ISSN: 1411-4674

Fuzzy Logic System For Optimization of Thermal Generator Unit Operation On Peak Load Conditions

Nadjamuddin Harun and Faizal A. Samman*)

ABSTRACT

This paper proposes the application of *fuzzy logic system* as a decision support system to optimize economic operations of thermal generating systems on peak load conditions. This investigation takes a case study on scheduling thermal generating units operation in South Sulawesi interconnected power system. Fuzzy logic system used in this paper has *single-input multi-output* structure, where peak load information as an input variable, and 5 power generations of thermal generator units respectively as output variables. Peak load information from load centers is obtained and processed by five fuzzy implication rules. Fuzzy optimizer provides decisions on how much power should be release by thermal generating units to meet optimal load-power balancing. Optimization results show that fuzzy logic optimizer could give a significant efficiency on operational costs of thermal generator units in South Sulawesi power system.

INTRODUCTION

Power System Interconnection, which has increasingly grown, has not had optimal scheduling on power generations. Power system operation still uses classical generating starting from generator having smaller operational cost until ones having larger costs. That method has been classical approach since it has a number of disadvantages. Therefore, an effort to search for new better methods to optimize operational costs of power scheduling in South Sulawesi System is presented in this manuscript.

There are two main problems that should be solved in electric power scheduling. Firstly, *unit commitment,* which determines *shut-down* and *start-up* schedules of generator units. This is important to minimize fuel cost expenditures. Secondly, *economic dispatch*, which is an operation to determine power supply by every generator unit. This is important to minimize generating operation costs.

In accordance with the generating scheduling, it is assumed that electrical load for every hour has been determined. In initial condition, before all generator units startup, the short-term load values have been predetermined through estimation.

[1]Dept. of Electrical Engineering – The University of Hasanuddin at Makassar
E-mail: faizalas@engineer.com

And deviations from new estimations will be known after concurrent load values have been measured. Those deviations occur because of large variety of load demanding time-by-time. In a large power system, those deviations will cause significantly decreasing efficient operational costs. Thus, the problem faced is the execution of uncertainty unit commitment operation.

In general, techniques to solve generating scheduling problems have been assessed using several methods. Methods that have been utilized, i.e. Dynamic Programming, Linear Programming, Integer Programming, Lagrange Method, *Brand and Bound* method, Artificial Intelligent Methods including Artificial Neural Networks. Besides those methods, *fuzzy logicsystems* [1] has been widely developed and utilized.

Fuzzy logic approach is on its way and is developed to handle several engineering problems that have not solved properly [2]. Therefore, its application in power systems having uncertainty information for examples load deviations can handle the real problem [3]. Hopefully this technique can also make optimal decisions to distribute power generating charged to all generator units properly and efficiently [4]. Fuzzy logic application would be able to give better contributions in science and technology development especially to make regeneration of new concepts and methodologies in economic operation of power systems. Indeed, energy efficiency by applying fuzzy method will be useful to guarantee sustainable national development in Indonesia.

FUZZY LOGIC

Fuzzy Logic Controllers (FLC) have been extensively utilized in many fields of engineering applications. As one of the intelligent control systems, FLC has been used in some electronic equipment. For instances, it has been used in rice cooker to determine when stop cooking, air-conditioning systems to prevent unwanted temperature fluctuations, single button control for washing machines, automatic motor-control for vacuum cleaners with recognition of surface condition and degree of soiling, etc.

In automotive, fuzzy logic has been applied to automatic transmission controller, automobile cruise control, optimized fuel-consumption, efficient and stable control of car-engines as well as anti-lock brake systems, etc. In power systems, fuzzy logic has potential application in optimizing cost for power generating, increasing the quality actions of the relays in power system protection.

The most application of fuzzy logic is in control engineering applications [1]. As an alternative and non-conventional control methodology, fuzzy logic controller (FLC) emerges not to replace all conventional control system, but to complement to improve efficiency and optimized function of industrial control applications. There are three basic operations in FLC as follow:

1. Fuzzification process. This process fuzzifies the crisp inputs based on their related membership function form. The membership functions are performed by fuzzy sets.
2. Fuzzy inference process. This process executes fuzzification outputs to produce inferences values based on their fuzzy implication rules. This process also aggregates all inference values to produce fuzzy implication outputs.
3. Defuzzification process. This process evaluated fuzzy output to yield crisp output based on their fuzzy consequence values.

