International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 1, January- 2013

Thermal Unit Commitment Using Fuzzy Logic

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Abstract

The Unit Commitment Problem is to determine a minimal cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand while satisfying a set of operational constraints such as power generation-load balance, spinning reserve, operating constraints, minimum up time & minimum down time, etc. The production cost includes fuel, startup, shutdown, and no-load costs. Several conventional methods are available to solve the unit commitment problem. This paper describes the application of fuzzy logic algorithm for determining short term commitment of thermal units in electrical power generation. This method allows a qualitative description of the behavior of the system, the system characteristics and response without the need for exact mathematical formulations. It is demonstrated through a numerical example that a fuzzy logic based approach achieves a logical and feasible economic cost of operation of the power system, which is the major object of Unit commitment. The results obtained from fuzzy logic based approach are compared with the priority list method solution to unit commitment problem.

Index Terms— Unit Commitment problem (UCP), Fuzzy Logic Algorithm, Priority List Method

1. Introduction

There have been several mathematical programming techniques proposed so far to solve unit commitment problems. They include Priority List, Dynamic Programming,
Branch and Bound, Lagrangian Relaxation, Simulated Annealing, Expert Systems, Artificial Neural Networks [7]. The most commonly used method being simple and fast by electricity utilities is the priority list method. This method is used to rank generating units in a heuristic with increasing operation cost.
Fuzzy Logic Algorithm provides a solution to UCP working with a population of individuals each representing a possible solution. Together with a set of the main genetic operators of crossover and mutation this method provides a powerful global search mechanism, whose computation code is simple. Fuzzy logic (FL) is useful in reducing the need for complex mathematical models in problem solving. Fuzziness is used to describe uncertainty, which is applicable to the UCP. Loading of generators, start up cost, incremental cost and production cost are considered to be fuzzy variables with the UCP. Fuzzy logic (FL) is useful in reducing the need for complex mathematical models in problem solving. Fuzziness is used to describe uncertainty, which is applicable to the UCP.
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2. Thermal Unit Commitment Problem Formulation

2.1 Fuel cost (FC)

For a given set of N committed units (i = 1 ... N) at hour H (j = 1…H), the total fuel cost at that particular hour, is minimized by economically dispatching the units subject to the following constraints: [1]
(i) The total generated power must be equal to the demand.
(ii) The power produced by each unit must be within certain limits.
This problem can be stated as follows.

$$\text{Min FC} = \sum_{h=1}^{H} \sum_{i=1}^{N} U_{ih} (FC_i)\, P_{ih} \qquad \dots (1)$$

ISSN: 2278-0181
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where, U_{ih} is the status of the unit i at hour h=1 (ON) or 0 (OFF)
P_{ih} is the Power output of unit i at hour h in MW

2.2 Start-up cost (ST)

As, the temperature and pressure of thermal unit must be changed slowly, a certain amount of energy will be expended to bring the unit online. This energy, does not result into any MW generation from the unit, is called start up cost. There are two approaches to treat a thermal unit in down period namely cold start and banking. The first allows the unit's boiler to cool down and then heat back up to operating temperature in time for a schedule turn on. The second requires that sufficient energy be input to the boiler to just maintain the operating temperature. The exponential function for the start up cost is given by

$$ST_i = b1\,[l - \exp(-b3 * X_i)] + b2 \quad \ldots \quad (2)$$

bl, b2 and b3 are start-up cost parameters and X_i the number of consecutive hours for which the unit i has been down [4].

2.3 Objective function

The objective (or cost) function (OF) of the UCP is to determine the state of the units U_{ih} (0 or 1) at each period H, so that the overall operation cost is a minimum within the scheduling time span.

$$\text{Min OF} = \sum_{h=1}^{H} \sum_{i=1}^{N} U_{ih}\,(FC_i)\,P_{ih} + ST_i\,U_{ih}\,(1-U_{i,h-1}) \ \ldots \ (3)$$

Subjected to the constraints [1]

(i) Total power generated should meet the load requirement and system losses,

$$P_G = P_D + P_L \quad \ldots \ (4)$$

where P_G is power generated, P_D is the power demand and P_L is the power losses.

