in period T and $SLDOR_{T,i}$ is violation of lower limit curve of command reservoir i in period T.

Equations 13 and 14 show generation capacity constraint of hydro power plant:

$$PH_{T,i} = QP_{T,i} \times (HT_{T,i} - H\phi) \times EFF_i \times K \tag{13}$$

$$PH_{T,i} \langle PHMAX_i \tag{14}$$

Where:

$PH_{T,i}$ is energy generation of hydro power plant reservoir i in period T, $QP_{T,i}$ is the flow rate into reservoir turbine i in period T, $HT_{T,i}$ is dynamic height of reservoir i in period T, EFF_i is turbine output of reservoir i, K is a constant coefficient equal to $\frac{9.81}{1000}$, $PHMAX_i$ is the maximum monthly generation capacity of hydro power plant and $H\varphi$ is the tail water height of reservoir i in period T.

Equation 15 shows generation capacity constraint in thermal power plant:

$$PTMAX_j \rangle PH_{T,j} \rangle PTMIN_j \tag{15}$$

Where:

$PTMAX_j$ is the maximum energy generation of thermal power plant j in each period,

$PTMIN_j$ is the minimum energy generation of thermal power plant j in each period and $PH_{T,j}$ is energy generation of thermal power plant j in period T.

Equation 16 shows of input and output energy constraint of system:

$$PX_T \langle PXMAX_T \langle PT_T \langle PIMAX_T \tag{16}$$

Where:

PH_T is output to adjacent systems, PT_T is input from adjacent systems, $PXMAX_T$ is the maximum output capacity to adjacent systems and $PXMIN_T$ is the maximum input capacity from adjacent systems.

The signs of all the aforementioned parameters are plus.

Problem formulation

The problem for optimal operation in a reservoir is formulated on the basis of minimizing the costs of meeting needs and flood controlling. The functions are as follows:

First objective function (costs): Minimize:

$$Z1 = \sum_{j=1}^{n}\sum_{T=1}^{36} PT_{T,j} \times COT_{T,j} + \sum_{i=1}^{k}\sum_{T=1}^{36} PH_{T,i} \times COH_{T,i} + \sum_{T=1}^{36} PX_T \times COX_T + \sum_{T=1}^{36} PI_T \times COI_T$$
$$+ \sum_{i=1}^{k}\sum_{T=1}^{36} SLUPR_{T,i} \times COSLUPR_{T,i} + \sum_{i=1}^{k}\sum_{T=1}^{36} SLDOR_{T,i} \times COSLDOR_{T,i} + \sum_{i=1}^{k}\sum_{T=1}^{36} SLQD_{T,i} \times COSLQD_{T,i}$$

Where objective function statement are energy generation cost of thermal power plants, energy generation cost of hydro power plants, output cost (calculated with minus sign), input cost, and penalty for violation of command curve upper and lower limit and unsupplied water respectively.

The parameters used in the aforementioned equations are as follows:

$PT_{T,j}$ is the amount of generated energy in Tth month from jth thermal unit, $COT_{T,j}$ is energy generation cost in Tth month from jth thermal unit, $PH_{T,i}$ is the amount of generated energy in Tth hydro from ith thermal unit, $COH_{T,i}$ is energy generation cost in Tth month from ith thermal unit, PX_T is the output energy of hydroelectric system into adjacent systems in period T, COX_T is the output energy cost of hydroelectric system in period T (with minus sign), PT_T is the input energy of hydroelectric system from adjacent systems in period T, COT_T is the input energy cost of hydroelectric system from adjacent systems in period T, $SLUPR_{T,i}$ is the violation of command curve upper limit of reservoir ith in Tth period, $COSLUPR_{T,i}$ is penalty for violation of command curve upper limit of reservoir ith in Tth period, $SLDOR_{T,j}$ is the violation of command curve lower limit of reservoir ith in Tth period, $COSLDOR_{T,j}$ is penalty for violation of command curve lower limit of reservoir ith in Tth period,

Figure 2. Khouzestan location within Iran.

