Application of Fuzzy-Flower Pollination Algorithmfor Peak Load Forecasting on National Holiday

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***Abstract*—Application of Type-2 Fuzzy Logic System (T2FLS) has became attention for a short-term load forecasting problems solution. This paper presentsapplication optimization membership function of antecedent (X,Y) and consequent (Z) interval type-2 Fuzzy Logic System using Flower Pollination Algorithm (FPA) for short-term load forecasting on national holiday. This method has being implemented on the historical peak load data during 14 national holidays case study in Jawa-BaliIndonesia electrical power system in 2011. Flower Pollination Algorithm (FPA) will be applied to optimize interval Footprint of Uncertainty (FOU) membership functions of interval type-2 fuzzy logic system. The test result showed Main Absolute Percentage Error (MAPE) is less than type-2 Fuzzy Logic System (FLS) and optimization type-2 FLS-Big Bang Big Crunch Algorithm. Finally, this paper defined Main Absolute Percentage Error (MAPE) 2.040612143% for type-2 FLS, 1.279257143% for optimization type-2 FLS-Big Bang Big Crunch Atgorithm and 1.091543571% for optimization type2 FLS-Flower Pollination Algorithm.**

Keywords:Type-2 Fuzzy Logic, Flower Pollination Algorithm, MAPE, Membership Function, National Holiday

I. INTRODUCTION

The most important thing in electric power transmissionsystem isthe precise calculation of power generation that meet a certain required load [1]. Requiredload at certainfine can be solved by load forecast technique. Load forecastingis classifiedintothree categoriesthat areshort-term load forecasting,mid-term load forecasting andlong-term load forecasting [2]. Research on load forecastingbecomesvery importantin modern countryespeciallyshort-term load forecasting becausethe appearance ofenergy marketwhich is very competitive [2]. Load forecasting on holiday becomes an interest because itdiffers from ordinary days [3]. Arenormally implemented in load forecasting that is conventional method and intelligent method [4,5]. Conventional method isstatistical method.A complex nonlinear system with series uncertainty factor is difficult to solve using conventional method. Sometimes it leads to high inaccurate of load forecasting [5]. Intelligent method hasabilityto givebetter performance in handling non-linear problem[5]. Intelligent methodwhich is often usedon load forecastingthat is Artificial Neural Network (ANN) [6-9] and fuzzy logic [10-14]. The advantageof ANN isits abilitytolearnthe historical load pattern. However, conventional ANN model sometimes has overfitting problems which result in improper forecasting results.[15]. Moreover, it is often difficult to obtain the best ANN due to tiresome tuning and trial-and-error process [5].

On the other hand,FuzzyLogic (FL) providessimple way tosolvesome drawbacks which are feedback which is vague, ambiguous, inexact, noise, or missing information to get on exact conclusion. Linguisticvariableis usedtorepresent parameter of an FL system operation. FL uses "if X and Y then Z" isan approachnotmathematical solving. It is very usefulincontrollingcomplexnonlinearsystem, which is unsolvable by mathematical model [16]. Fuzzy logic is foundbyProf.Zadehwhich has developed into fuzzy logic type 2 [17]. FLSs type-1 cannotdirectlyhandlethe uncertainty ofrule, because it uses certain type-1 fuzzy set (that isfullyexplainedbysingle numericvalues). On the other hand, type-2 FLSs isusefulin difficult situationto determineexact numericmembership function, andthe uncertainty ofmeasurement [18]. Type-2 FLSs can be usedin uncertainty situationto determinethe exact membership valuesuch asin training where the data is influencedby noisy [18].

In this research, authors apply fuzzy logic type 2 method which is optimized by using flower pollination algorithm in order to forecast peak load on Indonesian national holiday. Flower pollination algorithm isoptimizationmethod which is inspiredbyflower pollination process [19]. This methodis claimed more efficientthan GA and PSO [19].

II. INTERVAL TYPE-2 FUZZY LOGIC

Fuzzy logic system type 2 isthe expansionof fuzzy logic system type 1 wheremembership function of fuzzy logic system type 2 hastwo membership degrees that areprimaryandsecondary membership degrees.Fuzzylogic system type 2consists offuzzification, a set of rules (rules), *fuzzy*inference machine andoutput processor. Output processoron fuzzylogic system type 2consists of*type-reducer*anddefuzzification. *Type-reducer*change*fuzzy*type-2 set intosome*fuzzy*type-1set; one of them uses*Kernik Mendel Algoritm (KMA)*anddefuzzificationwhich will resultingoutput crisp (output crisp). Fuzzy logic system type 2 is alsocharacterizedby*IF-THEN*rule, butits *antecedent*and*consequence*membership setsistype-2. Generally, fuzzy logic system type 2can be seen onfigure 1.

