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Fuzzy-Logic-Based Approach to Solve the Unit-Commitment Problem

Assad Abu-Jasser[1], Mohammed M. Hijjo[2]
[1, 2] *Electrical Engineering Department, the Islamic University of Gaza, Palestine*

Abstract—This study presents an application ofthe fuzzy-logic to solve the unit commitment problem in general and in particular to find unit combinations and their generation scheduling to bring the total operating cost to a minimum, when subject to a variety of constraints. This approach allows a qualitative description of the behavior of a certain system,the system's characteristics, and the response without the need for exact mathematical formulations. This approach is demonstrated by employing a four-generation-units thermal power plantas a case study. The goal is to show that a fuzzy-logic-basedapproach achieves logical, feasible, and economical operation of the power generation plant, which is the main objective of solving the unit commitment problem. It is worth mentioning that the algorithm in this study benefits from the dynamic programming and fuzzy logic approaches in orderto obtain preferable unit combinations at each time period and the ability of representing the results in terms of input variables. The numerical results obtained by the fuzzy-logic-based approach are compared with dynamic programmingto demonstrate its superiority and these results have shown that the performance of the proposed approach exceeds that of the dynamic programming.

Keywords—Unit commitment, economic dispatch,fuzzy-logic,dynamic programming, and optimization

I. INTRODUCTION

In all power stations, investment is quite expensive and the resources needed to operate them are rapidly becomingsparser. As a result, the focus today is on optimizing the operating cost of power stations. In the present world, meeting the power demand as well as optimizing generation has become a necessity. *Unit commitment (UC)* in power system refers to the optimization problem for determining the on/off states of generating units that minimize the operating cost subject to variety of constraints for a given time horizon [1]. The solution of theunit commitment problem (UCP) is a complex optimization problem. The exact solution of the UCP can be obtainedby complete enumeration of all feasible combinations of generating units, which could be huge number. The unit-commitment is commonly formulated as a non–linear, large scale, mixed integer combinational optimizationproblem.

Summary of the different methods used in the solution of the UC problem may be found in Fahd [2]. The Dynamic Programming (DP) method as in Hobbs and Huang [3, 4] based on priority list is flexible, but the computationaltime suffers from dimensionality. As Zhuang and Redondo, Lagrangian relaxation (LR) for UCP [5, 6] was superior to DP due to its higher solutionquality and faster computational time. However, Dekranjanpetch said that numerical convergence and solution quality of LR are notsatisfactory when identical units exist [7]. With the adventof heuristic approaches, genetic algorithm (GA) as Kazarlis[8],evolutionary programming(EP) as Juste[9], simulated annealing (SA) asMantawy[10], and tabu search (TS) as SelimShokri [11] have been proposed to solve the UC problems. The results obtained by GA, EP, TS and SA required a considerable amount of computational time especially for large system size.

The use of fuzzy logic has received increased attention in recent years because of its worth in dropping the requirement for difficult mathematical models in problem solving. Relatively, fuzzy logic employs linguistic terms, which deal with the causal relationship between input and output variables. For this reason, fuzzy logic approach makes it easier to manipulate and solve many problems, particularly where the mathematical model is not explicitly known, or is hard to solve. Moreover, fuzzy logic as a new technique, which approximates reasoning, while allowing decisions to be made efficiently.

In this paper, to achieve a good unit commitment planning under fuzzy approach, generation cost and load demand are all specifiedas a fuzzy set notation. Fuzzy Logic Techniques is then proposed to yield the desired commitment schedule. In order to show the advantages of this proposed approach, the four-generating units of the Tuncbilek Thermal Plant in Turkey is chosen as test systems.

II. UNIT COMMITMENT PROBLEM

The unit commitment problem can mathematically be described as follows in Equation (1).

$$Min\, F_i(P_i^t, U_i^t) = \sum_t \sum_i [(a_i P^2 + b_i P + c_i) + SC_i^t\,(1 - U_i^{t-1})]U_i^t \quad (1)$$

Where:$F_i(P_i^t)$ is generator fuel cost function in quadratic form,anda_i, b_i and c_i are coefficients of unit i, and P_i^t is the power generation of unit i at time*t*.

