Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 7, No. 3, August, Pp. 219-230

A modified maximum power point tracking with constant power generation using adaptive neuro-fuzzy inference system algorithm

Indhana Sudiharto*1, Eka Prasetyono[2], Anang Budikarso[3], Safira Fitria Devi[4]
Politeknik Elektronika Negeri Surabaya, Indonesia[1,2,3,4]

Article Info

Keywords:
Maximum Power Point Tracking, Constant Power Generation, Adaptive Neuro-Fuzzy Inference System, SEPIC Converter

Article history:
Received: May 19, 2022
Accepted: August 15, 2022
Published: August 31, 2022

Cite:
I. Sudiharto, E. Prasetyono, A. Budikarso, and S. Fitria Devi, "A Modified Maximum Power Point Tracking with Constant Power Generation Using Adaptive Neuro-Fuzzy Inference System Algorithm", *KINETIK*, vol. 7, no. 3, Aug. 2022. https://doi.org/10.22219/kinetik.v7i3.1452

*Corresponding author.
Indhana Sudiharto
E-mail address:
indhana@pens.ac.id

Abstract

Renewable energy is being used to lessen the consumption of fossil fuels. Solar energy is a common source of renewable energy. Solar energy is the most promising source of energy due to its long-term sustainability and availability. The output power of solar panels is strongly influenced by the intensity of sunlight and the temperature of the solar panels. Maximum Power Point Tracking (MPPT) control, which aims to optimize the output power of solar panels, is commonly used to increase the efficiency of solar panels. However, MPPT control often causes overvoltage disturbance in systems directly connected to the load. To limit the output power of solar panels, additional Constant Power Generation (CPG) control is required. In this research, a solar panel system will be created to supply submersible DC pumps without any energy storage devices. DC-DC SEPIC Converter is designed with MPPT control combined with CPG control to limit the output power of the converter using the Adaptive Neuro-Fuzzy Inference System method by 150 watts. When the output power of the solar panel is less than the power limit, then MPPT mode will work. While CPG mode works when the PV output power is greater than the limit power. The results of this research showed that the system can provide optimal power generated by solar panels in MPPT mode by increasing efficiency by up to 38.05% and CPG mode can limit power to 150 Watts to avoid overvoltage disturbance at load.

1. Introduction

Along with technological developments, the need for electrical energy is increasing and causing the availability of fossil fuels on earth to be dwindling. The use of renewable energy is an effort made to replace energy with fossil fuels, one of which is solar energy by using solar panels. Solar energy is not only widely available, but it is also environmentally friendly because it does not pollute the environment. However, the efficiency of the solar panel output power is strongly influenced by the intensity of sunlight and the temperature of the solar cell. Thus, when the intensity of sunlight changes, the solar cell's output power changes as well. As a result, most solar panel systems have MPPT control, or maximum power point tracking. The purpose of MPPT control is to obtain the maximum power that can be generated by solar panels and improve the efficiency of using solar panels[1]. By adjusting the duty cycle value on the dc-dc converter, Maximum Power Point Tracking will help ensure that the solar panel always operating at its maximum point or maximum power point (MPP)[2], [3]. The efficiency of using solar panels will increase with the use of MPPT.

The use of solar panels in maximum conditions can cause several disturbances, including overcurrent and overvoltage on the load side[4]. To prevent this, mppt control modifications can be made with CPG control or constant power generation. CPG is a method used to limit the power generated by solar panels. Thus, solar panels will produce power according to load needs and can avoid overvoltage and overcurrent[2]. Additionally, because no extra safety equipment is required, modifying controls by adding CPG controls is the most affordable option.

Many methods using both conventional and artificial intelligence, including Incremental Conductance[2], Perturb and Observe[5], and Grey Wolf Optimization[6], have been used in recent MPPT-CPG research. The Adaptive Neuro-Fuzzy Inference System is the algorithm that will be used in this research (ANFIS). ANFIS is one of the artificial intelligence methods that combines the advantages of fuzzy logic and artificial neural networks[3]. The ANFIS algorithm was chosen due to its benefit of being able to categorize data and identify patterns, as well as having the ability to adapt and learn quickly and can be trained without relying on enough expert knowledge, such as fuzzy logic models[7].