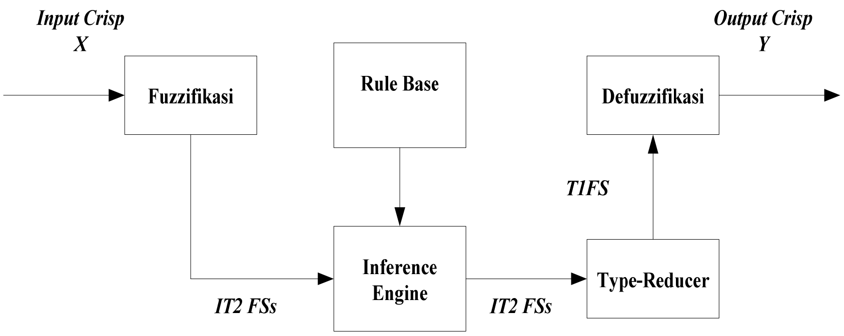

Fig 1.Type-2 Fuzzy Logic System (T2FLS) Structure [17]

A. Interval Type-2 Fuzzy Set

IntervalType-2 FuzzySet (IT2FS) is denoted $\tilde{A}$.$\mu\tilde{A}$is membership function with $x \in X$ and $u \in Jx \subseteq [0,1]$. Characteristicof IT2FS can be recognized on the following equation:

$$\tilde{A} = \int_{x\in X}\int_{x\in J_x} \frac{\mu\tilde{A}(x,u)}{(x,u)} Jx \subseteq [0,1] \qquad (1)$$

Primaryvariable x which has domain X;$u \in U$, secondary variable, have domain Jx for each $x \in X$; $Jx$is expressed primary membership of x.$\tilde{A}$iscombination of all primary membership (Jx) which is expressed the Footprint of Uncertainty (FOU) of $\tilde{A}$. The equation can be seen as follows:

$$FOU(\tilde{A}) = \cup_{\forall x\in X} Jx = \{(x,u); u \in Jx \subseteq [0,1]\} \qquad (2)$$

Jx is interval with the following equation:

$$Jx = \left\{(x,u); u \in \left[\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)\right]\right\} \qquad (3)$$

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

$$FOU(\tilde{A}) = \cup_{\forall x\in X} \left[\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)\right] \qquad (4)$$

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

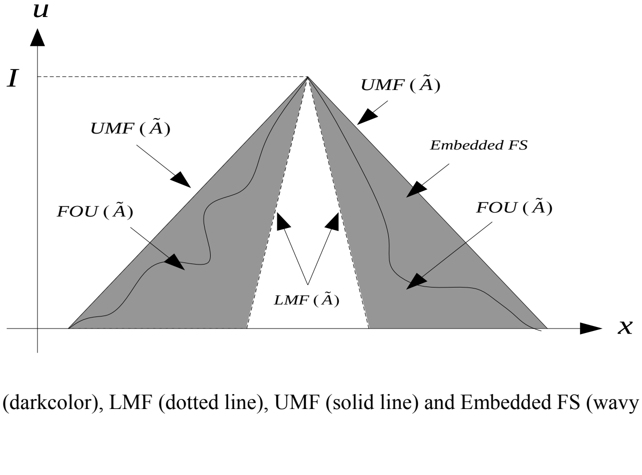

Fig 2. FOU (darkcolor), LMF (dotted line), UMF (solid line) and Embedded FS (wavy line) [17]

B. Interval Type-2 Fuzzy Membership Function Operations

Interval type-2fuzzy set operation which is represented by FOUis doneby using two intervalsthat is*Upper Membership Function (UMF)*and*Lower Membership Function (LMF)*. Operation on*membership function fuzzy interval type-2*can be seen on figure3:

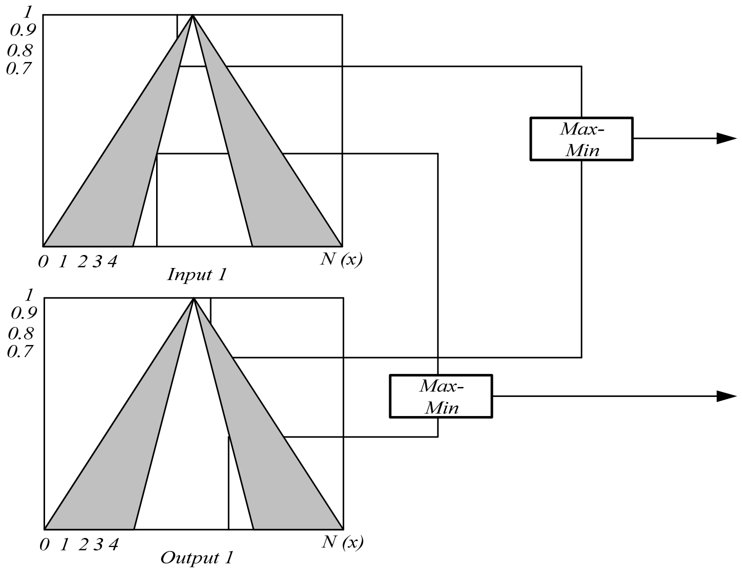

Fig 3. Operation fuzzy set interval type-2 (IT2FLS)

C.Kernik Mendel Algorithm

On interval type-2 fuzzy, processof searching the centroid can be doneby using Kernik Mendel Method.This searching methodis formulatedas follows:

$$Y_{Cos}(x') = \bigcup_{\substack{f^n \in F^n(x') \\ y^n \in Y^n}} \frac{\sum_{n-1}^{N} f^n y^n}{\sum_{n-1}^{N} f^n} = [yl, yr] \quad (5)$$

$$y_1 = min_{k\in[1,N-1]} \frac{\sum_{n=1}^{k} \bar{f}^n \underline{y}^n + \sum_{n=k+1}^{N} \underline{f}^n \underline{y}^n}{\sum_{n=1}^{k} \bar{f}^n + \sum_{n=k+1}^{N} \underline{f}^n} \equiv \frac{\sum_{n=1}^{L} \bar{f}^n \underline{y}^n + \sum_{n=L+1}^{N} \underline{f}^n \underline{y}^n}{\sum_{n=1}^{L} \bar{f}^n + \sum_{n=L+1}^{N} \underline{f}^n}$$

$$y_r = max_{k\in[1,N-1]} \frac{\sum_{n=1}^{k} \underline{f}^n \bar{y}^n + \sum_{n=k+1}^{N} \bar{f}^n \bar{y}^n}{\sum_{n=1}^{k} \underline{f}^n + \sum_{n=k+1}^{N} \bar{f}^n} \equiv \frac{\sum_{n=1}^{R} \underline{f}^n \bar{y}^n + \sum_{n=R+1}^{N} \bar{f}^n \bar{y}^n}{\sum_{n=1}^{R} \underline{f}^n + \sum_{n=R+1}^{N} \bar{f}^n} \quad (6)$$