A. Problem Constrains

The minimization of the objective function is subjected to two kinds of constraints, the system constraints and the units' constraints and these can be formulated in the following two subsections:

B. System Constraints

(i) Power Balance Constraints: For satisfying the load balance in each stage, the forecasted load demand should be equal to the total power of the generated power for feasible combination, below system hourly power balance operation in Equation(2), where the total *power load demand* at a certain period is P_D^t

$$\sum_{i=1}^{N} P_i^t U_i^t - (P_D^t) = 0 \tag{2}$$

(ii) Hourly Spinning Reserve: R must be met as per Equation(3).

$$\sum_{i=1}^{N} P_i^{max} U_i - (P_D) = R \qquad t = 1, 2, 3 \ldots.T \tag{3}$$

C. Unit Constraints

(i) Generation Limits: Each unit must satisfy the generation range so this certain rated range must not be violated as in Equation(4).

$$P_i^{min} U_i^t \le P_i \le P_i^{max} U_i^t \qquad i = 1, 2, 3 \ldots. N \tag{4}$$

Where: P_i^{min} and P_i^{max} are thegeneration limitsof unit i

(ii) Ramp-Up and Ramp-Down Constraints: To avoid damaging the turbine, the electrical output of a unit cannot change by more than a certain amount over a period of time. Here for each unit, output is limited by ramp up/down rate at each hour as follows in Equation(5) and Equation(6):

$$P_i^{t-1} - P_i^t \le RD_i if(U_i^t = 1) \,\&\, (U_i^{t-1} = 1) \tag{5}$$
$$P_i^t - P_i^{t-1} \le RU_i if(U_i^t = 1) \,\&\, (U_i^{t-1} = 1) \tag{6}$$

Where:$RD_i$and $RU_i$are respectively the ramp down and ramp up rate limit of unit i

III. FUZZY LOGIC IMPLEMENTATION

Fuzzy logic provides not only a meaningful and powerful representation for measurement of uncertainties but also a meaningful representation of blurred concept expressed in normally language. Fuzzy logic is a mathematical theory, which encompasses the idea of vagueness when defining a concept or a meaning. For example, there is uncertainty or fuzziness in expressions like `large` or `small`, since these expressions are imprecise and relative. Variables considered thus are termed `fuzzy` as opposed to `crisp`. Fuzziness is simply one means of describing uncertainty. Such ideas are readily applicable to the unit commitment problem.

A. Fuzzy Unit-Commitment Problem Model

The objective of every electric utility is to operate at minimal cost while meeting the load demand and spinning reserve requirements. In the present formulation, the fuzzy variables associated with the UCP are load capacity of generator (LCG), incremental fuel cost (IC), start-up cost (SUC) as an input variables and production cost (PRC) as output variable. Below we present briefly explaining of mentioned fuzzy variables:

- **The load capacity of generator** is considered to be fuzzy, as it is based upon the load to be served.
- **Incremental fuel cost**is taken to be fuzzy, because the cost of fuel may change over the period of time, and because the cost of fuel for each unit may be different.
- **Start –up costs**of the units are assumed to be fuzzy, because some units will be online and others will be offline. And it is important to mention that we includethe start costs, shut costs, maintenance costs and crew expenses of each unit as a fixedvalue that is start-up cost. So, start-up cost of a unit is independent of the time it has been off line (it is afixed amount).
- **Production cost** of the system is treated as a fuzzy variable since it is directly proportional to the hourly load.
-

Also, uncertainty in fuzzy logic is a measure of no specificity that is characterized by possibility distributions. This is similar to the use of probability distributions, which characterize uncertainty in probability theory. The possibility distributions attempt to capture the ambiguity in linguistically describing the physical process variables.

B. Fuzzy Set Associated with the Unit-Commitment

After identifying the fuzzy variables associated with unit commitment, the fuzzy sets defining these variables are selected and normalized between 0 and 1 This normalized value can be multiplied by a selected scale factor to accommodate any desired variable.