The use of modified MPPT-CPG control requires a converter, in this research the MPPT mode and CPG mode work to adjust the duty cycle value using the SEPIC Converter. MPPT mode will work when the PV output power condition is less than the limit power value or $P_{LIMIT}(P_{PV}<P_{LIMIT})$. While CPG mode will work when the PV output power is more than the limit power value or $P_{LIMIT}(P_{PV}>P_{LIMIT})$. The purpose of the modified MPPT-CPG control is to ensure that the load connected to the solar panel always receives optimal power while also being able to limit the power so that it does not exceed the load's requirements using the Adaptive Neuro-Fuzzy Inference System algorithm that can find the best solution for the system. This way, interference like overvoltage can be avoided when using solar panels with MPPT control[5]. To determine the performance of the MPPT-CPG control modifications, a simulation will be carried out using MATLAB software with varying irradiation values.

2. Research Method

In this research, the system utilizes two solar cells with a capacity of 135 Wp which are arranged in parallel to get the maximum output power that can be supplied to the load using the MPPT method and limit the power that will be supplied to the load by using the CPG method. The submersible DC pump used works with 150 Watts of power. The block diagram of the system is shown in Figure 1.

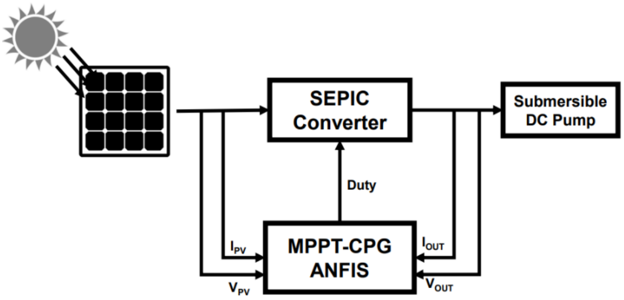


Figure 1. Adaptive Neuro-Fuzzy Inference System-based MPPT-CPG system

In this research, the Adaptive Neuro-Fuzzy Inference System (ANFIS) algorithm will be used. This algorithm is a Fuzzy Inference System (FIS) combined with an Artificial Neural Network (ANN) algorithm. ANFIS carries out the learning process as done by ANN and determines decisions as in FIS [8]. Thus, the advantage of the ANFIS algorithm is that it can provide the best solution required by the system. In addition, ANFIS can form a rule by itself.

ANFIS is designed by combining 2 controls, namely MPPT mode and CPG mode. The parameters used to determine the running of the MPPT mode or CPG mode are the PV output power (P_{PV}), and the limiting power (P_{LIMIT}). The determination of the P_{LIMIT} value is based on the need for a submersible DC pump load, which is 150 Watts. If the P_{PV} value is less than P_{LIMIT}(P_{PV}<P_{LIMIT}), then the MPPT-ANFIS mode works to obtain optimal power according to environmental conditions. So that the PV power will be controlled to produce power at the maximum point. If the PPV value is greater than P_{LIMIT}(P_{PV}>P_{LIMIT}), then the CPG-ANFIS mode will work to keep the converter output power from exceeding the power limit or the desired load requirement[6]. ANFIS control in MPPT mode and CPG mode will adjust the duty cycle of the SEPIC converter so that it can produce power according to load requirements.

2.1 SEPIC Converter

SEPIC (Single Ended Primary Inductor Converter) is a DC-DC converter that can increase or decrease the input voltage by adjusting the duty cycle of the switching components [9]. Unlike the Cuk converter, SEPIC has the same output voltage polarity as its input (non-inverting)[10].

Figure 2 shows the circuit of the SEPIC Converter which consists of 2 inductors, 2 capacitors, a MOSFET, and a diode. When the switch is on, the diode will be open, the supply current will flow to L_1 and L_2 will drain its energy to C_1. In this condition, no electricity flows to the load [11]. When the switch is off, the circuit will form a loop with L_1, C_1, and the load in series. Inductor I_{L2} current will flow towards the load with negative polarity. In the switch off or closed condition, the inductor will flow energy through the diode and the capacitor will be in a charge condition. The greater the duty cycle value, the value of the output voltage will be greater. Because the longer the inductor is in charge, the greater the inductor voltage[12]. SEPIC Converter has advantages, namely the value of the input current ripple is small, has isolation capacitors on the input and output sides to protect the circuit from short or overload conditions, and can produce an output voltage of up to 0 Volts [13].

