DESIGN OF WIND POWER PLANTS USING SAVONIUS-DARRIEUS TURBINES WITH MAGNETIC POLE GENERATORS

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Abstract

The utilization of wind energy as a renewable energy source presents a strategic solution to address the limitations of fossil fuel resources and the growing demand for energy. This study aims to design and test a hybrid Savonius-Darrieus Wind Power Plant (WPP) prototype equipped with a variable magnetic pole generator to optimize the conversion of fluctuating wind energy into electrical energy. The research method employed is Research and Development (R&D), comprising stages of literature review, 2D and 3D design, prototype assembly, and functional testing conducted in the coastal area of Kenjeran Beach, Surabaya. The testing involved variations in the number of magnetic poles (2 and 4) and pulley ratios (2:1 and 3:1), using an anemometer and multimeter for measurement. The results of the study produced a complete design of the Savonius-Darrieus WPP prototype with a length of 100 cm, a width of 100 cm, and a height of 80 cm. The generator used is a permanent magnet generator based on an AC fan motor dynamo type YYW25-6-17004L, utilizing coin-type neodymium magnets with a diameter of 1 cm and a thickness of 0.6 cm.

Keyword: *renewable energy, PLTB, Savonius-Darrieus Turbine , Magnetic Pole Generator*

I. INTRODUCTION

Wind energy is a form of kinetic energy that can be converted into electrical energy through the use of wind turbines that drive power generators and are commonly referred to as Wind Power Plants (PLTB). This process involves converting mechanical energy from turbine rotation into electrical energy that can be used for various purposes. Indonesia as an archipelagic country has quite large wind energy potential, especially in coastal and highland areas. According to research published in the Journal of Renewable Energy Research (2021), Indonesia has an average wind speed of 3-6 m/s in various regions, which is sufficient to drive small to medium-scale wind turbines.

Vertical axis wind turbines are an ideal choice for areas with fluctuating winds. Fluctuating winds are wind speeds that always change drastically at rapid intervals (Widyanto et al., 2018). For this reason, this type of turbine is needed because it can work without the need for a wind direction tracker and is effective at low wind speeds. The combined Darrieus wind turbine is a type of wind turbine consisting of several forms of Darrieus rotors that are arranged in such a way that they can increase the efficiency of the wind turbine. The Darrieus wind turbine is a type of wind turbine that has a helix-like shape and is rotated by the wind to generate electrical energy. The Darrieus wind turbine itself has the disadvantage that it is less efficient than other types of wind turbines such as the Savonius wind turbine and the Horizontal Axis Wind Turbine (HAWT)(Irawan, 2024). he advantage of the Darrieus wind turbine is that it has a higher power coefficient (cp) and a lower wind speed compared to the Savonius wind turbine power coefficient (mulyo. sugeng, 2020).

The Savonius turbine is a type of vertical wind turbine that has a simple design and relatively low production costs. This turbine works by utilizing the drag force generated by the difference in wind pressure on the surface of the propeller. The advantage of the Savonius turbine lies in its ability to operate at low wind speeds, making it suitable for application in areas with moderate wind potential such as Indonesia. Based on a study conducted by the International Journal of Engineering Science and Technology (2020), the efficiency of the Savonius turbine can be increased by modifying the blade shape and using lightweight materials. This modification not only increases efficiency but also allows for reduced production and installation costs, making it a viable option for local scale implementation. However, this turbine has a drawback, namely its very low power coefficient (Hartadi, 2022).

Vertical axis wind turbines are an ideal choice for areas with fluctuating winds. They can operate without the need for wind direction tracking and are effective at low wind speeds. In particular, the combination of Savonius and Darrieus turbines (hybrid) offers a solution to overcome the weaknesses of each turbine. Savonius excels in starting torque, while Darrieus has better power efficiency at medium to high wind speeds. (Kumar & Nikhade, 2015).