The sets defining the load capacity of the generator are as follows:
LCG = {Low, Below Average, Average, Above Average, High}

The incremental cost is stated by the following sets:
IC = {Zero, Small, Large}

The sets representing the start– up cost are shown below:
SUC = {Low, Medium, High}

The production cost, chosen as the objective function, is given by:
PRC= {Low, Below Average, Average, Above Average, High}

Based on the aforementioned fuzzy sets, the membership functions are chosen for each fuzzy input and output variable as shown in Figure 1 through Figure (4). For simplicity, a triangular shape is used to illustrate the membership functions considered here. Once these sets are established, the input variables are then related to the output variable by If–Then rules as described next.

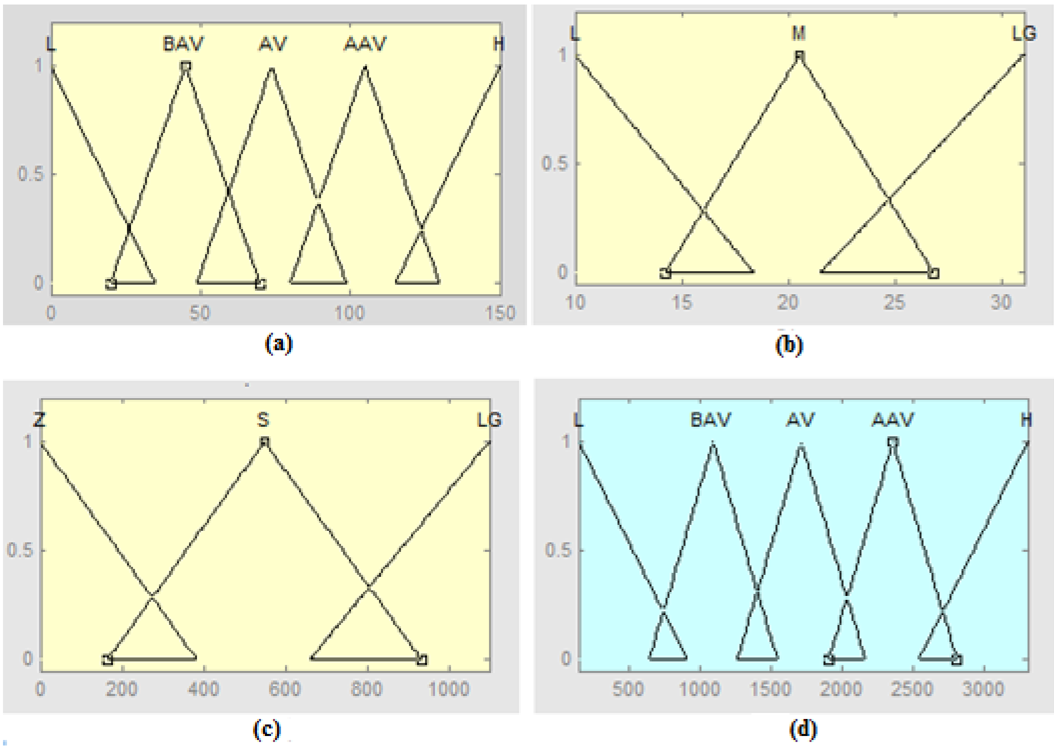


***Figure (1):*Membership Function of input/output Variables**
(a) LCG Membership(b) IC Membership(c) SUC Membership(d) PRC Membership

C. Fuzzy If–Then Rules

If fuzzy logic based approach decisions are made by forming a series of rules that relate the input variables to the output variable using If–Then statements. TheIf (condition) is an antecedent to the Then (consequence) of each rule. Each rule in general can be represented in this manner:*If (condition) Then (consequence)*

Note that Load capacity of generator, incremental fuel cost, and start–up cost are considered as input variables and production cost is treated as the output variable. This relation between the input variables and the output variable is given as: Production cost = {Load capacity of generator} **AND** {Incremental fuel cost} **AND** {Start–up cost}

In fuzzy set notation this is written as,$PRC = LCG \cap IFC \cap SUC$

Hence, the membership function of the production cost, μ PRC is computed as follows in Equation (7):

$$\mu PRC = \mu LCG \cap \mu IFC \cap \mu SUC \textbf{ Or } \mu PRC = \min\{\mu LCG, \mu IFC, \mu SUC\} \quad (7)$$

