ISBN 978-623-7525-37-0

Photovoltaic's characteristics modelling based on fuzzy time series

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Abstract

Recently, fulfillment of energy needs is predominated by utilization of fossil energy. Fossil energy is limited resources and less eco-friendly. Based on that, researches began to develop clean energy based on renewable resources, solar as main energy's source for humankind's live is one of them. The potential of solar energy in Indonesia is estimated 207,8 GWp, the largest around other renewable resources. Due to sunshine year-round, Indonesia become suitable place to develop solar-based energy technology, especially photovoltaic (PV). PV is device that is converted solar energy into electricity. PV has its own characteristics, such as ambient temperature, irradiation, humidity, and wind velocity as input parameters and cell temperature, voltage, current, and power as output parameters. All of characteristics can be obtained by direct measurement which need more device and waste time. To simplify in understanding all of these parameters, modelling is needed. This research will be shown PV characteristics modelling based on fuzzy time series (FTS). FTS is one of fuzzy logic method to predict future data based on historical data. The focus of modelling is output parameters, such as voltage (V), current (I), and power (P). The collected data will be divided into some classes with same intervals before fuzzy sets are created. After that, fuzzy logic processes will be done to obtain the modelling results. Margin of Error is obtained by compare of the modelling results and collected data. They are 3,9% for voltage; 24,7% for current at intervals of 0,05 and 34,8% at intervals of 0,2; 21,5% for power at intervals of 7 and 34,8% at intervals of 20.

Keywords: Renewable Energy, Solar Energy, Photovoltaic, Fuzzy Time Series, Margin of Error

1. Introduction

Fulfillment of energy needs is predominated by utilization of fossil fuel of which produces carbon emission. Fossil fuels has two big demerits, which is its limited availability and the carbon dioxide emissions from the fossil fuel combustion (Irsyad et al., 2018). Some of the solutions pushed for decreasing the carbon production are: using a better technology for combustion to reduce greenhouse gas emission, limit the usage of fossil fuels, increase efficiency of combustion, and increase the efficiency of combustion, and increase the usage of renewable energy (Irsyad et al., 2018).

One of prominent renewable energy is solar energy. The potential of solar energy in Indonesia is estimated 207,8 GWp (BPPT: Indonesia Energy Outlook, 2018), the largest around other renewable resources. Devices that can convert solar energy into electricity directly is photovoltaic (PV). PV or solar cells and their concomitant energy systems have repeatedly demonstrated extreme viability and durability over the past quarter century in thousands of earth satellites, space missions, and more recently, terrestrial applications (Jr., 1982).

PV is a source of energy very sensitive to climatic variations, such as cloud motion and surrounding weather. It can affect PV's performance to produce electricity (Severiano et al., 2017). Therefore, analyzing PV's characteristics is important to done, so that the best performances of PV can be attained. There are input parameters (irradiation, ambient temperature, humidity, wind velocity) and output parameters (cell temperature, voltage, current, power) that is needed to obtained to explain PV's characteristics. All of these parameters can be obtained by both direct measurement and modelling. To simplify researchers' work, modelling is needed.

This paper will describe PV's characteristics by Fuzzy Time Series (FTS). The modelling system with FTS captures patterns from past data, then is used to project future data, the process also does not require a complicated system as in genetic algorithms and neural networks, making it easy to develop (Haris, 2010).

This modelling will focus on output parameters of PV systems (voltage, current, and power).

2. Research methodology

This modelling used Chen method FTS (Chen, 1996). This method is impovement of Song method FTS which is proposed to predict number of enrollments of the University of Alabama (Song and Chissom, 1993).

Historical data is obtained by direct measurement Itenas Solar Power Plant, as can be seen in Fig. 1. It collected 721 data for each charcteristics (V, I, and P) as can be seen in Table 1. The measurement is held on December 31, 2018 from 6 a.m. until 6 p.m.

Fig. 1: Itenas Solar Power Plant Instalation

Table 1: Direct Measurement on December 31 2018

Time (WIB)	Voltage /V (V)	Current/I (A)	Power/P (Watt)
06.00	111	0,151	16,761
06.01	118,9	0,157	18,6673
07.01	115,4	0,763	88,0502
08.01	119,6	2,051	245,2996
09.01	118,6	3,616	428,8576
10.01	116,8	2,07	241,776
11.01	123,2	4,25	523,6
12.01	112,7	4,65	524,055
13.01	111,5	2,839	316,5485
14.01	118,5	7,05	835,425
15.01	117,7	1,606	189,0262
16.01	118,6	0,625	74,125
17.01	136,3	0,552	75,2376
18.00	104,7	0,074	7,7478

The modelling results will be shown after modelling is done. Then, it is important to obtain Margin of Error (MoE) by comparing direct measurement data and modelling results.

