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A Model And Analysis Of Photovoltaic Modules With Irradiation And Temperature Variations Based On Simulation Technology

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Article Info	ABSTRACT
Keywords: Photovoltaics (PV), Irradiation, Temperature, IV and PV Characteristics, Simulation	This article discusses the modeling and analysis of Photovoltaic (PV) modules with irradiation and temperature variations using simulation technology. Modeling is carried out on solar modules through the pn junction principle, a PV module model with temperature independence of photocurrent sources, diode saturation currents, and series resistances based on the Shockley diode equation. The photovoltaic process of solar radiation, PV cells convert a portion of the photovoltaic potential directly into electricity with IV and PV output characteristics. Electromagnetic radiation from the sun's energy is converted into electricity through the photovoltaic effect. The photovoltaic module simulation process with Matlab/Simulink, is carried out to observe the performance through the IV and PV characteristics of the solar module. The model, which is developed in a user-friendly manner using the Simulink block, shows the results of the PV characteristics when irradiation increases, the output current increases and the output voltage also increases. This results in a net increase in power output with increased irradiation at constant temperature.
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INTRODUCTION

Photovoltaic (PV) is a technology that produces direct current (DC) electricity from semiconductor solar panels (solar cells) when illuminated by photons expressed in Watts (W) or kiloWatts (kW). The process of converting electrical energy from solar cells takes place continuously, known as New Renewable Energy (EBT). The use of EBT as an alternative energy for power plants continues to be studied and implemented in an effort to overcome the oil and gas energy crisis. Photovoltaic module technology as part of EBT sources makes an important contribution in supporting the electricity system that supports economic growth. EBT support through power plant innovation with affordable and sustainable access is an important factor for a country in economic development, industrial progress and public welfare. In India, growth and access to affordable and sustainable electricity are basic needs, the demand for electricity in India continues to increase and is still dominated by coal-based supplies, due to industrialization and urbanization.

PV has become a symbol technology for future sustainable energy supply systems in many countries, includingIndonesia. A large amount of money is investedin research, development, implementation of renewable energy in the electricity sector. The government has made a substantial market introduction program and the industry is investing in renewable energy-based electricity production facilities, but it is still relatively low at around 18.2% of renewable energy compared to coal-fired power plants. The achievement of electricity production in 2020 reached 292.0 TWh for the on-grid system and off grid sourced from the Company's power plantsNational Electricity (PLN) and non-PLN. Around 62.0% of electricity production comes from Coal-Fired Power Plants, 18.2% EBT, 17.6% gas, and only 2.3% oil. The realization of new renewable energy (EBT) power plant capacity until the end of 2020 reached 10,467 megawatts (MW). The trend of increasing EBT power plant capacity continues to come from a number of projects.

The potential for renewable energy from solar energy in Indonesia is in the fairly good category, based on the map of renewable energy potential for solar energy in several regions. The highest solar intensity is found in the regions of Banten, West Java, Central Java, Nusa Tenggara and Papua. However, technically, the regions of North Sumatra, South Sumatra, West Kalimantan, East Kalimantan generally have quite high potential compared to other provinces. Specifically, the province of North Sumatra is ranked 4th out of 34 provinces. The potential for PLTS is 11,851 MW. Currently, the utilization of renewable energy, especially solar energy, is relatively low, as seen from the data released by the National Energy Council evaluation report (DEN, 2022).

The utilization of solar renewable energy is still in the minimal category, this is influenced by factors related to the intermittent nature of PLTS. namely voltage and frequency that can change drastically influenced by sunlight conditions that can change drastically if there is a shadow effect by clouds and the surrounding environment. However, the potential for solar renewable energy has very good prospects and needs to be developed in an effort to support the implementation of solar as a power plant [3]. Reconstruction and development of renewable energy potential and multilateral investment from the industry provide a guarantee of reliable and sustainable energy supply, to increase installed electricity capacity. Solar photovoltaic (PV) technology has become an increasingly important energy supply option. The substantial decline in the cost of solar PV power generation (80% reduction since 2008) has increased the competitiveness of solar PV, reduced the need for subsidies and allowed solar to compete with other power generation options in several markets. While most of the operating solar power projects are in developed countries [4]. In Indonesia, which is rich in renewable energy sources and geographical wealth, Indonesia's renewable energy potential for power generation is 3,868 GW. Several renewable energy sources that can generate electricity are as shown in Table 1.

