PENENTUAN DIMENSI TURBIN ANGIN DAN RASIO GEAR BERBASIS LOGIKA FUZZY DI JALAN RAYA KALIGAWE

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OPTIMIZING POWER PRODUCTION OF HIGHWAY WIND TURBINE USING FUZZY LOGIC

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ABSTRACT

This paper discusses the optimization of highway wind turbine power. In this study, the results of the study of the prototype of the higway wind turbine (HWWT) model were used as input to perform analysis based on fuzzy logic. At very low wind speeds at 3 m/s, it will be formulated with turbine blade dimensions and gear sizes to get optimal results using fuzzy Mamdani. Fuzzy logic is used to determine power production based on the parameters, such as; turbine dimensions, gear ratios, and wind speed. A Simulink Matlab has been used in order to analyze the proposed works. There are 2 types of sizes used in HWWT, namely the blade dimension of 20 cm and the dimension of 60 cm; gear dimensions 28 and 60. The results show that power production is 3.47 watt on a blade dimension of 20 cm with a gear size of 28 cm and a wind speed of 3 m/s. While the blade dimension is 20 cm with a gear size of 60 cm and a wind speed of 3 m/s, power production is 7.13 watt. Therefore, an optimization of power production in low level wind speeds is possible in HWWT by applied of Fuzzy Mamdani analysis.

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1. INTRODUCTION

Wind energy generation is growing rapidly around the world and will continue to do so for the foreseeable future [1][2]. a Researchers are working to maximize the conversion of energy available from winds that exist around the world [3][4]. One of the very available sources of wind energy and renewable energy sources is the wind turbulence created by vehicles on the highway which can help generate electrical energy [5][6].

The problem is how to transmit energy in the form of local wind energy into potential electrical energy [7]. Small-scale utilization of this type of energy can generate enough electricity for a renewable energy system on the highway [8][9]. Meanwhile, in large scale applications it can be connected to the grid [10].

The solution to this problem is to optimize the vertical axis wind turbine with low wind speed [11][12][13]. In addition, the vertical axis wind turbine (VAWT) rotates more effectively as the number of passing vehicles increases [14]. The calculation of wind energy from highway wind turbines [15]. shows that the wind power extracted from the highway increases when the vehicle passes through the highway as compared to no moving vehicle. While the wind direction on both sides of the rotor is opposite due to the opposite motion of the vehicle, and vice versa the aerodynamic force can move the rotor [16][17].

Previous research discusses the New Toll Highway Wind Power Plant . This study uses magnetic levitation techniques in the system to rotate turbines at low wind speeds [18]. In the research of vertical shaft wind turbines as an alternative energy for street lighting a prototype test of the three-blade and two-bladed savonius vertical shaft wind turbine showed that the performance of the three-blade wind turbine was better than the two-blade rotor from theoretical calculations [19]. The effect of torsion angle on the performance of the savonius wind turbine aims to determine the performance characteristics and shape of the Savonius helical wind turbine at various helical angles in the study of the effect of torsion angle on the performance of the Savonius wind turbine [20]. development of windmills that work on the principle of highway wind energy based on the study of the potential of wind energy from the highway [21]. Calculating numerically the amount of power that can be extracted from the local highway wind due to vehicle movement using the unsteady Reynolds-averaged Navier - Stokes (URANS) method for modeling the atmospheric boundary layer (ABL), the results show that the average extraction power increases by about 317% when compared to without vehicle movement [22]. To evaluate the performance of VAWT and to determine the interaction mechanism between a moving vehicle and a turbine, with a three-dimensional fluid dynamics computation simulation based on the Reynolds-Averaged Navier eStokes equation, the results show that the maximum average power coefficient is 0.00464, which corresponds to an average power of 139 , 60 W [23]. In the Design and Fabrication of Vertical Axis Toll Road Windmills the design can start rotating in a wind speed of 5 mph in a speed of 7 mph [24]. Design and analyze a VAWT model that utilizes wind turbines generated by road traffic using Pro/E and CFD software [25]. The use of wind turbines on the highway to store, provide and distribute electricity for the highway and surrounding areas The idea is to install a small wind generator (with a diameter of 8 cm) inside a concrete block that functions as a guard (barrier) on the highway (in the middle and side) to generate electricity with wind generated by vehicles passing on the highway [26]. Research on the optimization of the design and analysis of wind turbines as an alternative technology used for highway lighting. The results of the design show that the Darrieus type vertical wind turbine is optimal for highway lighting with two turbine blades, 300 turbine blade torsion angles, a rotor diameter of 300. 350 mm, and a rotor height of 1,050 mm for an average wind speed of 2.1 m / s with the power generated by the wind turbine of 1.908 Wh [27].

Several previous studies regarding wind turbine control used fuzzy logic. Simulates the dynamics of wind system behavior, suitable mathematical models for horizontal axis wind turbines and synchronous generators [28][29]. Fuzzy logic control of variable speed wind turbines with multiple induction generators (DFIG) [30][31][32]. Permanent magnet synchronous generator (PMSG) based wind turbine control to improve transient stability during grid disturbances [33]. Improve the short-term frequency response capability of the DFIG -energy storage system [34].

Several researchers have analyzed and conducted trials on highway wind turbines with several existing methods, but none have used fuzzy logic to analyze the optimization of highway wind turbines at low wind speeds. In this paper, fuzzy logic method is used to optimise the power of highway wind turbines based on the dimensions of blade arm length, gear ratio and wind speeds are proposed.

2. RESEARCH PROPOSED METHOD

2.1. The Highway wind turbine

The Highway wind turbine is an alternative energy technology capable of converting wind energy on the highway into electrical energy. The wind turbine has two types, namely the vertical axis wind turbine and the horizontal type. The working principle of the horizontal axis type wind turbine is based on the lifting force of wind energy and the vertical axis type wind turbine based on the pulling force caused by wind movement [35].

The vertical axis turbine technology can be used as an alternative technology for highway wind energy conversion. In addition, the vertical axis wind turbine has the advantage that it has the capability to withstand turbulence flow and allows it to rotate easily in low wind flows [27].

2.2. System Model Analysis

This paper focuses on the analysis of fuzzy logic in highway turbine models. This research begins with the stage of determining the research model consisting of a turbine model input, then analysis using fuzzy logic, then producing the turbine model output and power output as shown in Figure 1.

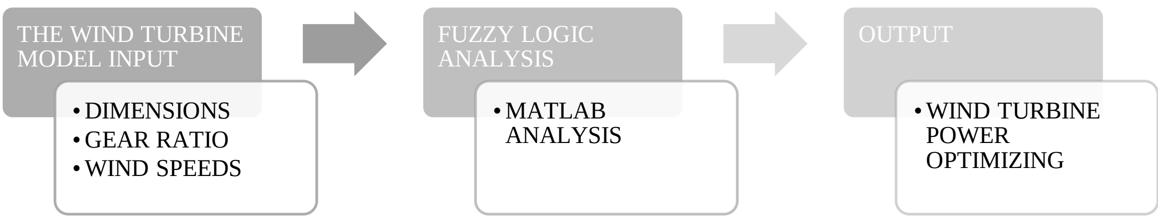

Figure 1. Highway Wind Turbine Analysis Model

The input model consists of wind turbine dimensions, gear ratios, and wind speed. While in the fuzzy logic process optimization analysis of highway wind turbines is carried out using Fuzzy Mamdani algorithm. The output is highway wind turbine power optimizing.