However, the challenges faced in developing this technology include significant power fluctuations due to unstable winds, system efficiency that still needs to be improved, and a fairly long battery charging time. Therefore, based on the background of the problem, the study aims to design a prototype of a hybrid Savonius-Darrieus wind turbine system that is suitable for areas with fluctuating wind speeds.

II. THEORY

1) Wind Energy

Wind energy is a form of kinetic energy that comes from the movement of air. The use of wind energy for power generation also has several advantages, namely as a renewable energy source, a clean energy source, relatively cheaper construction and operating costs compared to fossil fuel power plants.

The available wind energy can be calculated using the following wind power equation (Kusbiantoro et al., 2013):

$$P\omega = Cp. 0{,}5. p. A. v^3$$

Pϖ = Wind Power (watt)
Cp = Power Coefficient (0,3)
p = Air Density (1,225 kg/m^3)
A = Turbine Sweep Area (m^3)
v = Wind velocity (m/s)

2) Wind Turbines and Their Types

The following is a classification of turbines based on their axis:

a) Horizontal Axis Turbine: Wind turbines with a horizontal axis or shaft are wind turbines that rotate on a horizontal axis. This type of wind turbine is the most commonly used for commercial applications. (Octari, 2024).

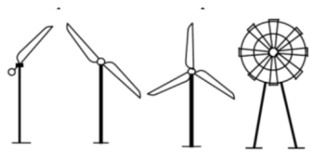

Figure 1 Horizontal turbine type
Source : (Sarwanto et al., 2017)

b) Vertical Axis Turbine: Vertical axis turbines rotate on a vertical axis and have a vertical rotor shaft. The use of this rotor is that the turbine does not need to be directed in the direction the wind is blowing. This is very useful in areas where the wind is very variable or has turbulence.

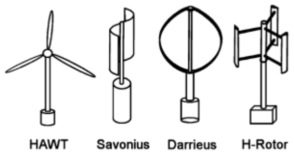

Figure 2 Vertical turbine type
Source:
https://engineeringsadvice.com/advantages-and-disadvantages-of-savonius-wind-tur

3) Hybrid PLTB System

The Savonius-Darrieus hybrid wind power generation system (PLTB) is a combination of two types of vertical axis wind turbines, namely the Savonius and Darrieus turbines.

a) *Savonius*:
The Savonius wind turbine was first introduced by a Finnish engineer named Sigurd J. Savonius in 1922. The following are the advantages of the Savonius turbine:
- Has high starting torque.
- Effective at low wind speeds.
- Using the principle of differences in air pressure on the blades.

b) *Darrieus*:
Darrieus turbine is one type of wind turbine. Since it was patented in 1931. Here are the advantages of the Darrieus turbine:
- Has a higher power coefficient (Cp) at medium to high wind speeds.
- Uses aerodynamic lift to generate rotation.

By combining these two types of turbines, the hybrid system is able to work optimally at various wind speeds, from low to high, and has good self-starting capabilities. (Rassoulinejad-Mousavi et al., 2013). The following is the hybrid system performance formula:

$$P\text{in} = (\tfrac{1}{2}. p. A. v^3)$$

With the total mechanical power produced by the hybrid system is

$$P\text{ out} = (\text{Cp,Sav}\cdot\text{PSav})+(\text{Cp,Dar}\cdot\text{PDar})$$

Information =

Cp,Sav = Savonius turbine power coefficient.

Cp,Dar = Darrieus turbine power coefficient.

PSav = Input power for the Savonius turbine.

PDar = Input power for the Darrieus turbine.