FUZZY SETS

Classical set theory is based on bivalent logic where a number or object is either a member of a set or not. For example, an object is either black or white. In theoretic terms, it says that the same object cannot simultaneously be a member of a set and its complement. With fuzzy set theory, an object can be a member of multiple sets with a different degree of membership in each set. We might be able to allow the same object be considered "small" to some degree and be considered "large" to another degree. The degree of membership of an object in a fuzzy set expresses the degree of compatibility of the object with the linguistic term represented by the fuzzy membership functions. Figure 1 shows the fuzzy sets of five linguistic term: very small (VS), small (S), medium (M), large (L) and very large (VL). In fuzzy logic the overlap between fuzzy membership function (fuzzy set of a linguistic term) is possible.

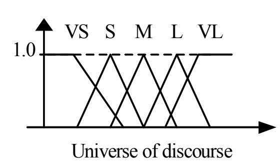

Figure 1: Membership functions for 5 fuzzy terms.

FUZZY IMPLICATION RULES

Fuzzy logic is built from accumulating consequences of some implication rules then the resulting accumulation is used to decide an action. The fundamental difference between classical inferences and fuzzy inferences is in the range of their truth-values. While each classical proposition is required to be either true or false, the truth or falsity of a fuzzy proposition is a matter of degree. The difference between the range of the truth-values of classical and fuzzy propositions is that fuzzy inference rules that seem to be conflicting can be true at the same time.

Consider the following rules:

Rule 1: IF temperature is cold THEN heating on

Rule 2: IF temperature is normal THEN heating off

In classical set theory a temperature is either cold or normal, but never both. Therefore only one of the before mentioned rules is applied on the control of the heating. In fuzzy set theory a crisp value can be a member of multiple sets. A certain temperature can be considered cold to a certain degree and be considered normal to another degree. Both rules will then apply, because the precondition for both rules is true to a certain degree.

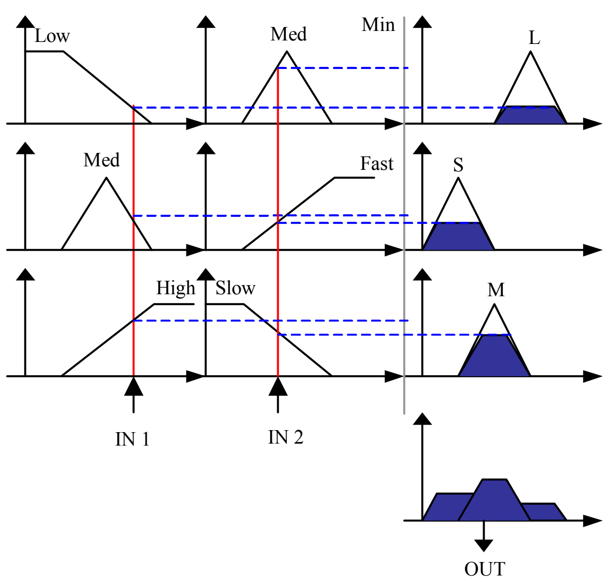

Figure 2: Fuzzy inference mechanism of Mamdani method with three fuzzy rules.

Some information or knowledge base is required to build fuzzy implication rules. Proper implication rules affect the performance of the FLC. There are several fuzzy inference methods that are possibly used. Among others, Mamdani method and Takagi-Sugeno method are commonly used in practices. In this paper, Mamdani method is utilized to build FLC. Figure 2 shows an example of Mamdani inference method with three fuzzy rules.

Example of 3 fuzzy implication rules based on figure 2:

1. IF X is Low AND Y is Intermediate THEN Z is Large
2. IF X is Medium AND Y is Fast THEN Z is Small
3. IF X is High AND Y is Slow THEN Z is Medium

DEFUZZIFICATION

All consequences of fuzzy rules are aggregated. Thus the output of the FLC is a fuzzy set that represents the possible distribution of the control action. For practical use, a crisp control output is usually required. Therefore a defuzzification interface is necessary to convert the inferred fuzzy control action into a non-fuzzy (crisp) value. Among the suggested defuzzification strategies, the center of gravity method is the most commonly used.

UNIT COMMITMENT AND POWER SYSTEM OPERATIONS

Unit commitment could be stated as optimal decision making processes in scheduling start-up and shutdown of generator units, in order to minimize operation costs during power reserve still adequate [5, 6, 7]. Problem in unit commitment is unsolved load deviation problems in scheduling power system operation. Hence, the following assumptions are proposed:

- System Load in every observation is constant and is known (obtained from load estimation).
- Transmission losses (energy losses) are neglected.
- Thermal power reserve has been predetermined.

