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A NEW APPROACH TO NEEDS ANALYSIS: POWER PLANT MODELLING AND ANALYSIS IN SUSTAINABLE RENEWABLE ENERGY LEARNING

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ABSTRACT

This research examines renewable energy modelling and analysis to develop future power plants in higher education. A new approach in needs analysis through modelling and analysis of renewable energy generation to design future power plants. The case study focuses on a solar power plant and a hydroelectric power plant in Tomuan Holbung Village Bandar Pasir Mandoge Asahan Regency, North Sumatra, Indonesia. The potential energy sources of hydropower and solar power plants in Tomuan Holbung Village were mapped and measured and then simulated, resulting in a hydropower potential of 5.92 MW. As for the potential of solar energy from the measurement results and obtained average daily radiation of solar energy reaches 5.9 kWh/m2. This research also explores the application of the research results in a real problem-based e-module for learning. The practicality of the real problem-assisted e-module model has been tested in a small class test on 4 student respondents who participated in the study, showing the results of the practicality of using the renewable energy e-module of 80% declared practical. The concept of mapping, modelling and analysis of real situations applied to learning becomes a reference in understanding future electrical energy needs whose potential is spread across several regions in Indonesia. This approach offers new insights and methodologies that can be adapted for sustainable power plant design and enriches the learning experience in the field of renewable energy.

Keywords: *Five Renewable Energy; Hydro Power;Photovoltaic;Sustainable Power Plant; Riil Problem Based Learning*

1. INTRODUCTION

Renewable energy plays a crucial role in tackling climate change and is one of humanity's biggest challenges today[1]. Using renewable energy such as solar, wind, hydro, and biomass offers a solution to reduce greenhouse gas emissions from burning fossil fuels[2],[3]. Renewable energy does not produce greenhouse gas emissions when used, so it can help reduce the impact of climate change[4], [5]. Renewable energy also contributes to reducing our dependence on depleting and expensive fossil fuels and creating new jobs in the green energy sector[6],[7]. Countries worldwide increasingly realize these benefits and invest in developing renewable energy technologies[8]. Renewable energy has great potential, but several challenges remain to overcome, including at the economic, technological, and social levels[8], [9]. With constantly evolving technological innovations and supportive policies, renewable energy could be the key to a more sustainable and environmentally friendly future[10]. The importance of renewable energy in the context of climate change is not only limited to reducing emissions but also includes diversifying energy sources and encouraging technological innovation that can help us out of the current climate crisis[11], renewable energy thus makes a significant contribution to global efforts to slow the rate of global warming[12].

Energy transition conditions will have an impact on several sectors and human resource development needs[13], [14] because each cycle of the energy transition requires research, development, and

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decommissioning, so the challenge and urgency in realizing clean and sustainable energy, one of which is the readiness of Human Resources (HR) with the potential conditions of New Renewable Energy with scattered locations, so systematic and balanced education is needed[15]. Higher education is responsible for developing innovative human resources[16]. One of the fields of study that plays a vital role in strengthening the competence of human resources in New Renewable Energy is the Electrical Engineering Study Program[17]. However, in practice, it still needs to be solved, and problems related to the procurement of learning products in the field of EBT, which are relatively expensive with a limited number of units, so practical, economical, and sustainable learning device innovations are needed[18].

The skills gap in the green energy sector refers to the difference between the skills the current workforce possesses and the skills required for future jobs related to renewable energy. Some key points include Skilled Labour Needs[19]: There is an urgent need for a skilled workforce in renewable energy technologies to support the energy transition. (1) Training and Education: Better training and education are needed to prepare a workforce with relevant skills.(2) Industry and Education Cooperation: There is a need for cooperation between the green energy industry and educational institutions to develop curricula that meet labor market needs. (3)Investment in Skills Development: Investment in skills development is essential to ensure the workforce can adapt to new technologies and sustainable working methods. PwC's Green Jobs Barometer report shows that the increase in renewable and low-carbon energy generation will be constrained by a significant skilled labor shortage, which must be addressed by more than the existing energy sector workforce[20], [21].