So the efficiency of the hybrid system can be calculated by (Kumar & Nikhade, 2014) :

$$\eta\, Hybrid = \frac{P\ in}{P\ out}\ .100\%$$

4) Airfoil Naca

NACA airfoil is a geometric shape that has been established by NACA and is a standard in designing an airfoil. In naming and numbering models of the airfoil series, NACA has established coding standards such as 1-digit, 2-digit, 4-digit, and 5-digit series. Such as the selection of the symmetrical NACA 4412 airfoil, the meaning is as follows (Ignatius et al., 2020):

- The first number is the maximum chamber on the chord line in hundredths of a chord.
- The second number is the maximum position of the chamber on the chord line in tenths of a chord from the leading edge.
- The last two numbers are the maximum thickness value in hundredths of a chord.

According to research (Rogowski et al., 2020) NACA 0018 has high aerodynamic performance efficiency.

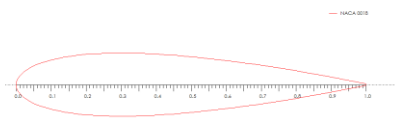

Figure 3 NACA 0018 Simulation
Source: xblade software personal documentation

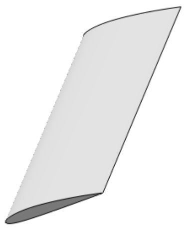

Figure 4 NACA 0018 Design
Source: xblade software personal documentation

5) Shaft

The shaft is a mechanical component that functions to transmit power or rotation from the wind turbine to the pulley system, which then drives the generator. (Gangsar Prayogo et al., 2021). The performance of the shaft is very important because it determines the efficiency and reliability of the wind power generation system. The main functions of the shaft in the wind power system:

- Transmits torque from the turbine to the pulley.
- Absorbs mechanical loads due to wind forces on the turbine blades.
- Provides a mechanical connection between the turbine and the pulley-generator system.

6) Pulley & V-belt

The definition of a pulley is a mechanical device that is used to support the movement of a v-belt or circular belt to run a groove force that functions to transmit power. The way a pulley works is often used to change the direction of the force given and transmit rotational motion. A belt or v-belt is a connecting transmission made of rubber that has a trapezoidal cross-section, in the use of a belt the belt is wrapped around the V-shaped pulley groove, the part of the belt that wraps around the pulley will experience a curve so that the width of the inside will increase. Belts or v-belts are widely used because v-belts are very easy to handle.

An electric generator is a machine that can convert kinetic (mechanical) energy into electrical energy (Rizki et al., 2018). The generator works based on the principle of electromagnetic induction which can occur if a coil is moved on a magnet. It can also happen the other way around, a magnet is moved against a solenoid. A solenoid is a cylindrical coil of wire with very close spacing between the coils. Both of these objects can produce electromagnetic induction or electromotive force induction (Aminuddin, 2020).

A permanent magnet generator (PMSG) is a type of electric generator that uses permanent magnets to produce a magnetic field. The main advantages of a PMSG are its high efficiency, compact design, and ability to operate at low rotational speeds, making it ideal for wind power generation systems. (Mathew, 2007).

The main function of PMSG in PLTB is to convert mechanical energy from wind turbines into electrical energy that can be used to charge batteries or directly to electrical loads. PMSG works based on the principle of electromagnetic induction. The electrical voltage (V) produced by the stator coil is influenced by:

- Magnetic flux (ϕ) produced by a permanent magnet.
- Number of turns of wire (Nc) in the coil.
- Rotation frequency (f) of the rotor.

III. METHODE

This final project research uses the type of development research or research and development. The R&D method is applied in various fields, including science, technology, business, and industry, with the aim of increasing understanding, innovation, and competitive advantage. (Sugiyono, 2013). The following is a flowchart to describe the research method from start to finish.

