Wave: Jurnal Ilmiah Teknologi Maritim
(Journal of Maritime Technology)

Vol. 19 No. 01, June 2025: page: 14-22
p - ISSN: 1978-886X
e - ISSN: 2614-641X

Experimental Study of Integrated Fan Turbine in Oscillating Water Column with Valve System in Venturi Directional and Solar Energy as Hybrid Energy Converter

Madi Madi[1,*], Muhammad Gufran Nurendrawan Bangsa[1] and Bintari Citra Kurniawan[1]
[1] Energy System Engineering, Institut Teknologi Sumatera,
South Lampung, Indonesia

Article Info

Article history:
Received May 15, 2025
Revised June 24, 2025
Accepted June 25, 2025

Keywords:
Experimental Study
Oscillating Water Column
Venturi Directional
Solar Energy
Hybrid Energy Converter

ABSTRACT

Indonesia, with a maritime area of 7.081.000 km², has significant marine and energy potential. Its vast ocean can generate up to 1995 MW of energy, primarily from strong tidal movements, which can drive turbines to produce electricity. Indonesia's coastal topography supports tidal energy generation, and as a tropical country on the equator, it also has significant solar energy potential, with an average solar irradiation of 217 GWh/year. However, both energy sources are underutilized due to technological challenges, especially in remote areas. Current technologies like Oscillating Water Column (OWC) and Tidal Power Modifier (TPM) are not yet optimal for electricity generation. This experimental model is developed with a flow rectifier system in the venturi tube, which increases the fluid velocity based on continuity theory. Performance evaluation was conducted by recording electrical parameters like voltage and current generated by the turbine and solar PV. Test results showed that the hybrid turbine and solar PV system produced higher electricity output than the turbine without solar energy, with an average electric power of 2.24 x 10^3 watts, and a more optimal hybrid efficiency of 2233.33%.

Corresponding Author:
Madi Madi
Energy System Engineering, Institut Teknologi Sumatera
South Lampung, Indonesia
madi@tse.itera.ac.id

INTRODUCTION

Indonesia is an archipelagic country and a maritime nation, with a total sea area of 7,081,000 km² (Satrio, et al., 2023; Mukhtasor, 2014). As a maritime territory, Indonesia possesses immense marine potential. This is profitable cause the ocean align with the daily activities for residents (Satrio, et al., 2025; Madi, et al., 2021; Madi, et al., 2019).

The total power that can be generated from Indonesia's sea area can reach up to 1995 MW (Mukhtasor, 2014; Madi, et al., 2023). This occurs because a significant portion of Indonesia's waters experiences strong movements due to the influence of the moon's gravitational force, which causes ocean tidal waves (Abror, 2020; Satrio, et al., 2024). This movement can be harnessed to drive turbines that can generate electricity with high efficiency. Additionally, Indonesia's coastal-dominated topography allows for direct access to rising sea levels (Husnayaen, et al., 2022)

Besides its vast marine potential, Indonesia, as a tropical country located along the equator, also has significant solar energy potential, with varying levels of solar radiation across different regions. Based on available data, Indonesia's average solar radiation reaches 217 GWh/year, making solar power generation systems a viable alternative for renewable energy sources or as a supporting power for the power plant innovations (Syahputra & Soesanti, 2021).

Ironically, the potential development of these two energy resources has not been fully optimized to meet Indonesia's electrification needs (Madi, et al., 2024; Madi, et al., 2022). This is due to challenges in resource management, primarily caused by slow technological advancements, particularly in remote and coastal areas (Madi, et al., 2024; Madi, et al., 2021). In fact, combining these two energy sources could create a continuous energy resource, helping to increase energy (Khurshid, et al., 2024)

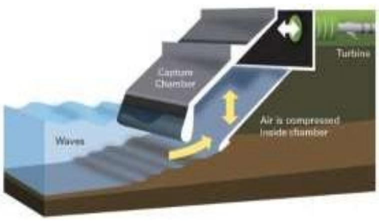

Figure 1. Oscillating Water Column

One technology currently used worldwide is the Oscillating Water Column (OWC), which employs an eight-shaped column to direct airflow toward the turbine (Khurshid, et al., 2024). However, the turbine movement in this technology is relatively inconsistent due to the bidirectional nature of its airflow system. Apart from OWC, there is also the Tidal Power Modifier (TPM) technology, which uses a valve-based airflow system. However, this technology generates optimal energy for meeting electricity needs in a given region (Madi, et al., 2021).