2.3. Wind Turbine Model

The wind turbine model to be used is the savonius type vertical axis wind turbine in this study [36] as shown in Figure 2.

Figure 2. Vertical Wind Turbine Model [36]

As a reference, the measurement results in the research [36] are as shown in Table 1:

Table 1. Measurement Result in Research [36]

DIMENSIONS OF BLADE (cm)	GEARS	WIND SPEEDs (m/s)	POWER EXPERIMENT [33] (W)	FUZZY LOGIC OPTIMIZATION (W)
84	60	6.5	6	6.71
64	28	8	5.08	5.83
64	60	4.5	6	6.73

The specifications are as shown:

a. Arm length 84 cm with a gear ratio of 60: 1 at a wind speed of 6.5 m/s produces a maximum power of 6 watts.

b. Arm length 64 cm with a gear ratio of 28: 1 at a wind speed of 8 m/s produces a maximum power of 5.08 watts.

c. Arm length 64 cm with a gear ratio of 60: 1 at a wind speed of 4.5 m/s produces a maximum power of 6 watts.

Table 1 shows that the average value of the Mean Squared Error (MSE) is 0.53. From the maximum data, the existing data is 6.73 watts.

2.4. Highway Wind Turbine Model

The field observation data has resulted in the potential wind energy of the vehicle with an average wind speed of 3 m/s, so the turbine dimensions are as shown in Table 2:

Table 2. Field Observation Data of Experimental

DIMENSIONS OF BLADE (cm)	GEAR	WIND SPEED (m/s)
20	28	3
20	60	3

The dimensions of the turbine with a blade arm length of 20 cm correspond to the location of the highway wind turbines with a gear ratio of 28 to 60 and a wind speed of 3 m/s.

3. RESULTS AND DISCUSSIONS

Analysis of the power generated by the wind turbine model based on highway wind speed using fuzzy logic. In fuzzy analysis matlab, there are 3 steps of processes such as fuzzification, fuzzy rule base, fuzzy inference engine. The following are the results of the research:

a. Fuzzyfication

In the turbine reference model it is assumed that the variable input is the turbine, gear, and wind speed, while the variable output is power. Then we can explain the parameters for input and output fuzzfication as Figure 3.

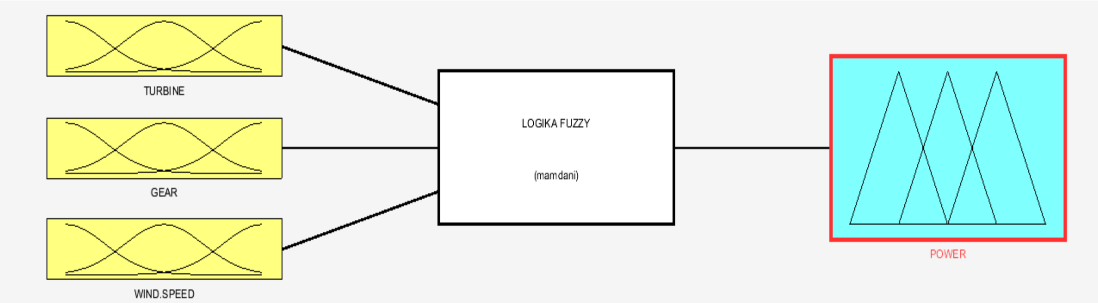

Figure 3. Highway Wind Turbine Optimization Fuzzyfication

b. Fuzzy Ruled Base

The formation of a fuzzy knowledge base is represented by a group of rules in the form of an IF-THEN statement in the rule of the wind turbine voltage fuzzy system as shown.

[r1] If Short Turbine And Small Gear And Low Wind Then Low Power

[r2] If Short Turbine And Small Gear And High Wind Then High Power

[r3] If Short Turbine And Big Gear And Low Wind Then High Power

[r4] If Short Turbine And Big Gear And High Wind Then High Power

[r5] If Long Turbine And Small Gear And Low Wind Then Low Power

[r6] If Long Turbine And Small Gear And High Wind And Low Power

[r7] If Long Turbine And Big Gear And Low Wind Then High Power

[r8] If Long Turbine And Big Gear And High Wind Then High Power

c. Fuzzy Inference Engine
Fuzzy Inference Engine is used to evaluate and represent all rules simultaneously to generate conclusions. In the inference engine, the MIN function is applied to each rule in the application, the implication is that if in the form of a rule if – then use min while or max function, or then the max function is applied in figure 4.

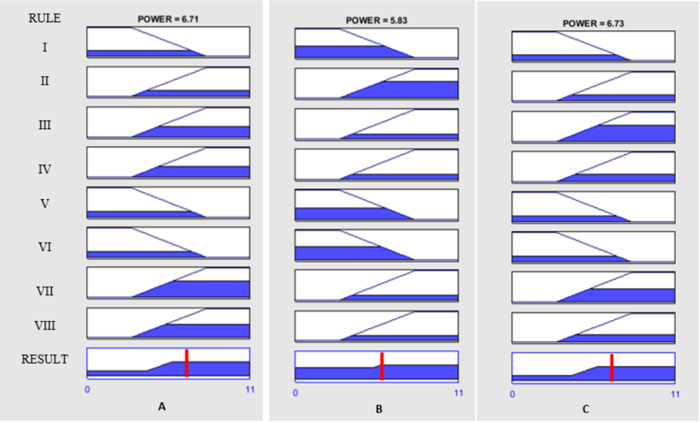

Figure 4. Fuzzy Inference Engine on the turbine reference model

The results of the Fuzzy Inference Engine on the turbine reference model in the Figure 4 are:

a. In the matlab simulation with an arm length of 84 cm with a gear ratio of 60: 1 at a wind speed of 6.5 m/s, it produces 6.71 watt while in the turbine model the resulting power is 6 watt as shown in Figure 4A.
b. In the matlab simulation with an arm length of 64 cm with a gear ratio of 28: 1 at a wind speed of 8 m / s, it produces 5.83 watt while in the turbine model the resulting voltage is 5.08 watt as shown in Figure 4B.
c. In the matlab simulation with an arm length of 64 cm with a gear ratio of 60: 1 at a wind speed of 4.5 m / s, it produces a power of 6.73 watt while in the turbine model the resulting voltage is 6 watt as shown in Figure 4C.

So that the average value of the Mean Squared Error (MSE) is 0.53. From the maximum data, the existing data is 6.73 watt.

The results of the Fuzzy Inference Engine on the the highway wind turbine in the Figure 5 are:

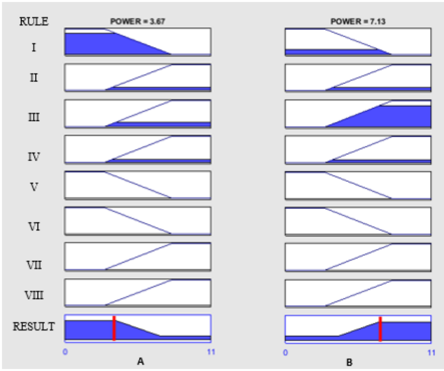

Figure 5. Fuzzy Inference Engine on the highway turbine

The results of the Fuzzy Inference Engine on the highway wind turbine in the Figure 5 are:

a. Figure A on a blade dimension of 20 cm with a gear of 28 cm and a wind speed of 3 m/s shows the result of 3.67 watts.
b. Figure B on a blade dimension of 20 cm with a gear of 60 cm and a wind speed of 3 m/s shows the result of 7.13 watts.

