1995年度日本オペレーションズ・リサーチ学会
秋季研究発表会

The Application of Fuzzy Dynamic Programming to Power System Planning and Operation Problems

Hokkaido University Graeme GIBSON
Hokkaido University Hiroyuki KITA
Hokkaido Inst. of Technology Ken-ichi NISHIYA
01503151 Hokkaido University Jun HASEGAWA

Abstract

This paper presents a new fuzzy dynamic programming technique for solving multistage decision problems in power system operation. It uses a fuzzy decision process called the preference factor, which equates the mathematical preference of one decision function with respect to another. To investigate its validity, it was applied to the hydrothermal scheduling problem, which offers an ideal application for dynamic programming. Results showed that this technique produces an operating band giving solution flexibility.

1. Introduction

Multistage decision making is an important part of power system operation planning and is usually performed by dynamic programming (DP). Various planning problems exist such as hydrothermal scheduling, thermal generating unit maintenance scheduling, economical load dispatching and unit commitment [1,2]. However, these problems all deal with elements that contain a degree of uncertainty. If fuzzy theory, or more specifically, fuzzy membership functions are used to represent load and natural hydraulic flows, then it naturally follows that the thermal production cost will also become a fuzzy membership function [2]. Further, it is then necessary to use fuzzy mathematical techniques to compare the various state costs for a given time stage and to choose the minimum cost path accordingly. In this paper, this is performed by the *preference factor* DP technique and applied to the hydrothermal scheduling problem. Therefore, we can expect a final solution that will have a fuzzy band for reservoir storage levels.

2. Decision Process

Many problems are such that a multistage decision process is required for obtaining the optimal operation of a system. Often in power system operation planning, the *optimal operation* is cost oriented. In cases where decisions at a later stage do not affect the operation of the system at earlier stages then the problem (solution process) becomes the minimisation of an objective function where a given stage, k, has a number of possible system states which result in decision requirement corresponding to the operation objective. If ordered decision making is performed, then a solution can be obtained (DP approach). The initial state of this process can be defined by Equation (1) and the minimisation objective function can be defined by Equation (2). The operating state $\underline{X}_k$ at stage k is determined by the decision value $\underline{U}_k$ which corresponds to the transition from operating state $\underline{X}_{k-1}$ of the (k-1)th stage to stage k. Thus, the incremental increase in the objective function value for this transition is defined by $f_k(\underline{X}_k,\underline{U}_k)$. It follows that the objective function value at the previous stage is $F_{k-1}(\underline{X}_{k-1})$ and the value to stage k is $F_k(\underline{X}_k)$.

$$F_0(\underline{X}_0)=0 \tag{1}$$

$$F_k(\underline{X}_k)=\min_{\underline{U}_k}.\ \{F_{k-1}(\underline{X}_{k-1})+f_k(\underline{X}_k,\underline{U}_k)\} \tag{2}$$

3. Dealing with Uncertainty

Preference Factor Technique

First, if we consider 2 rectangular shaped membership functions, we are able to formulate a mathematical technique to select the *preferred* function. We have chosen rectangular functions for mathematical simplicity due to the lengthy integration calculations required. Although this technique considers fuzzy membership functions, the mathematical application is not strictly fuzzy theory, instead it is an offspring of probability theory. The general formula is given in Equation (3).

$$PF(A,B)=\frac{\int_{-\infty}^{\infty}\mu_A(x)\int_{x}^{\infty}\mu_B(y)dydx}{\int_{-\infty}^{\infty}\mu_A(x)dx\int_{-\infty}^{\infty}\mu_B(x)dx} \tag{3}$$

PF(A,B) denotes that this particular formula compares fuzzy number B with respect to A to determine A's preference factor value. This value can then be compared with a prenominated constraining value, β, to determine the relative optimality of both functions. The mathematical definition of β is given in Equation (4).

$$\begin{array}{ll} \beta \leq PF(A,B) \leq 1-\beta & ;A=B \\ PF(A,B) < \beta & ;B<A \\ 1-\beta < PF(A,B) & ;A<B \end{array} \quad (4)$$