$SLQDT_{T,i}$ is water shortage in reservoir ith in Tth period, $COSLQDT_{T,i}$ is penalty for water shortage in reservoir ith in Tth period, n is the number of thermal power plants and k is the number of hydro power plants.

In final result of cost function, the amount of penalty is subtracted from objective function and the remainder is announced as cost. The second and third objective function (flood controlling): for controlling the output from reservoir in monthly intervals so that no flood occurs, parameter $FLD_{T,i}$ is defined as flood in the blow statement:

If $DRF_{T,i} \geq QF_i \Rightarrow FLD_{T,i} = DRF_{T,i} - QF_i$ (17)

If $DRF_{T,i} \langle QF_i \Rightarrow FLD_{T,i} = \phi$ (18)

Where:

QF_i is the average flow rate of river of 30 input scenarios.

$$QF_i = \frac{\sum_{j=1}^{30} \sum_{i=1}^{36} QI_{T,i,s}}{30 \times 36} \quad (19)$$

Therefore, there should be:

$$MinimizeZ2 = \sum_{T=1}^{36} FLD_{T,1} \quad (20)$$

$$MinimizeZ3 = \sum_{T=1}^{36} FLD_{T,2} \quad (21)$$

Index 1 is for Karoun and index 2 is for Dez.

Case study

Khouzestan is a province in southwest of Iran and covers an area of about 64236 km^2. It is located at 47°, 42’ and 50°, 39’ east longitude of Greenwich meridian and 29°, 58’ and 32°, 58’ north of the equator, bordering Lorestan Province on the north, Isfahan Province on the northeast, Ilam Province on the northwest, Chaharmahal and Bakhtiari Province and Kohgiluyeh and Boyer-Ahmad Province on the east and south east respectively, Persian Gulf on the south and Iraq on the west. Figure 2 shows location of Khuzestan Province within South west of Iran.

RESULTS

This model has been solved by the proposed algorithm based on GA. Considering the fact that there are 3 objective functions for this problem, the evolution of objective function and its part are shown in Figures 3, 4 and 5. The answer converges to the optimal value in 41st generation.

Model results

The model answers are shown by the charts and compared by the presented parameters. First, we compare the costs resulted from the proposed model with

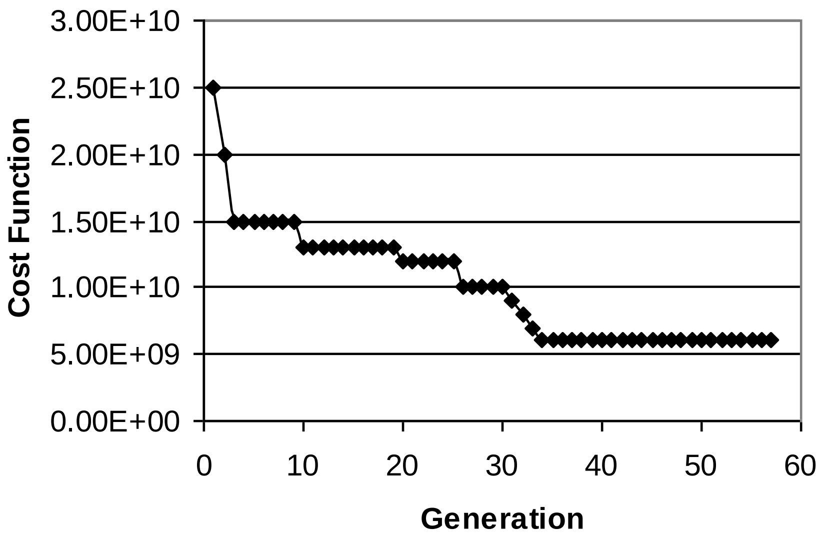

Figure 3. Evolution in cost objective function.