2.1 Divison of Data

Direct measurement data is divided into several division in the same intervals. Voltage is divided into 11 divisions at intervals of 4; current is divided into 191 divisions at intervals of 0,05 and 50 divisions at intervals 0,2; power is divided into 151 divisions at intervals of 7 and 53 divisions at intervals of 20. The division of data can be seen in Table 2. This divisions will become basic of fuzzy sets division.

Table 2: Divisions of Direct Measurement Data

Voltage			Current						Power					
			Intervals 0,05			Intervals 0,2			Intervals 7			Intervals 20		
Divisions	Min.	Max.	Divisions	Min.	Max.	Divisions	Min.	Max.	Divisions	Min.	Max.	Divisions	Min.	Max.
U1	100	103	U1	0,02	0,06	U1	0	0,1	U1	3	9	U1	3	22
U2	104	107	U2	0,07	0,11	U2	0,2	0,3	U2	10	16	U2	23	42
U3	108	111	U3	0,12	0,16	U3	0,4	0,5	U3	17	23	U3	43	62
U4	112	115	U4	0,17	0,21	U4	0,6	0,7	U4	24	30	U4	63	82

U5	116	119	U5	0,22	0,26	U5	0,8	0,9	U5	31	37	U5	83	102
U6	120	123	…	…	…	…	…	…	…	…	…	…	…	…
U7	124	127	U187	9,32	9,36	U46	9	9,1	U147	1025	1031	U49	963	982
U8	128	131	U188	9,37	9,41	U47	9,2	9,3	U148	1032	1038	U50	983	1002
U9	132	135	U189	9,42	9,46	U48	9,4	9,5	U149	1039	1045	U51	1003	1022
U10	136	139	U190	9,47	9,51	U49	9,6	9,7	U150	1046	1052	U52	1023	1042
U11	140	143	U191	9,52	9,56	U50	9,8	9,9	U151	1053	1059	U53	1043	1062

2.2 Fuzzy Sets Division

FTS is fuzzy logic method. Therefore, it is important to define all of data into fuzzy sets. Fuzzy sets division can be seen in Table 3.

Table 3: Fuzzy Sets Division

Voltage			**Current**						**Power**					
			Intervals 0,05			**Intervals 0,2**			**Intervals 7**			**Intervals 20**		
Fuzzy Sets	**Linguistic Values**	**Center Values**	**Fuzzy Sets**	**Linguistic Values**	**Center Values**	**Fuzzy Sets**	**Linguistic Values**	**Center Values**	**Fuzzy Sets**	**Linguistic Values**	**Center Values**	**Fuzzy Sets**	**Linguistic Values**	**Center Values**
A1	100	102,15	A1	0,02	0,0451	A1	0	0.1	A1	3	13.185	A1	3	13.185
A2	104,3	106,45	A2	0,0702	0,0953	A2	0,2	0.3	A2	23,37	33.555	A2	23,37	33.555
A3	108,6	110,75	A3	0,1204	0,1455	A3	0,4	0.5	A3	43,74	53.925	A3	43,74	53.925
A4	112,9	115,05	A4	0,1706	0,1957	A4	0,6	0.7	A4	64,11	74.295	A4	64,11	74.295
A5	117,2	119,35	A5	0,2208	0,2459	A5	0,8	0.9	A5	84,48	94.665	A5	84,48	94.665
A6	121,5	123,65	…	…	…	…	…	…	…	…	…	…	…	…
A7	125,8	127,95	A187	9,3572	9,3823	A46	9	9,1	A49	980,76	990,945	A147	1030,84	1034,36
A8	130,1	132,25	A188	9,4074	9,4325	A47	9,2	9,3	A50	1001,13	1011,315	A148	1037,88	1041,4
A9	134,4	136,55	A189	9,4576	9,4827	A48	9,4	9,5	A51	1021,5	1031,685	A149	1044,92	1048,44
A10	138,7	140,85	A190	9,5078	9,5329	A49	9,6	9,7	A52	1041,87	1052,055	A150	1051,96	1055,48
A11	143	-	A191	9,558	-	A50	9,8	-	A53	1062,24	-	A151	1059	-

The number of fuzzy sets division is same as the division of direct measurement data. Center values is mean between An and An+1.