In fuzzy logic analysis, there are four stages of mathematical calculations fuzzification, fuzzy rule base, fuzzy inference engine, and defuzzification. The following are the results of a mathematical research.

a. Fuzzification
In the fuzzification analysis of the input variables on the turbine dimensions, gear ratios and wind speed and the output variables on the power, namely:
1. The input variable dimensions of the turbine consist of 2 fuzzy sets, namely SHORT and LENGTH which is shown in Figure 6 with the degree of membership for the blade length of 20 cm :

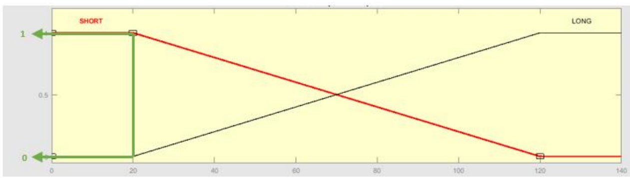

Figure 6. The input variable dimensions of the turbine

µ SHORT 20 cm = (120 - 20) / (120 - 20) = 1
µ LENGTH 20 cm = (20 - 20) / (120 - 20) = 0
Based on the calculation, the membership function value for the blade length of 20 cm is 1 while the height is 0.

2. The input variable gear ratio 28, input variable which consists of 2 fuzzy sets, namely SMALL and BIG which is shown in Figure 7 with the degree of membership for the gear ratio 28 :

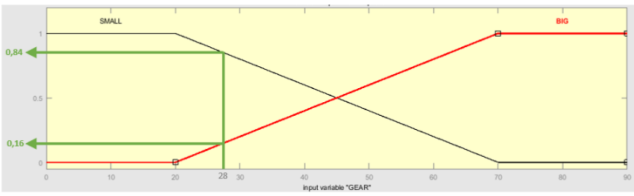

Figure 7. The input variable gear ratio 28

µ SMALL 28 cm = (70 - 28) / (70 - 20) = 0.84

µ BIG 28 cm = (28 - 20) / (70 - 20) = 0.16

Based on the calculation, the membership function value for the gear ratio size 28 is the low limit of 0.84 while the high limit is 0.16.

3. The input variable gear ratio 60, which consists of 2 fuzzy sets, namely SMALL and BIG which is shown in Figure 8 with the degree of membership for the gear ratio 60 is.

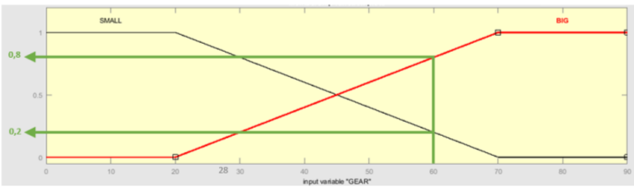

Figure 8. The input variable gear ratio 60

µ SMALL 60 cm = (70 - 60) / (70 - 20) = 0.2

µ BIG 60 cm = (60 - 20) / (70 - 20) = 0.8

Based on the calculation, the membership function value for the gear ratio size 60 is the low limit of 0.2 while the high limit is 0.8.

4. The input variable wind speed input variable which consists of 2 fuzzy sets, namely LOW and HIGH, which is shown in Figure 9 with the degree of membership for a wind speed of 3 m/s is.

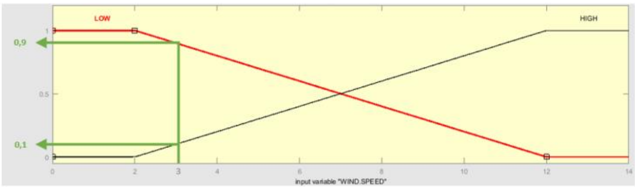

Figure 9. The input variable gear ratio 28

µ LOW 3 m / s = (12 - 3) / (12 - 2) = 0.9

µ HIGH 3 m / s = (3 - 2) / (12 - 2) = 0.1

Based on the calculation, the membership function value for the wind speed of 3 m / s is the low limit of 9.8 while the high limit is 0.1.

5. The voltage output variable which consists of 2 fuzzy sets, namely LOW and HIGH which is shown in Figure 10 with the degree of membership for a wind speed of 3 m/s is.

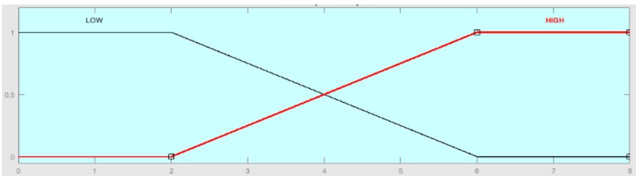

Figure 9. The voltage output variable

Based on the calculation, the membership function value for the output voltage is obtained.

$$\mu\, VOLTAGE\ LOW\ (X) = \begin{pmatrix} 1 & X \leq 3 \\ \frac{8-X}{8-3} & 3 < X < 8 \\ 0 & 8 \leq X \end{pmatrix} \mu\, VOLTAGE\ HIGH\ (X) = \begin{pmatrix} 1 & 8 \leq X \\ \frac{X-3}{8-3} & 3 < X < 8 \\ 0 & X \leq 8 \end{pmatrix}$$

b. fuzzy rule base

The formation of a fuzzy rule base is represented by a collection of rules in the form of an IF-THEN statement. The rule of fuzzy determination system power wind turbine is as follows:

[r1] If Turbine Short And Small Gear And Low Wind Then Low Power
[r2] If Turbine Short And Small Gear And High Wind Then High Power
[r3] If Turbine Short And Big Gear And Low Wind Then High Power
[r4] If Turbine Short And Big Gear And High Wind Then High Power
[r5] If Long Turbine And Small Gear And Low Wind Then Low Power
[r6] If Long Turbine And Small Gear And High Wind Then Low Power
[r7] If Long Turbine And Big Gear And Low Wind Then High Power
[r8] If Long Turbine And Big Gear And High Wind Then High Power

c. fuzzy inference engine

In the inference engine with MIN function applied to each rule on the application functionality in the form of rule implications if if-then using and. An overview of the implications of the Max-Min function is given as follows:

a) INFERENCE ENGINE INPUT

[r1] α 1 = min (μ SHORT turbine n μ SMALL gear n μ wind LOW)

[r2] α 2 = min (μ SHORT turbine n μ SMALL gear n μ wind HIGH)

[r3] α3 = min (μ SHORT turbine n μ BIG gear n μ wind LOW)

[r4] α4 = min (μ SHORT turbine n μ BIG gear n μ wind HIGH)

[r5] α5 = min (μ turbine LENGTH n μ gear SMALL n μ wind LOW)

[r6] α6 = min (μ turbine LENGTH n μ gear SMALL n μ wind HIGH)

[r7] α7 = min (μ turbine LENGTH n μ gear BIG n μ wind LOW)

[r8] α8 = min (μ turbine LENGTH n μ gear BIG n μ wind HIGH)

The results of the inference engine turbine dimensions of 20 cm, gear ratio 28, and wind speed of 3 m/s are as shown in Table 3:

Table 3. Result Inference Engine Turbine With Gear Ratio 28

RULE	**RESULT INFERENCE ENGINE**			**RESULT α (min)**
	TURBINE DIMENSIONS	**GEAR RATIO**	**WIND SPEED**	
I	1	0,84	0,9	0,84
II	1	0,84	0,1	0,1
III	1	0,6	0,9	0,6
IV	1	0,16	0,1	0,1
V	0	0,84	0,9	0
VI	0	0,84	0,1	0
VII	0	0,16	0,9	0
VIII	0	0,16	0,1	0