From this definition it can be seen that β can not be set above 0.5 as this value represents equality between membership functions. If we make the assumption as given in Equation (5), there are 4 resulting derivatives corresponding to the 4 configurations excluding cases where there is no overlap (not shown in this paper).

$$PF(A,B) + PF(B,A) = 1 \quad (5)$$

4. New Fuzzy DP Approach for Hydrothermal Scheduling

Formulation of Hydrothermal Problem

In this paper, in order to investigate the validity of this new fuzzy DP approach to the multistage decision process it was necessary to choose a simple example problem. For this purpose, the minimising of thermal power production costs for a set time period was chosen together with a single hydroelectric power station to provide a hydrothermal co-ordination problem. For this planning problem, the stages consist of individual time intervals and the DP method to determine the reservoir water level. The corresponding thermal production cost function then becomes the following :

$$C_k^0 = 0 \quad (6)$$

$$C_k^t = \min_{\{j\}} . \{C_j^{t-1} + C(j, t-1; k, t)\} \quad (7)$$

Here, C_k^t is the total cost from the initial time interval to the end of time interval t where the water level (operating state) is defined by k. In addition, C(j,t-1;k,t) is the transition cost from state j at the end of the previous time interval t-1 to state k at the end of the next time interval t.

5. Numerical Examples

Test Model

Simulations were carried out on the following system model to test the validity of this new method.

- scheduling period = 1 year (1456 time intervals)
- 2×100MW generators
- reservoir volume range = 0~1060[t/s.day] : divided into 265 units each of 4[t/s.day]
- 9-unit thermal generating system

Test Results

Fig.1 gives the scheduling solution obtained by the preference factor DP technique. The 2 different lines denote the upper and lower limits of the operating band which would not existent if the solution were obtained deterministically. We made the assumption that it was not necessary to apply a fuzzy band to the forecasted load data because it has only a small error with limited variation. Conversely, the forecasted natural hydraulic inflow has a much greater variation in error due to complicated weather conditions. We applied a 5% band to these values to account for this uncertainty or fuzziness. The preference factor constraining value was set at β=0.475. Although not shown in this paper, it should be noted that the operating band was smaller than that for the case where β=0.45, thus demonstrating the effectiveness of adjusting this value. This has the effect of further restricting the number of possible equivalent costs and hence reduces the size of the operating band.

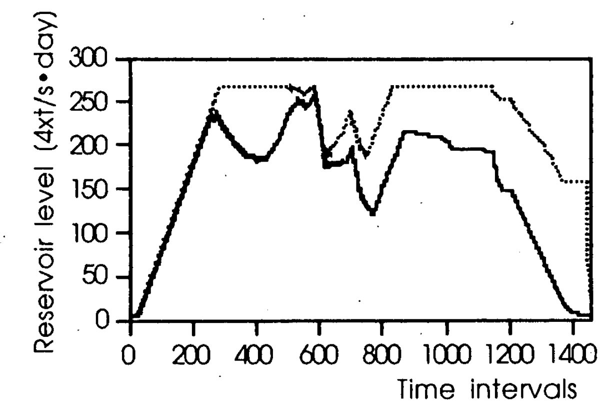

Fig.1 Scheduling solution
(Inflow band=5% for β=0.475)

6. Conclusions

This paper presented a new approach for solving multistage decision problems in power system operation where elements containing uncertainty exist. Fuzzy functions and numbers were used to express the inherent uncertainty elements, namely, load demand, natural hydraulic flows and the corresponding power generation levels and thermal power production costs. The results obtained have an operating band which reflects the robustness and flexibility of the solution. This allows the system operator to carry out operation within this range to suit any given scenario.

References

[1] C. Huang, et al.: "Fuzzy Approach for Generator Maint. Scheduling", EPSR Proc. Vol.24, pp.31-38, 1992.

[2] J. Hasegawa, et al.: "A Method that Considers Uncertainty in Power System Planning" (in Japanese), IEEJ Power Tech. Meeting , paper PE-93-175, 1993.