Where:μLCG, μIC and μSUC are memberships of load capacity of generator, incremental fuel cost and start–up cost, respectively. Using the above notation, fuzzy rules are written to associate fuzzy input variables with the fuzzy output variable. Based upon these relationships, and with reference to Figure (1), the total sum of rules are 45 thatcould be composed because there are five subsets for *load capacity of generator*, three subsets for *incremental cost* and three subsets for *start–up cost*(5×3×3=45). Rule 11as an example could be written as follows:

If(load capacity of generator is below average, **and** incremental fuel cost is low**and** start–up cost is small), **then** production cost is below average.So,the fuzzy results must be defuzzified by a certain defuzzification method after relating the input variable to the output variable as in Table (1). That is called a defuzzification process to achieve crisp numerical values.

Table (1): **Used Fuzzy Rules That Relates Input / Output Fuzzy Variables**

Rule	LCG	IC	SUC	PRC	Rule	LCG	IC	SUC	PRC
1	L	L	Z	L	**24**	AV	M	LG	AV
2	L	L	S	L	**25**	AV	LG	Z	AV
3	L	L	LG	L	**26**	AV	LG	S	AV
4	L	M	Z	L	**27**	AV	LG	LG	AV
5	L	M	S	L	**28**	AAV	L	Z	AAV
6	L	M	LG	L	**29**	AAV	L	S	AAV
7	L	LG	Z	L	**30**	AAV	L	LG	AAV
8	L	LG	S	L	**31**	AAV	M	Z	AAV
9	L	LG	LG	L	**32**	AAV	M	S	AAV
10	BAV	L	Z	BAV	**33**	AAV	M	LG	AAV
11	BAV	L	S	BAV	**34**	AAV	LG	Z	AAV
12	BAV	L	LG	BAV	**35**	AAV	LG	S	AAV
13	BAV	M	Z	BAV	**36**	AAV	LG	LG	AAV
14	BAV	M	S	BAV	**37**	H	L	Z	H
15	BAV	M	LG	BAV	**38**	H	L	S	H
16	BAV	LG	Z	BAV	**39**	H	L	LG	H
17	BAV	LG	S	BAV	**40**	H	M	Z	H
18	BAV	LG	LG	BAV	**41**	H	M	S	H
19	AV	L	Z	AV	**42**	H	M	LG	H
20	AV	L	S	AV	**43**	H	LG	Z	H
21	AV	L	LG	AV	**44**	H	LG	S	H
22	AV	M	Z	AV	**45**	H	LG	LG	H
23	AV	M	S	AV					

D. Defuzzification Process

One of the most commonly used methods of defuzzification is the **Centroid** or center of gravity method. Using this method, the production cost is obtained as follows in Equation (8):

$$ProductionCost = \frac{\sum_{i=1}^{n}\mu(PRC)_i \times PRC_i}{\sum_{i=1}^{n}\mu(PRC)_i} \qquad (8)$$

Where:$\mu(PRC)_i$ is the membership value of the clipped output,$(PRC)_i$, the quantitative value of the clipped output and ns the number of the points corresponding to quantitative value of the output.

IV. THE FUZZY-BASED-APPROACH ALGORITHM

In solving the UCP, two types of variables, first one are units states at each period $U_{i,t}$which are integer or binary (0 – 1) variables, and second are the units output power variablesP_i^t, which are continuous variables need to be determined. This problem can be considered into two sub-problems. The first is combinatorial optimization problem in **U**, while the other is a non–linear one in **P**.

AFuzzy-Based-Approachis proposed and implemented to solve this complicated optimization problem.The proposed technique is not much different from the hybrid- fuzzy dynamic programming [12] until it gives an alternative unit combinations and so different total production cost. This is accomplished by bringing the defuzzification process forward to the inside of check loop. At the same time, the economic dispatch problem is solved by employing the quadratic programming routine and Figure (2) shows the flowchart of the proposed algorithm. The suggested approach will provide feasible unit-combinations for the dynamic programming and for the fuzzy logic based approach.