Table 1. Potential of renewable energy in Indonesia

Energy	Potential	Utilization
Sun	3.295	0.27
Hydro	95	6.69
Bio Energy	57	3.09
Bayu	155	0.15
Geothermal	24	2.34

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Energy	Potential	Utilization
Sea	60	0
Total	3,686	12.54

From table 1, it can be seen that the utilization aspect of renewable energy potential from solar energy for power generation is classified as very low, this can be seen from the utilization of renewable energy as an alternative source of new power generation which is utilized around 0.008194%, this shows that the potential of solar PV panels needs to be increased again to optimize the target of achieving the national energy mix.

Literature Review

Mathematical Model Photovoltaic Module

Principle of PV operation, Solar cells are made of materials called semiconductors, which have weakly bound electrons that occupy an energy band called the valence band. When energy exceeding a certain threshold, called the band gap energy, is applied to the valence electrons, their bonds are broken and the electrons are “free” to move into a new energy band called the conduction band where they can “conduct” electricity through the material. Thus, the free electrons in the conduction band are separated from the valence band by the band gap (measured in electron volts or eV). The energy required to free these electrons can be supplied by photons, which are particles of light. Figure 1. shows the ideal relationship between energy (vertical axis) and spatial boundaries (horizontal axis). When a solar cell is exposed to sunlight, photons strike the valence electrons, breaking their bonds and pumping them into the conduction band. There, specially designed selective contacts collect the conduction band electrons and push them into an external circuit. Electrons that lose their energy by doing work in an external circuit such as pumping water, turning a fan, driving a sewing machine motor, a light bulb, or a computer, are returned to the solar cell by the return loop of the circuit through a second selective contact, which returns them to the valence band with the same energy they started with. This movement of electrons in the external circuit and contacts is called an electric current. The potential at which electrons are sent out into the outside world is slightly less than the threshold energy that excites electrons; that is, the band gap.

Thus, in a material with a band gap of 1 eV, electrons excited by a 2 eV photon or by a 3 eV photon both still have a potential slightly less than 1 V (i.e., the electrons are sent out with an energy of 1 eV). The electric power produced is the product of the current times the voltage; that is, the power is the number of free electrons times the potential [5]. The principle of PV is shown in figure 1.

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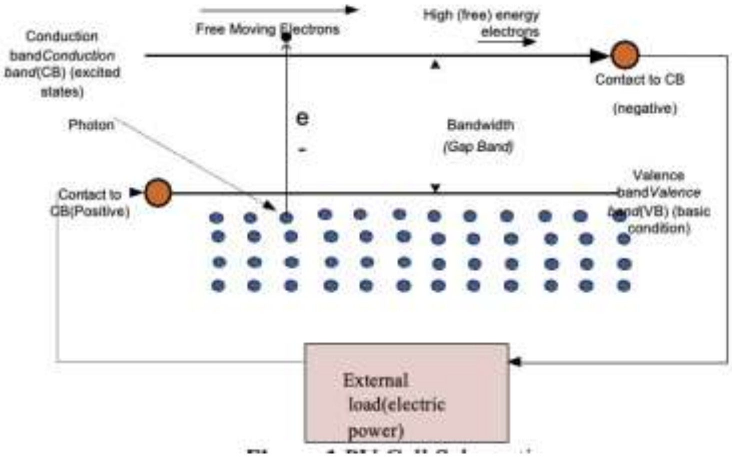

Figure 1. PV Cell Schematic

Figure 1, shows the principle of PV Cell Schematic. Electrons are injected by photons from the valence band to the conduction band. There they are extracted by selective contact to the conduction band of an n-doped semiconductor at higher (free) energy and sent to the outside world through a wire, where they do some useful work, then returned to the valence band at lower (free) energy by selective contact to the valence band (p-type semiconductor).

Solar cells are basically pn junctions made of thin semiconductor layers. Electromagnetic radiation from solar energy sources can be directly converted into electricity through the photovoltaic effect. The photovoltaic effect converts energy from sunlight into electrical energy. Photovoltaic technology converts solar radiation into electrical energy by utilizing batteries as a storage of electrical energy used in everyday life. The equivalent circuit of a PV cell is shown in Figure 2.

