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Electrical Daily Load Forecasting In Ramadhan Using Type-2 Fuzzy Logic In Sulselrabar System

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Abstract

This study discusses the daily electricity load forecasting 24 hours on 150 kV electric power systems sulselrabar. Forecasting electrical load requires the accuracy of the results with a small error. Peak load forecasting methods used to use smart methods Interval Type-1 Fuzzy Logic (IT1FL) and Interval Type-2 Fuzzy Logic (IT2FL) to predict the needs of the electrical load 1 Ramadan 2016. As input data, it was used load data from 2012 through 2016 for the same day each 1st of Ramadhan each year, and as comparative data, it was used actual load data 1, 2016. For the Ramadhan input variable, it was used two of the data Variation Load Difference (VLD Max) 2015 as an input variable X, VLD Max 2016 as an input variable Y. From the simulation results obtained highly accurate results where each method produces a very small error, where for methods of using IT1FL of 1.607778264% while using IT2FL by, 1.344510913%.

Keywords: *Type-1 Fuzzy Logic, Type-2 Fuzzy Logic, MAPE, Load Forecasting*

1. Introduction

Electric load forecasting is an important part of power system operation in order to achieve optimal planning in operation of the systems [1]. Load forecasting is covering short-term, medium-term and long-term load forecasting. Short-term load forecasting is required for controlling and scheduling the operation of power systems [2]. Medium and long-term load forecasting is required for maintenance, fuel purchases, plant development and planning of future distributions. Accurate load forecasting has a significant impact on the operation and production costs of electric utilities [3]. Research on load forecasting has spawned numerous papers and journals [4]. These publications have led to the development of various methods of forecasting. This method is classified into two categories: The classical approach (conventional method) and an artificial intelligence method.

The classical approach is based on statistical methods, which cannot accurately represent the complex nonlinear relationship between the load and a series of factors such as daily and weekly rhythms of time that can lead to high error in load forecasting [4]. Artificial intelligence method has the ability to provide better performance when dealing with nonlinear data. The advantages of artificial intelligence method compared to conventional method are computational technique and simple algorithm, structural simplicity and high accuracy performance without having to solve any nonlinear equations into mathematical equations. Therefore, the author in this research discusses the hybrid method in the load forecasting, which is a suggestion of earlier researchers. Thus the method of interval type 2 fuzzy inference system is used in this research. Interval type-2 fuzzy inference system (IT2FIS) becomes a concern for short-term load forecasting because it has a simple concept and high-performance identification.

IT2FIS is the formulation and mapping process from input to output using interval type 2 fuzzy logic [5-9]. One of the advantages of fuzzy logic is the knowledge and experience of experts can be easily used and applied. Interval Type-1 Fuzzy Logic and Interval Type-2 Fuzzy Logic is used in this research for load forecasting in Sulawesi Selatan, Tenggara dan Barat (Sulselrabar) system especially for 1 Ramadhan 2016. In the proposed method, we do not take environmental factors as variable. The Sulselrabar electrical system is used because, this system has been growing, and requires further study on load forecasting. Several previous studies have been conducted and show satisfactory results [9-21].

2. Research Methods

The implementation of IT2FL for peak load forecasting on 1 Ramadhan 2016 is done by using three stages, namely the preparation stage (pre-processing), processing stage and final stage (post-processing) [4].

2.1. Pre-Processing

Preparation stage is the preparation of peak load data on 24 hours to look for load difference (LD), typical load difference (TLD), maximum weekdays (max WD) and variation load difference (VLD). Load difference (LD) for maximum load is a load difference within 4 days before the days which is given by [22]:

$$LD_{MAX}(i) = \frac{MaxSD(i) - MaxWD(i)}{MaxWD(i)} x100 \quad (1)$$

$$MaxWD_{(i)} = \frac{WD_{(i)d-4} + WD_{(i)d-3} + WD_{(i)d-2} + WD_{(i)d-1}}{4} \quad (2)$$

MaxSD (i) is the peak load on a special day and maxWD is the average of maximum load 4 days before the days. Then, looking for a distinctive characteristic of a typical peak load or typical load difference (TLD_{MAX} (i)) by averaging the peak load of similar LD_{MAX} (i) in previous years. After that, calculating the variation load difference, which is the difference between Load Difference (LD) and Typical Load Difference (TLD_{MAX} (i)) which can be seen by the following equation:

$$VLD_{\max}(i) = LD_{\max}(i) - TLD_{\max}(i) \quad (3)$$

$$TLD_{\max}(i) = \frac{LD_{\max}(i-1) + LD_{\max}(i-2) + LD_{\max}(i-3)}{3} \quad (4)$$

Peak load data which is used to calculate Max WD and LD max is based on (1) and (2) equations respectively and the results are presented in Table 1 and 2.