Based on those assumptions, then unit commitment can be formulated as follows:

Objektive Function: Minimize (fuel cost + start-up cost)

$$\text{Cost} = \sum_{H=1}^{N}\sum_{i=1}^{J}\left(\text{FCost}_i\{G_i(H)\} + \text{SCost}_i\right),\ H = 1,2,..,N \qquad (2)$$

Cost = Total cost in all observation periods.
FCost_i = Fuel Cost required to generate power as G_i by i^{th} generator on H hour.
SCost_i = Start-up Cost start-up for i^{th} generator.
N dan J = Total of observation period and generator unit.

With constraint then load and power generating balancing:

$$\sum_{i=1}^{J} G_i(H) = L(H) \qquad H = 1,2,..,N \qquad (3)$$

$G_i(H)$ = Power generated by i^{th} unit.,at hour H.
L(H) = Load at hour H.

The generating capacity is,

$$P_{min} \le P_{iH} \le P_{max} \qquad H = 1,2,..,N \qquad (4)$$

P_{min} = Minimum generating capacity for i^{th} unit.
P_{max} = Maximum generating capacity for i^{th} unit.
P_{iH} = Power generated by i^{th} unit.,at hour H.

And the margin of *spinning reserve* is,

$$\sum_{i=1}^{J} P_{max} S_{iH} \ge L(H) + R(H) \quad ,H = 1,2,..,N \qquad (5)$$

S_{iH} = I^{th} unit state (ON atau OFF)
R(H) = Power reserve permitted at hour H
L(H) = Load at hour H.

Based on objective function of unit commitment, then for any condition, fuel cost Fcost(H,J) should be predetermined to calculate total costs. Fuel cost is determined through economic operation of on-line units in J condition on hour H. Determination of fuel cost is an estimation process itself, which is assessed on economic operation of power systems [8].

Objective Function: Minimize Fuel Cost:

$$Cost(H,J) = \sum_{i=1}^{J} F_i(G_i) \qquad (6)$$

$F_i(G_i)$= Fuel cost i^{th} unit commonly represented in quadratic equation as follow:

$$F_i(G_i) = a_i(G_i)^2 + b_i G_i + c_i \qquad (7)$$

Constraints:

(1) $\sum_{i=1}^{J} G_i(H) = L(H)$ (2) $P_{min} \leq P_{iH} \leq P_{max}$ (8)

Solution of the problem can be found by using Lagrange method [5, 9].

OPERATION OF THERMAL GENERATING UNITS IN SOUTH SULAWESI

Operational costs optimization of thermal generator is intended to obtained optimal combinations of thermal generator units in order to minimize fuel costs. Thus economic operation of power systems will be maintained.

Thermal generators that will be optimized in this investigations are operated by PT. PLN (Persero) Regional VIII South Sulawesi Interconnected Power System.

In this investigations, thermal generator interconnected into 30 kV, 70 kV dan 150 kV transmissions lines will be analyzed. Non-government thermal generator is not considered because there are non-technical components in the “Contract”, for examples, transmission costs, fixed operational costs, daily operational costs, generator costs per unit, and so on.

Data required for optimized thermal generators are,

1. Capacity data for thermal generator.
2. Input-output data for thermal generator.
3. Load flow data in South Sulawesi power system.
4. Daily load data in South Sulawesi power system.

Capacity data of thermal generator in Interconnected South Sulawesi power system is shown in Table 1. Input-output Data and input-output equation as well as generating cost thermal equation are shown Table 2 and 3 respectively. Table 4 exhibits Fuel Cost Input-Output equivalent equation and Incremental Fuel Cost.

From generator conditions shown in Table 1, it looks that there four generator units that can not be utilized by the time optimal scheduling will be conducted in the South Sulawesi Power System.

Table 1: Capacities of Thermal generator South Sulawesi.

Branch Sector	Generator	# Unit	Power (MW)		Note
			Terpsg	Mampu	
Gen. Tello 30 kV	PLTU Unit 1	1	12.50	0.00	NO
	PLTU Unit 2	1	12.50	11.50	--
	PLTG Westcan	1	14.47	12.50	--
	PLTG Alsthom 1	1	21.35	15.00	--
	PLTD Mirrless	2	5.68	3.00	--
Gen. Tello 70 kV	PLTG Alsthom 2	1	20.10	0.00	NO
Gen. Tello 150 kV	PLTD Mitsubushi 1	1	12.60	10.50	--
	PLTD Mitsubushi 2	1	12.60	0.00	IM
	PLTD SWD 1	1	12.40	0.00	OH
	PLTD SWD 2	1	12.40	10.50	--
	PLTG GE 1	1	33.40	33.00	--
	PLTG GE 2	1	33.40	33.00	--

Note: NO = Not-ready to Operate
IM = In Maintenance,
OH = OverHaul.

