Fuzzy Logic Approach for Unit Commitment of Load Dispatching

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Abstract: With the rapidly changing technologies in the power industry, new power references addressing new technologies are coming to the market. So there is an urgent need to keep track of international experiences and actions taking place in the field of modern unit-commitment (UC) problem. in this paper A work on fuzzy logic based technique for solving the problem of unit commitment in any electric utility is presented in this paper. Fuzzy logic is selected because of its capability of qualitative representation of the results in terms of input variables. The most economic operating schedule and all the feasible schedules and their respective cost of operation are estimated. A four-unit system is considered as an example and the above mentioned values were computed.

Keywords: Fuzzy Logic, Load Dispatching, Unit Characteristics

I Introduction

People use less electricity on saturdays than on weekdays, less on sundays than on saturdays, and at a lower rate between midnight and about 7: 00 a.m. Than during the day. Faced with this situation, electric utilities usually have fewer steam-electric generating units in service during lighter load periods [1, 2]. The problem is to determine which, if any, generating units should be removed from service to get maximum economy. If the generating units were all the same, the problem would be rather simple. Generally, however, the generating units have been placed in service over a long period of time, perhaps 20 to 30 years. Usually there are no more than two identical units on a utility's power system [3].

If sufficient generation to meet the peak is kept on line throughout the day, it is possible that some of the units will be operating near their minimum generating limit during the off-peak period. The problem confronting the system operator is to determine which units should be taken offline and for how long.

The load variation is continuous and the load must me met with the available resources economically. This is done by committing (switching ON) and de-committing (switching OFF) of the units in the power station. By only running the most economic units, the load can be supplied by those units operating closer to their best efficiency. Thus committing the correct number and kind of units such that the load is met at least operating cost is the problem of unit commitment [4].

II General Background and Concepts

Various approaches have been developed to solve the optimal UC problem. These approaches have ranged from highly complex and theoretically complicated methods to simple rule-of-thumb methods. The scope of operations scheduling problem will vary strongly from utility to utility depending on their mix of units and particular operating constraints [5–7].

The economic consequences of operation scheduling are very important. Since fuel cost is a major cost component, reducing the fuel cost by little as 0.5% can result in savings of millions of dollars per year for large utilities [8, 9].

A very important task in the operation of a power system concerns the optimal UC considering technical and economical constraints over a long planning horizon up to one year. The solution of the exact long-term UC [10, 11] is not possible due to exorbitant computing time and, on the other hand, the extrapolation of short-term UC to long-term period is inadequate because too many constraints are neglected such as maintenance time and price increases, etc.

The problem of unit commitment is difficult to solve because of the uncertainties associated with it. For example, the availability of fuels, imprecise load forecasts, variable costs affected by the loading of generating units of different fuels or water rates, and losses caused by reactive flows are some of the unpredictable issues. Such problems of uncertainties and inconsistencies pose a problem to the economic operation of the utility under consideration. Further, there are different constraints that are associated with the unit commitment problem [12, 13]. They are discussed in detail below

Power Generation - Load Balance

Generation should meet the load demand and the spinning reserve plus transmission losses [**?**]. In this work, transmission losses are neglected.

$$P_i = PD + \text{Spinning Reserve} \qquad (1)$$

where P_i is the real power generation of i^{th} plant and PD is the total power demand.

Operating Constraint

Operating constraint is the real power limits on the generator output. The generator output should not exceed the specified limits in the problem. i.e.,

$$P_{i-min} = P_i = P_{i-max} \tag{2}$$

where P_{i-min} is the lower limit of the real power output of i^{th} unit and P_{i-max}, the upper limit of the real power output of the i^{th} unit.

Minimum Up Time

Once the unit is running, it should not be turned off immediately.

Minimum Down Time

Once the unit is decommitted, there is a minimum time before it can be recommitted.

Spinning Reserve

Spinning reserve is the term used to describe the total amount of generation available from all units synchronized on the system minus the present load plus losses being supplied. Spinning reserve must be carried so that the loss of one or more units does not cause too far a drop in system frequency.

Start Up Cost

A simplified time dependent start up cost is taken as follows hot start up cost if down time is less than or equal to cold start hours start up cost = cold start cost, otherwise.