Switch point of L and R are as follows:

$$\underline{y}^L \le yl \le \underline{y}^{L+1} \quad (7)$$

$$\bar{y}^R \le yr \le \bar{y}^{R+1}$$

The searching of*centroid* value is doneby following equation:

$$Centroid = \frac{(yl+yr)}{2} \quad (8)$$

III. FLOWER POLLINATIONALGORITHM

Flower Pollination Algorithm(FPA) isanoptimization methodwhich is taken based oncharacteristic of flower pollination. In using this method,there are rulesof flower pollination phenomenon characteristic, *flower constancy*phenomenon, andpollination behavioras follows:

1. Biotic pollinationand cross-pollinationare consideredas global pollination process where pollinatorcarriespollen (pollen-carrying) doingLévy*Flights*movement.
2. Abiotic pollination and single pollinationare considered as local pollination.
3. *Flower constancy* is considered aschance (probability) reproductionwhich is proportionalwith similarity from two involved flowers.
4. Local and global pollinationsare regulatedby switch probability$\in = [0,1]$

There are two fundamental things on this algorithm that is global andlocal pollinations. On global pollination, pollen from flower is carriedbyanimal pollinatorssuch asinsectandpollen can dolong-distance travelbecause insect can flyand move in large area. This processplus flower constancy phenomenon can be represented mathematically as:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - g^*) \quad (9)$$

withx_i^tdeclarespollen*i*orvectorsolution$x_i$oniteration*t*, andg_* isthe best solutiononongoing iteration. Parameter *L* ispollination power. Because insect can moveinto long-distancewith different step, wecan useLévy*Flights*toimitatethis characteristic efficiently, that iswe take*L>0*fromLévy distribution.

$$L \sim \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\pi\lambda}{2}\right)}{\pi} \frac{1}{s^{1+\lambda}} \ , (s \gg s_0 > 0) \qquad (10)$$

$\Gamma(\lambda)$is gamma standard function, andthis distributionis appliedto$s > 0$ step. Then,local pollinationand flower constancy can be represented as:

$$x_i^{t+1} = x_i^t + \in (x_j^t - x_k^t) \qquad (11)$$

withx_j^tandx_k^tarepollen from different flowersof similar plant species. This rule imitates flower constancy phenomenon in limited environment. Mathematically, ifx_k^tandx_k^tcome fromsimilar population, then this rule becomes*random walk*localif we take$\epsilon$from uniform distribution [0,1].

IV. Peak Load Forecasting On National Holiday Using IT2FL-Flower Pollination Algorithm

There are three steps which is done toapply fuzzy type 2-flower onpeak loadforecasting onholidaynationalthat ispre-processing, processing and post-processing [7].

A. Pre-Processing

*Pre-Processing*ispreparation ofpeakloaddata onnationalholidaytoobtain Load Difference (LD), Typical Load Difference (TLD), Maximum Weekdays (max WD) andVariationLoadDifference(VLD). Load Difference (LD) isthe difference ofload 4 daysbeforenational holiday which is given by:

$$LD_{MAX}(i) = \frac{MaxSD(i) - MaxWD(i)}{MaxWD(i)} x100 \qquad (12)$$

$$MaxWD_{(i)} = \frac{WD_{(i)d-4} + WD_{(i)d-3} + WD_{(i)d-2} + WD_{(i)d-1}}{4} \qquad (13)$$

*max*SD(i) ispeak load on holidayand*maxWD*isthe average of maximum load 4 daysbeforeholiday. After thatcalculate the Typical Load Difference (TLD_{MAX}(i))that isaveragingthe peak load of LD_{MAX}(i) which is similarin previous year.Then looking for*Variation Load Difference*that isthe differencebetween Load Difference (LD) fromTypical Load Difference (TLD_{MAX}(i))withfollowingequation:

$$VLD_{max}(i) = LD_{MAX}(i) - TLD_{MAX}(i) \qquad (14)$$

$$TLD_{max}(i) = \frac{LD_{MAX}(i-1) + LD_{MAX}(i-2) + LD_{MAX}(i-3)}{3} \qquad (15)$$

To calculate Max WD and LD max based on (12) and (13) equations can be seen on Table 1and Table 2.