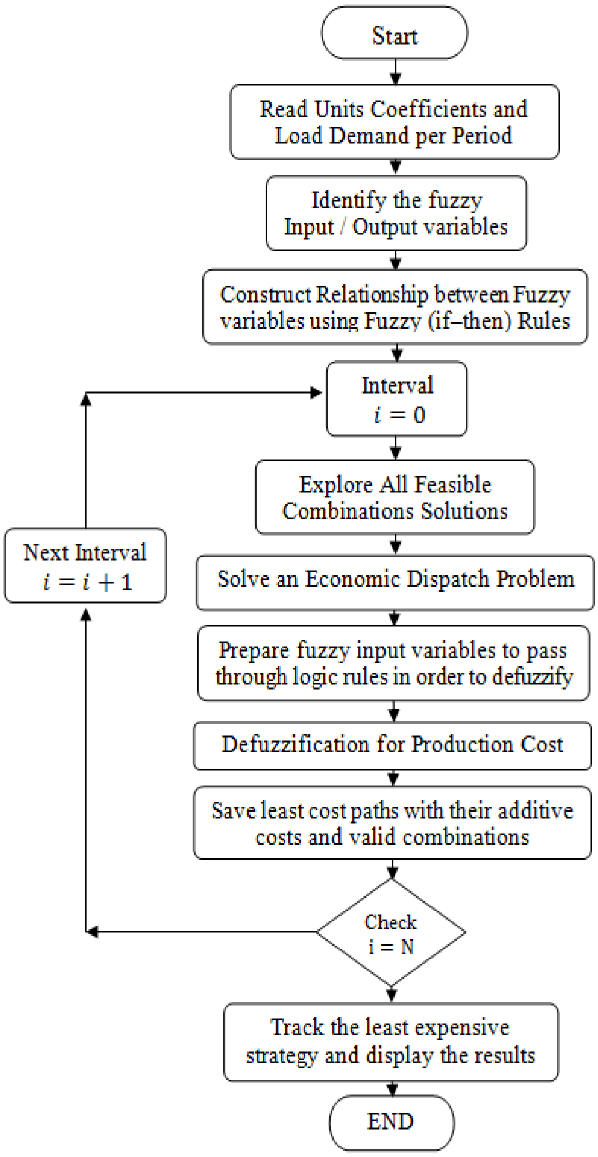


Figure (2):**Flowchart of the Fuzzy Logic-Based-Approach**

V. FOUR-GENERATION-UNITS MODEL (CASE STUDY)

The Tuncbilek thermal plant in Turkey with four units has been considered as case study [13]. The daily load demand related to this model is divided into eight periods. The unit-commitment problem is then solved employing the proposed approach.Table (2) contains the unit characteristics of the four units and these are the power generation limits, the cost coefficients, start-up/shut-down cost, and ramp rates.

Table (2):**Characteristics ofthe Four-Generation-Units**

Unit No.	Generation Limits		Running Cost			Start-up Cost		Ramp Rates	
	P_{min} (MW)	P_{max} (MW)	A ($/MW^2.h)	B ($/MWh)	C ($/h)	SC ($)	SD ($)	RU (MW/h)	RD (MW/h)
1	8	32	0.515	10.86	149.9	60	120	6	6
2	17	65	0.227	8.341	284.6	240	480	14	14
3	35	150	0.082	9.9441	495.8	550	1100	30	30
4	30	150	0.074	12.44	388.9	550	1100	30	30

Alsoa load demand for eight periodsduring the day is given in Table (3)and shown graphically in Figure (3).