The dynamics of ocean tides are influenced by the gravitational forces of the moon and the sun, as well as the Earth's centrifugal force (Su, 2024). Tidal wave energy is generated by the wind that continuously blows over the ocean surface, transferring energy to the waves (Abror, 2020). The Oscillating Water Column (OWC), a tidal energy technology, utilizes air pressure within an oscillating column to drive a turbine and generator, with two main components: an air chamber that converts wave energy into pneumatic energy, and a power take-off system that transforms it into electricity power using a generator (Abror, 2020).

Therefore, to enhance airflow toward the turbine, the Venturi tube principle is applied. In this design, the venturi tube has a narrower space in the middle than at the inlet and outlet sections. The venturi tube is a device for measuring fluid dynamics, where the continuity principle is applied to the reduction in the tube's length on flow acceleration. According to the fundamental principle of continuity, the airflow striking the turbine will accelerate, thereby increasing the turbine's performance and efficiency (Saham & Rezaey, 2024). Furthermore, to maximize electricity production, a hybrid energy system is implemented, integrating tidal energy and the solar energy system.

Wave: Jurnal Ilmiah Teknologi Maritim
(Journal of Maritime Technology)

Vol. 19 No. 01, June 2025: page: 14-22
p - ISSN: 1978-886X
e - ISSN: 2614-641X

METHOD

This study begins with a literature review from various relevant sources as a basis for designing a prototype system, especially related to renewable energy technologies. The next stages include the process of identifying and designing the system, preparing tools and materials, fabricating the prototype, and initial testing to evaluate performance. Based on the evaluation results, system updates and further testing are carried out to assess the effectiveness of improvements. All data is then analyzed and identified for use as a reference in preparing the final report.

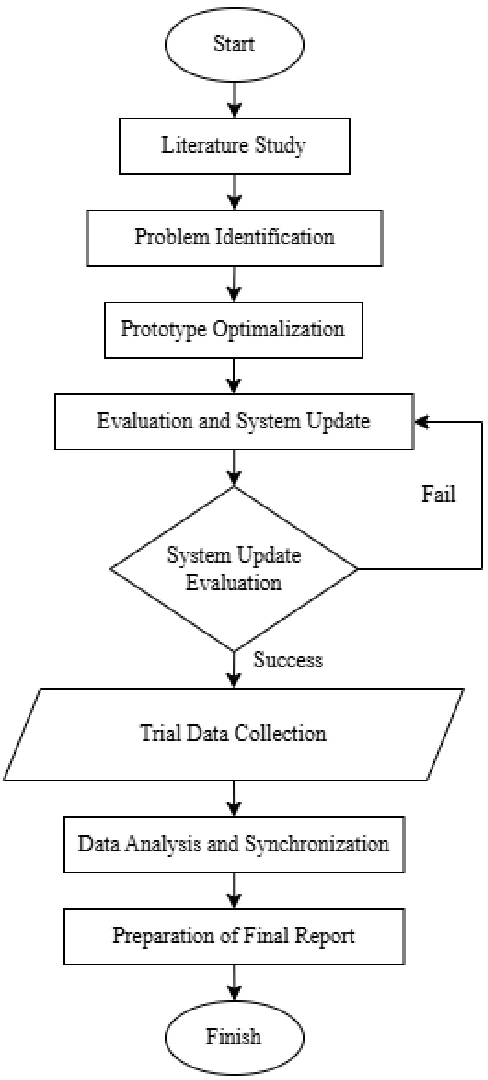

Figure 2. Flowchart

Geometry

The geometric representation of wave energy with the directional Venturi tube model and solar panel integration can be shown in **Figure 3**, while the overall model dimensions can be presented in **Table 1, Table 2, and Table 3,** which have been attached in the following figures and tables.