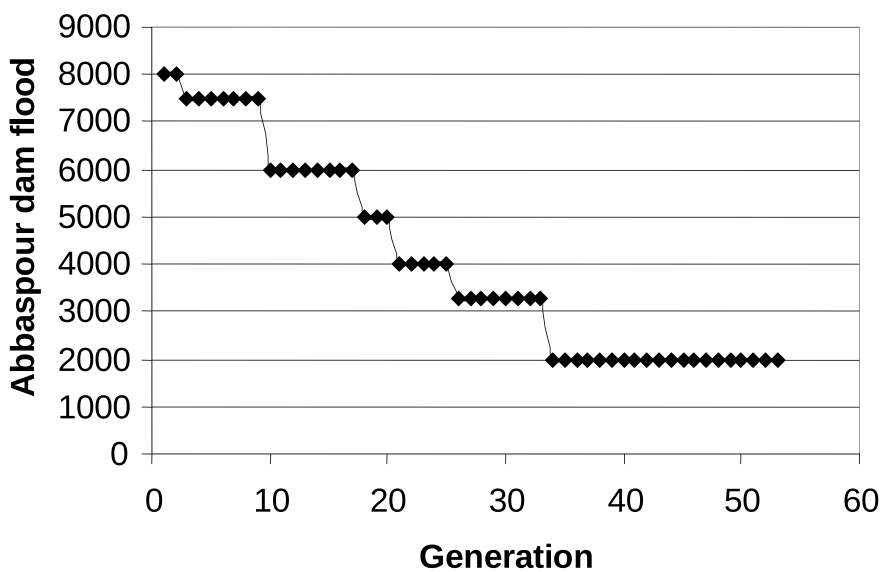

Figure 4. Evolution in Abbaspour dam flood objective function.

that of HTCOM-III model and the real value. This comparison is shown in Figure 6. Based on it, the system costs are higher than HTCOM-III and lower than the real system. The difference is due to considering the flood controlling in calculations which results in decrease of energy generation of hydroelectric power plant and consequently decrease the reservoir volume. Therefore, to meet energy needs, the energy generation of thermal power plants and energy input increase. Energy generation in thermal power plants costs higher and increases the total costs. It is clear that the energy generation cost in model is lower than in the real model and that is because uncertainty in model is lower than in the real model but if all parameters of the model is assumed to be uncertain too, model results would still be better than the real performance and that is because of the structure of model and the approach to the real model. One reason the model performance is better than the real model is assuming different scenarios for uncertain parameters. In this way, model is exposed to different situations and finally the best answer from all aspects is selected. The comparison graph of energy generation from the model, real performance and HTCOM-III is shown in Figure 7. Looking at the chart, it could be seen that energy generation in model is lower than the real model and HTCOM-III model, and that is

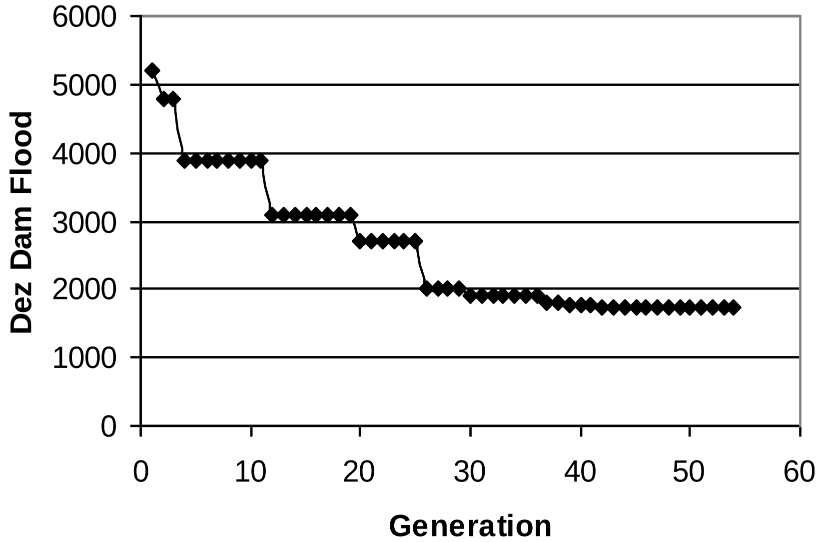

Figure 5. Evolution in Dez dam flood objective function.