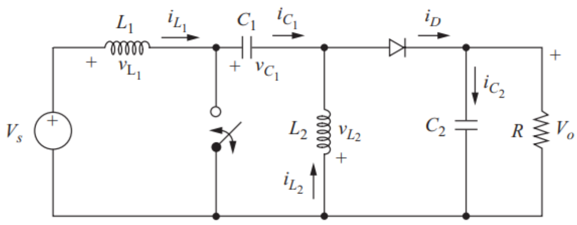


Figure 2. SEPIC Converter [7]

The SEPIC converter circuit in this research has a function as a voltage control from the solar panel to the load by setting the duty cycle value. The output voltage value from the converter will affect the water discharge that can be flowed by the submersible pump. The SEPIC converter can work to increase and decrease the submersible pump supply voltage with a working power of 150 Watts. Table 1 is the SEPIC Converter design used.

Table 1. Design of SEPIC Converter

Parameters	Values
V_{IN}	17.8 V_{DC}
$f_{switching}$	40 kHz
V_{OUT}	11 V_{DC}
$L_1 = L_2$	75.618μH
$C_1 = C_2$	15000 μF

2.2 Adaptive Neuro-Fuzzy Inference System

In this research, the algorithm used is the Adaptive Neuro-Fuzzy Inference System or ANFIS. In MPPT mode, the ANFIS algorithm is used to find the maximum power output from the solar panel. Meanwhile, in CPG mode, the ANFIS algorithm is used to control and limit the solar panel output power so that it does not exceed the load requirement. The output of the ANFIS algorithm in both MPPT mode and CPG mode is a variable of the duty cycle value which is used as a PWM generator in the converter.

The Adaptive Neuro-Fuzzy Inference System or ANFIS is a multilayer feedforward network that combines the advantages of fuzzy logic and artificial neural networks to map the input space to the output space [14]. The inference system used in ANFIS is the Takagi-Sugeno model [15]. ANFIS will group the input-output data in the form of fuzzy if-then rules, and will produce input-output data pairs obtained from the training results with the hybrid algorithm [16], [17]. The hybrid algorithm for learning consists of 2 different methods, namely least squares estimation and back-propagation to update parameter values in the membership function. The smaller the error value is, the better the ANFIS control is made. The structure of ANFIS consists of 5 layers with different functions as shown in Figure 3.

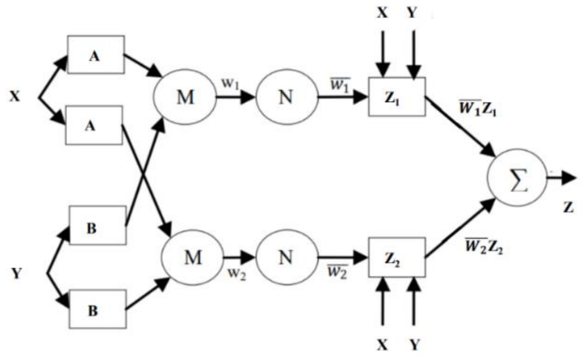


Figure 3. Adaptive Neuro-Fuzzy Inference System Structure [15]

Assuming the input values are x and y with the output being z, then:

Rule 1: if x is A_1 and y is B_1, then $z_1 = p_1x + q_1y + r_1$

Rule 2: if x is A_2 and y is B_2, then $z_2 = p_2x + q_2y + r_2$

A brief description of the layers in ANFIS can be seen below:

1. Layer 1

   Each input node in this layer is an adaptive node that produces a degree of membership for a certain value. The output of this layer is:

$$O_{1,i} = \mu_{A_i}(x_1) \text{ for i= 1, 2}$$
$$O_{1,j} = \mu_{B_j}(y_1) \text{ for j= 1, 2}$$

Where, $O_{1,i}$ dan $O_{1,j}$ are the outputs of the i-th node in layer 1, while μ_{A_i} dan μ_{B_j} are membership functions. If a triangular membership function is used, then the calculation of the value is shown in Equation 1.

$$\mu_{A_i}(x_1) = max\left[min\left(\frac{x_1 - a_1}{b_1 - a_1}, \frac{c_1 - x_1}{c_1 - b_1}, 0\right)\right] \quad (1)$$

Where, a_1, b_1, dan c_1 are parameter sets that vary depending on the membership function. This parameter is also called the premise parameter [18].