Table 2: Input-output data of Thermal generator in South Sulawesi Power System.

Generator	Input			Output (MW)
	NHR	Ltr/Jam	Rp/Jam	
PLTU Unit 2	0.446	1282.25	512900	2.875
	0.414	2380.5	952200	5.75
	0.398	3432.75	1373100	8.625
	0.375	4312.5	1725000	11.5
PLTG Westcan	0.878	2743.75	1646250	3.125
	0.68	4250	2550000	6.25
	0.49	4593.75	2756250	9.375
	0.452	5650	3390000	12.5
PLTG Alsthom 1	0.757	2838.75	1703250	3.75
	0.52	3900	2340000	7.5
	0.442	4972.5	2983500	11.25
	0.427	6405	3843000	15
PLTG GE 1	0.585	4826.25	2895750	8.25
	0.42	6930	4158000	16.5
	0.359	8885.25	5331150	24.75
	0.332	10956	6573600	33
PLTG GE 2	0.559	4611.75	2767050	8.25
	0.406	6699	4019400	16.5
	0.357	8835.75	5301450	24.75
	0.329	10857	6514200	33
PLTD Mitsubishi 1 MFO	0.291	763.875	305550	2.625
	0.281	1475.25	590100	5.25
	0.225	1771.88	708752	7.875
	0.265	2782.5	1113000	10.5
PLTD SWD 2 MFO	0.302	792.75	317100	2.625
	0.292	1533	613200	5.25
	0.231	1819.13	727652	7.875
	0.264	2772	1108800	10.5
PLTD Mirrless	0.351	131.625	52650	0.375
	0.291	218.25	87300	0.75
	0.273	307.125	122850	1.125
	0.278	417	166800	1.5

Table 3: Input-Output equation and Cost Thermal generator equation.

No	Unit Generator	Input-Output Equation (H_i) (Litre/Hour)	Fuel Cost Equation (F_i) (Rp/Hour)	Incremental Fuel Cost Equation (IFC) (Rp/MWh)
1	PLTU 2	$43.125 + 447.8\ P – 6.6087\ P^2$	$17250 + 179120\ P – 2643.5\ P^2$	$179120 – 5287\ P$
2	PLTG Westcan	$1480.1 + 470.2\ P – 11.5\ P^2$	$888060 + 282120\ P – 6900\ P^2$	$282120 – 13800\ P$
3	PLTG Alsthom 1	$2050.3 + 190.1\ P + 6.6\ P^2$	$1230180 + 114060\ P + 3960\ P^2$	$114060 + 7920\ P$
4	PLTG GE 1	$2772 + 251.6\ P – 0.1\ P^2$	$1663200 + 150960\ P – 60\ P^2$	$150960 – 120\ P$
5	PLTG GE 2	$2450.3 + 263\ P – 0.2\ P^2$	$1470180 + 157800\ P – 120\ P^2$	$157800 – 240\ P$
6	PLTD Mitsubishi 1 MFO	$484.3438 + 99.4807\ P + 10.8588\ P^2$	$193738 + 39792.3\ P + 4343.52\ P^2$	$39792.3 + 8687.04\ P$
7	PLTD SWD 2 MFO	$439.0250 + 135.8526\ P + 7.7141\ P^2$	$175610 + 54341\ P + 3085.64\ P^2$	$54341 + 6171.28\ P$
8	PLTD Mirrless	$61.3125 + 174.5\ P + 41.33P^2$	$24525 + 69800\ P + 16532\ P^2$	$69800 +33063\ P$

Table 4: Input-Output Equivalent Equation of Fuel Cost and Incremental Fuel Cost.

No	Bus of Generator	Input-Output Equivalent Equation (Rp/Jam)	IFC Equivalent Equation (Rp/MWh)
1	Tello 150 kV PLTG	$3198360 + 153240\ P – 40\ P^2$	$153240 – 80\ P$
2	Tello 150 kV PLTD	$362225.2 + 48298.32\ P + 40\ P^2$	$48298.32 – 3608.09\ P$
3	Tello 30 kV	$381800.1 + 359755\ P – 4757.38\ P^2$	$359755 – 9514.76\ P$

Based on load flow analysis, then power transmission losses coefficient is obtained, i.e. B_{mn} with constraint $1 \leq m \leq 6$, and $1 \leq n \leq 6$ for 6 power plant. Data in Table 5 is obtained by using computer program for peak load condition.