Industry and educational institutions should integrate simulation-based learning models in the electrical engineering curriculum[22][23]. This model allows students to gain a deep understanding of renewable energy technologies through virtual practical experiences that mimic real-world scenarios[22], [24][25]; for example, simulating the design of photovoltaic systems or water turbines can provide insight into the operational challenges and technical decisions faced by engineers in the field[26][27]. Virtual Reality (VR) learning models in electrical engineering education offer an innovative approach that can enhance students' skills and readiness for the green energy industry[26], [28]. VR enables interactive and immersive simulation of working environments, where students can experiment with renewable energy system designs and understand operational dynamics without high risk or cost[29]. According to a study[30], the use of VR in engineering education has shown significant improvements in concept understanding and knowledge retention, which are essential assets in preparing the workforce for the challenges of the energy transition..

Conducting a needs assessment is critical in developing an effective simulation learning model, especially in electrical engineering education[31]. This assessment allows educators to identify the specific needs of students and industry and customize learning materials to match the competencies required in the green energy sector. A study by Damir Ljuhar [32] emphasizes the importance of need assessment in designing simulation learning modules that can holistically improve students' practical and theoretical skills.

Integrating research results into the learning model provides added value for electrical engineering students, enriching their learning experience with up-to-date knowledge and practical applications of the theories learned. The following steps can be taken to incorporate research results into the learning model[33][34].

Material Update: Periodically update the learning materials with the latest research findings in renewable energy[35]. (1)Researcher-Educator Collaboration: Encourage collaboration between researchers and educators to integrate research results into the curriculum. (2)Case Studies: Case studies based on research results teach complex concepts and encourage creative problem-solving. (3)Research-based Projects: Providing projects that allow students to apply research results in authentic contexts. (4)Student Publications: Encouraging students to contribute to scientific publications, broadening their understanding of the research process. In this way, students learn from textbooks and engage directly with cutting-edge developments in electrical engineering, preparing them to become innovators and leaders in the green energy sector

2. METHODOLOGY

2.1 Research Stages

The research stages were carried out using the mechanism as shown in Figure 1.