Table 1. Peak Load In 2016

$WD(i)_{d-4}$	$WD(i)_{d-3}$	$WD(i)_{d-2}$	$WD(i)_{d-1}$	MaxSD(i)
577.96	536.22	583.10	589.64	609.70
562.64	513.60	560.86	563.12	606.52
537.60	497.91	527.11	541.81	615.86
517.76	498.68	516.53	533.25	641.13
526.03	489.66	525.30	546.27	596.93
539.42	528.80	550.95	571.02	591.33
536.83	529.59	558.15	567.28	520.18
559.59	573.80	584.02	595.88	574.02
599.36	617.64	634.73	649.16	627.04
587.65	655.20	658.25	692.32	657.29
614.61	689.41	682.15	686.51	656.71
614.24	689.49	675.38	682.78	659.18
611.61	683.15	663.73	694.33	664.00
612.52	704.85	692.95	710.65	675.02
608.56	698.42	676.79	691.70	691.70
614.76	681.74	661.68	701.46	695.61
603.86	651.71	661.77	677.62	695.79
723.27	754.12	783.38	741.25	770.25
816.40	836.67	842.27	853.60	856.00
801.50	821.69	791.02	815.15	812.24

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767.76	792.92	772.03	817.63	793.92
700.07	733.94	705.36	782.02	759.78
636.80	662.42	663.73	769.47	694.37
580.44	610.82	615.25	680.07	628.03

2.2. Processing

Fuzzyfication design of X and Y input is using IT2MF Editor. There are 11 membership functions is used [23], namely :

- Negative Very Big (NVB), range : [-48 -48 -40 -32.5 -48 -48 -40 -28.5 -48]
- Negative Big (NB), range : [-40.5 -32 -24.5 -36.5 -32 -20.5]
- Negative Medium (NM), range : [-32.5 -24 -16.5 -28.5 -24 -12.5]
- Negative Small (NS), range : [-24.5 -16 -8.5 -20.5 -16 -4.5]
- Negative Very Small (NVS), range : [-16.5 -8 -2.5 -12.5 -8 2.5]
- Zero (ZE), range : [-8.5 0 4.5 -4.5 0 8.5]
- Positive Very Small (PVS), range : [-2.5 8 12.5 2.5 8 16.5]
- Positive Small (PS), range : [4.5 16 20.5 8.5 16 24.5]
- Positive Medium (PM), range : [12.5 24 28.5 16.5 24 32.5]
- Positive Big (PB), range : [20.5 32 36.5 24.5 32 40.5]
- Positive Very Big (PVB), range : [28.5 40 48 48 32.5 40 48 48 48]

Examples of fuzzy rules can be seen in Table 2.

Table 2. Fuzzy Rules

No.	Antecedent		Consequent
Rules	X	Y	Z
1	NM	PS	PS
2	PVB	NS	PVB
3	NM	PM	PM
4	NM	PB	PB
5	NS	PM	PM
6	NS	PS	PS
7	NM	ZE	ZE
8	NM	PVS	PVS
9	NVB	ZE	ZE
10	NVB	ZE	ZE
11	NVB	NVS	NVS
12	NVB	ZE	ZE
13	NVB	ZE	ZE
14	NVB	ZE	ZE
15	NVB	PVS	PVS
16	NVB	PVS	PVS
17	NM	PS	PS
18	NM	PVS	PVS
19	NS	PVS	PVS
20	NS	PVS	PVS
21	NS	PVS	PVS
22	NS	PVS	PVS
23	NS	ZE	ZE
24	ZE	ZE	ZE

2.3. Post-Processing

After getting VLD_{MAX} forecasting value, then forecast load difference:

$$Forecast\ LD_{MAX}(i) = Forecast\ VLD_{MAX}(i) + TLD_{MAX}(i) \quad (5)$$

Peak load forecasting can be calculated:

$$P'_{MAX}(i) = MaxWD(i) + \frac{(ForecastLD_{MAX}\, xMaxWD(i))}{100} \quad (6)$$

The smaller error obtained show the accuracy of the proposed method is higher. The absolute error can be expressed as follows:

$$Error = \left| \frac{P_{forecast} - P_{actual}}{P_{actual}} \right| x100\% \quad (7)$$

$$Error = \left| \frac{P'_{MAX}(i) - MaxSD(i)}{MaxSD(i)} \right| x100\% \quad (8)$$

The research flowchart is shown in the following figure.