Table 5: Transmissions lost coefficient in South Sulawesi Power System.

m\n	1	2	3	4	5	6
1	0.0462	-0.0059	-0.0058	-0.0056	0.0150	-0.0071
2	-0.0059	0.0090	0.0089	0.0087	-0.0078	0.0100
3	-0.0058	0.0089	0.0088	0.0086	-0.0079	0.0093
4	-0.0056	0.0087	0.0086	0.0084	-0.0077	0.0092
5	0.0150	-0.0078	-0.0079	-0.0077	0.0605	-0.0050
6	-0.0071	0.0100	0.0093	0.0092	-0.0050	0.0184

Besides power transmission losses, daily average load is also required. Electric load value is one of the constraints to obtain economic power scheduling from active powers that should be generated by all thermal generator units. Daily load data for South Sulawesi power system is not presented in this paper

Based on load curve information and calculation of transmission losses on peak load condition then: system losses = 11.01 MW. Maximum peak load is added to system losses = 333.30 MW. And average load = 0.5(180.35+216.65) = 198.5 MW.

From those data, load range can be calculated is set become input variables in fuzzy logic controller. Maximum load of thermal generator can be obtained by subtracting maximum peak load by average load of the system. Minimum load can be obtained from data at PLN about generator operation while minimum peak load occurs. Maximum load of thermal generator = 333.30–(198.5+ 11.01)=123.79 MW, and the minimum load is 90.3 MW.

From the optimization using Lagrange method, it seems that unit GE 2, Mitsubishi 1, and SWD 2 should always be generated in maximum power output when peak load occurs. Then no need to use fuzzy logic controller system for those three generator units.

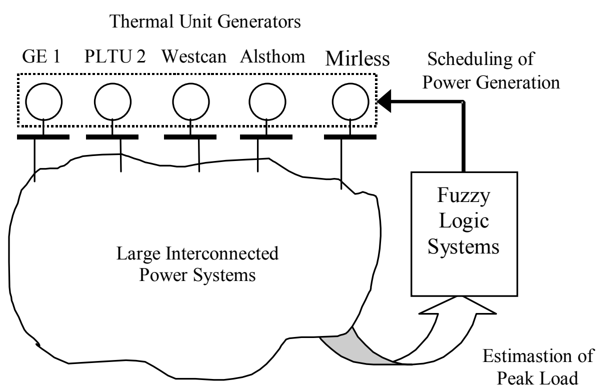

Figure 3: Generating scheduling of generator units.

FUZZY LOGIC APPLICATION IN ECONOMIC OPERATION OF POWER SYSTEM

Unit commitment and economic generation of power system using Lagrange methods have not been fully tackle economic problems in power system operation. Therefore, this paper proposes the use of fuzzy logic controller to handle the unsolved problems in power system operations.

Membership function of input variable (electric load) is shown in Figure 4. Table 6 shows entry points of the membership functions for 5 linguistic terms.

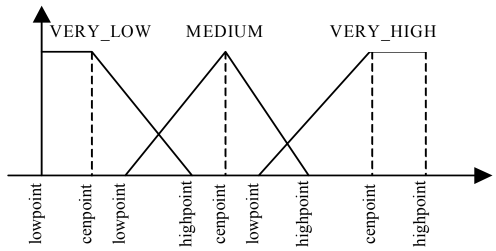

Figure 4: Outlines of the input terms.

Table 6: Linguistic term and data for membership function of load input variables.

No.	**Linguistic term**	lowpoint **(MW)**	Cenpoint **(MW)**	Highpoint **(MW)**
1	VERY_LOW	90	91.5	99.25
2	LOW	91.5	99.25	107
3	MEDIUM	99.25	107	114.75
4	HIGH	107	114.75	122.5
5	VERY_HIGH	114.75	122.5	124

Table 7: Linguistic term and data for membership function of power generation output variables.