(ii) Spinning reserve at each hour must be satisfied to cover any shortfall in generation,

$$P_G = P_D + \text{Reserve} \quad \ldots \ (5)$$

(iii) Each generator must operate within its minimum and maximum power output limits,

$$P_{MIN} < P_G < P_{MAX} \quad \ldots \ (6)$$

(iv) The consecutive number of hours for which a generating unit must remain on (minimum up time, MUT) or off (minimum down time, MDT) should not get violated,

$U_{ij} = 1$ for $T_{i\ on} <$ MUTi and $U_{ij} = 0$ for $T_{i\ off} <$ MDTi where, $T_{i\ on}$ and $T_{i\ off}$ is the consecutive number of hours for which the unit is on and off till the end of last hour respectively.

3. Test System

In order to prove effectiveness of Fuzzy Logic for solving UCP, it is applied to test system of four units (n =4) over time period of eight hours (H = 8).

Table 1
Load Demand & Reserve requirement of Test System.

Period	Demand	Reserve + Demand
01	400	450
02	470	530
03	520	600
04	510	540
05	360	400
06	240	280
07	240	290
08	450	500

Table 2
Generating Unit Characteristics of Test System.

					Start Up Cost Parameters				
Unit	**Max Cap**	**MUT**	**MDT**	**I.C**	**b1**	**b2**	**b3**	**SDC**	**AFLC**
1	80	3	2	-1	350	158	0.4	0	20.8
2	250	2	1	-2	400	162.6	0.9	0	18
3	300	4	2	1	1100	421.1	0.48	0	17.4
4	60	2	3	-4	0.02	0.02	0.01	0	23.8

4. Short Term Thermal UCP by Priority List Method

4.1 Priority List Method

From a modelling point of view, Priority listing is the simplest method. The calculation time for this method is small, even for large systems. This makes the methods eligible for our purposes .An important disadvantages of this method is that it is not consider accurate. Also state transition costs are not taken into account.

4.2 Implementation detail

The simplest unit commitment solution method consists of creating a priority list of units, a simple shut –down rule or priority –list scheme could be obtained after an exhaustive enumeration of all unit combinations at each load level. The priority list could be obtained in a much simpler manner by noting the average full load production cost (AFLC) which is simply the net heat rate at full load multiplied by the fuel cost. At each hour when the load is dropping, determine whether dropping the next unit on the priority list will leave sufficient generation to supply the load plus spinning reserve requirements. If not, continue operating as is; if yes, go to the next step.

- Determine the number of hours, H, before the unit will be needed again. That is assuming that the load is dropping and will then go back up some hours later.
- If H is less than the minimum shut –down time for the next step; if not, go to next step.
- Calculate two costs. The first is the sum of the hourly production costs for the next H hour s with the unit up. Then recalculate the same sum for the unit down and add in the smart-up cost for either cooling the unit or banking it, whichever is less expensive. If there is sufficient savings from shutting down the unit, it should be shut down, otherwise keep it on.
- Repeat this entire procedure for the next unit on the priority list. If it is also dropped, go to the next and so forth.

4.3 Result of Test system with Priority List Method

Table 3
Result for Test system with Priority List Algorithm based
approach

Hr	Units ON/OFF Schedule				P_G MW	Total Cost
	1	2	3	4		
1	0	1	1	0	550	9978
2	0	1	1	0	550	9738
3	0	1	1	1	610	11166
4	0	1	1	1	610	11166
5	0	1	1	0	550	9738
6	0	0	1	0	300	5238
7	0	0	1	0	300	5238
8	0	1	1	0	550	9968
Cumulative Cost in Indian Rupees (INR) 72,240						

5. Short Term Thermal UCP by Fuzzy Logic Method

5.1 Fuzzy Variable

Fuzzy logic is a mathematical theory which encompasses the idea of vagueness when defining a concept or a meaning. i.e. there is uncertainty or “Fuzziness “ in expression 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.

In the present formulation, the fuzzy variables associated with unit commitment problem are:

1. Load Capacity of the Generator (LCG)

ISSN: 2278-0181
Vol. 2 Issue 1, January- 2013

2. Incremental Cost (IC)
3. Start Up Cost (SUP)
4. Production Cost (PRC)

In general, the Load Capacity of Generator is taken to be fuzzy, as it is based upon the load to be served. Incremental fuel cost is also taken to be fuzzy, because the cost of fuel may change over a period of time, and may be different for each unit. Further the start-up costs of the unit are assumed to be fuzzy, because some units take more time than others to be placed on line. Finally Production Cost of the system is treated as fuzzy variable since it is directly proportional to the hourly load. Certain other variables such as, minimum up and down times, spinning reserve and generator limitations are considered as crisp variables in the unit commitment problem.