The results of the inference engine turbine dimensions of 20 cm, gear ratio of 60, and wind speed of 3 m/s are as shown in Table 4:

Table 4. Result Inference Engine Turbine With Gear Ratio 60

RULE	**RESULT INFERENCE ENGINE**			**RESULT α (min)**
	TURBINE DIMENSION	**GEAR RATIO**	**WIND SPEED**	
I	1	0,2	0,9	0,2
II	1	0,2	0,1	0,1
III	1	0,8	0,9	0,8
IV	1	0,8	0,1	0,1

V	0	0,2	0,9	0
VI	0	0,2	0,1	0
VII	0	0,8	0,9	0
VIII	0	0,8	0,1	0

In the table, inference engine input α results obtained from the application of the rule base fuzzification to get the value of α used for inference engine output.

b) INFERENCE ENGINE OUTPUT

In the results of the inference engine output, the turbine dimensions are 20 cm, the gear ratio is 28, and the wind speed is 3 m / s based on the output fuzzification, the results as shown in Table 5:

Table 5. Result inference engine output With Gear Ratio 28

RULE	RULE BASE	RESULT INFERENCE INPUT	RESULT INFERENCE OUTPUT
I	LOW	0,84	3,8
II	HIGH	0,1	3,5
III	HIGH	0,16	3,8
IV	HIGH	0,1	3,5
V	LOW	0	8
VI	LOW	0	8
VII	HIGH	0	3
VIII	HIGH	0	3

While the results of the inference engine output are as follows, the turbine dimensions are 20 cm, the gear ratio is 60, and the wind speed is 3 m/s based on the output fuzzification, the results as shown in Table 6:

Table 6. Result inference engine output With Gear Ratio 60

NO.	RULE	RULE BASE	RESULT INFERENCE INPUT	RESULT INFERENCE OUTPUT
1.	I	LOW	0,2	7
2.	II	HIGH	0,1	3,5
3.	III	HIGH	0,8	7
4.	IV	HIGH	0,1	3,5
5.	V	LOW	0	8
6.	VI	LOW	0	8
7.	VII	HIGH	0	3
8.	VIII	HIGH	0	3

In the table the inference output results are obtained from the results of the inference input calculated mathematically based on the fuzzification of the output according to the rule base output.

d. Defuzzification

Defuzification uses the Center Average Defuzzifier method because the output of the membership function of several fuzzy processes has the same form. The following Defuzification uses the Center Average Defuzzifier method.

In the results of the Defuzzification the turbine dimensions are 20 cm, the gear ratio is 28, and the wind speed is 3 m / s based on the output fuzzification, the results are as follows:

$$x = \frac{0{,}84 * 3{,}8 + 0{,}1 * 3{,}5 + 0{,}16 * 3{,}8 + 0{,}1 * 3{,}5 + 0 * 8 + 0 * 8 + 0 * 3 + 0 * 3}{0{,}84 + 0{,}1 + 0{,}16 + 0{,}1 + 0 + 0 + 0 + 0}$$

$$= 3{,}75$$

So, the voltage generated in the mathematical calculations on the gear ratio 28 is 3.75 watts.

In the results of the Defuzzification the turbine dimensions are 20 cm, the gear ratio is 60, and the wind speed is 3 m / s based on the output fuzzification, the results are as follows:

$$x = \frac{0{,}2 * 7 + 0{,}1 * 3{,}5 + 0{,}8 * 7 + 0{,}1 * 3{,}5 + 0 * 8 + 0 * 8 + 0 * 3 + 0 * 3}{0{,}2 + 0{,}1 + 0{,}8 + 0{,}1 + 0 + 0 + 0 + 0}$$

$$= 6{,}417$$

So, the voltage generated in the mathematical calculations on the gear ratio 60 is 6.417 watts.

4. CONCLUSION

The results showed that on a blade with a dimension of 64 cm with a gear of 28 and a wind speed of 3 m/s, the voltage generated in mathematical calculations was 3.75 watts, while in the matlab analysis the resulting voltage was 3.67 watts so that the value of the Mean Squared Error (MSE) is 0.0064. On a blade with dimensions of 84 cm with a gear of 60 and a wind speed of 3 m/s, the voltage in mathematical calculations is 6.417 watts while in the matlab analysis the resulting voltage is 7.13 watts so that the Mean Squared Error (MSE) value is 0.966.

It can be concluded that fuzzy logic is able to simulate turbine dimensions and low wind speeds and optimize the power generated by wind turbines.

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OPTIMASI ENERGI LISTRIK TURBIN ANGIN JALAN RAYA MENGGUNAKAN LOGIKA FUZZY

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ABSTRACT

Penelitian ini membahas tentang optimasi daya turbin angin jalan raya. Model ditentukan dari hasil kajian dari prototipe model turbin angin jalan raya sebagai masukan untuk melakukan analisis berbasis logika fuzzy mamdani. Pada kecepatan angin yang sangat rendah yaitu 3 m/s akan diformulasikan dengan dimensi sudu turbin dan ukuran roda gigi untuk mendapatkan hasil yang optimal menggunakan fuzzy Mamdani. Logika fuzzy digunakan untuk menentukan produksi daya berdasarkan parameter, seperti; dimensi turbin, rasio roda gigi, dan kecepatan angin. Matlab Simulink digunakan untuk menganalisis daya yang dihasilkan sedangkan perhitungan matematis logika fuzy untuk pembandingnya sehingga didapatkan nilai eror pada analisis logika fuzzy. Ada 2 jenis ukuran yang digunakan dalam turbin angin jalan raya, yaitu dimensi sudu 20 cm serta dimensi roda gigi 28 dan 60 pada kecepatan angin 3 m/s. Hasil penelitian menunjukkan bahwa pada dimensi sudu 20 cm dengan ukuran roda gigi 28 cm pada kecepatan angin 3 m/s produksi daya sebesar 3,75watt dalam perhitungan matematis, sedangkan pada analisis matlab tegangan yang dihasilkan adalah 3,67watt dengan nilai Mean Squared Error (MSE) adalah 0,0064. Sedangkan dengan ukuran roda gigi 60 cm yang dihasilkan adalah 6,417watt dalam perhitungan matematis sedangkan pada analisis matlab tegangan yang dihasilkan adalah 7,13watt sehingga Mean Squared Error (MSE) nilainya adalah 0,966. Oleh karena itu, optimasi produksi daya pada kecepatan angin tingkat rendah dimungkinkan di turbin angin jalan raya dengan menerapkan analisis Fuzzy Mamdani dengan nilai Mean Squared Error (MSE) yang rendah.

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5. INTRODUCTION

Pembangkit energi angin berkembang pesat di seluruh dunia dan akan terus berkembang di masa mendatang [1] [2]. Para peneliti bekerja untuk memaksimalkan konversi energi yang tersedia dari angin yang ada di seluruh dunia [3][4]. Salah satu sumber energi angin dan sumber energi terbarukan yang sangat tersedia adalah turbulensi angin yang ditimbulkan oleh kendaraan di jalan raya yang dapat membantu menghasilkan energi listrik [5][6].

Permasalahannya adalah bagaimana mentransmisikan energi berupa energi angin lokal menjadi energi listrik potensial [7]. Pemanfaatan skala kecil dari jenis energi ini dapat menghasilkan listrik yang cukup untuk sistem energi terbarukan di jalan raya [8][9]. Sedangkan pada aplikasi skala besar dapat dikoneksikan dengan grid [10].