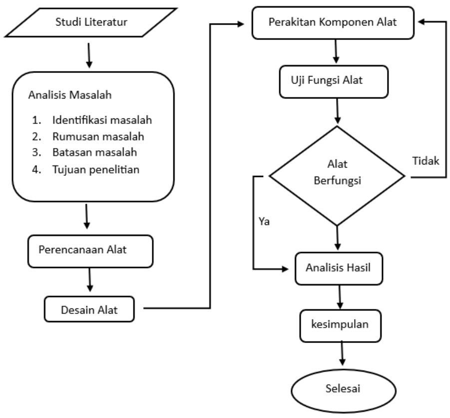

Figure 5 diagram alir penelitian

1) Desain 2D

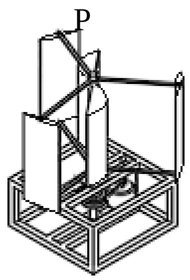

Figure 6 2D Design of PLTB

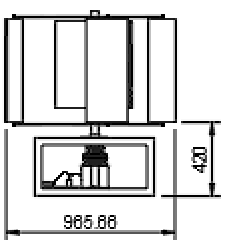

Figure 7 Dimensions of PLTB

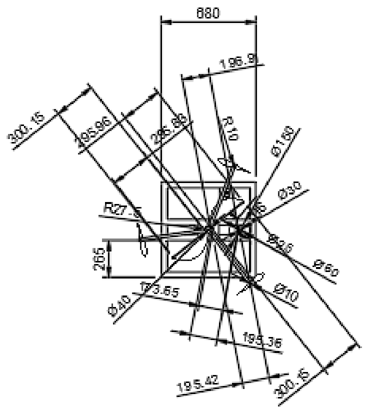

Figure 8 Component dimension size

IV. RESULTS AND DISCUSSION

1. Hasil Rancang Bangun

The Savonius-Darrieus hybrid PLTB tool has a tool length of 100 cm, a width of 100 cm and a height of 80 cm. The following are the complete specifications of the components of the Savonius-Darrieus hybrid PLTB tool:

a. PLTB Framework

Length (p)	Width (l)	Height (T)	Material s
60 cm	60 cm	24 cm	Hollow Galvanis 2x2x0.6 cm

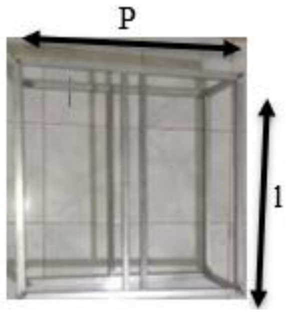

Figure 9 PLTB Framework

b. Savonius-Darrieus Hybrid Turbine Shaft Shaft Diameter

Shaft Diameter	Height	Materials
1 cm	85 cm	Poros Stainless steel 304

Figure 10. Savonius-Darrieus Hybrid Turbine Shaft

c. Savonius Turbine Blade Support

Figure 11. Savonius Turbine Blade Support

d. Darrieus Turbine Blade Support

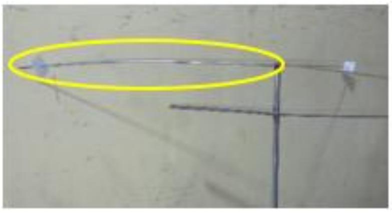

Figure 12. Darrieus Turbine Support

e. Savonius Turbine Blades

Length (p)	Height (T)	Radius (r)	Material
30 cm	40 cm	15	Seng Galvalum 020

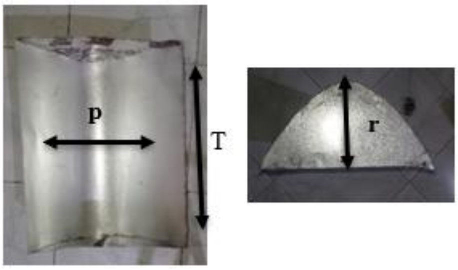

Figure 13. Savonius Turbine Blades

f. Bilah Turbin Darrieus

Wdith (L)	Height(T)	Naca Type	Material
17 cm	60 cm	0018	Foamboard 0.5 cm

Figure 14. Darrieus Turbine Blades

g. Bearing

Type	Inner Diameter	Material
Bearing kfl000	1 cm	Zinc alloy

Figure 15. Bearing

h. Pulley

No.	Jenis	Inner D.	Outer D.	Material
Pulley 1	Timing *pulley* 20t	0.8 cm	2 cm	Alumunium
Pulley 2	*Timing pulley* 40t	1 cm	3 cm	Alumunium
Pulley 3	*Timing pulley* 60t	1 cm	4.5 cm	Alumunium