5.2 Fuzzy sets

After identify in the fuzzy variables associated with unit commitment, the fuzzy sets defining these variables are selected and normalized between 0 and 1 [2]. 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, Incremental cost, Start up cost, and Production cost are as follows [6],
LCG (MW) = {Low, below average, Above Average, High}
IC (INR) = {Zero, Small, Large}
SUP (INR) = {Low, Medium, High}
PRC (INR) = {Low, Below Average, Average, Above Average, High}

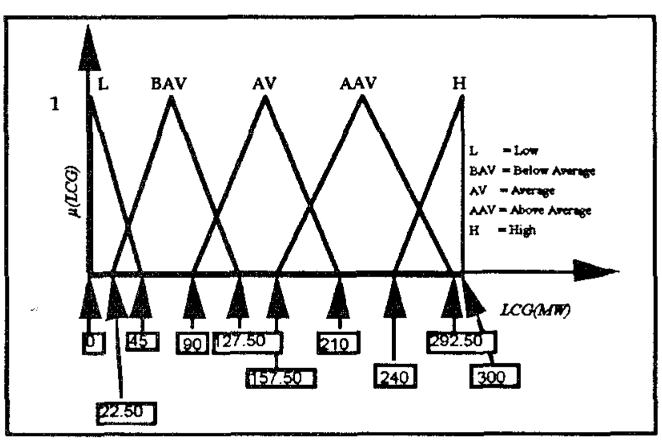

Fig 1: Membership Function of LCG

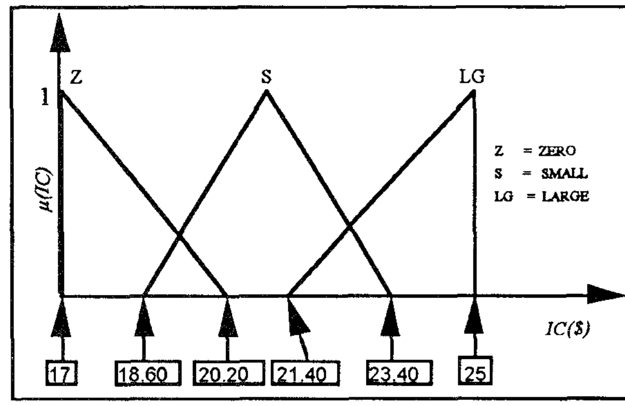

Fig 2: Membership Function of IC

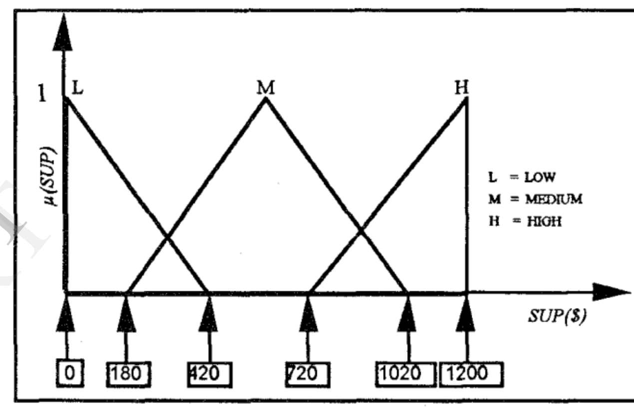

Fig 3: Membership Function of SUP

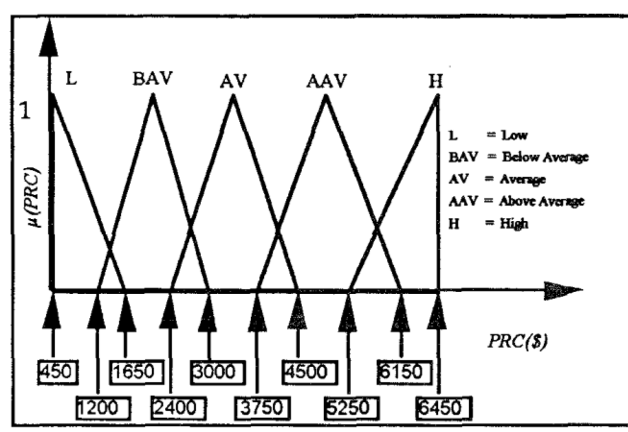

Fig 4: Membership Function of PRC

Using Production cost as output variable and load capacity of generator, Incremental cost and Start up costs as input variables, the fuzzy sets describing LCG, IC, SUP and PRC are illustrated in Figs. 1, 2,3 and 4 [3]. Note that ranges of each subset are chosen in a subjective manner. For example, given that the load range can be served by the generator is between 0 – 300MW, the subset low LCG may be chosen to be between 0 – 45 MW. In this context, high LCG could be chosen with in a range of 240 – 300 MW. Similarly the subsets for other variables can also be linguistically defined.