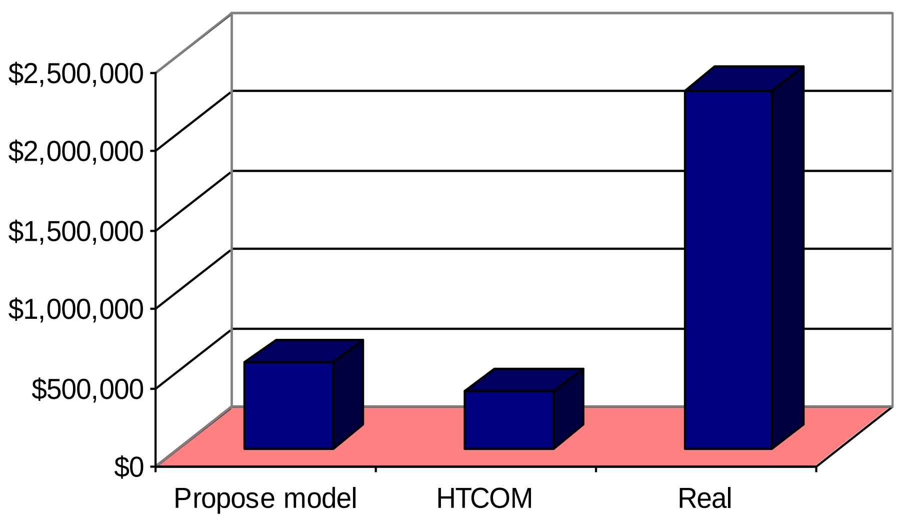

Figure 6. Cost comparison chart in the proposed model, HTCOM-III and the real value.

because of cost objective function and flood controlling in the proposed model which decrease water storage in reservoir and consequently energy generation in hydroelectric power plants. Therefore, the model moves toward output decrease and input increase to compensate energy shortage. That is why the amount of output is lower than the real amount and the amount of input higher.

Figure 8 shows the calculated amount of flood by the model in a total of 36 months period for Abbaspour and Dez dams and its comparison with HTCOM-III model. As it is shown in the chart, the calculated amount of flood in model is considerably lower (about 0.1) than that in HTCOM-III model because of including the flood controlling function in the proposed model and not in HTCOM-III.

DISCUSSION

1) Specifying parameters such as flood increase costs. Considering parameters such as flood control parameters in storage dams which part of its volume is assumed for flood control lead up to increasing costs.
2) NSGA-II algorithm could be used as a powerful tool for solving multipurpose complicated problems in storage dams, hydropower plants and thermal power plants.
3) The proposed model incurs higher cost and generates lower energy than HTCOM-III. In return, the calculated

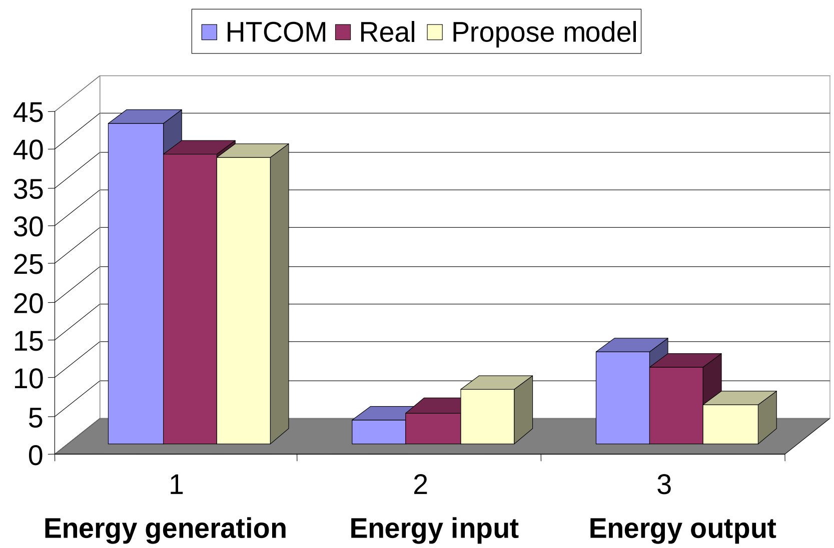

Figure 7. Energy generation comparison chart in the proposed model, real value and HTCOM-III.