Table(3): **Daily Load demand**

Period	Demand (MW)
1	168
2	150
3	260
4	275
5	313
6	347
7	308
8	231

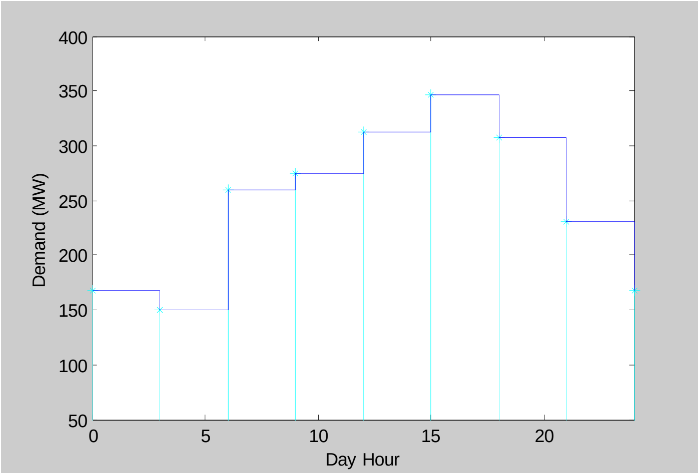


Figure (3): **Daily Load Demand**

As explained in fuzzy implementation section, taking theproduction cost as the output variable, and the load capacity of generator, incremental fuel cost and start–up cost as input variables, the fuzzy sets describing LCG, IC, SUC and PRC are previously shown in Figure (1). And here it is important to note that we choose the ranges of each subset after some experiments in a subjective manner.For example, if the load range that can be served by the largest generator is between 0to 150 MW,Then low LCG could be chosen within a range of 0 MW– 35 MW and this allows a relative and virtual evaluation of the linguistic definitions with the numerical values.Similarly, the subsets for other variables can be linguistically defined and it is clear that the range of LCG and PRC is wider than IC and SUP, so we make five zones for each wide fuzzy variable and three zones only for other narrower ones.

VI. SIMULATION RESULTS

The algorithm for the unit commitment problem of the four-generating units at the Tuncbilek thermal power plant in Turkey is formulated applying the fuzzy logic. A MATLAB computer program to solve the problem was developed. The results obtained by the fuzzy logic approach provide crisp values of the production cost in each period for every given fuzzy input variables. The complete set of results, for the given load demand are summarized in Table (4). A comparison with dynamic programming is also shown in the same figure that indicates thatthe fuzzy logic approach outcomes are comparable and better than to those of dynamicprogramming. A fuzzy logic approach overall resultsare near to those obtained by dynamic programming technique. Thus we indicatethat in fuzzy logic approachwhich used variables, such as, low load capacity of generator, medium production costs, large incremental fuel costs, large start–up costsetc, are the normal ways in which system parameters and behavior can be linguistically described. These linguistic descriptions ultimately tend to provide quantitative values that include the imprecision that inherently exists in such descriptions.

Table (4): **Generation Schedule of the Four Units Plant and the Production Costs**

Period	Demand (MW)	FLA Commitment		DP Commitment	
		Combinations	Cost ($)	Combinations	DP Cost ($)
1	168	0 1 1 0	3977.29	0 0 1 1	4343.57
2	150	1 1 1 1	3740.68	0 0 1 1	3438.31
3	260	0 1 1 1	6104.21	0 1 1 1	6736.43
4	275	0 1 1 1	5984.21	1 1 1 1	6848.95
5	313	1 1 1 1	6954.98	1 1 1 1	7747.68
6	347	1 1 1 1	7780.28	1 1 1 1	8815.98
7	308	1 1 1 1	6141.76	1 1 1 1	7596.66
8	231	1 1 1 0	5133.15	0 1 1 1	5544.93
		Sum	45816.6	Sum	51072.5

Next figure shows a cost comparison between dynamic programming versus fuzzy logic approach that obtained by demonstrated fuzzy logic approach.