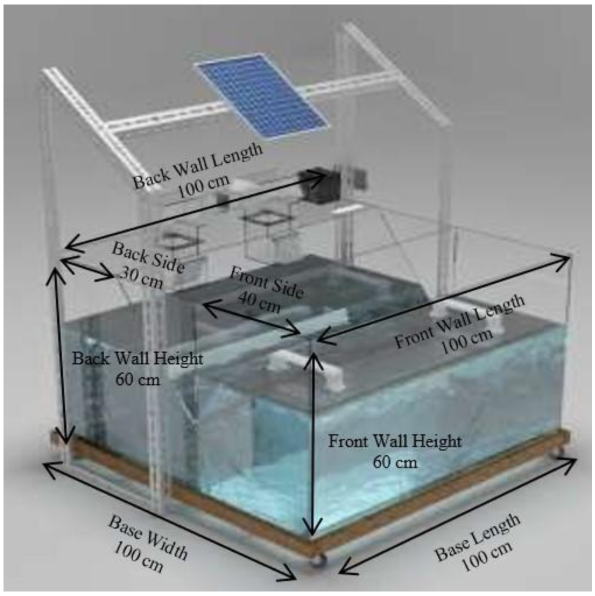

Figure 3. Design and Geometry Model

Table 1. Column Geometry

Geometry	Value	Unit
Base Length	100	cm
Base Width	100	cm
Front Wall Length	100	cm
Front Wall Height	60	cm
Back Wall Length	100	cm
Back Wall Height	60	cm
Front Side Wall Length	40	cm
Back Side Wall Length	30	cm

Table 2. Venturi Geometry

Geometry	Value	Unit
Outer Surface Large Tube	9.6	cm
Inner Surface Large Tube	9	cm
Large Tube Length	16	cm

Outer Surf Acceleration	9.6-5.1	cm
Inner Surf Acceleration	9-4.5	cm
Acceleration Tube Length	5	cm
Outer Surf Small Tube	5.1	cm
Inner Surf Small Tube	4.5	cm
Small Tube Length	5	cm

This model has five main components as the key instruments, namely the Venturi Tube, Column, Turbine, Generator, and Solar Panel.

Table 3. Turbine Geometry

Geometry	Value	Unit
Turbine Diameter	3.8	cm
Shaft Diameter	0.2	cm
Inner Diameter Turbine	4.5	cm
Outer Diameter Turbine	5.1	cm
Turbine Case Length	5	cm

Fabrication

The main materials used in the fabrication of the model are acrylic and 3D printing materials. The entire column is made of 5 mm-thick acrylic, while the Venturi tube is made of 3 mm thick acrylic. For the funnel section, which has a non-perpendicular geometric shape, 3D printing technology with PLA+ filament is utilized to achieve precision and strength and durability.

Additionally, to enhance the strength of the column, a wooden support frame is added as a reinforcement to withstand water pressure during functional prototype testing. The turbine used is a plastic fan turbine. The 15 Wp monocrystalline solar panel was chosen because it is efficient, space-saving, and suitable for prototype scale. For the solar panel frame, angle iron is chosen as the primary material, cause stability and durability.

Data Processing

After the instruments are completed, conduct an initial functional test to evaluate the success of the model's operation. The initial functional test will require equipment such as a tachometer, multimeter, and LED connected to the generator.

(a) (b)

Figure 4. Fabrication Model
(a) Comprehensive Model (b) Venturi Model

The performance test will be conducted over 20 seconds, demonstrating that the variation in turbine voltage output is a result of the turbine's successful operation. This voltage variation is caused by differences in wave height. The fluctuating wave height, influenced by the rising and falling wave conditions, compresses the air inside the column, which then passes through the rectifier tunnel and drives the generator to power the lamp as a functional test indicator.

The recorded wave height data indicates that the column in this model effectively simulates ocean waves. Additionally, the presence of electrical voltage data and the illuminated indicator lamp confirms the model's successful functionality in generating electrical energy.

RESULTS AND DISCUSSION

Model Principle

The solar panel absorbs photon energy from the sun, which is then converted into electrical energy. The electricity generated by the solar

Vol. 19 No. 01, June 2025: page: 14-22
p - ISSN: 1978-886X
e - ISSN: 2614-641X

panel is transferred to the battery through Pulse Width Modulation. The electrical energy is stored in the battery from the first energy source (solar power).