2. Layer 2
This layer is each node will be multiplied by each incoming input. This layer calculates the weight of each MF and gets the input value x_1 from the first layer which represents the fuzzy set of input values. The output of this layer is the firing strengths of each rule. The calculations on layer 2 are shown in Equation 2.

$$O_{2,i} = w_i = \mu_{A_i}(x) \times \mu_{A_j}(y)\ for\ i = 1{,}2 \tag{2}$$

3. Layer 3
This layer is a normalization layer where each node has a fixed value. The nodes are categorized in N which shows the normalization process for the firing strengths of the previous layer. The output of this layer is the normalized firing strengths whose calculations are shown in Equation 3.

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2} for\ i = 1{,}2 \tag{3}$$

4. Layer 4
This layer is the output layer resulting from the inference process. The nodes in this layer are adaptive. In this layer, calculations will be made for the defuzzification process with Equation 4.

$$O_{4,i} = \overline{w_i z_i} = \overline{w_i}(p_i x + q_i y + r_i) for\ i = 1{,}2 \tag{4}$$

In layer 4, p_1, q_1, and r_1 are called linear parameters or consequent parameters.

5. Layer 5
This layer is the output layer which adds all the input values from the 4th layer and converts the fuzzy values into crisp values. This layer consists of 1 node 'Σ'. This layer adds up all incoming nodes with Equation 5[19].

$$O_{5,i} = \sum_i \overline{w_i z_i} = \frac{\sum_i w_i z_i}{w_1 + w_2}\ for\ i = 1{,}2 \tag{5}$$

The input variable for MPPT control is obtained from the solar panel output power, while the input variable for CPG control is obtained from the SEPIC converter output power. The ANFIS training data used in both controls were obtained from simulation results using the Fuzzy algorithm.

2.2.1 Design of Maximum Power Point Tracking

MPPT consists of a DC-DC converter that is installed between the solar panel and the load which is controlled by an algorithm to change the duty cycle value of the power converter so that it gets the maximum output voltage and current value with a certain value of solar radiation and temperature [1].

The process of tracking the maximum power output of the solar panel using the ANFIS algorithm begins by sensing the current and voltage of the solar panel output. Then the calculation of the value of the solar panel output power will be carried out. MPPT-ANFIS control input is the value of slope S(t) and change of slope ΔS(t)[20]. The input for the ANFIS algorithm is obtained from Equation 6 and Equation 7.

$$S(t) = \frac{P(t) - P(t-1)}{V(t) - V(t-1)} \tag{6}$$

$$\Delta S(t) = S(t) - S(t-1) \tag{7}$$

The result of dividing the value of P by V is called the slope. To achieve the MPP value, the slope value =0 [21], [22]. The direction of the slope is determined by the ratio of P and V. With the characteristics of the converter used, the direction of the duty cycle will be determined. If the result of the comparison (slope) produces a positive value, the duty cycle value is increased, and if it produces a negative value, the duty cycle value is reduced. The data slope S(t) in this research is 5 triangular membership functions used to represent the input slope value shown in Figure 4.