2.3 Fuzzification

Fuzzification is process that converts numerical value into linguistic value. For example, voltage in 6 a.m is 111 Volt, this value is higher than center values between A3 and A4 and lower than center values between A4 and A5 as can be seen in Table 3, therefore fuzzification of 6 a.m data is A4. All of fuzzification can be seen in Table 4.

Table 4. Fuzzification

Time (WIB)	**V (V)**	**Fuzzification of V**	**I (A)**	**Fuzzification of I at Intervals of 0,05**	**Fuzzification of I at Intervals of 0,2**	**P (Watt)**	**Fuzzification of P at Intervals of 7**	**Fuzzification of P at Intervals of 20**
06.00	111	A4	0,151	A4	A2	16,761	A3	A2
06.01	118,9	A5	0,157	A4	A2	18,6673	A3	A2
06.02	111,5	A4	0,161	A4	A2	17,9515	A3	A2
06.03	112,1	A4	0,168	A4	A2	18,8328	A3	A2

06.04	108,1	A3	0,164	A4	A2	17,7284	A3	A2
06.05	110,6	A3	0,169	A4	A2	18,6914	A3	A2
06.06	110,4	A3	0,173	A4	A2	19,0992	A3	A2
06.07	116,7	A5	0,171	A4	A2	19,9557	A3	A2
…	…	…	…	…	…	…	…	…
17.57	113,2	A4	0,099	A3	A1	11,2068	A2	A1
17.58	105,2	A2	0,089	A2	A1	9,3628	A2	A1
17.59	112,8	A4	0,08	A2	A1	9,024	A2	A1
18.00	104,7	A2	0,074	A2	A1	7,7478	A2	A1

2.4 Fuzzy Logic Relationships (FLR) and Fuzzy Logic Relationship Groups (FLRG)

Relation between each time series is must be done. It is called Fuzzy Logic Relationships (FLR) as can be seen in Table 5. After that, FLR which has same current state is grouped into same Fuzzy Logic Relationships Group (FLRG) as can be seen in Table 6.

Table 5: Fuzzy Logic Relationships

Time Series	Current State V	Next State V	Current State of I at Intervals of 0,05	Next State of I at Intervals of 0,05	Current State of I at Intervals of 0,2	Next State I of at Intervals at 0,2	Current State of P at Intervals of 7	Next State of P at Intervals of 7	Current State of P at Intervals of 20	Next State of P Intervals of 20
06.00 → 06.01	A4	A5	A4	A4	A2	A2	A3	A3	A2	A2
06.01 → 06.02	A5	A4	A4	A4	A2	A2	A3	A3	A2	A2
06.02 → 06.03	A4	A4	A4	A4	A2	A2	A3	A3	A2	A2
06.03 → 06.04	A4	A3	A4	A4	A2	A2	A3	A3	A2	A2
06.04 → 06.05	A3	A3	A4	A4	A2	A2	A3	A3	A2	A2
06.05 → 06.06	A3	A3	A4	A4	A2	A2	A3	A3	A2	A2
…	…	…	…	…	…	…	…	…	…	…
17.55 →17.56	A3	A4	A3	A3	A2	A2	A3	A2	A2	A2
17.56 →17.57	A4	A2	A3	A3	A2	A2	A2	A2	A2	A1
17.57 →17.58	A2	A4	A3	A3	A2	A1	A2	A2	A1	A1
17.58 →17.59	A4	A2	A3	A2	A1	A1	A2	A2	A1	A1
17.59 →18.00	A2	A4	A2	A2	A1	A1	A2	A2	A1	A1
17.59 → 18.00	A4	A2	A2	A2	A1	A1	A2	A2	A1	A1

Table 6: Fuzzy Logic Relationships Group

Voltage		Current				Power			
		Intervals of 0,05		Intervals of 0,2		Intervals of 7		Intervals of 20	
Current State	***Next State***	***Current State***	***Next State***	***Current State***	***Next State***	***Current State***	***Next State***	***Current State***	***Next State***
A2	A4	A1	A2	A1	A1 A4 A8	A1	A1 A2 A12 A24	A1	A1 A5 A9
A3	A3 A4 A5	A2	A2 A14 A29	A2	A1 A2 A3 A4	A2	A1 A2	A2	A1 A2 A3 A4
A4	A2 A3 A4 A5 A6	A3	A2 A3	A3	A2 A3 A4	A3	A2 A3 A4	A3	A2 A3 A4
A5	A3 A4 A5 A6 A7 A10	A4	A3 A4 A5	A4	A3 A4 A5	A4	A3 A4 A5	A4	A3 A4 A5
A6	A4 A5 A6 A7 A10	…	…	…	…	…	…	…	…
A7	A5 A6	A121	A168	A46	A44	A142	A135	A50	A47
A9	A4 A5 A9	A122	A94 A124	A47	A25	A145	A82 A133	A51	A29 A47
A10	A5 A6 A10	A123	A130	A49	A39	A151	A119	A53	A42