TABLE I. Peak Load In 2013

National Holidays Peak Load in 2013 (MW)				
$WD(i)_{d-4}$	**$WD(i)_{d-3}$**	**$WD(i)_{d-2}$**	**$WD(i)_{d-1}$**	**MaxSD(i)**
19782.00	18608.00	17525.00	16872.00	15780.00
17094.00	18296.00	18968.00	19424.00	17354.00
22146.00	20961.00	19903.00	19764.00	18650.00
21276.00	20643.00	19568.00	21315.00	19477.00
18309.00	20350.00	20134.00	19735.00	18307.00
19099.00	21123.00	21734.00	21506.00	19071.00
17337.00	17151.00	16201.00	14942.00	13777.00
17151.00	16201.00	14942.00	13777.00	14058.00
21252.00	21380.00	20828.00	18496.00	18853.00
18897.00	21910.00	21968.00	21592.00	19914.00
20120.00	18429.00	20732.00	20627.00	18782.00
20768.00	19744.00	18612.00	20299.00	18723.00
20333.00	20730.00	20953.00	19293.00	17875.00
21862.00	21677.00	21327.00	21428.00	18662.00

TABLE II. VLD max forIdulFitri I 2012and 2013

Year	Max WD	LD Max	TLD max	VLD max
2013	16407.8	-16.034	-14.926	-1.1077
2012	15994.5	-17.628	-14.385	-3.2425

B. Processing

The operation of FLS Type-2 is similar withoperation on fuzzy type-1, but FLS Type-2 has FOU whichismembership functionthat is limitedbyUpper Membership Function (UMF) andLower Membership Function (LMF).

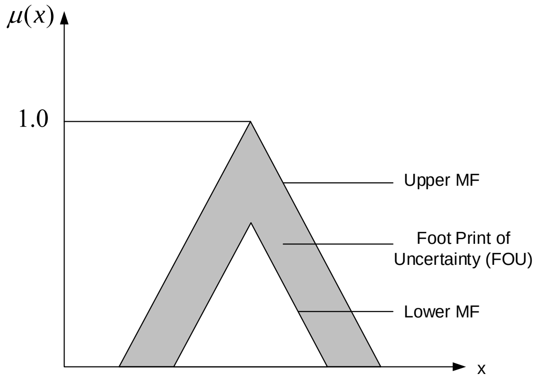

Fig4. FOU fuzzy type 2

The rule of fuzzy IF-THEN is used inthis methodtoforecastpeakloadwhich is declared as follows:

IF X is A_i AND Y is B_i THEN Z is C_i

X and Y inputs byusing IT2MF Editor infuzzificationdesign, there are 11 membership functionswhich are used [7], that is:

Negative Very Big (UNVB and LNVB)
Negative Big (UNB and LNB)
Negative Medium (UNM and LNM)
Negative Small (UNS and LNS)
Negative Very Small (UNVS and LNVS)
Zero (UZE and LZE)
Positive Very Small (UPVS and LPVS)
Positive Small (UPS and LPS)
Positive Medium (UPM and LPM)
Positive Big (UPB and LPB)
Positive Very Big (UPVB and LPVB)

Examples of fuzzy rules can be seen in Table 3.

TABLE III. Fuzzy Rules

No.	Antecendent		Consequent
Rules	X	Y	Z
1	NVS	NVS	NVS
2	PVS	PVS	PVS
3	ZE	NVS	NVS
4	PVS	ZE	ZE
5	PVS	PVS	PVS
6	NVS	PM	PM
7	NVS	PS	PS
8	ZE	PS	PS
9	ZE	ZE	ZE
10	ZE	PM	PM
11	NVS	NVS	NVS
12	PVS	NVS	NVS
13	ZE	PVS	PVS
14	ZE	PVS	PVS

The rule of rule editor intable 3 can be seen as follows:
[R1] IF X is NVS AND Y is NVS THEN Z is NVS
[R2] IF X is PVS AND Y is PVS THEN Z is PVS
[R14] IF X is ZE AND Y is PVS THEN Z is PVS

In choosing fuzzy set using max rule is by taking the biggest valuewhich is appropriate withmembership degree (μ) of input variable (X, Y) and output (Z) on New Year can be seen inTable 4.Valuewhich is madeinto input to X, Y and Z variables areVLDmaxfromholiday data.X isVLDmax (i) fromsimilar holidaybefore forecasting year. Y isVLDmax (i) fromholidaywhich is adjacentin forecasting year. Z is forecast of VLDmax (i). Variablevalue of X,Y and Z is madeasdividerto LMF and UMF parameters.After that, parameter value of LMF and UMF on FOU is optimizedbyusing flower pollination algorithm. X,Y and Z variables can be seeninfigure6,7 and 8.Flowchart of fuzzy type 2–flower pollination algorithm on peak load forecastingon national holidaycan be seen infigure 5.

C. Post-Processing

The next process islooking for*forecast load difference*value which can be declared as follows:

$$Forecast\ LD_{MAX}(i) = Forecast\ VLD_{MAX}(i) + TLD_{MAX}(i) \quad (16)$$

Thenpeak load forecastingon national holidaycan be calculated as follows:

$$P'_{MAX}(i) = MaxWD(i) + \frac{(ForecastLD_{MAX} x MaxWD(i))}{100} \quad (17)$$

To find outthe accuracyofproposed methodthenused absolute error equation. The smaller error which isobtainedindicatesthe used methodis better. Absolute error equation as follows:

$$Error = \left|\frac{P_{forecast} - P_{actual}}{P_{actual}}\right| x100\% \quad (18)$$

$$Error = \left|\frac{P'_{MAX}(i) - MaxSD(i)}{MaxSD(i)}\right| x100\% \quad (19)$$