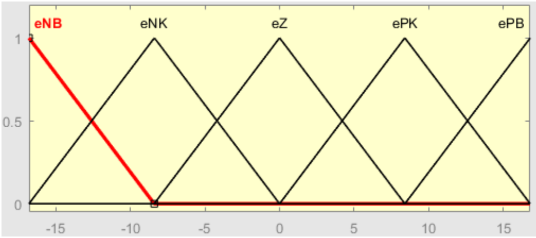


Figure 4. Membership Function of Input Error

Input change of slope ΔS(t) is obtained from the difference between the current slope value and the previous slope value. The membership function of the input change of slope ΔS(t) is shown in Figure 5 with 5 triangular membership functions

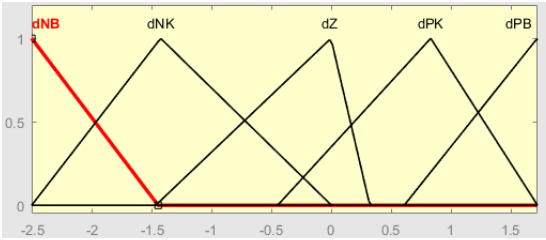


Figure 5. Membership Function of Input dError

The two inputs will then be processed by the ANFIS controller to get the value of the change in duty cycle (dDuty) according to the MPP conditions at a certain irradiation value and temperature. The membership function is 25 with a constant type for the value of the duty cycle change shown in Figure 6 which then enters the converter.

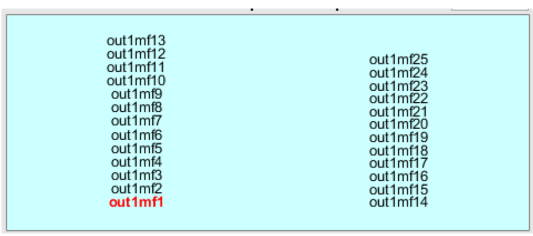


Figure 6. Membership Function of Output dDuty

2.2.2 Design of Constant Power Generation

The use of MPPT control can cause overvoltage disturbances in the load. To avoid this, the MPPT control is modified by adding Constant Power Generation (CPG). This modification is the cheapest way to avoid overvoltage because it does not need additional equipment [23]. CPG control will limit the output power of the solar panel according to the power requirement or called P_{LIMIT}. Constant Power Generation can work on either the right or left side of the MPP point [24].

Figure 7 shows the working principle of the CPG concept. It can be seen that the CPG control works when the PV output power value is in regions II and IV, namely the solar panel output power exceeds the limit power value, so that the CPG control will work to limit it according to the limit power value or P_{LIMIT} [25]. Then the MPPT mode will work in regions I, III, and V to get the maximum possible solar panel output power.

.

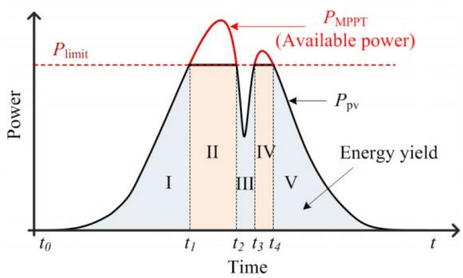


Figure 7. Working Principle of Constant Power Generation

The control process begins by sensing the converter's output current and voltage. Then the converter output power value will be calculated and the error value E(t) and change of error ΔE(t) will be calculated. The input for the ANFIS algorithm is obtained from Equation 8 and Equation 9.

$$E(t) = SP - E(t) \tag{8}$$

$$\Delta E(t) = E(t) - E(t-1) \tag{9}$$

The SP value is the limit power value that is determined according to the load requirements. The error data E(t) in this research consists of 5 triangular membership functions shown in Figure 8.

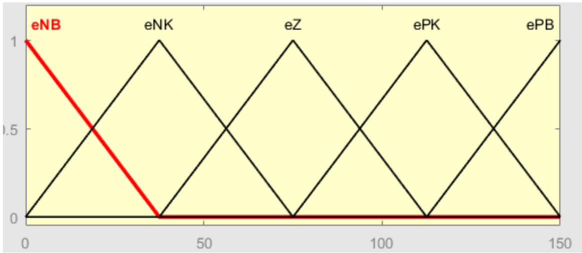


Figure 8. Membership Function for Error

Input delta error ΔE(t) obtained from the difference between the current error value and the previous error. Figure 9 shows the 5 triangular membership functions for the dError input.