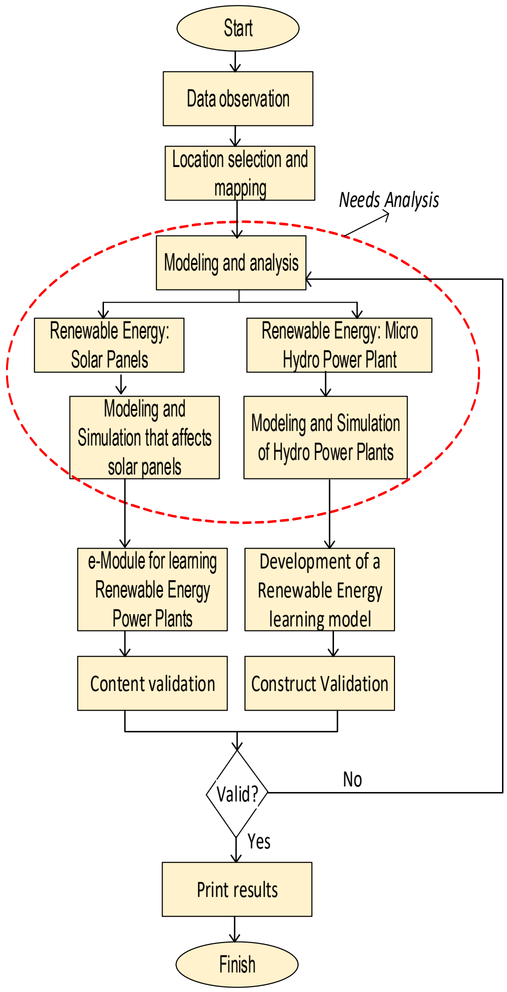

Figure 1: Research Stages

Figure 1 shows the research stages starting from observing field data in Tomuan Holbung Mandoge village, which is a sub-district in Asahan Regency, North Sumatra which has the potential for a watershed for the development of micro-scale hydroelectric power plants or Micro Hydro. Apart from that, observations were made of the potential of solar energy for generating electricity in Tomuan Hobung Village, Pasir Mandoge Village. The modeling and analysis stages of the initial observation results are needed to obtain a real picture of the potential produced by the two plants. This is needed to prepare the contents of the module that will be used by students in studying renewable energy power generation courses. There are two stages of the results of the analysis of the simulated model, namely, the validity of the model construct which is suitable for application in learning about sustainable future renewable energy and the validity of the content of the modules prepared for the learning tools which are the basis for developing Augmented Reality-based renewable energy learning which will be organize in further research after this needs analysis. All of these stages are depicted in the research stage mechanism in Figure 1.

2.2 Mapping the Potential of Hydroelectric Power Plants and Solar Power Plants

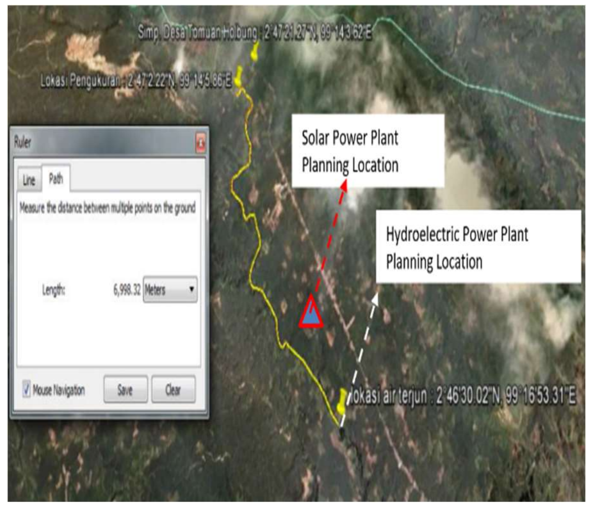

Figure 2: Mapping the Potential of Hydroelectric Power Plants and Solar Power Plants

Figure 2 shows the micro hydro potential mapping model, carried out by identifying the location of the turbo waterfall in Tomuan Holbung Village with characteristics suitable for a Micro Hydro generator, such as height, water discharge and flow speed. Hydrological measurements and analysis to estimate the potential electrical power that can be generated. Topographic mapping and geographical conditions around the waterfall location to determine the power plant development scheme. Evaluate ease of access and distance from settlements to support electricity distribution.

Mapping of solar power plant Potential, Identify areas that have optimal sunlight exposure throughout the day in the hilly areas in Tomuan Holbung Village which are protected from the influence of shadows from objects or objects that cover the surface of the solar panels. Measurement and analysis of solar radiation to estimate the potential electrical power that can be generated is carried out. Mapping of topography and geographical conditions around the location to determine the solar power plant development plan scheme. Evaluate ease of access and distance from settlements to support electricity distribution.

2.3. Mathematical models used in Hydro power and Photovoltaic

2.3.1. Hydro Power potential analysis model

Power potential analysis is carried out based on net-head and mainstay discharge. Water (hydraulic) power potential can be expressed as:

$$Pg = 9.8 * Q * hg \quad (1)$$

where;
Pg = potential power (kW)
Q = water flow rate (m3/sec)
hg = head (plunge height) gross (m)
9.8 = gravitational constant.

Analysis of Electric Power Potential (PEP), using the equation:

$$PEP = 9.8 * \eta * Q * hn \quad (2)$$

where:
PEP = electrical power coming out of the generator (kW)
Q = water flow rate (m3/sec)
nh = net head (plunge height) (m)
Ƞ = Conversion efficiency from hydraulic power to electric power

2.3.2. Mathematical Model of Solar Photovoltaics (PV)

Basic Principles of Photovoltaic Cells, Photovoltaic cells are semiconductor devices that can convert sunlight energy into electrical energy through the photovoltaic effect. When PV cells are exposed to sunlight, the electrons in the semiconductor will be excited and produce an electric current. The diode circuit is a fairly accurate model for describing the behavior of photovoltaic cells. Diode circuit models can be used to predict the current-voltage (I-V) and power-voltage (P-V) characteristics of PV cells. The parameters in the diode model equation can be identified through experimental testing or theoretical calculations. The PV circuit model is shown in figure 3.