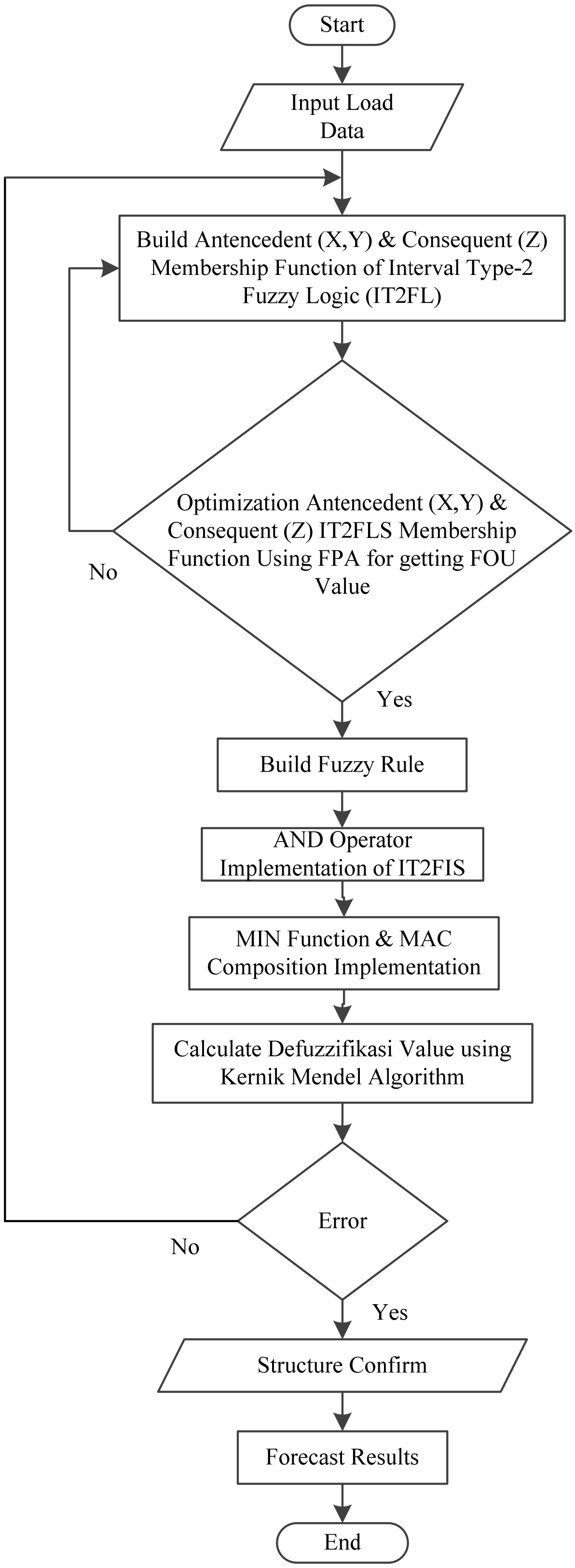

Fig5. Flowchart IT2FL-Flower for Peak Load Forecasting on National Holidays

TABLE IV. Establishment Of Rule Base For Input X in2013

Holidays Name	**Variable**	**VLD max**	**Membership Function (μ)**											**Set of**
			NVB	**NB**	**NM**	**NS**	**NVS**	**ZE**	**PVS**	**PS**	**PM**	**PB**	**PVB**	**X**
Tahun Baru Masehi	X	-3.278377375					0.819594344	0.1804						NVS
	Y	-2.900956448					0.725239112	0.27476						NVS
	Z	-2.900956448					0.725239112	0.27476						NVS