Figure 4. Data Collection

When the Tidal Generator Board is pressed downward, the water inside the Tidal Simulation Room (TSR) is compressed, creating a tidal wave in the Back Room. This tidal wave causes the float to rise. The increasing air pressure inside the Back Room, resulting from the tidal wave, forces the trapped air to enter the Venturi tube through Valve 1. The air then strikes the turbine and exits the Venturi tube through Valve 2. Before reaching the turbine, the air is accelerated by the narrowing cross-sectional area of the venturi tube.

When the TGB is lifted upward, the water inside the TSR is pulled up, forming an ebb wave in the Back Room. This ebb wave causes the float to move downward. The decreasing air pressure inside the Back Room, due to the ebb wave, causes external air to be drawn into the Venturi tube through Valve 3. The air then strikes the turbine and enters the Back Room through Valve 4. As before, the air is accelerated by the narrowing cross-sectional area of the venturi tube.

The mechanism repeats continuously as long as the TGB is in motion. The rotation generated by the turbine produces electrical energy, which is transferred to the battery through Pulse Width Modulation (PWM), serving as the output from the second energy source (Wave Power).

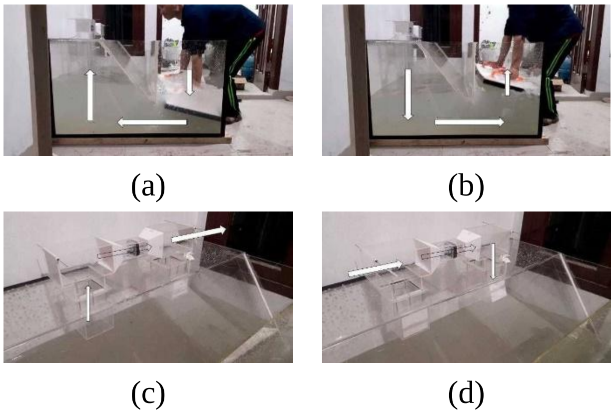

Figure 5. The Working Principle Model
(a) Tidal Waves (b) Low Waves
(c) Airflow Tides (d) Airflow Low

The performance improvement of the model was observed significantly following the assembly and installation of the new turbine. Performance evaluation was conducted systematically by recording and documenting essential electrical parameters, including the voltage and current output generated by the turbine and solar PV. The operationalization of these voltage and current values allows for the calculation of the power produced by the model.

Experimental Results

This model introduces innovation by incorporating a one-way air circulation valve mechanism. Current models used in the industrial scale still rely on two-way air circulation, which often causes delays when the turbine attempts to extract energy from the circulation. This model can generate a more optimal circulation due to the application of a directional venturi tube.

The following are the calculated results of current and voltage between turbines in **Table 4**, current and voltage of Solar PV in **Table 5**, and Theoretical power calculation between the two subjects and the combination in **Table 6**:

Table 4. Turbine Voltage and Current

Second	Voltage [V]	Current [A]
3	1.165	1.5×10^{-5}
6	1.862	4.0×10^{-5}
9	1.756	5.0×10^{-5}
12	2.224	4.0×10^{-5}
15	3.484	5.0×10^{-5}
18	3.229	5.0×10^{-5}
21	3.008	4.0×10^{-5}
24	1.760	3.0×10^{-5}
27	2.055	4.0×10^{-5}
30	2.759	6.0×10^{-5}
Ave	**2.421**	3.803×10^{-5}

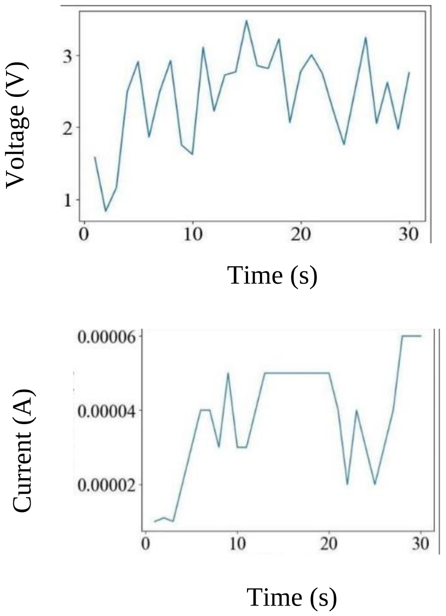

Figure 6. Graph Voltage and Current Turbine

Based on **Figure 6**, the experimental results were independently generated by the turbine. It can be observed that fluctuations occur due to waves. But, the current and voltage are consistent.