Shut Down Cost

The shut down cost has been taken equal to zero for every unit.

III Fuzzy Sets Associated with Unit Commitment

After the identification of the variables associated with unit commitment, the fuzzy set associated must be formulated. This forms the second step in fuzzy based solving of a problem [14, 15]. The selected fuzzy sets are normalized between 0 and 1. The fuzzy sets associated with the four fuzzy variables are given below:

1. Load capacity of generator (LCG):
LCG(MW) = {Low(low), Below average(bavg), Average(avg), Above average(aavg), High(high)}

2. Incremental Cost (IC):
IC(₹) = {Zero(zero), Small(small), Large(large)}

3. Start-up Cost (SUP):
SUP(₹) = {Low(low), Medium(med), High(high)}

4. Production Cost (PRC):
PRC(₹) = {Low(low), Below average(bavg), Average(avg), Above average(aavg), High(high)}

Based on the fuzzy sets, the membership functions are chosen for the fuzzy variables (Figure 1 through 4)

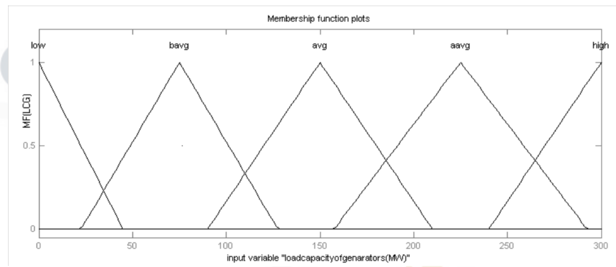

Figure 1: Membership Function of Load Capacity of Generator

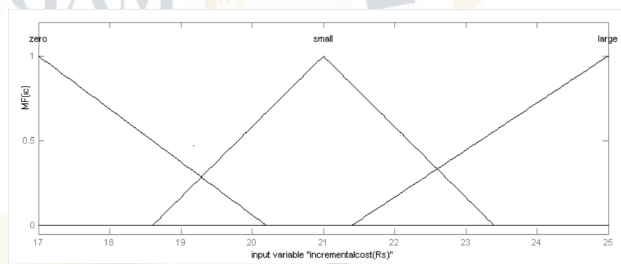

Figure 2: Membership Function of Incremental Cost

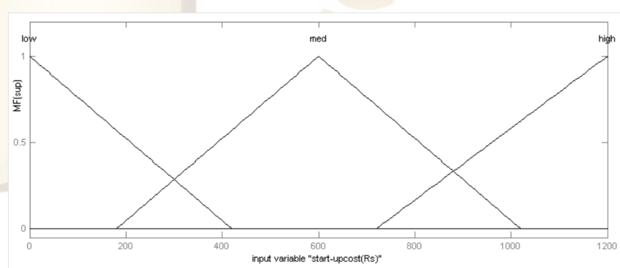

Figure 3: Membership Function of Start-up Cost

IV Fuzzy Rules

In a fuzzy logic based approach, decisions are made based on a set of If-Then rules relating the input and output variables. The If(condition) is an antecedent to the Then(consequence) of each rule [16]. The relation between input and output

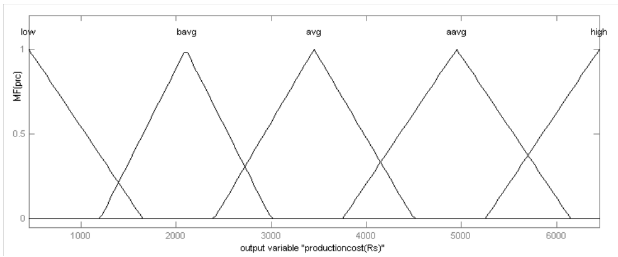

Figure 4: Membership Function of Production Cost

variables is given as follows:
Production Cost = {Load capacity of generator} and {Incremental cost} and {Start-up cost}
In fuzzy set notation this can be written as:

$$\mathrm{PRC} = \mathrm{LCG} \cap \mathrm{IC} \cap \mathrm{SUP} \tag{3}$$

Using the above notation, fuzzy rules are written associating fuzzy input variables with fuzzy output variable. The total number of rules that can be generated is 45 (since there are 5 subsets for load capacity of generator, 3 for incremental cost and 3 for start-up cost) [17, 18]. The rules are composed in the following manner:
If Load capacity of generator is (*) *and*
Incremental cost is (*) *and*
Start-up cost is (*) *Then*
Production cost is (*)
For example the first rule in the rule base consisting of the 45 rules is
If Load capacity of generator is low *and*
Incremental cost is zero *and* Start-up cost is low
Then Production cost is low.
After relating the input variables to the output variable, the fuzzy result must be defuzzified through a defuzzification process to get crisp numerical values. One of the most commonly used defuzzification method is centroid method. In this work the centroid method is used for defuzzification. In this, the production cost is obtained as:

$$\text{Production Cost} = \frac{\sum_{i=1}^{n} \mu(\mathrm{PRC})_i * \mathrm{PRC}_i}{\sum_{i=1}^{n} \mu(\mathrm{PRC})_i} \tag{4}$$

where, $\mu(\mathrm{PRC})_i$ is the membership value of the clipped output; $\mathrm{PRC})_i$, the quantitative value of the clipped output; and n is the number of the points corresponding to the quantitative value of the output.

V Example Problem and Simulation Results

The above-mentioned approach is applied to a sample system [1] comprised of four generating units whose characteristics and load patterns are listed in Table 1 and 2.

Table 1: Unit Characteristics

Unit No.	**Max (MW)**	**Min (MW)**	**Inc. Cost (₹ /MWh)**	**Start -up (₹)**	**No Load Cost (₹)**
1	80	25	21.88	350	214.00
2	250	60	19.00	400	586.62
3	300	75	18.46	1100	685.74
4	60	20	24.80	0.02	253.00

Table 2: Load Pattern

Hour	1	2	3	4
Load	450	530	600	540
Hour	5	6	7	8
Load	400	280	290	500

A MATLAB code developed for solving fuzzy logic based unit commitment problem is used to solve the sample problem. The results obtained using the fuzzy logic approach is tabulated against that obtained using the dynamic programming in table 3.

Table 3: Results

Load	**Optimal Combination**	**Dynamic Approach**	**Fuzzy Logic Approach**
450	0110	10718.36	8162.86
530	0110	10658.36	10892.50
600	0111	12460.36	13089.32
540	0110	10838.36	10892.50
400	0110	8318.36	8096.55
280	0010	5583.54	5568.17
290	0010	5758.14	5933.30
500	0110	10518.36	–
	1111	–	10167.44
Total Cost of Operation (₹)		**74853.86**	**72812.63**

A comparison of the results in Table 3 indicates that fuzzy logic approach is comparable to the dynamic programming approach. Further, fuzzy logic gives a lesser operating cost taking into account the start-up cost at the time of calculation unlike dynamic programming where the start-up cost is taken as constant and is added to production cost to obtain the total cost.

VI Conclusions

Unit commitment is a problem where ambiguity exists and such problems can be easily addressed to using fuzzy logic. The method used to solve the sample problem shown above can be applied to a problem with any number of units, each with entirely different costs and other parameters. It is also clear that the output can be explained easily in terms of the logical representation of the rules.

This paper gives an overview of the concept of UC problem, with practical requirements, the historical events, the present state, and techniques. The citations listed provide a rep-resentative sample of current engineering thinking pertaining to the next generation UC problem.

REFERENCES

[1] J. B. McClure and A. G. Mellor, "The effect of unit size on steam-electric generating station design," *Electrical Engineering*, vol. 71, no. 2, pp. 174–179, Feb 1952. [Online]. Available: https://doi.org/10.1109/EE.1952.6437961

[2] G. Montero, R. Pulido, C. Pineda, and R. Rivero, "Ecotaxes and their impact in the cost of steam and electric energy generated by a steam turbine system," *Energy*, vol. 31, no. 15, pp. 3391–3400, 2006, eCOS 2004 - 17th International Conference on Efficiency, Costs, Optimization, Simulation, and Environmental Impact of Energy on Process Systems. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0360544206000909

[3] A. J. Wood and W. B. F., *Power generation operation and control*, 2nd ed., John Wiley & Sons, 2009,.