r

Figure 16. Pulley 20 t

Figure 17. Pulley 40 t

Figure 18. Pulley 60 t

i. V-belt

Type	Length	Widht	Material
Timing Belt	20 cm	0.5 cm	Rubber

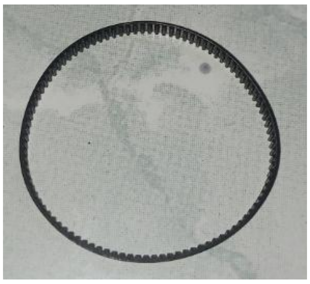

Figure 19. Timing Belt

j. Magnet

Type	Diameter	Thickness
Neodymium koin	1 cm	0.6 cm

Figure 20. Neodymium Magnets

k. Generator

Motor Type	Series	Current Type
Dinamo Fan AC Outdoor	YYW25-6-17004L	AC

Figure 21. Generator

l. Variabel Kutub Magnet

Figure 22. Magnetic Pole Variable

m. Assembly Alat Prototype PLTB Hybrid Savonius-Darrieus

Length (p)	Height (T)	Width (l)
100 cm	80 cm	100 cm

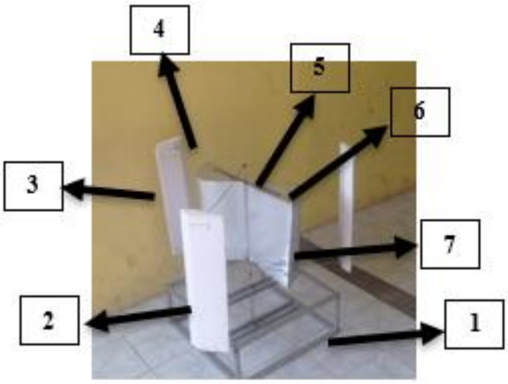

Figure 23. Savonius-Darrieus Hybrid PLTB Prototype Assembly

No.	Nama Komponen	Jenis material	Spesifikasi
1.	Kerangka alat PLTB	Hollow galvanis 2x2x0.6 Cm	60(p)x60(l)x40(T) cm
2.	Bearing	Zinc alloy	Bearing kfl000 1(D) cm
3.	Bilah turbin darrieus	Foamboard 0.5 cm NACA 0018	17(L)X60(T) cm
4.	Penyangga bilah turbin darrieus	Batang stainless steel 304	0.3((D)x50(p) cm
5.	Tiang penyangga bilah tubin savonius-darrieus	Poros stainless steel 304	1(D)x85(p) cm
6.	Penyangga bilah turbin savonius	Plat besi 0.2 cm	1.5(t)x40(p) cm
7.	Bilah turbin savonius	Seng galvalum 020	30(p)x40(T)x15(r)

1. Theoretical Calculation

Calculation of electrical power :

$$P = V \times I$$

Information =

P = Electrical power

V = Electrical voltage

I = Electric current

Savonius turbine calculation

- Wide sweep area (A)

A savonius $= D \times H$
$= 2r \times H$
$= 0{,}3m \times 0{,}4m$
$= 0{,}12\ m^2$

- Theoretical wind power (pw) at speed 3 m/s

$Pw = \frac{1}{2} \cdot \rho \cdot A \cdot v3$
$= 0{,}5 \cdot 1{,}225 \cdot 0{,}12 \cdot (3)^3$
$= 0{,}5 \cdot 1{,}225 \cdot 0{,}12 \cdot 27$
$= \approx 1{,}985$Wat