Table 5. Solar PV Voltage and Current

Second	Voltage [V]	Current [A]
3	6.14	3.5×10^{-4}
6	6.13	3.5×10^{-4}
9	6.12	3.5×10^{-4}
12	6.12	3.5×10^{-4}
15	6.12	3.5×10^{-4}
18	6.12	3.5×10^{-4}
21	6.12	3.5×10^{-4}
24	6.13	3.5×10^{-4}
27	6.12	3.5×10^{-4}
30	6.11	3.5×10^{-4}
Ave	**6.127**	$\mathbf{3.5 \times 10^{-4}}$

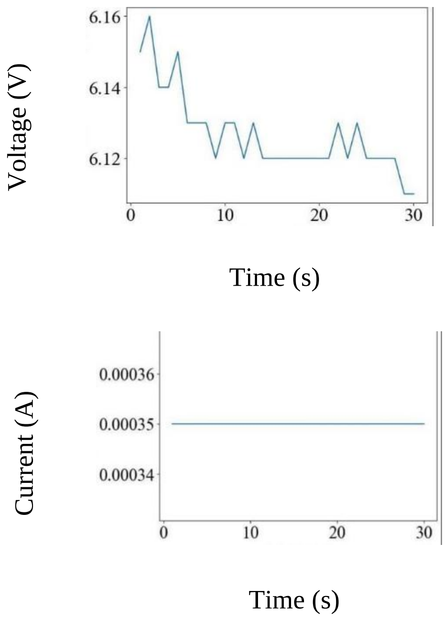

Figure 7. Graph Voltage and Current PV

Quite different from the turbine results, the voltage and current measurements of the Solar PV show a decrease in voltage power, while the current remains consistent. However, no excessive fluctuations were observed in the measurements conducted over 30 seconds.

Vol. 19 No. 01, June 2025: page: 14-22
p - ISSN: 1978-886X
e - ISSN: 2614-641X

Therefore, a combined power source is needed to prevent the voltage from continuously decreasing, ensuring consistency of the voltage and current.

Table 6. Theoretical Power Calculations

s	Turbine [W]	Solar PV [W]	Hybrid [W]
3	1.16×10^{-5}	2.14×10^{-3}	2.16×10^{-3}
6	7.44×10^{-5}	2.14×10^{-3}	2.22×10^{-3}
9	8.78×10^{-5}	2.14×10^{-3}	2.23×10^{-3}
12	8.89×10^{-5}	2.12×10^{-3}	2.23×10^{-3}
15	1.74×10^{-4}	2.12×10^{-3}	2.31×10^{-3}
18	1.61×10^{-4}	2.14×10^{-3}	2.30×10^{-3}
21	1.21×10^{-4}	2.14×10^{-3}	2.26×10^{-3}
24	5.28×10^{-5}	2.14×10^{-3}	2.19×10^{-3}
27	8.22×10^{-5}	2.14×10^{-3}	2.22×10^{-3}
30	1.65×10^{-5}	2.14×10^{-3}	2.30×10^{-3}
Ave	**9.6×10^{-5}**	**2.14×10^{-3}**	**2.24×10^{-3}**