No.	**Unit. Gen**	**Linguistic term**	Lowpoint **(MW)**	Cenpoint **(MW)**	Highpoint **(MW)**
1	GE 1	NSMALL	13.901	1503885	23.0738
		SMALL	1503885	23.0738	30.7592
		MEDIUM	23.0738	30.7592	32
		BIG	30.7592	32	32.5
		PBIG	32	32.5	33
2	PLTU 2	NSMALL	5.4425	5.468	5.4842
		SMALL	5.468	5.4842	5.5004
		MEDIUM	5.4842	5.5004	7.747
		BIG	5.5004	7.747	11
		PBIG	7.747	11	11.5
3	Westcan	NSMALL	9.5489	9.5745	9.59
		SMALL	9.5745	9.59	9.606
		MEDIUM	9.59	9.606	10.983
		BIG	9.606	10.983	12
		PBIG	10.983	12	12.5
4	Alsthom 1	NSMALL	4.5815	4.607	4.623
		SMALL	4.607	4.623	4.64
		MEDIUM	4.623	4.64	6.01
		BIG	4.64	6.01	8.5
		PBIG	6.01	8.5	10.0
5	Mirrless	NSMALL	2.4361	2.4617	2.4478
		SMALL	2.4617	2.4478	2.5
		MEDIUM	2.4478	2.5	2.8
		BIG	2.5	2.8	2.9
		PBIG	2.8	2.9	3.0

Figure 5, 6, 7, 8 and 9 shows output membership functions for power generating of GE1, Alsthom1, PLTU2, Mirrless and Westcan. Detail about entry points of the triangular and trapezoidal membership functions of those generators can be checked in Table 7 above.

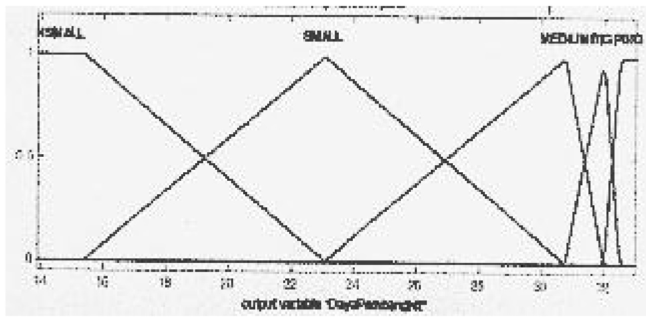

Figure 5: Output membership function of GE1 gen.

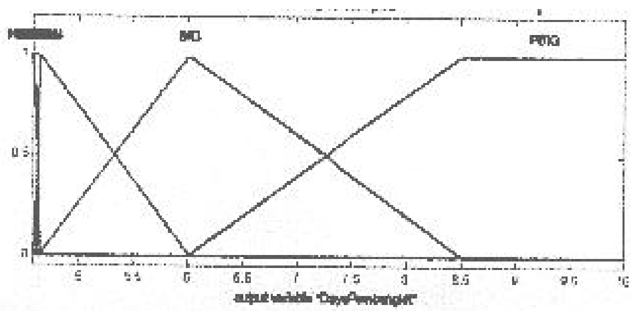

Figure 6: Output membership function of Alsthom1 gen.

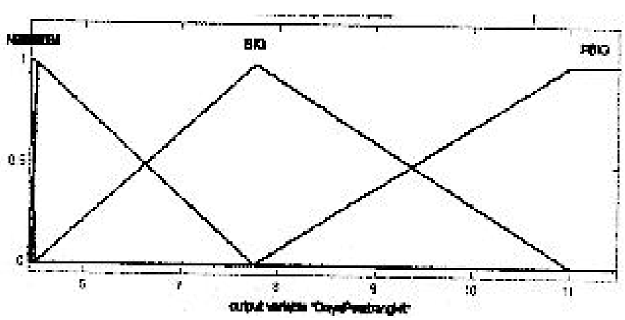

Figure 7: Output membership function of PLTU2.

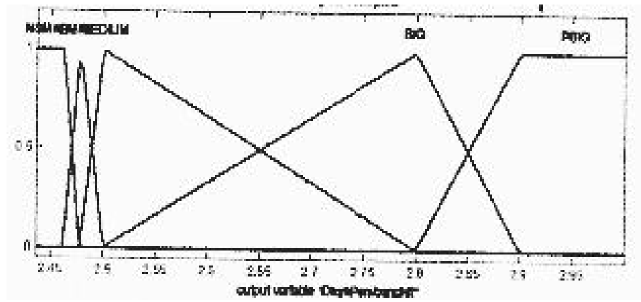

Figure 8: Output membership function of Mirrless gen.