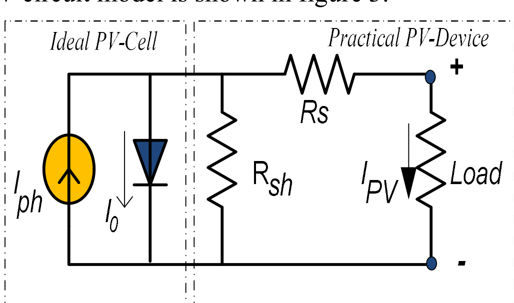

Figure 3: PV Cell Model

Figure 3 shows a diode circuit model. To model the behavior of PV cells, an equivalent circuit is used which consists of; Photovoltaic current source (Iph), iode (D) representing electron-hole recombination, Series resistor (Rs) representing internal resistance, Parallel resistor (Rsh) representing leakage current. The mathematical equation that describes the characteristics of PV cells based on the diode model is:

$$I = Iph - I0 [exp((V + IRs)/Vt) - 1] - (V + IRs)/Rsh \quad (3)$$

Where:
I = Electric current produced
Iph = Photovoltaic current
I0 = Diode saturation current
V = Terminal voltage
Vt = Thermal stress (kT/q)
Rs = Series resistor
Rsh = Parallel resistor

2.3.3. Content and Construct Validity Test in developing Renewable Energy Generation Learning Modules and Models

This research uses two types of validity instruments, namely content validity and construct validity. In the research, the Aiken's V approach was used for content validity analysis, while the Confirmatory Factor Analysis (CFA) approach was used for construct validity analysis. The statistically logical and popular concept of validity is content validity of the content validity of the items. Aiken's V is an approach formulated by Aiken for analysis of the Content Validity Coefficient based on the results of expert research of n people on learning model development items, in this case the extent to which Renewable Energy learning model development items in learning represent the construct being measured, as for the statistical formulation of Aiken's V, in the mathematical formulation of equation 1 to identify content validity, it is expressed as:

$$V = \frac{\sum S}{n(C-1)} \quad (4)$$

Formula description:
S = r-lo
lo = The lowest validity assessment number (in this case = 1)
C = The highest validity assessment number (in this case = 5).

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2.3.4. Practicality Test for Renewable Energy e-Module

Measuring the practicality of the development product was carried out using modeling and analysis assisted by Simulink Matlab software. This software can help data analysis through models and simulations for data analysis with clear process flow block diagrams[36]. Modeling is carried out on the basis of mathematical equations which are used to assess the level of practicality.

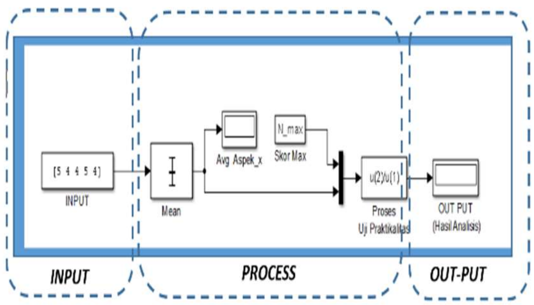

Figure 4: Simulation Model for Practical Testing of e-modules

System modeling in Simulink Matlab for testing the efficiency of e-modules for new and local energy power plants, follows the rules of the system analysis process with 3 major stages that must be considered, namely (1). Data Input (2). Process and (3) results (Output), as seen in the block diagram in Figure 4.