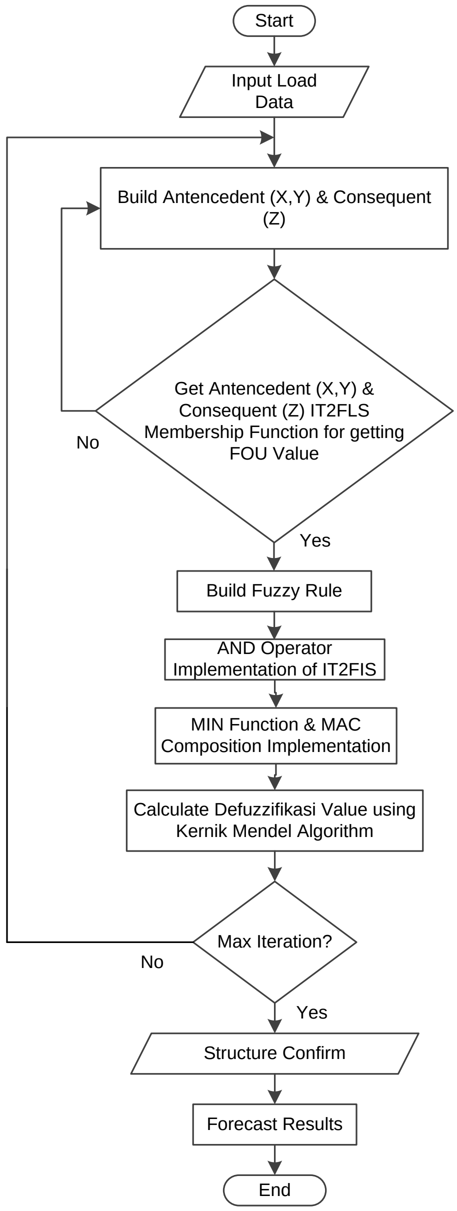

Figure 1. Flowchart IT2FL for Daily Peak Load Forecasting

3. Literature Review

3.1. Fuzzy Logic Type-2

The fuzzy type-2 set is a development of fuzzy type-1 which is re-defuzzy. The Fuzzy type-1 based-knowledge logic system is used to build the rules in an uncertainty fuzzy logic system (FLS). There are three reasons for uncertainty rules [6] :

1 Rules of antecedents and consequents can have different perception in different people.
2 Polling of group of experts on consequents is often different to the same rules as most experts do not agree on the rule.
3 The training data contains a lot of noise.

Type-2 fuzzy sets have their own membership levels are fuzzy. Rankings on type-2 fuzzy set can be on the subset of secondary membership. Similar with FLS Type-1, FLS Type-2 is also included FIS membership functions and defuzzification. The difference is that before the defuzzification process there is type reduction process which has several methods; one of them is Kernik Mendel Algorithm (KMA). Interval Type-2 Fuzzy Logic (IT2FL) structure can be seen in Figure 2. Figure 2 shows the process of IT2FL from an input value of crisp x set into the output value of Y=f(x) equation.

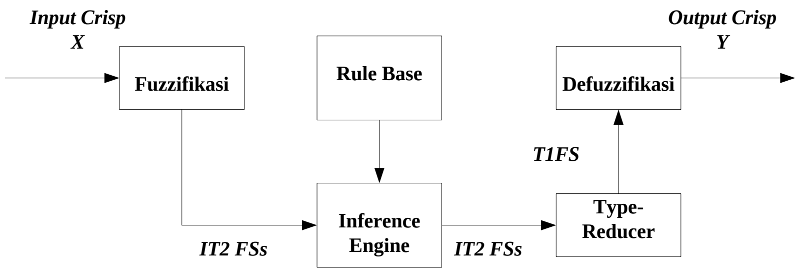

Figure 2. Type-2 Fuzzy Logic System (T2FLS) Structure

3.2. Interval Type-2 Fuzzy Set

An interval type-2 fuzzy set (IT2FS) is denoted Ã by the membership function $\mu\tilde{A}$ with $x \in X$ and $u \in Jx \subseteq [0,1]$, its characteristic can be recognized on the following equation:

$$\tilde{A} = \int_{x\in X}\int_{x\in J_x} \frac{\mu\tilde{A}(x,u)}{(x,u)} Jx \subseteq [0.1] \quad (9)$$

x is a primary variable; $u \in U$, secondary variable, have domain Jx for each $x \in X$; Jx is primary membership. Uncertainty of $\tilde{A}$ is the combination primary membership (footprint of uncertainty). The equation can be seen as follows:

$$FOU(\tilde{A}) = \bigcup_{\forall x\in X} Jx = \{(x,u); u \in Jx \subseteq [0,1]\} \quad (10)$$