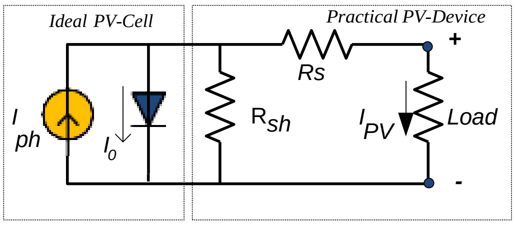

Figure 2. Diode Array as a PV Cell Model

The equivalent circuit in Figure 2 shows a PV module consisting of solar cells connected in series and parallel to obtain the desired voltage and current output levels. Each solar cell is essentially a pn diode. When sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. The transmitted light is absorbed in the semiconductor, using this light energy to excite free electrons from low energy states to higher unoccupied energy states. When the solar cell is illuminated, excess electron-hole pairs are generated throughout the solar cell, thus making the pn junction conductive and current will flow. Iph represents the photocurrent of the cell while Rsh and Rs are the intrinsic shunt and series resistance of the PV module, respectively.

Mathematical modeling of PV [6-8], the current source Iph represents the photocurrent of the cell. Rsh and Rs are the intrinsic shunt and series resistance of the cell, respectively. Usually the value of Rsh is very large and the value of Rs is very small, so it can be neglected to simplify the analysis. PV cells are grouped into larger units called PV modules which are then interconnected in a series-parallel configuration to form a PV array. PV cells are grouped into larger units called PV modules, which are then interconnected in a series-parallel configuration to form a PV array. The basic equations of semiconductor and photovoltaic theory that mathematically describe the IV characteristics of photovoltaic cells and modules. Iph of a photovoltaic module depends linearly on solar irradiance and is also affected by temperature are expressed in equation (1):

$$I_{ph} = [I_{SCr} + K_i(T_k - T_{ref})] * \frac{\lambda}{1000} \tag{1}$$

Where I_{ph}(A) is the current produced by light at nominal conditions (25∘C and 1000 W/m2), K_i is the short circuit current coefficient per unit temperature (0.0017A/K), T_k and Tref are the actual and reference temperatures in Kelvinb (K), respectively, λ is the irradiance on the device surface in units of (W/m2), and the nominal irradiance is 1000 W/m2. The details of the Simulink model to be constructed and the simulation of Iph are shown in Figure 2. The short-circuit current value of the module is ISCr taken from the data sheet of the reference model Iph for different insolation and temperature values are shown in Table 1.

The equation for the reverse saturation current module (Irs), is:

$$I_{rs} = I_{SCr} / [\exp(qV_{OC} / N_s kAT) - 1] \tag{2}$$

METHOD

The PV module model with moderate complexity including the temperature independence of the photocurrent source, diode saturation current, and series resistance is assumed based on the Shockley diode equation, irradiated with sunlight radiation, the PV cell converts part of the photovoltaic potential directly into electricity with IV and PV output characteristics. The PV model and simulation using equations (1) to (4) are simulated with the matlab simulink block with stages, as shown in figure 3.