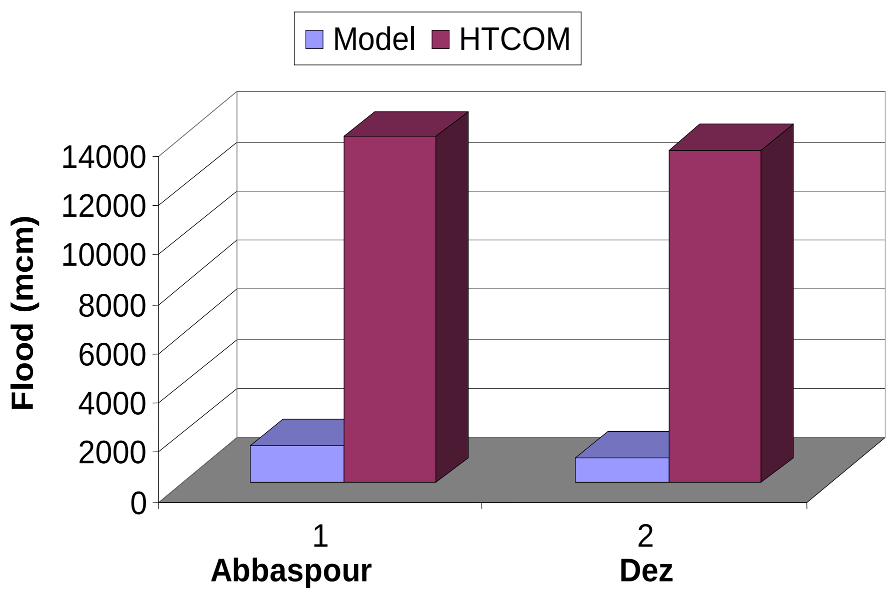

Figure 8. Comparison chart of flood in the proposed model, reality and HTCOM-III.

amount of flood is considerably lower.

4) If the parameters of an uncertain model, that are really uncertain, enter the model solving algorithm, the reliability of the answers increase. In an optimization model, for example, if the objective function is of a type of cost, the more uncertain the model becomes, the objective function shows higher cost comparing to a model which has uncertainty but it does not consider it. However, the answers of the first model are more reliable. On the other hand, uncertain model, especially those whose uncertainty are modeled by Mont Carlo method, does not result in a definite answer for the problem, and the answer is given as an expected value or standard deviation.

5) Although the increase of uncertain parameters makes the problem insolvable, the optimization method of scenarios solves huge problems with many uncertain parameters.

6) Despite the fact that the number of uncertain parameters has been increased in the model and the cost of model increases, the performance of model is considerably better than real performance; because the model considers the system as an integrated unit and studies all its actions in both time and location aspect.

REFERENCES

Chao L, Ruiyan Z, Jingyan Z (1990). Stochastic optimization of interconnected multi-reservoir power systems, IEEE Trans. On Power Sys., 5(4): 1487-1496.
Escudero LF (1996). Hydropower Generation Management Under Uncertainty Via Scenario Analysis and Parallel Computation, IEEE Trans. On power Sys., 11(2): 683-689.
Gonzalez JA, Nabona N (1994). Long-Term Hydrothermal Coordination with Natural Inflows Modeled through a PDF and Simulation Results, Sociedad de Estad´stica e Investigaci´on Operativa Top, 2(1): 59-84.
Mohammad Z, Meybodi A (2001). A Simulation Approach to Probabilistic Production Planning, Indiana, Kokomo, School of Business: pp. 728-730.
Mousavi H, Ramamurthy AS (2002). Multi-Reservoir design using Pontryagin Principle. Adv. Water Resour., 25: 677-687.
Ruey-Hsun L (2000). A Noise Annealing Neural Network for Hydroelectric Generation Scheduling with Pumped-Storage Units, IEEE Trans. On power Sys., 15(3): 1008-1013.
Teegavarapu R, Simonovic SP (2000). Short-Term Operation Model for Coupled Hydropower Reservoirs, J. Water Resour. Plann. Manage., 126(2): 98-106.