Jx is an interval with the following equation:

$$Jx = \left\{(x,u); u \in \left[\underline{\mu}_{\tilde{A}}(x), \overline{\mu}_{\tilde{A}}(x)\right]\right\} \quad (11)$$

From equation 2.5 FOU ($\tilde{A}$) can be expressed by the equation:

$$FOU(\tilde{A}) \equiv \bigcup_{\forall x\in X} \left[\underline{\mu}_{\tilde{A}}(x), \overline{\mu}_{\tilde{A}}(x)\right] \quad (12)$$

Where:
Jx = *Primary membership* of x
$\underline{\mu}\tilde{A}$ = *Lower Membership Function* (LMF) af $\tilde{A}$
$\overline{\mu}\tilde{A}$ = *Upper Membership Function* (UMF)of $\tilde{A}$

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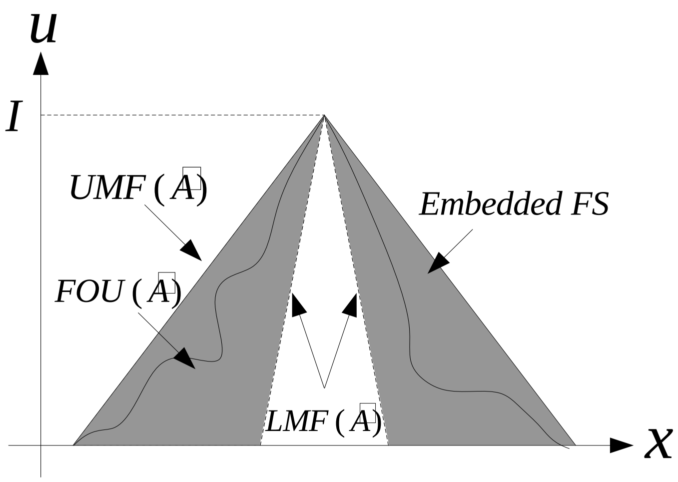

Figure 3. FOU (dark color), LMF (dotted line), UMF (solid line) and Embedded FS (wavy line).

3.3. Interval Type-2 Fuzzy Membership Function Operations

Operation on fuzzy interval type-2 set is almost the same as fuzzy type-1 set; but on the IT2FL logic system, the operation is performed on two intervals that are UMF (top) and LMF (below) at once. Operation on fuzzy interval type-2 membership function can be seen in Figure 4:

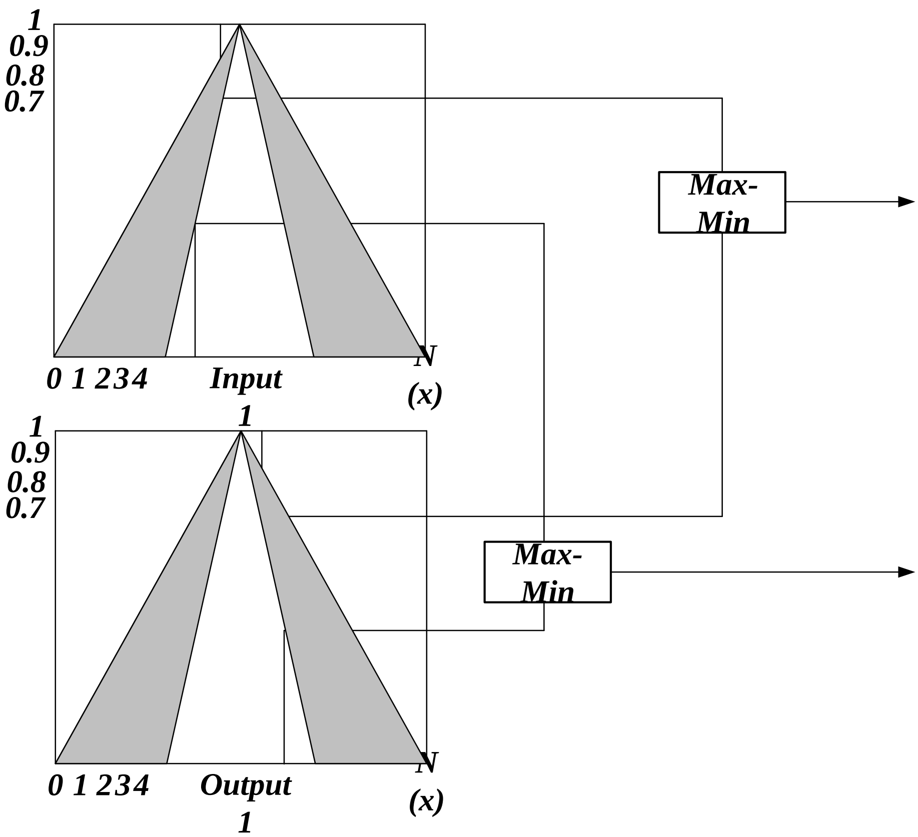

Figure 4. Operation fuzzy set interval type-2 (IT2FL)

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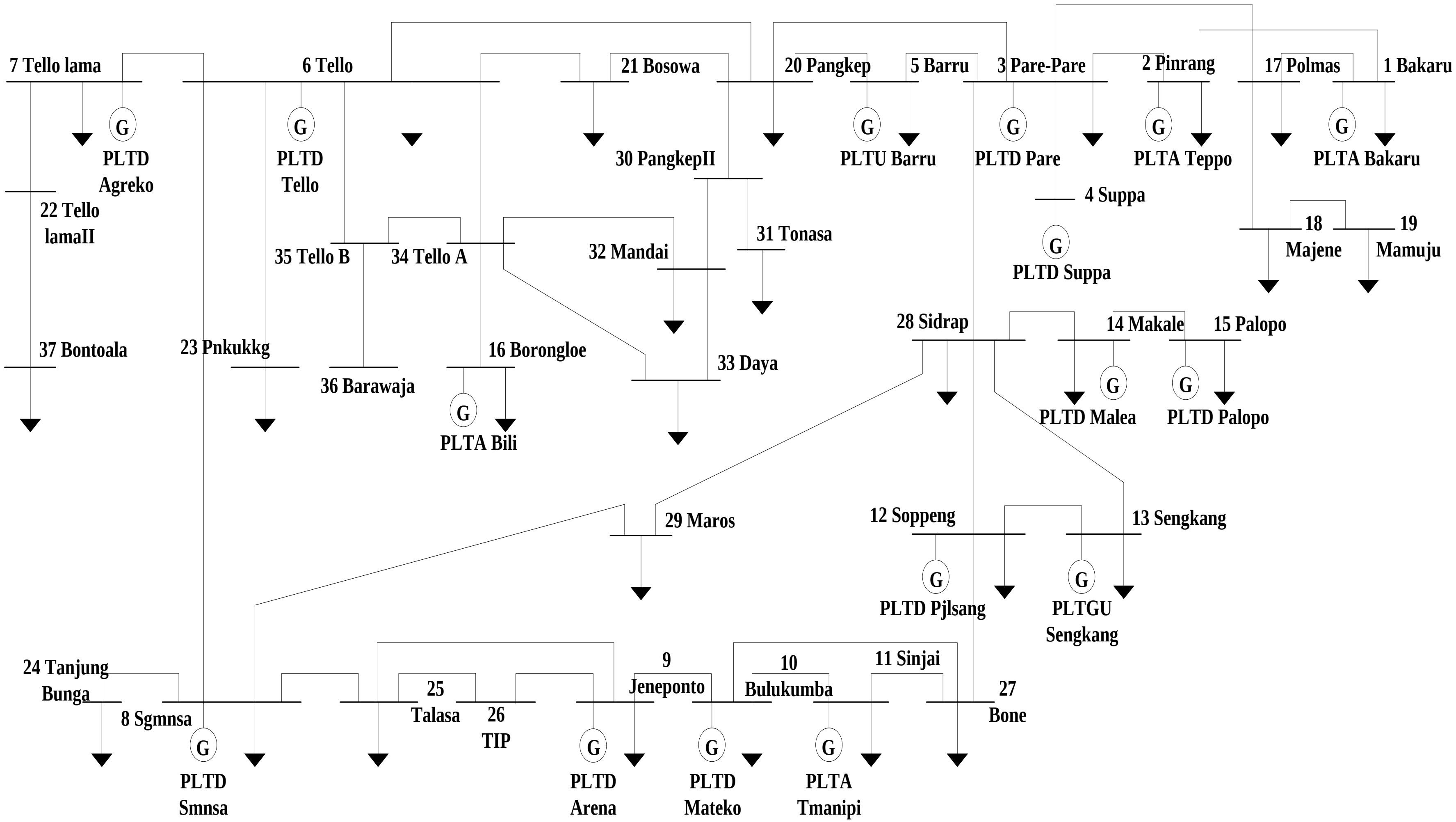