3. RESULTS

3.1. Analysis of the Potential Needs of the Pasir Mandoge Watershed

In Tomuan Holbung Village, there is a waterfall that is quite large and has unique characteristics, namely the turbo waterfall. A turbo waterfall is a waterfall that has very strong currents and falls freely with a sharp slope angle, so that it can be used optimally to drive electricity generating turbines. The water discharge is quite large and stable throughout the year. The height of the water fall is around 20-30 meters, with a very steep slope. The water flow is very fast, so it has the potential for large kinetic energy. The location of the waterfall is relatively close to residential areas, making it easier to access and distribute electricity.

The topographic conditions around the waterfall are hilly, supporting the development of Micro Hydro infrastructure. With the characteristics of its turbo waterfall, Tomuan Holbung Village, Bandar Pasir, Mandoge has excellent potential to be developed as a location for a micro-scale hydroelectric power plant. However, mapping and feasibility studies and technical analysis are carried out to determine the optimal capacity of power plants that can be built.

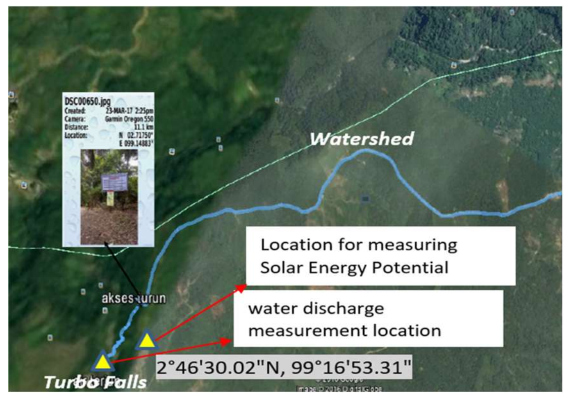

Figure 5: Location Mapping for Renewable Energy Potential Measurement

Figure 5. Tomuan Holbung village, which is located in the Bandar Pasir Mandoge sub-district, from satellite observations is located at 2o47'21.27"N, 99o14'3.63. This location was chosen to test the potential for renewable energy generation (Hydro power and PV), as shown in figure 5.

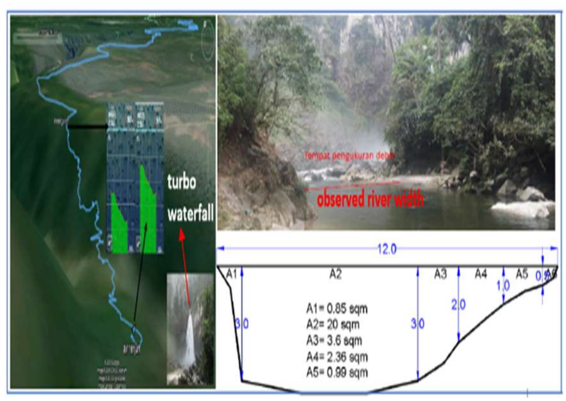

Figure 6: Measurement of Turbo Waterfall Potential for Power Generation

Figure 6 shows the results of observations of direct measurements of the potential of the River Basin in Tomuan Holbung Village, Bandar Pasir Mandoge, Asahan Regency. From the measurement results, data is obtained to determine the analysis of Cubication and Electric Power Potential. The

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measurement results obtained the following data; (1) Maximum Water Flow = 1.7 ms^{-1}; (2) Minimum Air Flow = 1.3 ms^{-1}; (3) Cross-sectional area 12 m^2, So, the water discharge (Q) is obtained:

Q = water flow x Cross-sectional area
Q = (1.7 + 1.3)/2 ms^{-1} x 12 m^2
Q = 18 $m3s^{-1}$

So the potential Power Generation Capacity, with Analysis of Electric Power Potential (EPP), using the equation, EPP = 9.8 * ꞃ * Q * hn;