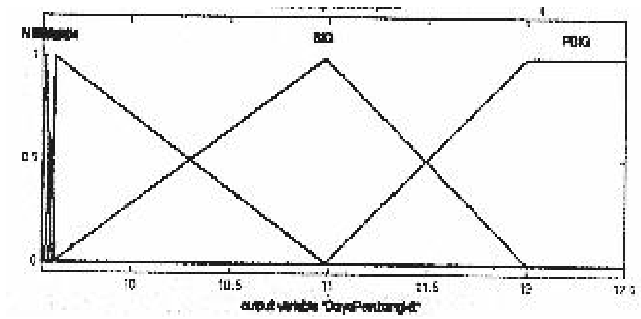

Figure 9: Output membership function of Westcan gen.

Based on empirical measurements and observation with knowledge basis about load-power balancing, then five fuzzy implication rules are constructed in the following:

1. If load very_low then power generation is nsmall.
2. If load low then power generation is small.
3. If load medium then power generation is medium.
4. If load high then power generation is big.
5. If load very_high then power generation is big.

The optimization results using above fuzzy implication rules will be discussed in the following section.

CONCLUSIONS

Optimization Result

As parameter of successful application of fuzzy logic system to optimize economic operation of power system, then comparisons between fuzzy optimization results with that of using Lagrange method (scheduled by PLN) will be observed.

Table 8 exhibits the optimization of power generating scheduled by PLN using Lagrange method. The observation is undertaken on May 14, 2001 in South Sulawesi Interconnected Power System. While Table 9 shows the results of power generating sheduled by fuzzy optimizer.

Based on Table 8 and 9, for every load, it seems that by using fuzzy logic controller, generating cost could be minimized. For example:

For load of 90.30 MW, generating cost can be minimized as

Rp.18,975,904.09/Jam – Rp.18,670,506.09/Jam = Rp.305,398.00/Jam.

So for load of 90.30 MW, thermal generating thermal operation cost in South Sulawesi Sistem using fuzzy logic optimizer is:

Operational Cost = Rp.18,670,506.09/Jam/90.30 MW = Rp.206,760.86/MWh.

While operational cost of thermal generating in South Sulawesi Sistem without fuzzy optimizer for a load of 90.30 MW on May 14, 2001 is:

Operational Cost = Rp.18,975,904.09/Jam/90.30 MW = Rp.210,142.90/MWh.

Table 10 concludes optimization results. It shows comparisons of generator operational costs scheduled by PT. PLN and by fuzzy logic optimizer used in this research on May 14, 2001. For five load values of all observed load values range between 90.3 – 120.3 MW, it looks that the operational costs can be reduced from 1.6094 % up to 2.8388 %. The larger the load demands the smaller operational costs of thermal generators.

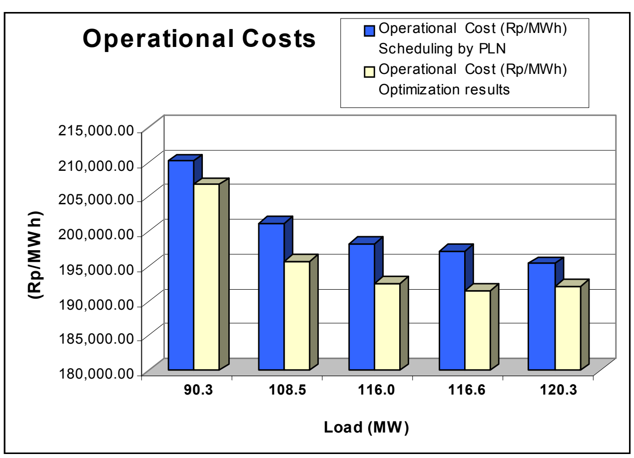

Figure 10: Bar chart of comparison operational costs.

From Figure 11, it looks that, the larger efficiency occurs while the load demanding is about 116 MW. It can also be concluded that the cost efficiency shows the quadratic curve, where the peak efficiency occurs in the medium of load demands of the peak load condition in South Sulawesi System. This fact is shown in Figure 11, where significant efficiencies occur while peak load are about 108.5MW, 116MW and 116.3MW.

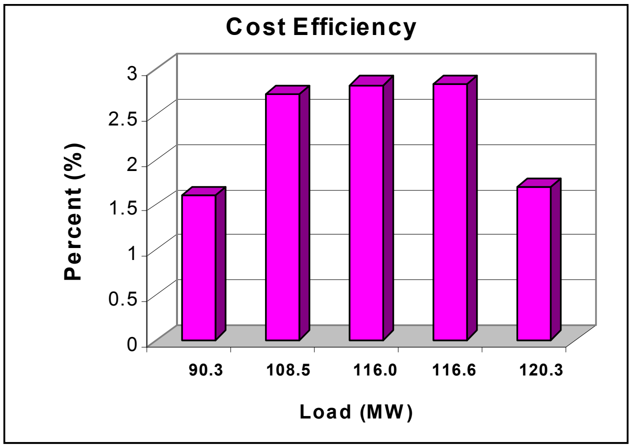

Figure 11: Bar Chart of the cost efficiency.