Figure 5. Sulselrabar System [10]

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Table 3. Establishment Of Rule Base For Input X in 1st Ramadhan 2016

Hours	Variable	VLD max	Membership Function (μ)				Set of
			NB	NM	PVS	PS	X
01.00	X	-13.53477757	0.383694394	0.616305606			NM
	Y	7.837201199			0.0406997	0.9593003	PS
	Z	7.837201199			0.0406997	0.9593003	PS

Table 4. Result Of Variable Calculations X, Y, Z on 1st Ramadhan 2016

Hours	Input			Set		
	X	Y	Z	X	Y	Z
1:00	-13.53477757	7.837201199	7.837201199	NM	PS	PS
2:00	38.15805202	-8.455067268	-8.455067268	PVB	NS	NS
3:00	-12.34897699	12.81561102	12.81561102	NM	PM	PM
4:00	-10.98277044	15.86782032	15.86782032	NM	PB	PB
5:00	-9.099179456	10.65770448	10.65770448	NS	PM	PM
6:00	-7.434924909	9.002263816	9.002263816	NS	PS	PS
7:00	-11.37068292	0.269638493	0.269638493	NM	ZE	ZE
8:00	-12.03990371	3.199737038	3.199737038	NM	PVS	PVS
9:00	-19.64995022	0.863689423	0.863689423	NVB	ZE	ZE
10:00	-19.60150714	1.756933675	1.756933675	NVB	ZE	ZE
11:00	-22.75197853	-2.897867872	-2.897867872	NVB	NVS	NVS
12:00	-20.16793366	-0.76171919	-0.76171919	NVB	ZE	ZE
13:00	-18.72397279	1.320215573	1.320215573	NVB	ZE	ZE
14:00	-23.01970881	0.154211021	0.154211021	NVB	ZE	ZE
15:00	-19.25924082	3.424255509	3.424255509	NVB	PVS	PVS
16:00	-18.30164779	4.941932377	4.941932377	NVB	PVS	PVS
17:00	-11.51601435	7.053862708	7.053862708	NM	PS	PS
18:00	-10.31446966	3.604203806	3.604203806	NM	PVS	PVS
19:00	-7.106373861	3.350674093	3.350674093	NS	PVS	PVS
20:00	-7.094262262	4.663216896	4.663216896	NS	PVS	PVS
21:00	-6.418655252	2.380709895	2.380709895	NS	PVS	PVS
22:00	-9.138939847	2.765256248	2.765256248	NS	PVS	PVS
23:00	-7.372420856	1.397545706	1.397545706	NS	ZE	ZE
0:00	1.060461042	1.539682191	1.539682191	ZE	ZE	ZE

Antecedent (X, Y) and consequent (Z) T2FIS figures as follows:

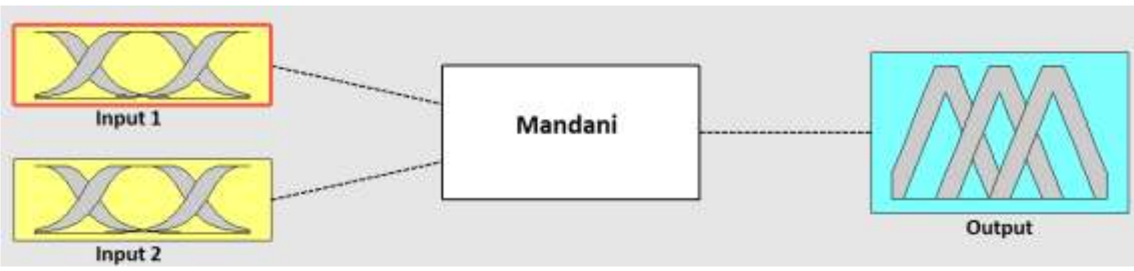

Figure 6. Design System

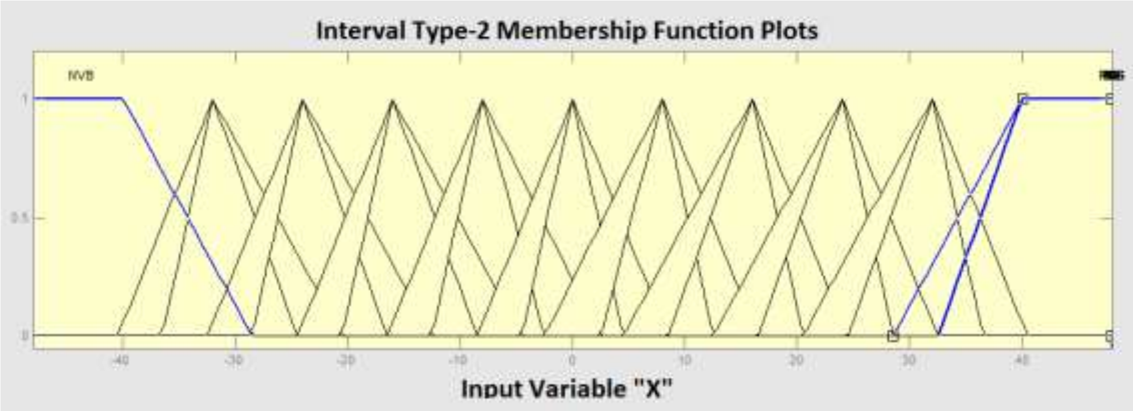

Figure 7. X,Y Input Design

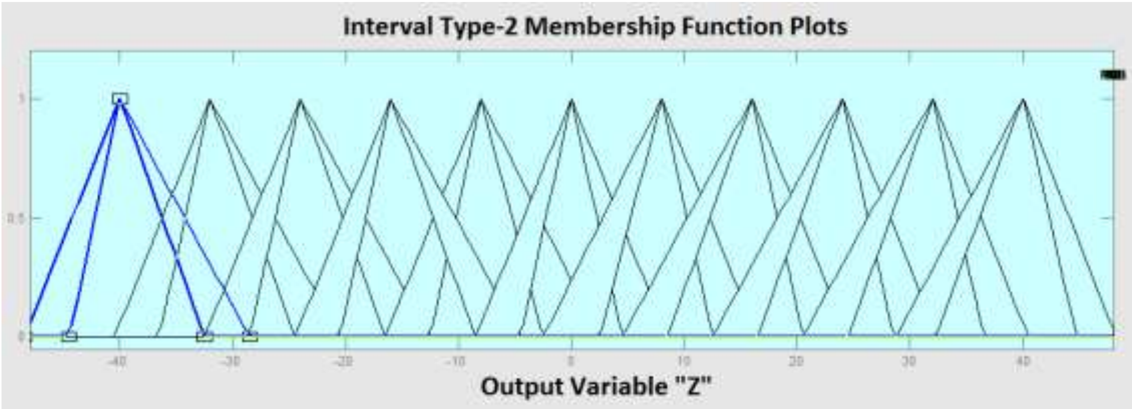

Figure 8. Z Output Design

4. Result & Analysis

The calculation of the input variable value X, Y, Z is to find the value of Load Difference Variable (VLDMAX) by first calculating WD Max, LD Max, TLDmax each input data of 2012-2015, which is calculated based on equation 1-4. The results of the calculation of variables X, Y, Z can be seen in table 3 above.

Figure 5 shows the single line diagram of the sulselrabar system, where there are 37 Buses, each serving load centers in the sulselrabar system. Table 3 shows an example of the calculation of the membership function fuzzy logic for 01.00 hours, and Table 4 shows the complete result of the membership function calculation.

Figure 6-8 shows the membership design function type-2 fuzzy logic using Matlab. Where each uses 11 membership functions. While the image forecasting results shown in graphs 8 and 9. Graph 8 is the result of load forecasting and graph 9 is the error of forecasting results with the method of comparison of type-1 fuzzy logic.

The data used is the peak load data of Sulselrabar electricity system started in 2012-2015 by using Interval Type-1 Fuzzy Logic method and Interval Type-2 Fuzzy Logic (IT2FL) as a comparison. Then, the data is devoted to four days before and during 1 Ramadhan 2016.

The test results by using the IT2 method as a proposed method for load forecasting showed excellent results, in which the Mean Absolute Percentage Error (MAPE) of VLD_{MAX} is 1.344510913%. By using IT1FL, MAPE is 1.607778264%. For complete results can be seen in figure 9-10.