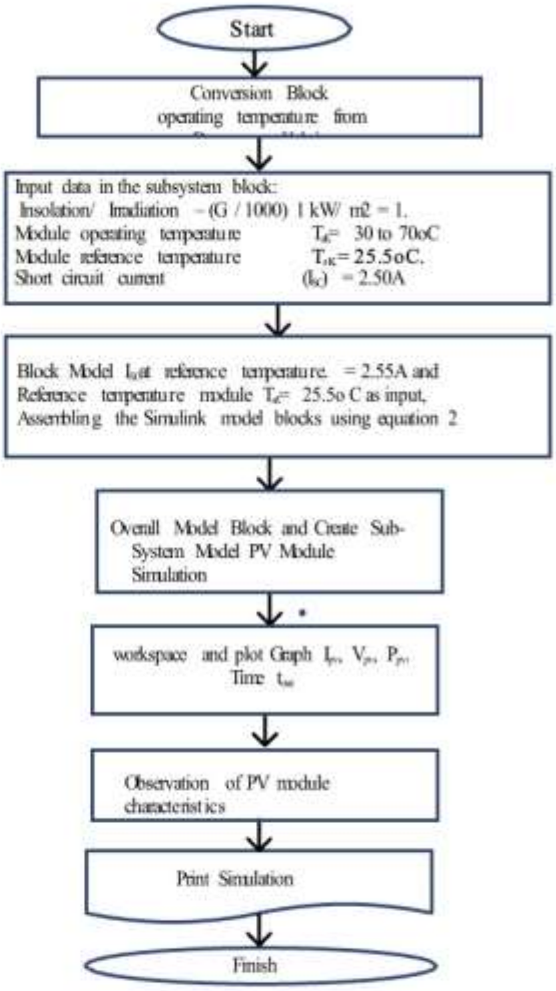

Figure 3. PV Simulation Design Stages

The simulation model stages in Figure 3 are arranged based on the mathematical equations of the PV module written in equations 1 to 4. The complete Simulink block will be arranged as shown in Figure 4.

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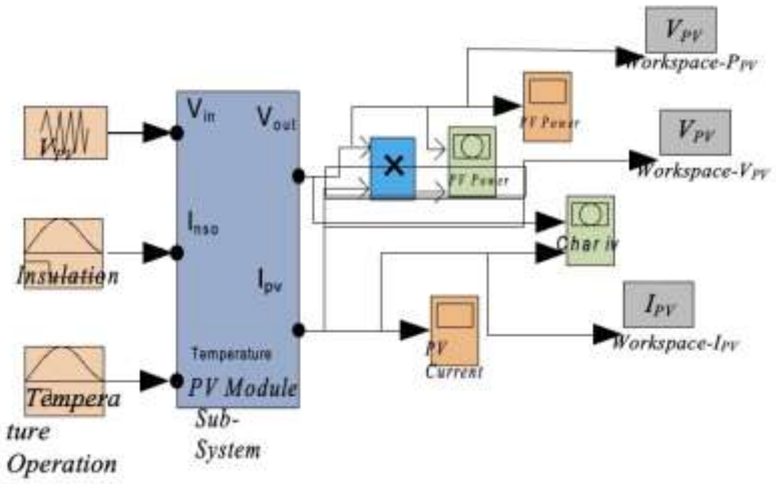

Figure 4. PV module simulation model block

Figure 4, shows the simulation model used in observing the characteristics of the PV module. The model in Figure 4 with irradiation input, operating temperature in Celsius and module voltage as input and provides output current Ipv and output voltage Vpv. The graph plot uses Matlab simulink with XY graph block with simulation observations including (Vpv,Ipv) and signal characteristics of (tout,Ipv). IV and PV characteristics under varying irradiation with constant temperature will be part of the PV module simulation observation. The step procedure for modeling the PV module is arranged in the Simulink model with equation guidelines and mathematical modeling procedures to obtain the characteristics of the PV module IV and PV. The Solar make 36 W PV module is taken as the reference module for simulation and the details of the system data used are shown in table 2.

Table 2. Solar Panel Module Data

Data	Parameters/Values
Power Rating	37W
Short Circuit Temperature Coefficient (Ki)	0.0012 A/0C
Open Circuit Voltage (VOC)	20.5 V
Short Circuit Careent ISCr	2.32 A
Ns (number of cells connected in series)	41
Np (number of cells connected in parallel)	1
k (Boltzman constant)	1.3805 × 10e-23 J/K
q (Electron charge)	1.6 × 10e-19 C
A = B (ideality factor)	1.6
Temperature (K)	273 K

RESULTS AND DISCUSSION

PV Model Simulation Based on Shockley Diode Equation with Irridation and Temperature Effects. The mathematical model of solar PV module based on the block of figure 4 based on current source, diode resistor, series and parallel is developed in a step by step procedure using equations (1) to (4). The solar module simulation is selected as a reference model and provides input parameters for modeling the observation of characteristic curves for irradiance and temperature given as input parameters. Simulation Observation-I: (PV), simulation of solar radiation variation {200 W/m2; 600 W/m2; 1000 W/m2} with constant temperature of 250C produces simulation results shown in figure 5.