- Savonius output power estimation

$P_{out\text{-}savonius} = Cp \cdot Pw$
$= 0{,}2 \cdot 1{,}985$
$= \approx 0{,}397$Watt

Darrieus turbine calculation

- Wide sweep area (A)

$A_{darrieus} = D \times H$
$= 0{,}17m \times 0{,}6m$
$= 0{,}102m2$

- Wind power

$Pw = 0{,}5 \cdot 1{,}225 \cdot 0{,}102 \cdot (3)^3$
$= \approx 1{,}684$Watt

- Darrieus Output Power

$P_{out\text{-}darrieus} = 0{,}35 \cdot 1{,}684$
$= \approx 0{,}589$Watt

Pulley calculation and rotation ratio, for example 1:3 ratio

Motor pulley = 20T (d1 = 2 cm)

Turbin pulley = 60T (d2 = 4.5 cm)

Rasio Pulley $= \frac{d2}{d1}$
$= \frac{4{,}5}{2}$
$= 2{,}25$

If the turbine rotates at 200 RPM, then =

$N_{generator} = N_{turbin} \cdot$ rasio pulley
$= 200 \cdot 2{,}25$
$= 450$RPM

Turbine efficiency

$P_{(out\text{-}total)} = P_{out}$ savonius $+ P_{out}$ darrieus
$= \approx 0{,}397 + 0{,}589$
$= 0{,}986$Watt

$P_{(angin - total)} = 1{,}985 + 1{,}684$
$= 3{,}669$Watt

$\eta_{turbin} = P_{(angin - total)} / P_{(out - total)} \cdot 100\%$
$= \approx 3{,}669 / 0{,}986 \cdot 100\%$
$= \approx 26{,}9\%$

V. CONCLUSION

After conducting the design and function test of the hybrid Savonius-Darrieus PLTB prototype with variable pulleys and magnetic poles, it can be concluded that the overall design of the hybrid Savonius-Darrieus PLTB prototype is 100 cm long, 100 cm wide, and 80 cm high with the specifications of the Savonius turbine having a length of 30 cm, a height of 40 cm, a radius width of 15 cm, and using galvalum zinc material with a thickness of 0.2 cm. While the Darrieus turbine has a blade length of 17 cm, a height of 60 cm, using the Naca 0018 type, and using foamboard material with a thickness of 0.5 cm. The tool frame uses galvanized hollow material 2x2x0.6 cm with a length of 60 cm, a width of 60 cm, and a height of 24 cm. The hybrid turbine shaft uses stainless steel shaft material with a shaft diameter of 1 cm, a shaft length of 85 cm. The Savonius turbine support is made of iron plate with a width of 1.5 cm, a length of 40 cm and a thickness of 0.2 cm. The darrieus turbine support is made of stainless steel rod with a diameter of 0.3 cm and a length of 50 cm. While the generator uses a permanent magnet generator type dynamo fan motor ac type YYW25-6-17004L with a neodymium coin type magnetic pole that has a diameter of 1 cm and a thickness of 0.6 cm.

REFERENCE

Aminuddin, J. (2020). Analisis Tegangan Keluaran Generator Listrik Frekuensi Rendah dengan Metode Conjugate-Gradient. *Jurnal Teras Fisika*, *3*(1), 142. https://doi.org/10.20884/1.jtf.2020.3.1.2729

Gangsar Prayogo, L., Dahlan, D., & Maulana, E. (2021). Analisis Energi Yang Dihasilkan Pada Pembangkit Listrik Tenaga Magnet Dengan Konsep V-Gate. *Semrestek 2020*, KE11–KE21. https://teknik.univpancasila.ac.id/semrestek/prosiding/index.php/12345/article/view/367

Ignatius, G. R., Sugiri, A., & Suudi, A. (2020). Perancangan dan Perhitungan Sudu Turbin Angin Horisontal NACA 4412 Variasi Sudut Serang Menggunakan Simulasi BEM. *Jurnal Ilmiah Teknik Mesin*, *8*(2), 34–37. https://doi.org/10.23960/fema.v8i2.7