EPP = Q x H x G x eff.
= 18 m 3/s x 9.8 x 42 m x 0.8
= 5927 W
EPP = 5.92 MW

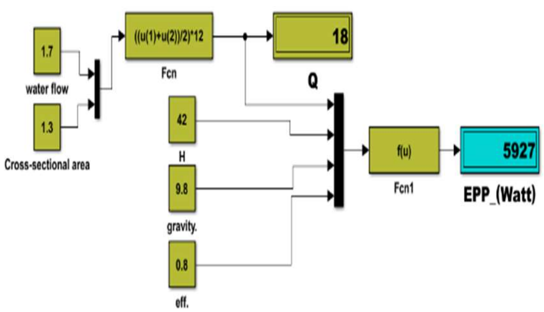

Figure 7: Simulation Model for Determining the Electrical Power Potential Value of the Turbo Waterfall Potential

Simulation of the Electrical Power Potential of the Turbo Waterfall in Tomuan Holbung Village (fig. 1) was carried out with several parameters based on a predetermined mathematical model, namely: Water Discharge (Q), Water discharge is the volume of water that flows per unit time, usually in units of m³/s. Water discharge can be measured directly at the turbo waterfall location. Fall Height (H) Fall height is the height difference between the water entry point into the turbine and the water exit point from the turbine. The height of the fall can be measured using a height measuring device. Turbine Efficiency (η) Turbine efficiency is the comparison between turbine output power and turbine input power. Turbine efficiency is usually around 70-90% depending on the type of turbine.

3.2. Analysis of PV Potential as a power generator in Tomuan Holbug village

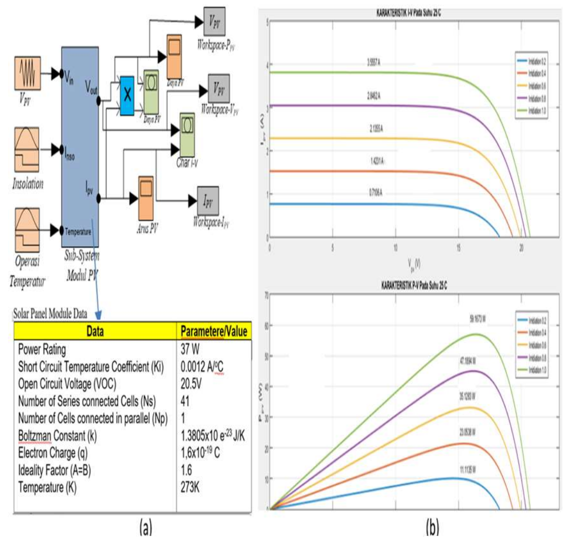

Figure 8: Image of PV Panel simulation results (a). Simulation model and parametric data ; (b).Simulation of several conditions of the influence of Irradiation with constant temperature on PV output current and power

Figure 8 shows the simulation output results which illustrate the decrease in current and output power due to changes in solar radiation, assuming the temperature is at a constant value of 250C, the higher the influence of irradiation the greater the I and P of the Solar Panel output, shown in table 1

Table1. Simulation results of the effect of irradiation with a constant temperature of 250 C on I and P

Variasi Irradiation	PV I-V (A)	PV P-V (W)
0.2	0.71	11.11
0.4	1.42	23.05
0.6	2.13	35.12
0.8	2.84	47.18
1	3.55	59.16

The simulation results from the simulation characteristics in Figure 1.b and the simulation values in Table 1 show the effect on the output current I, where the higher the irradiance (sunlight), the greater the output current I from the solar panel. This is because the more photons that hit the solar cell, the more electron-hole pairs are formed. The more electron-hole pairs formed will produce a greater electric current. So, the relationship between irradiance and output current is directly proportional. The higher the irradiance, the greater the output current. The effect on the output power of solar panels is the product of current (I) and voltage (V).

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The higher the irradiance, the greater the output current I as explained previously. Meanwhile, the voltage V will also slightly increase as the irradiance increases. Because both current (I) and voltage (V) increase with increasing irradiance, the output power (P) will be greater. The simulation results show that the relationship between irradiance and output power is directly proportional. The higher the irradiance, the greater the output power. In summary, the higher the influence of irradiance (solar radiation), the greater the current (I) and power (P) output from the solar panel, assuming a constant temperature of 25°C. the average daily radiation reaches 5.9 kWh/m2. This solar radiation value is considered good for the development of solar power plants.