5.3 Fuzzy *IF-Then* Rules

If fuzzy logic based approach decisions are made by forming a series of rules using if-then statements that relate the input variables to the output variables, then for each rule the *IF* (condition) is antecedent to the *Then* (consequence) of each rule. Each rule in general can be represented in the following manner: *IF* (antecedent) *Then* (consequence)

Now, the load capacity of the generator, start up cost and incremental cost are considered as input variables and production cost is treated as the output variable. This relation between the input variables and output variables is given as:

Production Cost = {Load Capacity of Generator} and {Incremental Cost} and {Start UP Cost}.

In Fuzzy Set notation, it is written as

$$PRC = LCG \cap IC \cap SUP$$

Hence the Membership Function of the Production Cost is

$$\mu PRC = \mu LCG \cap \mu IC \cap \mu SUP$$

or

$$\mu PRC = \min(\mu LCG, \mu IC, \mu SUP)$$

where μLCG, μIC, and μSUP are the memberships of load capacity of generator, incremental cost and start up cost respectively [5].

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 Figs 1-4, a total of total of 45 rules can be composed (since there are 5 subsets for load capacity of the generator, 3 subsets for Incremental cost, 3 subsets for Start up cost (5*3*3 = 45)). Fig.5 shows the relationship between some rules and can be applied to all 45.

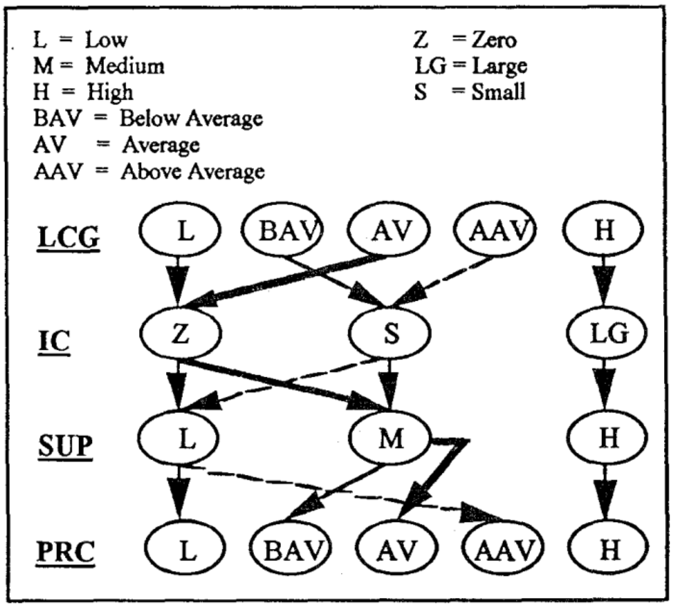

Fig 5: Relating Input variables to Output

The rules can be composed in the following manner:

If Load capacity of the generator is (.) and
Incremenatal cost is (.) and
Start up cost is (.)
Then Production cost is (.)

5.4 Defuzzification process

One of the most commonly used methods of defuzzification
is the centroid or centre of gravity method. Using this method,
the production cost is obtained as follows [3],

$$PRC=\sum_{i=1}^{n} [\mu(PRC)_i * (PRC)_i] / [\sum_{i=1}^{n} \mu(PRC)_i] \quad \ldots(7)$$

where,
$\mu(PRC)_i$ is the membership value of the clipped output
PRC_i is the quantitative value of the clipped output
n is the number of the points corresponding to quantitative
value of the output. Fig.6 illustrates the overview of Fuzzy logic based development.