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

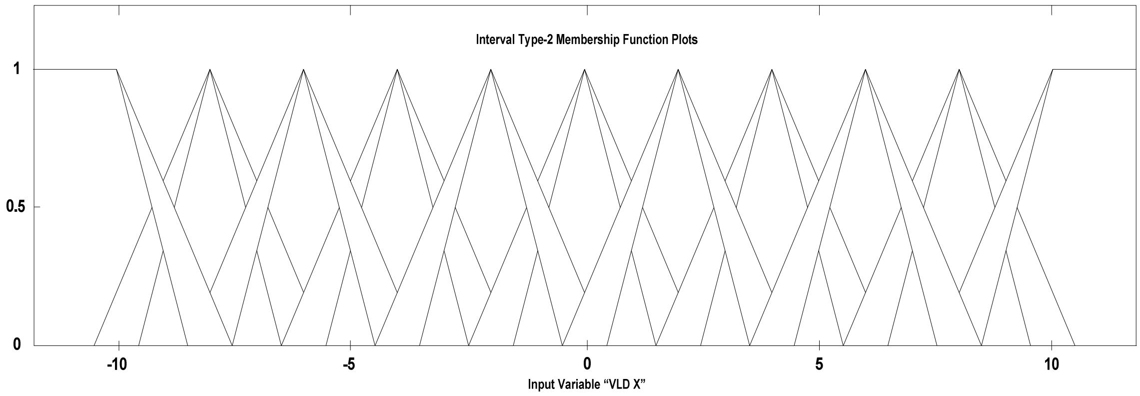

Fig6. Membership Function for Variable Input X T2FIS

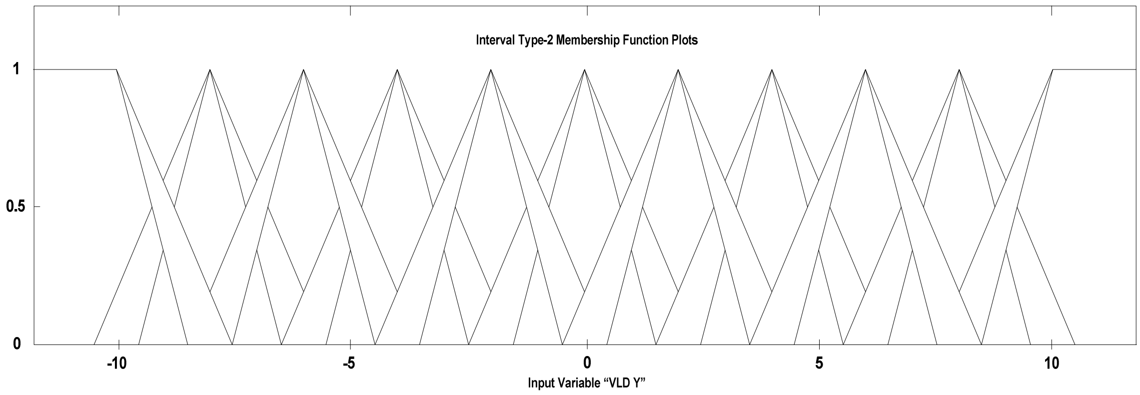

Fig7. Membership Function for Variable Input Y T2FIS

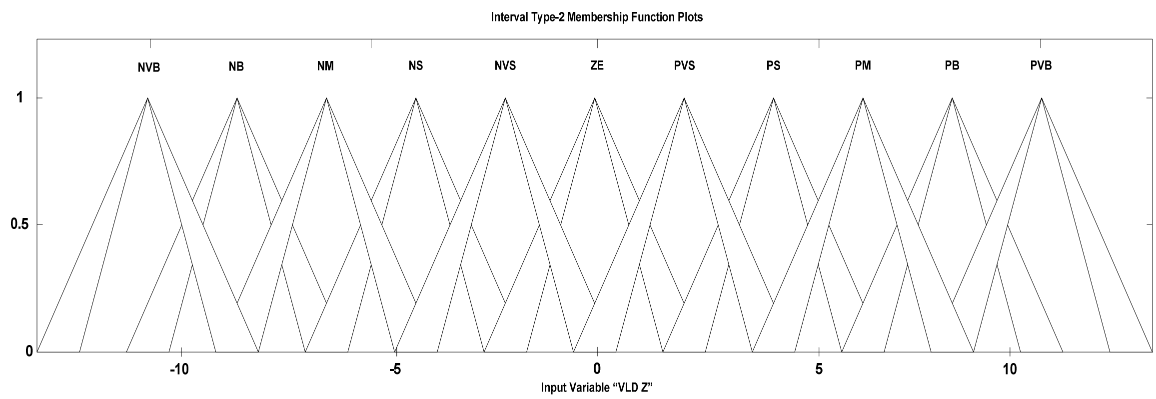

Fig8. Membership Function for Variable Input Z T2FIS

TABLE V. Results of VLD Forecast on National Holidaysin 2013

No	Holidays Name	*VLD Target*	*IT2*		*IT2-BBBC*		*IT2-FPA*	
			VLD	*Error(%)*	*VLD*	*Error(%)*	*VLD*	*Error(%)*
1	Tahun Baru Masehi	-0.4991174	-8.33E-17	0.4991174	2.60E-06	0.49912	2.40E-01	0.73912
2	Proklamasi Kemerdekaan RI	7.747350015	6.335949807	1.411400208	4.44	3.30735	6.2175138	1.529836
3	Idul Adha	1.798096345	3.837074835	2.03897849	1.6614151	0.136681	3.9896189	2.19152
4	Tahun Baru Hijriyah	1.489102443	2.001745655	0.51264321	1.536044	0.04694	1.4243154	0.064787
5	Maulid Nabi Muhammad SAW	2.111023655	0.494734243	1.616289412	0.4001156	1.710908	0.6373916	1.473632
6	Isra Mi'raj	-3.16375486	-4.38197748	1.218222625	-3.50451	0.340755	-3.108501	0.05525
7	Idul Fitri I	-1.10769635	-1.24260006	0.13490371	-3.36655	2.258854	-3.779479	2.671783
8	Idul Fitri II	-1.40378362	0.886052206	2.28983582	-2.096737	0.692953	-1.133795	0.26999
9	Wafatnya Yesus Kristus	0.682841593	2.004636904	1.32179531	0.96	0.27716	1.019094	0.33625
10	Kenaikan Yesus Kristus	-0.7062478	-1.15981594	0.453568141	-1.703642	0.997394	-0.894441	0.188194
11	Natal	2.901465684	2.00412206	0.897343623	1.6857153	1.21575	2.0552808	0.846185
12	Nyepi	2.917586794	-3.99736394	6.914950732	1.7917165	1.12587	2.052196	0.865391
13	Tahun Baru Imlek	-3.09738185	-4.99948118	1.902099329	-4.08	0.982618	-3.331338	0.233956
14	Waisak	-5.97359886	-1.16096757	4.8126313	-3.385094	2.58851	-3.782155	2.19144
Mean Average Percentage Error (MAPE)				**1.858841379**		**1.155775929**		**0.975523857**