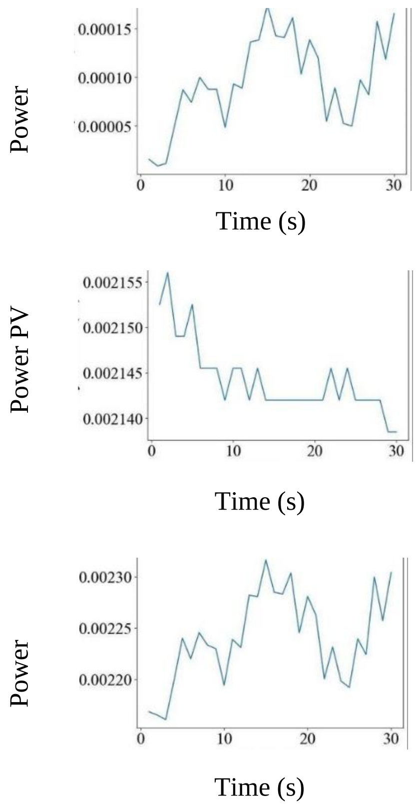

Figure 8. Theoretical Power Calculations

Based on the **Table 6**, the theoretical power generated by the turbine has an average of 9.6×10^{-5} W, while the Solar PV generates an average power of 2.144×10^{-3} W. Meanwhile, the hybrid system that combines both produces an average power of 2.240×10^{-3} W, slightly higher than the power generated by Solar PV alone.

The power generated by the turbine experiences significant fluctuations, ranging from 5.28×10^{-5} W to 1.74×10^{-4} W, which is likely influenced by wave variations. On the other hand, Solar PV shows a more stable power output with relatively constant values. When these two energy sources are combined in a hybrid system, the generated power is higher and more stable compared to relying on a single source.

The data presented in **Table 5** shows the voltage and current readings over a period of 30 seconds. The voltage values range between 6.11 V and 6.14 V, with an average of 6.127 V, indicating a relatively stable voltage output. Meanwhile, the current remains completely constant at 3.5×10^{-4} A throughout the entire measurement period.

The minimal variation in voltage suggests that the Solar PV system is operating under steady conditions with negligible fluctuations. The stable current output further confirms the reliability of the system in maintaining an electrical supply.

The data in **Table 4** presents voltage and current readings over a 30-second period. The voltage values fluctuate significantly, ranging from 1.165 V to 3.484 V, with an average of 2.421 V. Similarly, the current varies between 1.5×10^{-5} A and 6.0×10^{-5} A, averaging 3.803×10^{-5} A.

These fluctuations indicate that the turbine's electrical output is highly dependent on external factors, such as wave movement, which causes irregularities in voltage and current generation.

Unlike the stable readings observed in the PV.

CONCLUSION

In conclusion, the analysis of the turbine's voltage and current data shows significant fluctuations due to external factors like wave movement, leading to inconsistent power generation. In contrast, the Solar PV system demonstrates stable voltage and current values, ensuring a more reliable energy output. The turbine alone may not be sufficient as a standalone energy source due to its variability. However, integrating it with Solar PV in a hybrid system can help stabilize the overall power generation, combining the turbine’s potential with the consistent performance of Solar PV to achieve a more reliable and efficient energy solution.

The results from the tables indicate a clear contrast between the two energy sources. The turbine experiences significant voltage and current fluctuations, with values that rise and fall unpredictably due to wave variations. On the other hand, the Solar PV system maintains a steady voltage and current output, with minimal deviations throughout the measurement period. This suggests that while the turbine has the potential to generate power, its instability limits its effectiveness as a sole energy source. Meanwhile, Solar PV provides a consistent output but may be affected by environmental factors such as sunlight.

Further research can be focused on optimizing turbine geometry, such as the number of blades, pitch angle, to significantly increase the efficiency of energy conversion from air pressure to mechanical energy. Integration of energy storage systems that are more efficient in storing energy from two sources with different characteristics. As well as studies of long-term material resistance, especially on key components such as turbines, valves, and venturi systems against corrosive marine environments.

ACKNOWLEDGEMENTS

Thank you to the Directorate of Learning and Student Affairs, Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology for funding the 2023 Student Creativity Program in Karsa Cipta (PKM-KC) with the title, "Integrated Sun-Tidal Energy (ISTRY): Hybrid Energy Innovation Utilizing Solar and Tidal Energy in Coastal Areas”. Energy Systems Engineering Study Program at ITERA.

REFERENCE

Abror, M., 2020. *Studi Potensi Pembangkit Listrik Energi Gelombang Laut Sistem Oscillating Water Column (OWC) di Pesisir Kabupaten Trenggalek,* Surabaya: Universitas Islam Negeri Sunan Ampel.