[4] E. Allen and M. Ilić, *Unit Commitment for an Individual Power Producer*. London: Springer London, 1999, pp. 23–29. [Online]. Available: https://doi.org/10.1007/978-1-4471-0571-8_5

[5] S. Saurabh and M. Ahmed, "Optimization method for unit commitment in high-level wind generation and solar power," in *Advances in Communication, Devices and Networking*, R. Bera, S. K. Sarkar, and S. Chakraborty, Eds. Singapore: Springer Singapore, 2018, pp. 143–149.

[6] Y. Huang, P. M. Pardalos, and Q. P. Zheng, *Deterministic Unit Commitment Models and Algorithms*. Boston, MA: Springer US, 2017, pp. 11–47. [Online]. Available: https://doi.org/10.1007/978-1-4939-6768-1_2

[7] Z. Li, W. Wu, J. Wang, B. Zhang, and T. Zheng, "Transmission-constrained unit commitment considering combined electricity and district heating networks," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 480–492, April 2016. [Online]. Available: https://doi.org/10.1109/TSTE.2015.2500571

[8] Y. Xu, Z. Wang, W. Sun, S. Chen, Y. Wu, and B. Zhao, "Unit commitment model considering nuclear power plant load following," in *2011 International Conference on Advanced Power System Automation and Protection*, vol. 3, Oct 2011, pp. 1828–1832. [Online]. Available: https://doi.org/10.1109/APAP.2011.6180663

[9] B. Lu and M. Shahidehpour, "Unit commitment with flexible generating units," *IEEE Transactions on Power Systems*, vol. 20, no. 2, pp. 1022–1034, May 2005. [Online]. Available: https://doi.org/10.1109/TPWRS.2004.840411

[10] Y. Zhang, X. Han, M. Yang, B. Xu, Y. Zhao, and H. Zhai, "Adaptive robust unit commitment considering distributional uncertainty," *International Journal of Electrical Power & Energy Systems*, vol. 104, pp. 635–644, 2019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0142061518315254

[11] G. Morales-España, Álvaro Lorca, and M. M. de Weerdt, "Robust unit commitment with dispatchable wind power," *Electric Power Systems Research*, vol. 155, pp. 58–66, 2018. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378779617304005

[12] T. Li and M. Shahidehpour, "Dynamic ramping in unit commitment," *IEEE Transactions on Power Systems*, vol. 22, no. 3, pp. 1379–1381, Aug 2007. [Online]. Available: https://doi.org/10.1109/TPWRS.2007.901453

[13] Y. Xu, Z. Wang, W. Sun, S. Chen, Y. Wu, and B. Zhao, "Unit commitment model considering nuclear power plant load following," in *2011 International Conference on Advanced Power System Automation and Protection*, vol. 3, Oct 2011, pp. 1828–1832. [Online]. Available: https://doi.org/10.1109/APAP.2011.6180663

[14] S. C. Pandian and K. Duraiswamy, "Fuzzy logic implementation for solving the unit commitment problem," in *2004 International Conference on Power System Technology, 2004. PowerCon 2004.*, vol. 1, Nov 2004, pp. 413–418 Vol.1. [Online]. Available: https://doi.org/10.1109/ICPST.2004.1460030

[15] M. M. Lotfi and S. F. Ghaderi, "A compromised multi-objective solution using fuzzy mixed integer goal programming for market-based short-term unit commitment problem," *Journal of the Operational Research Society*, vol. 65, no. 1, pp. 23–36, 2014. [Online]. Available: https://doi.org/10.1057/jors.2012.172

[16] Y. Yang and M. Singhal, "Fuzzy functional dependencies and fuzzy association rules," in *DataWarehousing and Knowledge Discovery*, M. Mohania and A. M. Tjoa, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 1999, pp. 229–240.

[17] S. Saneifard, N. R. Prasad, and H. A. Smolleck, "A fuzzy logic approach to unit commitment," *IEEE Transactions on Power Systems*, vol. 12, no. 2, pp. 988–995, May 1997. [Online]. Available: https://doi.org/10.1109/59.589804

[18] C.-C. Su and Y.-Y. Hsu, "Fuzzy dynamic programming: an application to unit commitment," *IEEE Transactions on Power Systems*, vol. 6, no. 3, pp. 1231–1237, Aug 1991. [Online]. Available: https://doi.org/10.1109/59.119271