Solusi dari permasalahan tersebut adalah dengan mengoptimalkan turbin angin sumbu vertikal dengan kecepatan angin rendah [11][12][13]. Selain itu, turbin angin sumbu vertikal (VAWT) berputar lebih efektif dengan meningkatnya jumlah kendaraan yang lewat [14]. Perhitungan energi angin dari turbin angin jalan raya [15]. menunjukkan bahwa tenaga angin yang diekstraksi dari jalan raya meningkat ketika kendaraan melewati jalan raya dibandingkan dengan tidak ada kendaraan yang bergerak. Sedangkan arah angin pada kedua sisi rotor berlawanan karena gerakan kendaraan yang berlawanan, dan sebaliknya gaya aerodinamis dapat menggerakkan rotor [16][17].

Beberapa penelitian tentang turbin angin jalan raya antara lain: Teknik levitasi magnetik pada sistem untuk memutar turbin pada kecepatan angin rendah [18], turbin angin poros vertikal sebagai energi alternatif untuk penerangan jalan [19], Pengaruh sudut puntir terhadap kinerja kincir angin savonius [20][21], Metode unsteady Reynolds-averaged Navier - Stokes (URANS) untuk pemodelan lapisan batas atmosfer (ABL) [22], serta mengevaluasi kinerja VAWT dan mengetahui mekanisme interaksi antara kendaraan yang bergerak [23], Perancangan dan Pembuatan Kincir Angin Jalan Tol Sumbu Vertikal pada kecepatan angin 5 mph [24], Merancang dan menganalisis model VAWT menggunakan perangkat lunak Pro/E dan CFD [25], Penggunaan turbin angin di jalan raya untuk menyimpan, menyediakan dan mendistribusikan listrik pada jalan raya dan sekitarnya [26], Optimasi desain dan analisis turbin angin sebagai teknologi alternatif yang digunakan untuk penerangan jalan raya [27], mensimulasikan dinamika perilaku sistem angin, model matematika yang cocok untuk turbin angin sumbu horizontal dan generator sinkron menggunakan logika fuzzy [28][29], Kontrol logika fuzzy turbin angin kecepatan variabel dengan beberapa generator induksi (DFIG) [30][31], Meningkatkan kemampuan respon frekuensi jangka pendek dari DFIG sistem penyimpanan energi menggunakan logika fuzzy [32] [33], Kontrol turbin angin berbasis generator sinkron magnet permanen (PMSG) untuk meningkatkan stabilitas transien selama gangguan jaringan [34].

Penelitian penelitian tersebut hanya hanya memfokuskan dengan beberapa metode yang ada, namun belum ada yang menggunakan metode logika fuzzy untuk menganalisis optimasi turbin angin jalan raya pada kecepatan angin rendah. Dalam penelitian ini, metode logika fuzzy digunakan untuk mengoptimalkan daya turbin angin jalan raya berdasarkan dimensi panjang lengan blade, rasio roda gigi dan kecepatan angin.

6. RESEARCH PROPOSED METHOD

2.5. Turbin Angin Jalan Raya

Turbin angin jalan raya merupakan teknologi energi alternatif yang mampu mengubah energi angin di jalan raya menjadi energi listrik. Turbin angin memiliki dua jenis yaitu turbin angin sumbu vertikal dan turbin angin horizontal. Prinsip kerja turbin angin tipe sumbu horizontal didasarkan pada gaya angkat energi angin dan turbin angin tipe sumbu vertikal berdasarkan gaya tarik yang disebabkan oleh gerakan angin [35]. Teknologi turbin sumbu vertikal dapat digunakan sebagai teknologi alternatif untuk konversi energi angin jalan raya. Selain itu, turbin angin sumbu vertikal memiliki keunggulan yaitu memiliki kemampuan menahan aliran turbulensi dan memungkinkannya berputar dengan mudah pada aliran angin rendah [27].

2.6. Research System Model

Dalam penelitian ini ada beberapa langkah yang harus dilakukan pada analisis logika fuzzy pada model turbin angin jalan raya. Penelitian ini diawali dengan tahap penentuan model penelitian yang terdiri dari input model turbin, kemudian analisis menggunakan logika fuzzy, kemudian menghasilkan output model turbin dan output daya seperti terlihat pada Gambar 1.

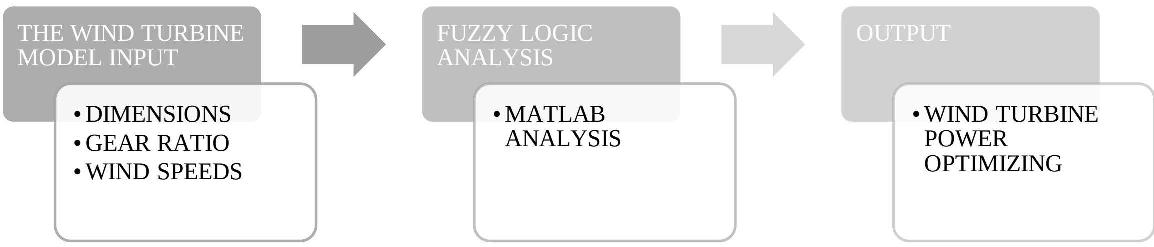

Figure 4. Highway Wind Turbine Analysis Model

Gambar 1 Model input terdiri dari dimensi turbin angin, rasio roda gigi, dan kecepatan angin. Sedangkan pada proses logika fuzzy analisis optimasi turbin angin jalan raya dilakukan dengan menggunakan algoritma Fuzzy Mamdani. Outputnya adalah pengoptimalan daya turbin angin jalan raya.

2.7. Proposed System Model

Untuk menghitung optimasi daya turbin angin jalan raya Gambar 2 Flowchart optimasi daya turbin angin jalan raya akan menjelaskan langkah-langkahnya.

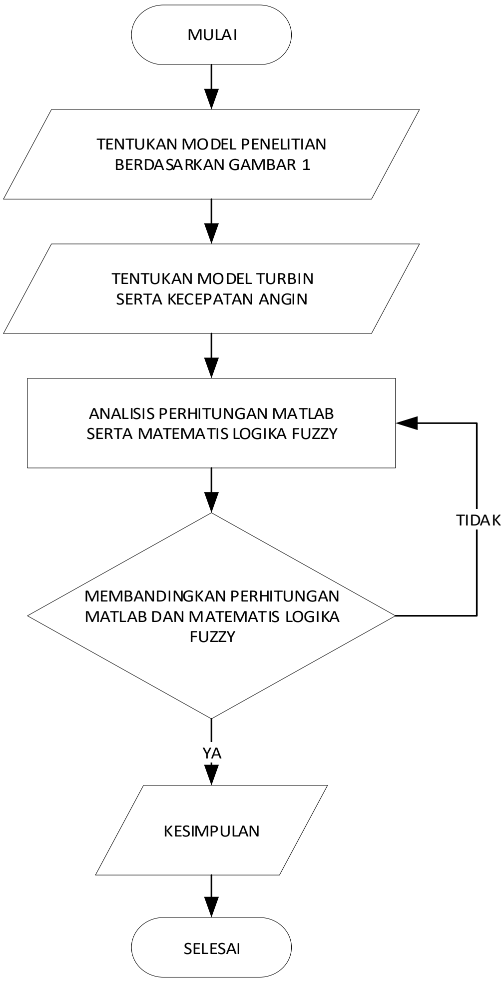

Figure 5 Flowchart optimasi daya turbin angin jalan raya

Berikut tahapan Flowchart Gambar 2, Tahapan pertama menentukan model penelitian terdiri dari input model turbin kemudian analisis menggunakan logika fuzzy kemudian menghasilkan output model turbin serta output tegangan. Tahap selanjutnya adalah menentukan model turbin serta kecepatan angin di jalan raya. Proses selanjutnya yaitu analisis daya yang dihasilkan model turbin angin menggunakan logika fuzzy yang terdiri dari Fuzzyfikasi, rule, mesin inteferensi, serta defuzzyfikasi mengunakan software matlab maupun perhitungan manual. Ketika hasil menunjukan nilai eror yang signifikan maka kembali kelangkah sebelumnya yaiu analisis menggunakan logika fuzzy. Jika menunjukan hasil eror yang tidak signifikan maka lanjut langkah terakhir. Langkah terakhir, penarikan kesimpulan.