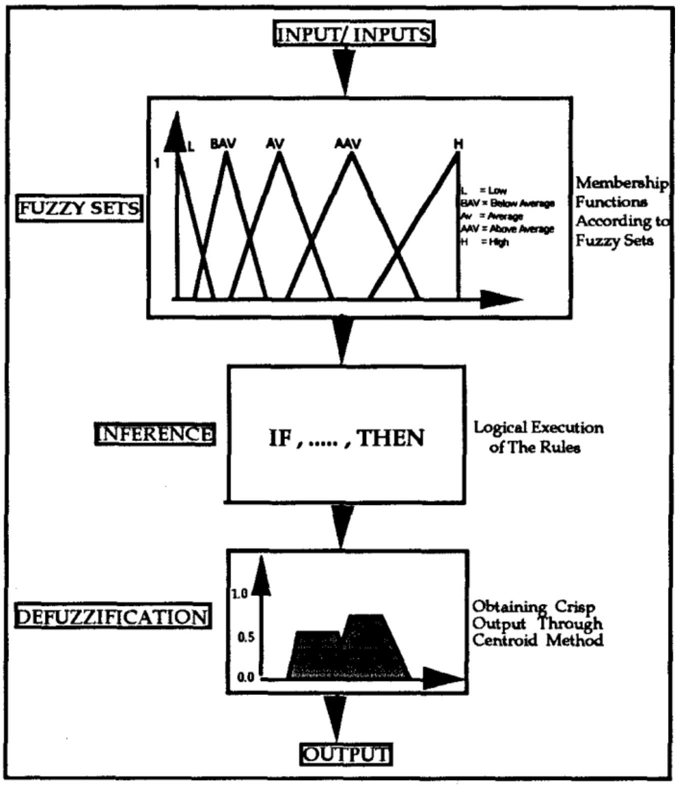

Fig 6:Overview of Fuzzy Logic based development.

5.5 Simulation Result of Test system with Fuzzy Logic Algorithm

A PC based code was developed to compute the values of the output for different input values. It calculates the crisp values of the outputs for different inputs [8], these results are presented in Table 4.The complete set of results of this approach for a given load pattern are calculated and compared with the conventional Priority list method results. The cost comparison is indicated between the fuzzy logic and priority list method in the cost comparison table.

Table 4
Result for Test system with Fuzzy Logic based Approach

Demand	**Hour**	**Unit Generation in MW**				**Total Cost in Rs**
		1	2	3	4	
450	1	0	150	300	0	9362.5
530	2	0	230	300	0	10862.5
600	3	0	250	300	50	11047
540	4	0	240	300	0	10862.5
400	5	0	100	300	0	8208
280	6	0	0	280	0	4885.7
290	7	0	0	290	0	4885.7
500	8	0	200	300	0	9554.4
Cumulative cost in Indian Rupees (INR) 69668.3						

6. Cost Comparison

Table 5
Cost comparison of Fuzzy Logic & Priority List based approach for UCP

Priority List Method :	**Fuzzy Logic Method :**
2,16,720 INR/Day	2,09,005 INR/Day

Priority list based method uses power output limits at their maximum value for selected generating units. Fuzzy logic based approach to UCP operates each generating unit within its minimum and maximum power operating limits and resulted the operating cost in INR as 2,09,005 INR/Day.
In this paper totally 8 periods are considered for the load demand, in which each period consisting of three hours, thus calculating for a period of 24 hours

7. Conclusion

This paper examined the feasibility of applying Fuzzy Logic & Priority List Method in solving short-term thermal unit commitment. An effective, robust UC solution is a necessary contribution to the operating On/Off plans of the generating units. Unit commitment is a problem where ambiguity exists and such problems can be easily addressed to using fuzzy logic. As the size of the system grows and more complicated constraints are imposed, it is often insufficient to rely on human intuition to achieve the optimal solution. Hence, fuzzy logic is implemented for solving the Unit Commitment problem. It was demonstrated that Unit Commitment problem can be solved using fuzzy logic and this method can be applied to any no. of units, each with different operating costs.

From this approach, it can be concluded that the outcomes are easily understood in terms of the logical representation of the rules. For costs obtained by conventional Priority list, the ON/OFF states of the units have been considered in order to meet to the load demand whereas, for cost obtained by fuzzy logic technique, only the ON state of units have been assumed. After assessment, it is observed that both, costs obtained and computation time by conventional Priority List method is more as compared to Fuzzy logic. Hence, Fuzzy logic is found to be very efficient as compared to conventional Priority List Method.

8. References

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