Kumar, A., & Nikhade, A. (2014). Hybrid Kinetic Turbine Rotors: a Review. *International Journal of Engineering Science & Advanced Technology*, *4*(6), 453–463. http://www.ijesat.org

Kumar, A., & Nikhade, A. (2015). Hybrid Kinetic Turbine Rotors: a Review. *International Journal of Engineering Science & Advanced Technology*, *4*(6), 453–463. http://www.ijesat.org

Kusbiantoro, A., Soenoko, R., & Sutikno, D. (2013). Pengaruh Panjang Lengkung Sudu Terhadap Unjuk Kerja Turbin Angin Poros Vertikal Savonius. *2*, 1–9.

M., & Irawan, H. (2024). Pengujian Turbin Angin Darrieus Dengan Penambahan Duel Stage Kombinasi Sudu. *Al Jazari : Jurnal Ilmiah Teknik Mesin*, *9*(1), 47–51. https://doi.org/10.31602/al-jazari.v9i1.14404

Octari, K. D. (2024). *Analisis Pemanfaatan Energi Angin sebagai Pembangkit Listrik Alternatif pada Turbin Angin Sumbu Vertikal dan Horizontal*. *8*, 23497–23502.

Widyanto, S. W., Wisnugroho, S., & Agus, M. (2018). Pemanfaatan Tenaga Angin Sebagai Pelapis Energi Surya pada Pembangkit Listrik Tenaga Hibrid di Pulau Wangi-Wangi. *Seminar Nasional Sain Dan Teknologi 2018*, 1–12.

R., & Hartadi, B. (2022). Pengaruh Kelengkungan Deflektor Turbin Savonius Modifikasi Untuk Turbin Hidrokinetik. *Al Jazari : Jurnal Ilmiah Teknik Mesin*, *7*(1), 16–25. https://doi.org/10.31602/al-jazari.v7i1.7106

Rassoulinejad-Mousavi, S. M., Jamil, M., & Layeghi, M. (2013). Experimental study of a combined three bucket H-rotor with savonius wind turbine. *World Applied Sciences Journal*, *28*(2), 205–211. https://doi.org/10.5829/idosi.wasj.2013.28.02.1429

Rizki, M., Budiman, A., & Puryanti, D. (2018). Barium Ferit (BaFe 12 O 19) Pasir Besi Batang Sukam Kabupaten Sijunjung Sumatera Barat. *Jurnal Fisika Unand*, *7*(1), 15–20.

Rogowski, K., Hansen, M. O. L., & Bangga, G. (2020). Performance analysis of a h-darrieuswind turbine for a series of 4-digit NACA airfoils. *Energies*, *13*(12). https://doi.org/10.3390/en13123196

Sarwanto, A. G., Budiarto, U., Zakki, A. F., Perkapalan, D. T., Teknik, F., & Diponegoro, U. (2017). Analisa Efektifitas *Wind Turbine* Sumbu Horizontal Dengan Variasi Jumlah Dan Jenis Airfoil Sebagai Sumber Energi Listrik Tambahan Pada Fisheries Inspection. *Jurnal Teknik Perkapalan*, *4*(4), 837–846.

Sathyajith, Mathew(2007) *Wind Energy Fundamentals, Resource Analysis and Economics.*

Sugiyono. (2011). Metode Penelitian Kuantitatif, Kualitatif dan R&D. Bandung: Alfabeta.

Widyanto, S. W., Wisnugroho, S., & Agus, M. (2018). Pemanfaatan Tenaga Angin Sebagai Pelapis Energi Surya pada Pembangkit Listrik Tenaga Hibrid di Pulau Wangi-Wangi. *Seminar Nasional Sain Dan Teknologi 2018*, 1–12.