Table 8: Scheduling of thermal generators in South Sulawesi system, on May 14, 2001.

Pukul	Load (MW)	GE 1 (MW)	GE 2 (MW)	Mitsubish. (MW)	SWD 2 (MW)	PLTU 2 (MW)	Westcan (MW)	Alsthom 1 (MW)	Mirrless (MW)	Cost Generating (Rp/Jam)
18:00	90.30	21.00	21.00	9.00	10.00	5.30	7.50	15.00	1.50	18,975,904.09
18:30	116.60	31.00	31.00	9.00	10.00	7.50	11.50	16.00	0.00	22,988,530.95
19:00	120.30	32.00	32.00	9.00	10.00	6.50	12.50	16.00	2.30	23,508,354.23
19:30	116.00	31.00	31.00	9.00	10.00	7.50	11.50	16.00	0.00	22,988,530.95
20:00	108.50	27.00	28.00	9.00	10.00	7.50	11.50	15.50	0.00	21,827,050.95

Table 9: Economic scheduling of thermal generators using Fuzzy Logic Systems.

Pukul	Load (MW)	GE 1 (MW)	GE 2 (MW)	Mitsubish. (MW)	SWD 2 (MW)	PLTU 2 (MW)	Westcan (MW)	Alsthom 1 (MW)	Mirrless (MW)	Cost Generating (Rp/Jam)
18:00	90.30	15.20	33.00	10.50	10.50	5.44	9.58	4.58	2.46	18,670,506.09
18:30	116.60	32.00	33.00	10.50	10.50	9.00	11.20	7.04	2.82	22,335,923.45
19:00	120.30	33.00	33.00	10.50	10.50	8.30	12.50	10.00	3.00	23,111,015.83
19:30	116.00	32.00	33.00	10.50	10.50	8.23	11.6	7.37	2.81	22,337,834.67
20:00	108.50	30.90	33.00	10.50	10.50	5.87	9.84	5.35	2.55	21,231,670.11

Table 10: Optimization results.

Load (MW)	Operational Cost (Rp/MWh)		Cost of Efficiency	
	Scheduling by PLN	Optimization results	(Rp/MWh)	%
90.30	210,142.90	206,760.86	3,382.04	1.6094
116.60	197,157.21	191,560.23	5,596.98	2.8388
120.30	195,414.42	192,111.52	3,302.90	1.6902
116.00	198,176.99	192,567.54	5,609.45	2.8305
108.50	201,170.98	195,683.59	5,487.39	2.7277

REFERENCES

[1] L. A. Zadeh. “Outline of New Approache to the Analysis of Complex Systems and Decision Processes”. IEEE Trans. on SMC, Vol.3, No.1, pp 28-44, January, 1973.

[2] H. J. Ziemmerman. ”Fuzzy Set Theory and Its Applications”. Kluwer Academic Publisher, 1992.

[3] E. Economakes. “Application of Fuzzy Concepts to Power Demand Forecasting”. IEEE Trans. on SMC, Vol.9, No.10, pp. 651-657, October, 1979.

[4] C-. C. Su, Y-. Y. Hsu. “Fuzzy Dynamic Programming: An Application to Unit Commitment.” IEEE Trans. on Power Systems. Vol.6, No.3, pp 1231-1237, August, 1991.

[5] Aoki, T. Satoh, M. Itoh, T. Ichimori. “Power System Unit Commitment Problem Using Lagrangian Relaxation and Non Differentiable Optimization Method”. International Conference on Optimization Techniques and Application, Singapore, April 8-10, 1987.

[6] A. I. Cohen, S. H. Wan. “A Method for Solving The Fuel Constrained Unit Commitment Problem.” IEEE Trans. on PWRS-2, pp. 608-614, August, 1987.

[7] T. S. Dillon, K. W. Edwin, H. D. Koch, R. C. Taud. “Integer Programming Approach to The Problem of Optimal Unit Commitment with Probabilistic Reserve Determination”. IEEE Trans. on PAS, Vol.97, No.6, pp. 2154-2166, Nov/Dec, 1978.

[8] A. J. Wood, B. F. Wollenberg. “Power Generation, Operation, and Control, Wiley, 1984.

[9] W. D. Stevenson, Jr. “Element of Power System Analysis”. McGraw-Hill, 1982.