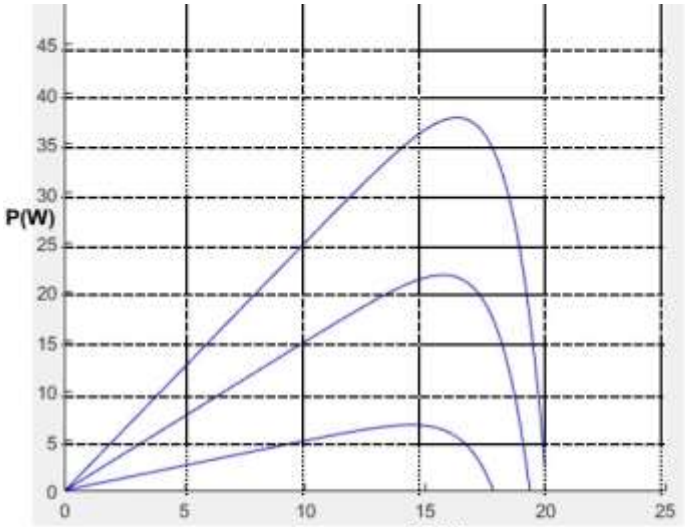

Figure 5. Variation of Solar Radiation {0.2; 0.6; 1} with constant temperature 250C

In the simulation result image of figure 4, the graph above shows that when the irradiation increases, the output current increases. The output voltage also increases. This results in a net increase in power output with increasing irradiation at constant temperature. Simulation Observation II: Characteristics of IV under constant irradiation with varying temperatures in degrees Celsius{250C;500 C;750 C}.

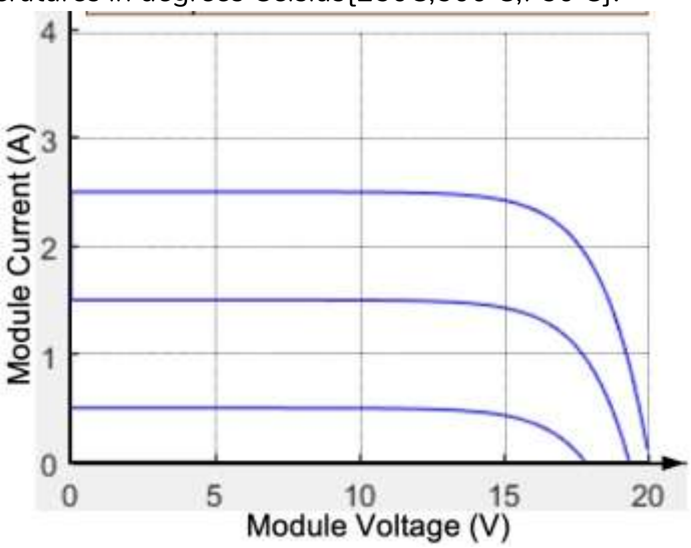

Figure 6. Characteristics of Temperature Variation {250C;500 C;750 C} with Constant Solar Radiation

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Figure 5, shows the simulation result graph showing the performance when the operating temperature increases, the current output increases slightly but the voltage output decreases drastically resulting in a net reduction in power output with increasing temperature. The results are verified based on the theory of the relationship between current and voltage due to increasing temperature on the solar panel, there is a match between the characteristic results. Simulation trials with changes in sunlight and temperature changes were further carried out with several data variations with the simulation results shown in Figure 7.

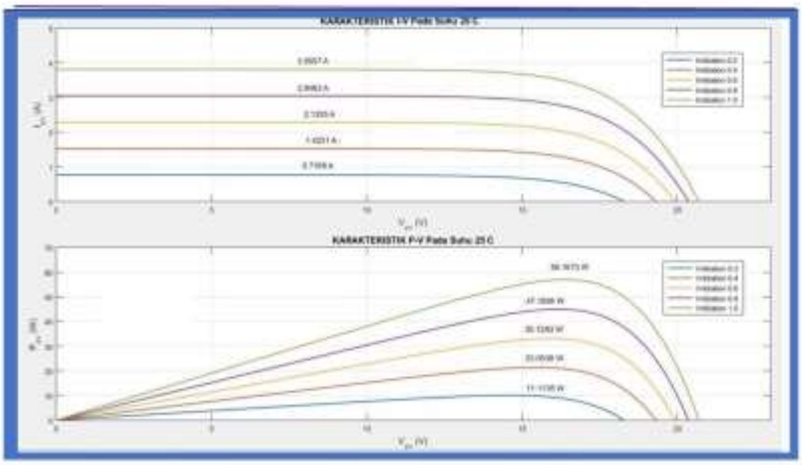

Figure 7. Simulation results of several conditions of the influence of irradiation with constant temperature on PV current and output power

Figure 7 shows the simulation output results that illustrate the decrease in current and output power due to changes in solar radiation, assuming the temperature 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 3.