2.8. Wind Turbine Model

Model turbin angin yang akan digunakan adalah turbin angin sumbu vertikal tipe savonius pada penelitian ini [36] seperti terlihat pada Gambar 3.

Figure 6. Vertical Wind Turbine Model [36]

Sebagai acuan, hasil pengukuran dalam penelitian [36] seperti terlihat pada Tabel 1:

Table 3. Measurement Result in Research [36]

DIMENSIONS OF BLADE (cm)	**GEARS**	**WIND SPEEDs (m/s)**	**POWER EXPERIMENT [33] (W)**	**FUZZY LOGIC OPTIMIZATION (W)**
84	60	6.5	6	6.71
64	28	8	5.08	5.83
64	60	4.5	6	6.73

Spesifikasi pada table 1 adalah sebagai berikut:

a. Panjang lengan 84 cm dengan rasio roda gigi 60:1 pada kecepatan angin 6,5 m/s menghasilkan daya maksimum 6 watt.
b. Panjang lengan 64 cm dengan rasio roda gigi 28:1 pada kecepatan angin 8 m/s menghasilkan daya maksimum 5,08 watt.
c. Panjang lengan 64 cm dengan rasio roda gigi 60:1 pada kecepatan angin 4,5 m/s menghasilkan daya maksimum 6 watt.

Tabel 1 menunjukkan bahwa nilai rata-rata Mean Squared Error (MSE) adalah 0,53. Dari data maksimum, data yang ada adalah 6,73 watt.

2.9. Highway Wind Turbine Model

Data observasi lapangan menghasilkan energi angin potensial kendaraan dengan kecepatan angin rata-rata 3 m/s, sehingga dimensi turbin seperti pada Tabel 2.

Table 4. Field Observation Data of Experimental

DIMENSIONS OF BLADE (cm)	GEAR	WIND SPEED (m/s)
20	28	3
20	60	3

Dimensi turbin dengan panjang lengan sudu 20 cm sesuai dengan lokasi turbin angin jalan raya dengan rasio roda gigi 28 dan 60 serta kecepatan angin 3 m/s.

7. RESULTS AND DISCUSSIONS

Analisis daya yang dihasilkan oleh model turbin angin berdasarkan kecepatan angin jalan raya menggunakan logika fuzzy. Pada matlab analisis fuzzy terdapat 3 tahapan proses yaitu fuzzifikasi, fuzzy rule base, fuzzy inference engine. Berikut hasil penelitiannya:

d. Fuzzyfication

Pada model referensi turbin diasumsikan bahwa input variabelnya adalah turbin, roda gigi, dan kecepatan angin, sedangkan output variabelnya adalah daya. Kemudian kita dapat menjelaskan parameter untuk fuzzfication input dan output seperti Gambar 4.

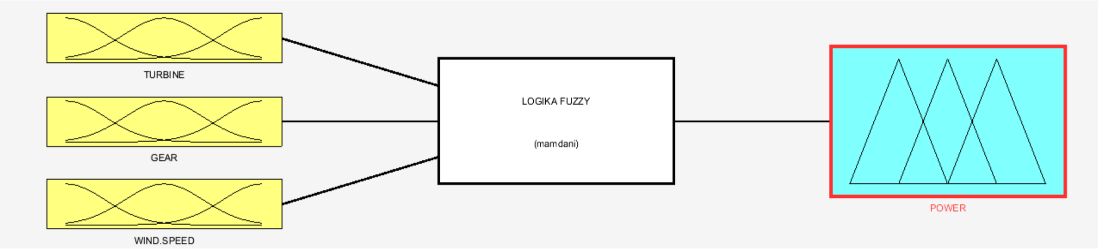

Figure 7. Highway Wind Turbine Optimization Fuzzyfication

e. Fuzzy Ruled Base

Pembentukan basis pengetahuan fuzzy diwakili oleh sekelompok aturan berupa pernyataan IF-THEN dalam aturan sistem fuzzy tegangan turbin angin adalah sebagai berikut:

[r1] If Short Turbine And Small Gear And Low Wind Then Low Power
[r2] If Short Turbine And Small Gear And High Wind Then High Power
[r3] If Short Turbine And Big Gear And Low Wind Then High Power
[r4] If Short Turbine And Big Gear And High Wind Then High Power
[r5] If Long Turbine And Small Gear And Low Wind Then Low Power
[r6] If Long Turbine And Small Gear And High Wind And Low Power
[r7] If Long Turbine And Big Gear And Low Wind Then High Power
[r8] If Long Turbine And Big Gear And High Wind Then High Power

f. Fuzzy Inference Engine

Fuzzy Inference Engine digunakan untuk mengevaluasi dan merepresentasikan semua aturan secara bersamaan untuk menghasilkan kesimpulan. Pada mesin inferensi, fungsi MIN diterapkan pada setiap aturan dalam aplikasi, implikasinya adalah jika dalam bentuk aturan jika – maka gunakan fungsi min while atau maks, atau kemudian fungsi maks diterapkan pada gambar 5.

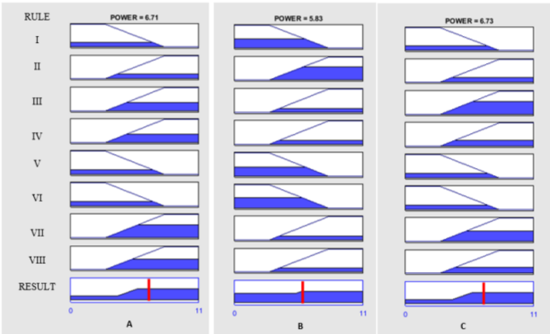

Figure 8 Fuzzy Inference Engine on the turbine reference model

Hasil Fuzzy Inference Engine pada model referensi turbin pada Gambar 4 adalah:

d. Sebuah. Pada simulasi matlab dengan panjang lengan 84 cm dengan gear ratio 60:1 pada kecepatan angin 6,5 m/s menghasilkan 6.71 watt sedangkan pada model turbin daya yang dihasilkan sebesar 6 watt seperti terlihat pada Gambar 5A.
e. b. Pada simulasi matlab dengan panjang lengan 64 cm dengan gear ratio 28:1 pada kecepatan angin 8 m/s menghasilkan 5,83 watt sedangkan pada model turbin tegangan yang dihasilkan 5,08 watt seperti terlihat pada Gambar 5B.
f. c. Pada simulasi matlab dengan panjang lengan 64 cm dengan gear ratio 60:1 pada kecepatan angin 4,5 m/s menghasilkan daya sebesar 6,73 watt sedangkan pada model turbin tegangan yang dihasilkan sebesar 6 watt seperti pada gambar Gambar 5C.

Sehingga nilai rata-rata Mean Squared Error (MSE) adalah 0,53. Dari data maksimum, data yang ada adalah 6,73 watt.