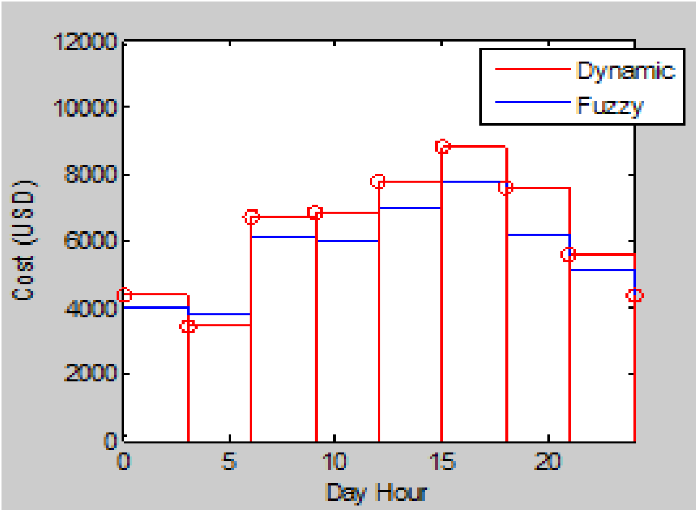
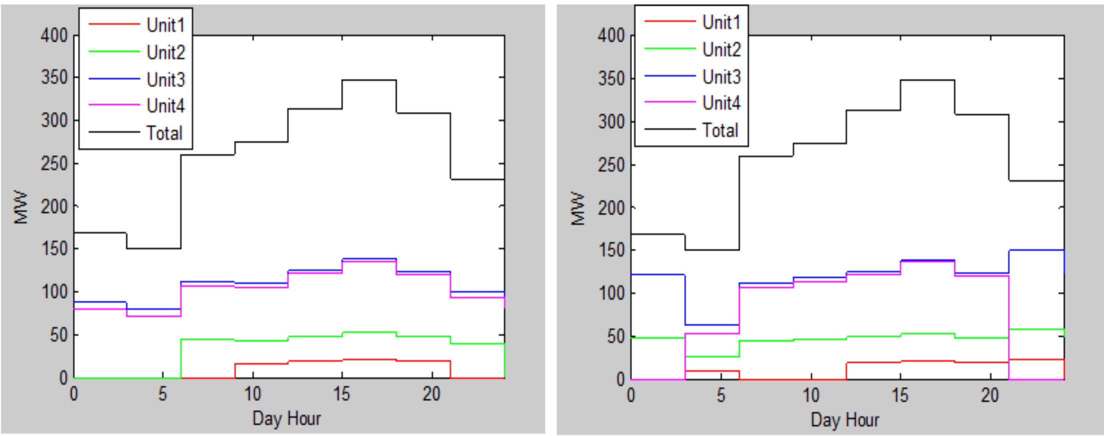


Figure (4): **Cost Comparison between Fuzzy-Logic and Dynamic Programming**

Note that the previousTable shows unit combinations, and in the next figure how much and power allocation for each unit and its corresponding operation schedule over a day.

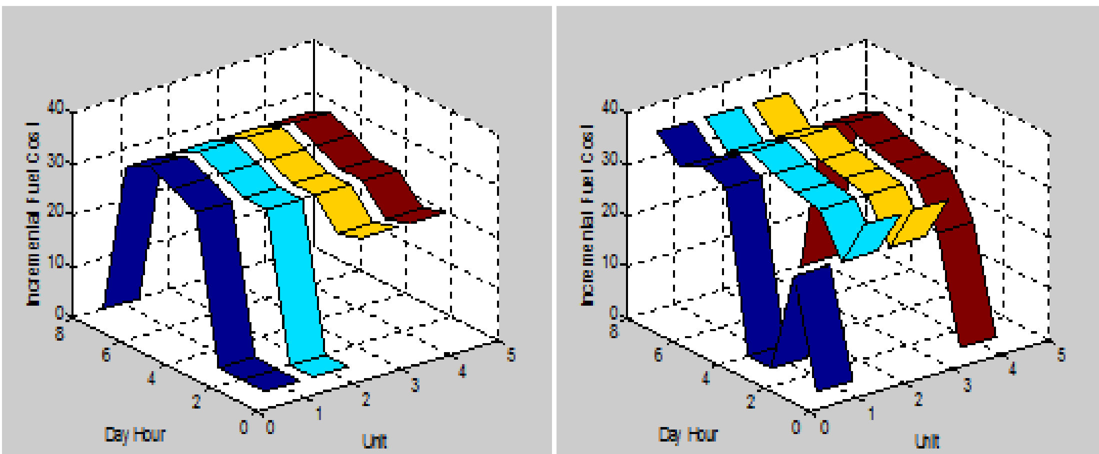


a) **b)**

Figure (5): **Unit Commitment**

(a) Dynamic Programming (b) Fuzzy-Logic-Based Approach

Other description of operation is the fuel consumption or in other words the incremental fuel cost corresponding to the operating conditions at each stage.



a) **b)**

Figure(6): **Incremental Fuel Cost**

(a) Dynamic Programming (b) Fuzzy-Logic-BasedApproach

The incremental fuel costs for each stage of operation for the fuzzy-logic approach as well as for the dynamic programming are shown in Figure (6). It can be seen that there are differences and this is due to the different unit-combination for each stage

VII. CONCLUSION

A fuzzy-logic-based approach has been developed for solving the thermalunit commitment problem of a four-unit power system to provide feasible unit combinations for every period of time.The daily load demand is divided into eight periods of time and during each period the load demand remains constant. A Matlab code has also been developed to handle the problem and after running the code, the approach has been successfully implemented and feasible unit combinations are obtained for each time periodthat satisfies the system constraints.