TABEL VI. Results of Peak Load forecastingon National Holidaysin 2013

No	Holidays Name	*Actual (MW)*	*IT2*		*IT2-BBBC*		*IT2-FLOWER*	
			Forecast (MW)	*Error(%)*	*Forecast (MW)*	*Absolute Error(%)*	*Forecast (MW)*	*Error(%)*
1	Tahun Baru Masehi	15780.00	15870.823	0.57556	15870.824	0.57556	15914.495	0.85232
2	Proklamasi Kemerdekaan RI	17354.00	17093.66	1.5002	16743.943	3.5154	17071.814	1.6261
3	Idul Adha	18650.00	19071.936	2.26239	18621.716	0.1517	19103.503	2.43165
4	Tahun Baru Hijriyah	19477.00	19583.12	0.54485	19486.717	0.04989	19463.589	0.0689
5	Maulid Nabi Muhammad SAW	18307.00	17989.69	1.7333	17971.115	1.8347	18017.697	1.5803
6	Isra Mi'raj	19071.00	18816.812	1.3329	18999.9	0.3728	19082.529	0.06045
7	Idul Fitri I	13777.00	13754.865	0.1607	13406.373	2.6902	13338.621	3.182

8	Idul Fitri II	14058.00	14413.331	2.52761	13950.469	0.7649	14099.896	0.29802
9	Wafatnya Yesus Kristus	18853.00	19123.823	1.4365	18909.787	0.30121	18921.895	0.36543
10	Kenaikan Yesus Kristus	19914.00	19818.335	0.4804	19703.632	1.0564	19874.307	0.1993
11	Natal	18782.00	18602.738	0.9544	18539.13	1.2931	18612.958	0.9
12	Nyepi	18723.00	17349.985	7.3333	18499.45	1.194	18551.17	0.9177
13	Tahun Baru Imlek	17875.00	17488.356	2.163	17675.261	1.1174	17827.443	0.2661
14	Waisak	18662.00	19700.253	5.56346	19220.431	2.99234	19134.771	2.53334
Mean Average Percentage Error (MAPE)				**2.040612143**		**1.279257143**		**1.091543571**