2.4 Defuzzification

Deffuzification is process that convert linguistic values into numerical values. It is the last step of FTS method. The modelling results is obtained on this step. On this modelling, defuzzification is mean values of next state's linguistic values on each current states. For example, next states of A7 in voltage are A5 and A6, linguistic values for each next states as can be seen in table 3 are 117,3 Volt and 121,5 Volt. Therefore, deffuzification for A7 in voltage is 119,35 Volt. All of deffuzifications can be seen in Table 7.

Table 7: Defuzzification

Voltage		Current				Power			
		Intervals of l 0,05		Intervals of 0,2		Intervals of 7		Intervals of 20	
Current State	Defuzzification	Current State	Defuzzification	Current State	Defuzzification	Current State	Defuzzification	Current State	Defuzzification
A2	112,9	A1	0,0702	A1	0.666666667	A1	64,6	A1	64,6
A3	112,9	A2	0,7228	A2	0.3	A2	6,52	A2	6,52
A4	112,9	A3	0,0953	A3	0.4	A3	17,08	A3	17,08
A5	120,7833333	A4	0,1706	A4	0.6	A4	24,12	A4	24,12
A6	123,22	…	…	…	…	…	…	…	…
A7	119,35	A121	8,6042	A46	8.6	A142	946,36	A50	940,02
A9	121,5	A122	4,8392	A47	4.8	A145	752,76	A51	756,69
A10	125,8	A123	7,55	A49	7.6	A151	833,72	A53	838,17

3. Results

Comparation between direct measurement data and modelling results can be seen on Fig. 2, Fig. 3, and Fig. 4.