The dynamic programming technique is also applied to the system model with the same loading conditions and constraints and feasible unit combinations have been obtained for each period.The fuzzy-logic-based approach and the dynamic programming have yielded different unit combinations, incremental fuel costs, and production costs for the eight operating periods. In four of the eight time periods, the unit combinations obtained by the two approaches were identical while, the production costs are never identical.

The daily production costs obtained by the fuzzy-logic approach amount to 45816.6 USD while these costs amount to 51072.5 USD when the dynamic programming approach is implemented. This means there is a saving of 10.29% in production costs obtained by the suggested fuzzy-logic-based approach.

REFERENCES

[1]. A J Wood and B F Wollenberg. ‘Power Generation Operation and Control.’ Addison Wiley and Sons, 2nd Edition, New York, 1996.

[2]. B. Gerald, Sheble and George N. Fahd (Feb 1993), “Unit Commitment Literature Synopsis”, IEEE Transactions on Power system, Vol.9, No.1, pp 128-133.

[3]. W J Hobbs, G Hermon, S Warner and G B Sheble. ‘An Enhanced Dynamic Programming Approach for Unit Commitment.’ IEEE Transactions on Power Systems, vol 3, no 3, 1988, pp 1201–1205.

[4]. Hsu, Y.Y., Su, C.C., Liang, C.C., Lin, C.J., and Huang, C.T., "Dynamic Security Constrained Multi-Area Unit Commitment,"IEEE Transactions on PWRS-6, No. 3 , pp. 1049-1055, August 1991.

[5]. Zhuang, F. and Galiana, F.D., "Towards a more Rigorous and Practical Unit Commitment by Lagrangian Relaxation," IEEE Transactions on PWRS-3, No. 2, pp. 763-773, May 1988.

[6]. N J Redondo and A J Conejo. ‘Short–term Hydro–thermal Coordination by Lagrangian Relaxation: Solution of the Dual Problem.’ IEEE Transactions on Power Systems, vol 14, February 1999, pp 89 –95.

[7]. S Dekranjanpetch, G B Sheble and A J Conejo. ‘Auction Implementation Problems using Lagrangian Relaxation.’ IEEE Transactions on Power Systems, vol 14, February 1999, pp 82–88.

[8]. S A Kazarlis, A G Bakirtzis and V Petridis. ‘A Genetic Algorithm Solution to the Unit Commitment Problem.’ IEEE Transactions on Power Systems, vol 11, February 1996, pp 83–92.

[9]. K A Juste, H Kita, E Tanaka and J Hasegawa. ‘An Evolutionary Programming Solution to the Unit Commitment Problem.’ IEEE Transactions on Power Systems, vol 14, November 1999, pp 1452–1459.

[10]. A H Mantawy, Y L Abdel–Magid and S Z Selim. ‘A Simulated Annealing Algorithm for Unit Commitment.’ IEEE Transactions on Power Systems, vol 13, February 1998, pp 197–204.

[11]. A H Mantawy, Y L Abdel–Magid and S Z SelimShokri. ‘Integrating Genetic Algorithm, Tabu Search and Simulated Annealing for the Unit Commitment Problem.’ IEEE Transactions on Power Systems, vol 14, no 3, 1999, pp 829–836.

[12]. Senthil Kumar and V. Palanisamy, "A Hybrid Fuzzy Dynamic Programming Approach to Unit Commitment," IE(I) Journal–EL Volume 88, March 2008

[13]. Ü B Filik and Mehmet Kurban . ‘Solving Unit Commitment Problem Using Modified Subgradient Method Combined with Simulated Annealing Algorithm.’ Mathematical Problems in Engineering, Vol (2010), Article ID 295645.