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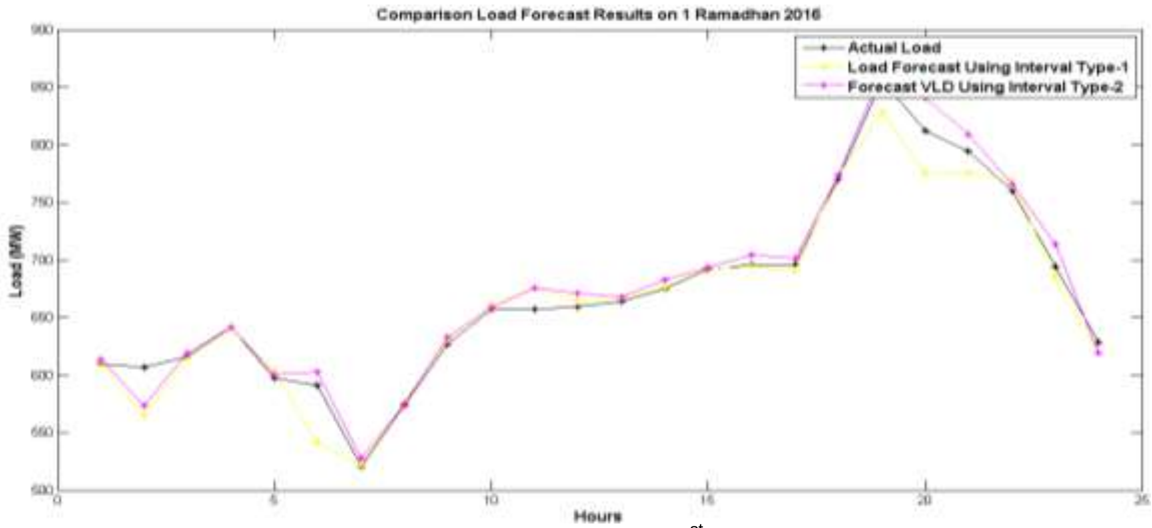

Figure 9. Results of Load Forecast for 1st Ramadhan in 2016

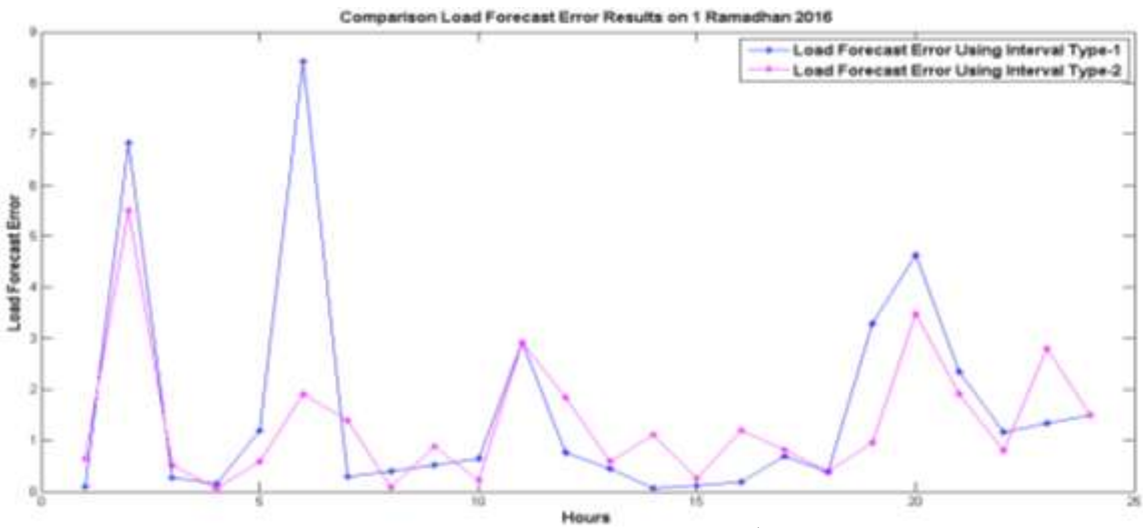

Figure 10. Results of Load Forecasting Error on 1st Ramadhan in 2016

5. Conclusions

Electrical Load Forecasting Day on the 1st of Ramadhan using intelligent methods based on Fuzzy Logic obtained very satisfactory results, with a very small error, this method is best used for short-term forecasting, medium and long-term. Error using Fuzzy Logic Type-2 of 1.607778264%, while using the proposed method Interval Type-2 Fuzzy Logic error is getting smaller in the amount of 1.344510913%. The application of intelligent methods for optimization of load forecasting is also highly recommended for yan forecasting methods used by PT. Perusahaan Listrik Negara (PLN) also still produce a sizable error.

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