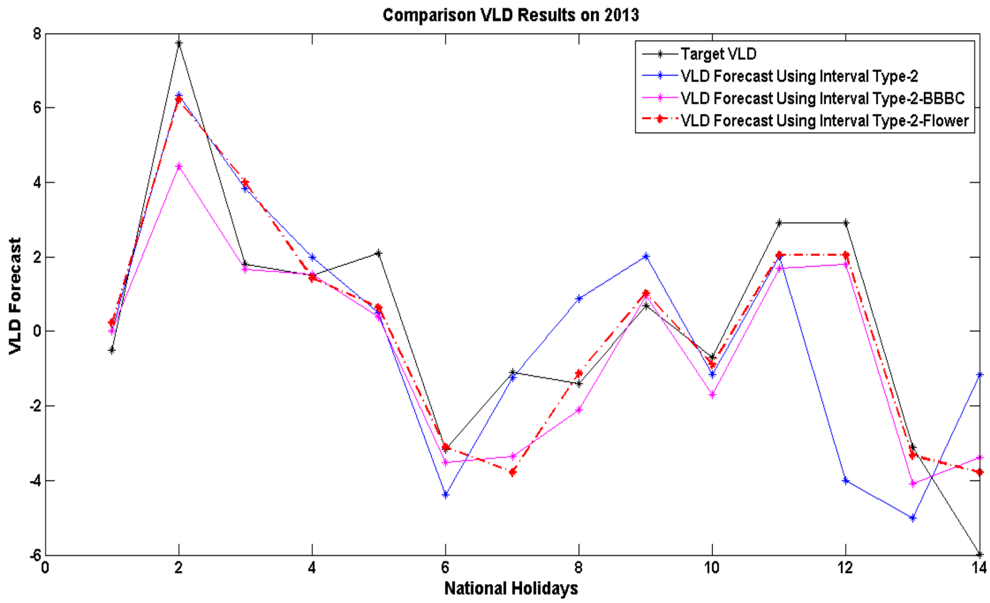

Fig9. Results of VLD Forecastingon National Holidays in 2013

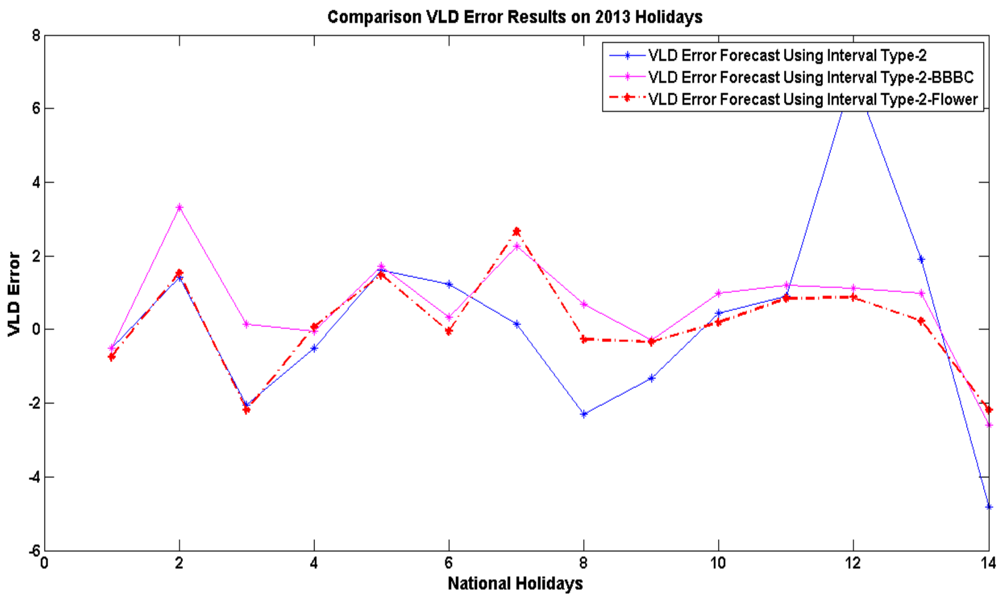

Fig10.Results of VLD Error Forecastingon National Holidays in 2013

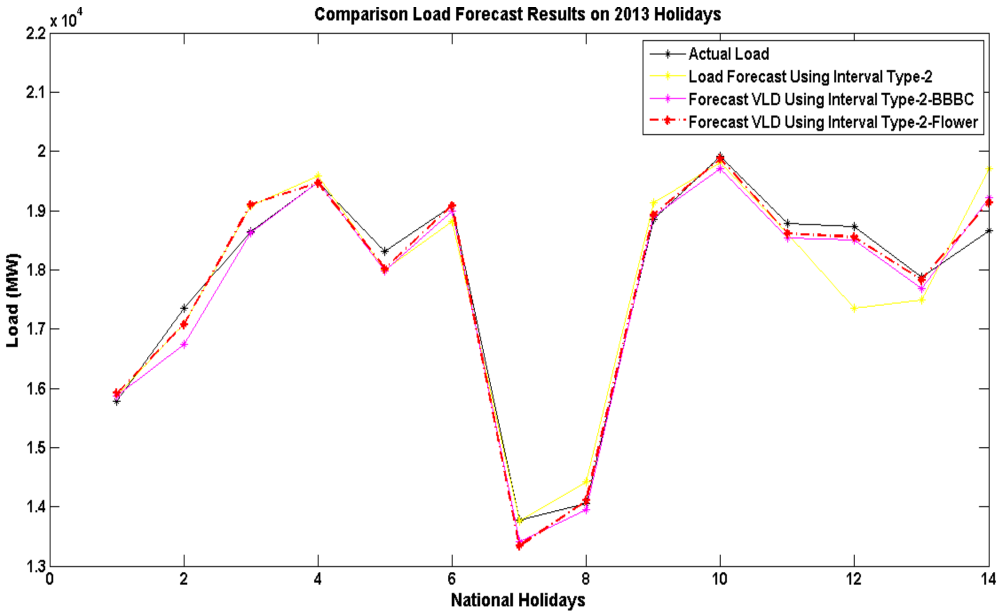

Fig11. Results of Load Forecast for National Holidays in 2013

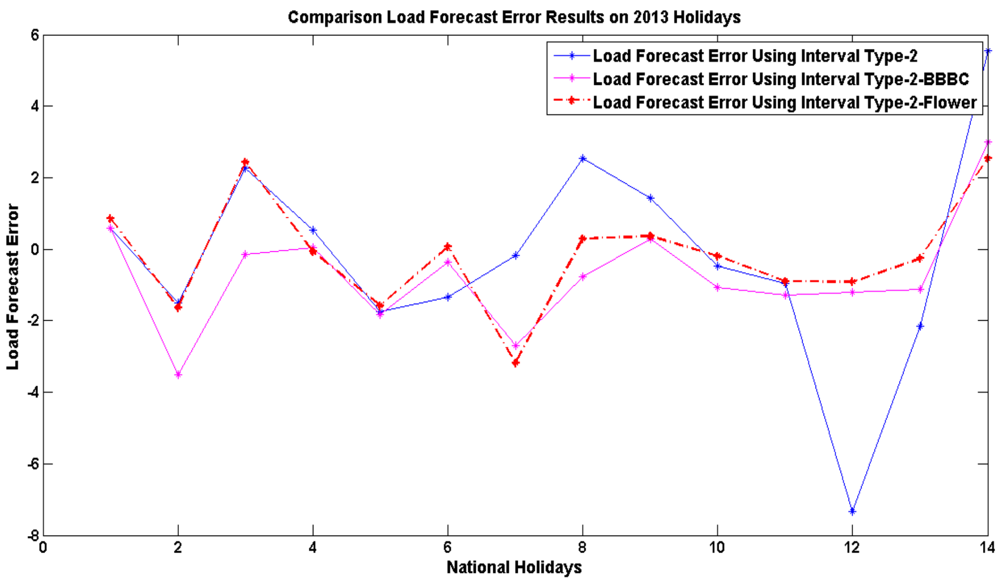

Fig12.Results of Load Forecasting Error onNational Holidays in 2013

V. Result And Analysis

The calculation results of forecasting error Type-2 Fuzzy Logic-Flower Pollination Algorithm using data from various types of load conditions on holidays where this result is just a case of forecasting in 2008 show in Table 5 and 6. Figure 9-12 show the results of the plotting. Interval Type-2 Fuzzy Logic-Flower Pollination Algorithm (IT2FPA) method and several methods such as the Interval Type-2 Fuzzy Logic (IT2FL), Interval Type-2 Fuzzy Logic-Big Bang Big Crunch (IT2FL-BBBC) as a comparison.

The test results by using IT2FPA method as a proposed method for load forecasting have Mean Absolute Percentage Error (MAPE) is 1.091543571%. By using IT2FL, MAPE is 2.040612143%. By using IT2FLBBBC, MAPE is 1.279257143%.

VI. Conclusions

Interval Fuzzy Logic Type-2 method which is optimized by using Flower Pollination Algorithm proposed in this research can be used to forecast the peak load during some holidays in Jawa-Bali system, Indonesia.The method has MAPE which is less than 2%. The method is very useful for operators to set up different scenarios for forecasting method.

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