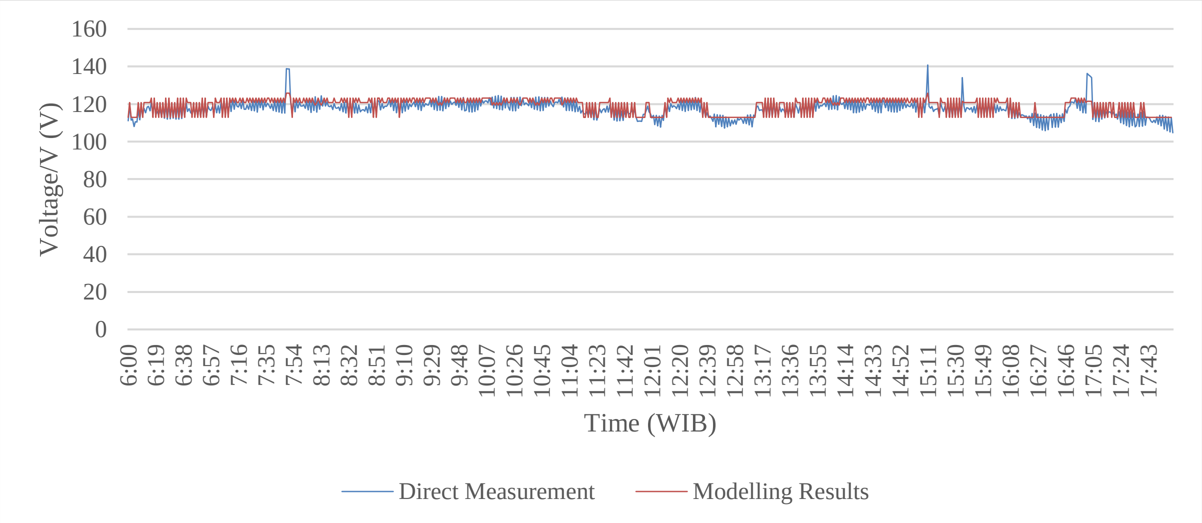

Fig. 2: Direct Measurement and Modelling Results Comparison for Voltage

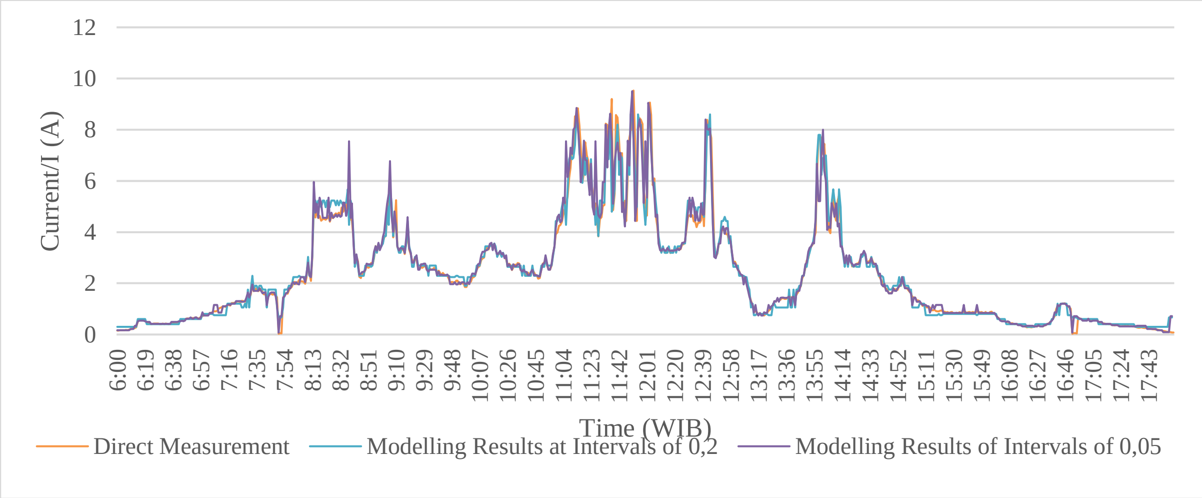

Fig. 3: Direct Measurement and Modelling Results Comparison for Current

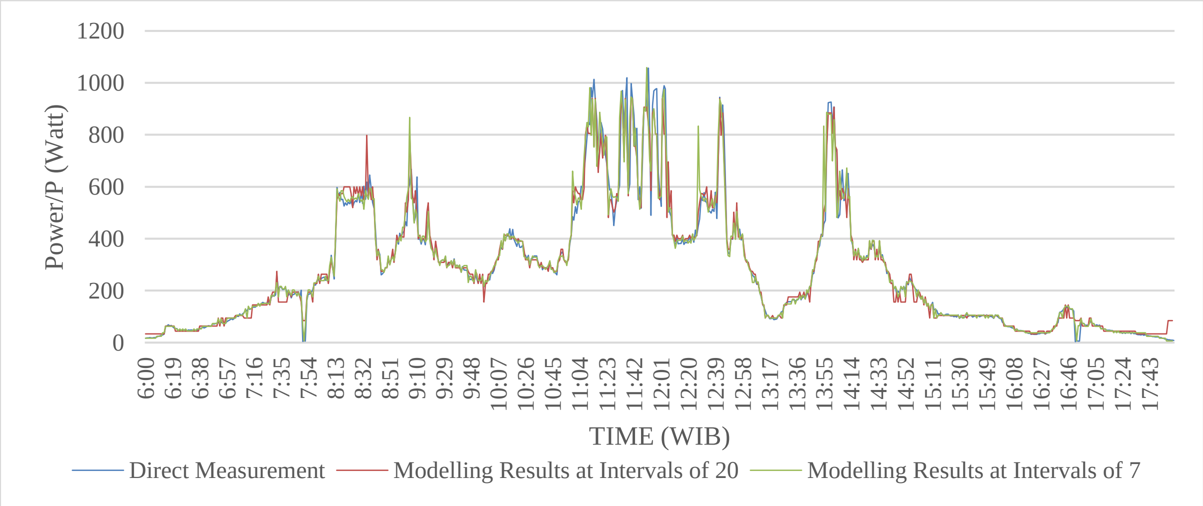

Fig. 4: Direct Measurement and Modelling Results Comparison for Power

4. Conclusion

Margin of Error (MoE) for each modelling is obtained by comparing the modelling results and direct measurement data. They are 3,9% for voltage; 24,7% for current at intervals of 0,05 and 33,1% at intervals of 0,2; 21,5% for power at intervals of 7 and 34,8% at intervals of 20. The modelling of voltage has the lowest MoE. It can be seen that voltage data is not as fluctuate as current and power data. It is clearly stated that the fluctuation in collected data will influence of the MoE. Narrow interval is needed in fluctuate data in order to obtain lower of MoE.

5. Nomenclature

I	Current	A
G	Irradiation	W/m^2
P	Power	Watt
Tc	Cell temperature	^0C
V	Voltage	V

Subscripts

MoE	Margin of Error
WIB	*Waktu Indonesia Barat* (Western Indonesian Time)

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