Hasil Fuzzy Inference Engine pada turbin angin jalan raya pada Gambar 6 adalah:

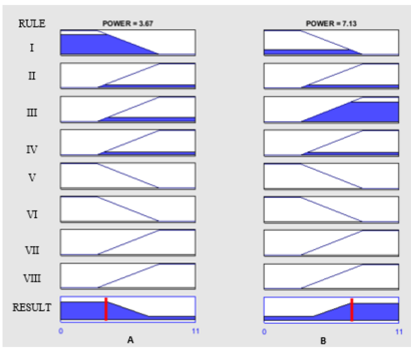

Figure 9 Fuzzy Inference Engine on the highway turbine

Hasil Fuzzy Inference Engine pada turbin angin jalan raya pada Gambar 5 adalah:

c. Sebuah. Gambar A pada dimensi sudu 20 cm dengan roda gigi 28 cm dan kecepatan angin 3 m/s menunjukkan hasil sebesar 3,67 watt.

d. b. Gambar B pada dimensi sudu 20 cm dengan roda gigi 60 cm dan kecepatan angin 3 m/s menunjukkan hasil sebesar 7,13 watt.

Dalam analisis logika fuzzy, terdapat empat tahapan perhitungan matematis yaitu fuzzifikasi, fuzzy rule base, fuzzy inference engine, dan defuzzifikasi. Berikut ini adalah hasil penelitian matematika.

e. Fuzzification

Pada analisis fuzzifikasi variabel input pada dimensi turbin, rasio roda gigi dan kecepatan angin serta variabel output pada daya yaitu:

6. Variabel input dimensi turbin terdiri dari 2 himpunan fuzzy yaitu SHORT dan LONG yang ditunjukkan pada Gambar 7 dengan derajat keanggotaan untuk panjang sudu 20 cm:

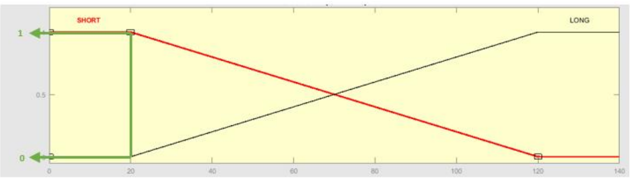

Figure 10 The input variable dimensions of the turbine

µ SHORT 20 cm = (120 - 20) / (120 - 20) = 1
µ LENGTH 20 cm = (20 - 20) / (120 - 20) = 0
Berdasarkan Gambar 7 hasil perhitungan didapatkan nilai membership function untuk panjang sudu 20 cm adalah 1 sedangkan tinggi adalah 0.

7. Variabel input gear ratio 28, variabel input yang terdiri dari 2 himpunan fuzzy yaitu SMALL dan BIG yang ditunjukkan pada Gambar 8 dengan derajat keanggotaan untuk gear ratio 28:

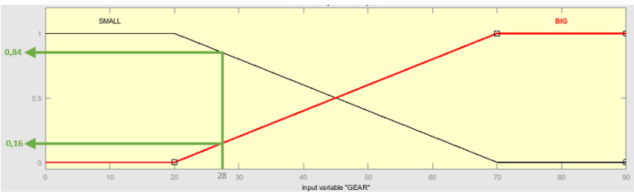

Figure 11 The input variable gear ratio 28

µ SMALL 28 cm = (70 - 28) / (70 - 20) = 0.84
µ BIG 28 cm = (28 - 20) / (70 - 20) = 0.16
Berdasarkan Gambar 8 hasil perhitungan didapatkan nilai membership function untuk gear ratio size 28 adalah batas bawah sebesar 0,84 sedangkan batas atas sebesar 0,16.

8. Variabel input gear ratio 60 yang terdiri dari 2 himpunan fuzzy yaitu SMALL dan BIG yang ditunjukkan pada Gambar 9 dengan derajat keanggotaan untuk gear ratio 60 adalah.

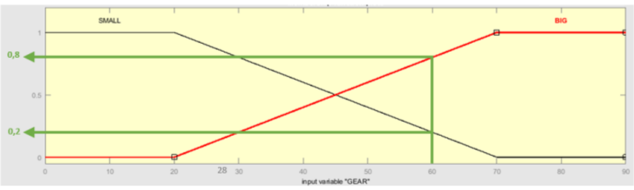

Figure 12 The input variable gear ratio 60

µ SMALL 60 cm = (70 - 60) / (70 - 20) = 0.2
µ BIG 60 cm = (60 - 20) / (70 - 20) = 0.8

Berdasarkan Gambar 9 hasil perhitungan didapatkan nilai membership function untuk gear ratio size 60 adalah batas bawah 0,2 sedangkan batas atas adalah 0,8.

9. Variabel input kecepatan angin variabel input yang terdiri dari 2 himpunan fuzzy yaitu LOW dan HIGH yang ditunjukkan pada Gambar 10 dengan derajat keanggotaan untuk kecepatan angin 3 m/s adalah.

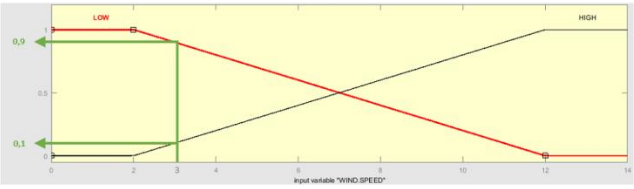

Figure 13 The input variable gear ratio 28

µ LOW 3 m / s = (12 - 3) / (12 - 2) = 0.9

µ HIGH 3 m / s = (3 - 2) / (12 - 2) = 0.1

Berdasarkan Gambar 10 hasil perhitungan didapatkan nilai membership function untuk kecepatan angin 3 m/s adalah batas bawah sebesar 9,8 sedangkan batas atas sebesar 0,1.

10. Variabel tegangan keluaran yang terdiri dari 2 himpunan fuzzy yaitu LOW dan HIGH yang ditunjukkan pada Gambar 11 dengan derajat keanggotaan untuk kecepatan angin 3 m/s adalah.

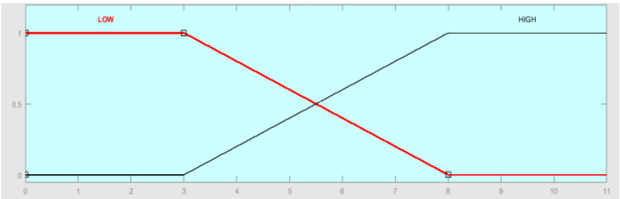

Figure 14 The voltage output variable

Berdasarkan Gambar 11 perhitungan diperoleh nilai fungsi keanggotaan untuk tegangan keluaran.

$$\mu\, VOLTAGE\ LOW\ (X) = \begin{pmatrix} 1 & X \leq 3 \\ \frac{8-X}{8-3} & 3 < X < 8 \\ 0 & 8 \leq X \end{pmatrix} \qquad \mu\, VOLTAGE\ HIGH\ (X) = \begin{pmatrix} 1 & 8 \leq X \\ \frac{X-3}{8-3} & 3 < X < 8 \\ 0 & X \leq 8 \end{pmatrix}$$

f. fuzzy rule base

Pembentukan basis aturan fuzzy diwakili oleh kumpulan aturan dalam bentuk pernyataan IF-THEN. Aturan sistem penentuan fuzzy power turbin angin adalah sebagai berikut:

[r1] If Turbine Short And Small Gear And Low Wind Then Low Power

[r2] If Turbine Short And Small Gear And High Wind Then High Power

[r3] If Turbine Short And Big Gear And Low Wind Then High Power
[r4] If Turbine Short And Big Gear And High Wind Then High Power
[r5] If Long Turbine And Small Gear And Low Wind Then Low Power
[r6] If Long Turbine And Small Gear And High Wind Then Low Power
[r7] If Long Turbine And Big Gear And Low Wind Then High Power
[r8] If Long Turbine And Big Gear And High Wind Then High Power

g. fuzzy inference engine

Pada mesin inferensi dengan fungsi MIN diterapkan pada setiap aturan pada fungsionalitas aplikasi berupa implikasi aturan jika-maka menggunakan dan. Ikhtisar implikasi dari fungsi Max-Min diberikan sebagai berikut:

c) INFERENCE ENGINE INPUT

[r1] α 1 = min (μ SHORT turbine n μ SMALL gear n μ wind LOW)

[r2] α 2 = min (μ SHORT turbine n μ SMALL gear n μ wind HIGH)

[r3] α3 = min (μ SHORT turbine n μ BIG gear n μ wind LOW)

[r4] α4 = min (μ SHORT turbine n μ BIG gear n μ wind HIGH)

[r5] α5 = min (μ turbine LENGTH n μ gear SMALL n μ wind LOW)

[r6] α6 = min (μ turbine LENGTH n μ gear SMALL n μ wind HIGH)

[r7] α7 = min (μ turbine LENGTH n μ gear BIG n μ wind LOW)

[r8] α8 = min (μ turbine LENGTH n μ gear BIG n μ wind HIGH)

Hasil dimensi turbin mesin inferensi 20 cm, rasio roda gigi 28, dan kecepatan angin 3 m/s seperti terlihat pada Tabel 3:

Table 3. Result Inference Engine Turbine With Gear Ratio 28

RULE	RESULT INFERENCE ENGINE			RESULT α (min)
	TURBINE DIMENSIONS	GEAR RATIO	WIND SPEED	
I	1	0,84	0,9	0,84
II	1	0,84	0,1	0,1
III	1	0,6	0,9	0,6
IV	1	0,16	0,1	0,1
V	0	0,84	0,9	0
VI	0	0,84	0,1	0

VII	0	0,16	0,9	0
VIII	0	0,16	0,1	0

Hasil dimensi turbin mesin inferensi 20 cm, rasio roda gigi 60, dan kecepatan angin 3 m/s seperti terlihat pada Tabel 4:

Table 4. Result Inference Engine Turbine With Gear Ratio 60

RULE	**RESULT INFERENCE ENGINE**			**RESULT α (min)**
	TURBINE DIMENSION	**GEAR RATIO**	**WIND SPEED**	
I	1	0,2	0,9	0,2
II	1	0,2	0,1	0,1
III	1	0,8	0,9	0,8
IV	1	0,8	0,1	0,1
V	0	0,2	0,9	0
VI	0	0,2	0,1	0
VII	0	0,8	0,9	0
VIII	0	0,8	0,1	0

Pada Tabel 3 dan 4 input mesin inferensi α hasil yang diperoleh dari penerapan rule base fuzzification untuk mendapatkan nilai α yang digunakan untuk output mesin inferensi.

d) INFERENCE ENGINE OUTPUT

Pada hasil keluaran mesin inferensi, dimensi turbin 20 cm, rasio roda gigi 28, dan kecepatan angin 3 m/s berdasarkan keluaran fuzzifikasi, hasilnya seperti terlihat pada Tabel 5:

Table 5. Result inference engine output With Gear Ratio 28

RULE	**RULE BASE**	**RESULT**	**RESULT**

		INFERENCE INPUT	INFERENCE OUTPUT
I	LOW	0,84	3,8
II	HIGH	0,1	3,5
III	HIGH	0,16	3,8
IV	HIGH	0,1	3,5
V	LOW	0	8
VI	LOW	0	8
VII	HIGH	0	3
VIII	HIGH	0	3

Sedangkan hasil keluaran mesin inferensi adalah sebagai berikut, dimensi turbin 20 cm, rasio roda gigi 60, dan kecepatan angin 3 m/s berdasarkan keluaran fuzzifikasi, hasilnya seperti terlihat pada Tabel 6:

Table 6. Result inference engine output With Gear Ratio 60

RULE	RULE BASE	RESULT INFERENCE INPUT	RESULT INFERENCE OUTPUT
I	LOW	0,2	7
II	HIGH	0,1	3,5
III	HIGH	0,8	7
IV	HIGH	0,1	3,5
V	LOW	0	8
VI	LOW	0	8
VII	HIGH	0	3
VIII	HIGH	0	3

Pada table 5 dan 6 hasil keluaran inferensi diperoleh dari hasil masukan inferensi yang dihitung secara matematis berdasarkan sesuai dengan keluaran rule base.

h. Defuzzification

Defuzifikasi menggunakan metode Center Average Defuzzifier karena keluaran dari fungsi keanggotaan beberapa proses fuzzy memiliki bentuk yang sama. Defuzification berikut menggunakan metode Center Average Defuzzifierifier.

Pada hasil Defuzzifikasi dimensi turbin 20 cm, gear ratio 28, dan kecepatan angin 3 m/s berdasarkan keluaran fuzzifikasi, hasilnya sebagai berikut:

$$x = \frac{0{,}84 * 3{,}8 + 0{,}1 * 3{,}5 + 0{,}16 * 3{,}8 + 0{,}1 * 3{,}5 + 0 * 8 + 0 * 8 + 0 * 3 + 0 * 3}{0{,}84 + 0{,}1 + 0{,}16 + 0{,}1 + 0 + 0 + 0 + 0}$$

$$= 3{,}75$$

Jadi, tegangan yang dihasilkan dalam perhitungan matematis pada gear ratio 28 adalah 3,75 watt.

Pada hasil Defuzzifikasi dimensi turbin 20 cm, gear ratio 60, dan kecepatan angin 3 m/s berdasarkan keluaran fuzzifikasi, hasilnya sebagai berikut:

$$x = \frac{0{,}2 * 7 + 0{,}1 * 3{,}5 + 0{,}8 * 7 + 0{,}1 * 3{,}5 + 0 * 8 + 0 * 8 + 0 * 3 + 0 * 3}{0{,}2 + 0{,}1 + 0{,}8 + 0{,}1 + 0 + 0 + 0 + 0}$$

$$= 6{,}417$$

Jadi, tegangan yang dihasilkan dalam perhitungan matematis pada gear ratio 60 adalah 6,417 watt.

8. CONCLUSION

Hasil penelitian menunjukkan bahwa pada sudu dengan dimensi 64 cm dengan roda gigi 28 dan kecepatan angin 3 m/s, tegangan yang dihasilkan dalam perhitungan matematis adalah 3,75 watt, sedangkan pada analisis matlab tegangan yang dihasilkan adalah 3,67 watt. bahwa nilai Mean Squared Error (MSE) adalah 0,0064. Pada sudu dengan dimensi 84 cm dengan roda gigi 60 dan kecepatan angin 3 m/s, tegangan dalam perhitungan matematis adalah 6,417 watt sedangkan pada analisis matlab tegangan yang dihasilkan adalah 7,13 watt sehingga Mean Squared Error (MSE) nilainya adalah 0,966.

Dapat disimpulkan bahwa logika fuzzy mampu mensimulasikan dimensi turbin dan kecepatan angin rendah serta mengoptimalkan daya yang dihasilkan oleh turbin angin.

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