Table 3. Simulation results of the influence of irradiation conditions with a constant temperature of 250C on PV current and output power

No	Irradiation Variations	PV IV(A)	PV PV(W)
1	0.2	0.71	11.11
2	0.4	1.42	23.05
3	0.6	2.13	35.12
4	0.8	2.84	47.18
5	1	3.55	59.16

From the simulation results table (Table 3), it can be seen that the effect of irradiation on the output power of solar panels is directly proportional, the greater the value of the irradiation parameter, the higher the PV IV and PV PV results from the output of solar cells. In line with the simulation in the research conducted related to the relationship between current in solar cells and temperature is linear. When the cell is not lit, the relationship between voltage and terminal current of the cell decreases given by the Shockley equation. When the cell is irradiated, photocurrent flows in the diode. The IV curve with increasing output power, and there is a shadow effect as a cause of reduced irridation has an impact on reducing the output power of solar cells.

CONCLUSION

The PV module is modeled using Matlab Simulink. The model parameters are based on equations 1-4. n. The value of each calculation in the Simulink model is verified by theoretical calculations, namely based on the equation proving that the simulation is in accordance with the characteristics and performance of the PV module. The step-by-step procedure for modeling the PV module is presented in the simulation showing the characteristics of the results of increasing temperature on the PV impacting the reduction in PV output power. This mathematical modeling procedure serves as an aid to encourage more people into photovoltaic research and gain a closer understanding of the characteristics of PV IV and PV modules. Solar panels made of elements that absorb photon energy from sunlight are converted into electricity. Solar radiation absorbed on the solar panel plate has an impact on increasing the cell temperature. The impact of increasing temperature causes the electrical power generated by the PV to decrease

REFERENCE

Anisah, S., & Tarigan, AD (2023). Planning of On Grid Rooftop Solar Power Plant as an Environmentally Friendly Alternative Energy Source. Journal of Information Technology and Computer Science (INTECOMS), 6(1), 503–510. Panca Budi Development University.

Aryza, S., Efendi, S., & Sihombing, P. (2024). A ROBUST OPTIMIZATION TO DYNAMIC SUPPLIER DECISIONS AND SUPPLY ALLOCATION PROBLEMS IN THE MULTI-RETAIL INDUSTRY. *Eastern-European Journal of Enterprise Technologies*, (3).

Aryza S dkk (2024) EFEKTIVITAS SIMULASI TERHADAP ANALISA KEHANDALAN TENAGA LISTRIK BERBASISKAN INTERNET OF THINK (IOT). *ESCAF*, 1226-1231.

Sri Wahyono, Firman L. Sahwandan and Feddy Suryanto. (2008). Review of the Development of Research on Solid Waste Processing in Palm Oil Mills

Wijono, Agung. (2014). Biomass Steam Power Plant Empty Oil Palm Fruit Bunches Feasibility Study and Environmental Impact. RAPI National Symposium XIII, (CI), 111–118.

Evridianto Dino, et al. (2022). Processing of Oil Palm Empty Fruit Bunches Biomass as Fuel for Steam Power Plants. Indonesian Journal of Social Technology.

Febryanti Fitri, et al. (2019). Utilization of Empty Oil Palm Fruit Bunch Waste into Bio-Char, Bio-oil and Gas Using Pyrolysis Method. Chemical Engineering Study Program. Faculty of Engineering. Mulawarman University.

Lubis, Z., & Aryza, S. (2023). AN IMPROVEMENT CONTROL PERFORMANCE OF AC MOTOR 3 PHASE WATER TOWER CENTRIFUGAL PUMP. *Jurnal Scientia*, *12*(04), 2086-2093.