3.3. Real Problem-Based Learning in Renewable Energy

Real problem-based learning is prepared from the results of observational studies, modeling and analysis in the field of renewable energy. The model developed in student-centered learning. A small class trial with a sampling of 4 students involved in this research was taught about actual problems that occurred in the village of Tomuan Holbung Bandar Pasir Mandoge. Integration of research results into learning materials was carried out by compiling e-Modules in the field of renewable energy which had previously been validated by experts. The results of research on measuring and simulating river flow for electricity generation and the use of solar panels to produce electricity with the influence of irradiation are interesting topics for students to study. Students can study theoretical concepts and relate them to research findings.

From the results of testing the practicality of the modules that have been prepared and the simulations used, through practicality testing the results obtained are as shown in table 2.

Table 2. Results of e-Module Practicality Assessment

Respondent	Practicality of the modules			
	Criteria a	Criteria b	Criteria c	Criteri ad
Resp. -1	4	5	4	4
Resp.-2	5	4	4	5
Resp. -3	4	4	4	5
Resp. -4	4	4	4	4

Measuring the practicality of the renewable energy learning e-Module, in a small class trial involving 4 student respondents, consisted of 4 aspects and assessment indicators, namely (a). Attraction aspect; (b) Aspects of the development process (c) Aspects of Ease of Use;, and (d) Aspects of Functionality of use;

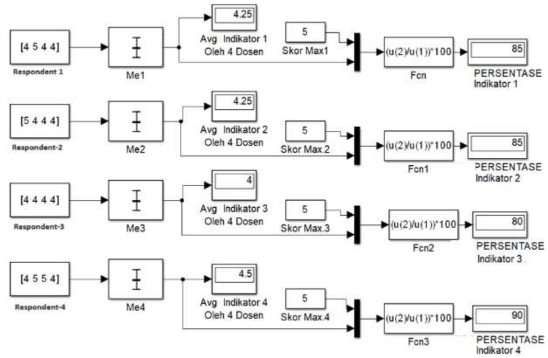

Figure 9: Practicality Simulation of Renewable Energy Learning e-Modules

Figure 9 is a simulation related to the practicality of e-modules using Simulink. It can be seen that the attractiveness aspect of indicators 1, 2 and 3 is stated to be very practical with the percentage value of indicator 1 being 85%, indicator 2 being 85% and indicator 4 being 90%. indicator 3 is declared practical with a presentation value of 80%. The average practicality value for aspect 1 is 85%. Showing e-modules developed from the results of real case-based research in Tomuan Holbung village showing practical e-modules used by students in learning renewable energy.

4. CONCLUSIONS

1. Tomuan Holbung Village has the potential for a turbo waterfall which can be used to generate electricity. Through analysis of measuring water discharge, fall height, and turbine efficiency, an Electric Power Potential of 5.92MW can be calculated. The potential for turbo waterfalls and river water resources, Tomuan Holbung village supports the net zero emissions policy in Indonesia, as well as being a solution to meet electricity needs in villages, especially areas that are not yet reached by the national electricity grid.

2.Tomuan Holbung Village is located in an area with quite high intensity of solar radiation, with average daily radiation reaching 5.8 kWh/m2. This solar radiation value is considered good for the development of solar power plants (PLTS). There is quite large and strategic land around the village that has the potential to be used as a PLTS installation location. This land has a suitable orientation and slope for placing solar panels.

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3. The practicality of the module was assessed as 80% practical by respondents, indicating that the material and content presented in the module are relevant to actual issues and real problems related to renewable energy. The topics discussed, such as resource potential, technology, and simulation applications in the field of renewable energy, are in accordance with local needs and context in Tomuan Holbung village. The module is equipped with clear instructions and guides to help students understand the learning path based on real problems in the field of renewable energy. The steps for solving problems in learning are presented based on integrating research results so that practically, with real experience, students can follow the learning process easily.

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