Husnayaen, et al., 2022. Physical assessment of coastal vulnerability under enhanced land subsidence in Semarang, Indonesia, using multi-sensor satellite data. *Advances in Space Research*, 61(8), pp. 2159-2179.

Khurshid, H. et al., 2024. Analysis of hybrid offshore renewable energy sources for power generation: A literature review of hybrid solar, wind, and wave energy systems. *Developments in the Built Environment,* Volume 19, p. 100497.

Madi, M. et al., 2023. Experimental Study of The Fan Turbine Performance in Oscillating Water Column with Airflow System in Venturi Directional as Wave Energy Converter. *Wave: Jurnal Ilmiah Teknologi Maritim,* XVII(1), pp. 19-26.

Madi, M. et al., 2022. Experimental Study on the Eff ect of Arm Design on the Performance of a Flap-Float Horizontal Ocean Wave Energy Converter. *Nasa More: International Journal of Maritime Science & Technology,* LXIX(2), pp. 77-83.

Madi, M. et al., 2024. Experimental Study on the Effect of Single Flow Disturber on the Performance of the Straight-Bladed Hydrokinetic Turbine at Low Current Speed. *Scientific Journal of Maritime Research,* Volume XXXVIII, pp. 43-54.

Madi, M. et al., 2024. Experimental Study on the Eff ect of Foil Guide Vane on the Performance of a Straight-Blade Vertical Axis Ocean Current Turbine. *Nase More: International Journal of Maritime Science & Technology,* LXXI(1), pp. 1-11.

Madi, M. et al., 2021. Studi Eksperimen Model Water Flow Deflector untuk Meningkatkan Performa Turbin Arus Laut Tipe Vertikal pada Kecepatan Arus Rendah. *Wave: Jurnal Ilmiah Teknologi Maritim,* XV(2), pp. 85-90.

Madi, M., Sasono, M. E. N., Hadiwidodo, Y. S. & Sujiatanti, S. H., 2019. Application of Savonius Turbine Behind the Propeller as Energy Source of Fishing Vessel in Indonesia. *IOP Conference Series: Materials Science and Engineering,* Volume DLXXXVIII.

Madi, M., Tuswan, T., Arirohman, I. D. & Ismail, A., 2021. Comparative Analysis of Taper and Taperless Blade Design for Ocean Wind Turbines in Ciheras Coastline, WestJava. *Kapal: Journal of Marine Science and Technology,* XVIII(1), pp. 8-17.

Mukhtasor, M., 2014. *Mengenal Energi Laut.* Surabaya: ICEES.

Parjiman, P., Daryanto, D., Subekti, M. & Rif'an, M., 2018. Simulasi Gelombang Laut untuk Pembangkit Listrik Tenaga Gelombang Laut (PLTGL). *Jurnal Teknik Elektro,* IX(1), pp. 50-57.

Saham, S. & Rezaey, S., 2024. Aerodynamic Efficiency Assessment of a Cross-Axis Wind Turbine Integrated with an Offshore Deflector. *Heliyon,* X(17).

Satrio, D. et al., 2025. Technical feasibility of implementing heaving device wave energy converter: a case study in Mentawai Waters, Indonesia. *Marine Systems & Ocean Technology,* XX(4).

Satrio, D. et al., 2024. A Numerical Study of the Effect of Depth Immersion and Rotation Direction on the Performance of Cross-Flow Savonius Turbines. *Scientific Journal of Maritime Science,* XXXVIII(2), pp. 250-262.

Satrio, D. et al., 2023. Effect of Positioning a Circular Flow Disturbance in Front of the Darrieus Turbine. *IOP Conference Series: Earth and Environmental Sciecne,* Volume MCLXVI.

Shintawati, D. W., 2019. *Studi Potensi Pembangkit Listrik Tenaga Gelombang Laut Sistem Oscillating Water Column (OWC) di Kelautan Indonesia,* Surakarta: Universitas Muhammadiyah Surakarta.

Su, Y., 2024. *The Influence of the Sun, Moon and Earth Tides.* Abu Dhabi, EWA Publishing.

Syahputra, R. & Soesanti, I., 2021. Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: A case study in Yogyakarta, Indonesia. *Energy Reports,* Volume VII, pp. 472-490.