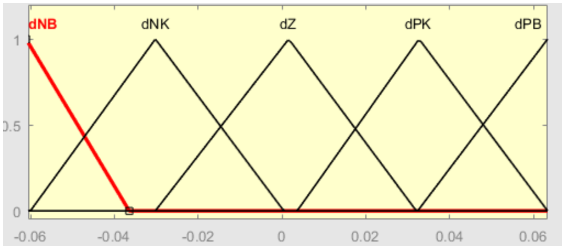


Figure 9. Membership Function for Change of dError

The two inputs will then be processed by the ANFIS controller to get the duty cycle value. Figure 10 shows 25 membership functions of constant type for the Duty value that goes to the converter.

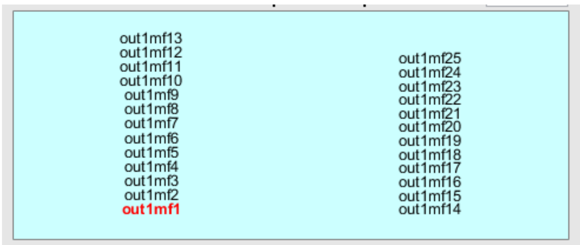


Figure 10. Membership Function for Duty

2.3 Submersible DC Pump

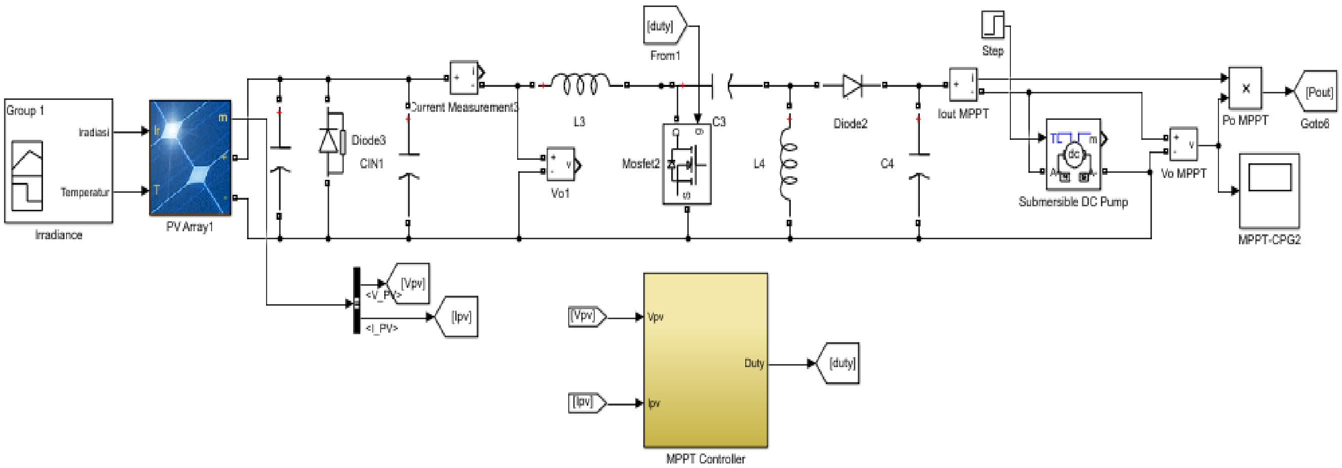
A submersible DC Pump is a centrifugal pump that is attached to an electric motor and operates submerged in water. The main part of the submersible pump is the impeller which will convert the motion energy of the prime mover into kinetic energy [26], [27]. The advantage of using a submersible dc pump is that there is no need for an initial drive, because the drive is carried out by water entering and rotating the impeller. In addition, because the pump works underwater, this pump can avoid the possibility of cavitation the pump [28]. In this research, the submersible DC pump used is the ZQB-12 type with a power of 150 Watts at 11 Volts. The pump used in this study can work with a minimum input power of 2.66 Watt.

3. Results and Discussion

ANFIS MPPT-CPG system simulation was carried out using MATLAB software which consisted of 2 solar panels with a capacity of 135 Wp arranged in parallel and connected to a SEPIC Converter with MPPT-CPG ANFIS control. The system will work to limit the converter output power according to the needs of the submersible dc pump, which is 150 Watts with a voltage of 11 Volts. The pump used in this research can operate with a minimum input power of 2.66 Watts.

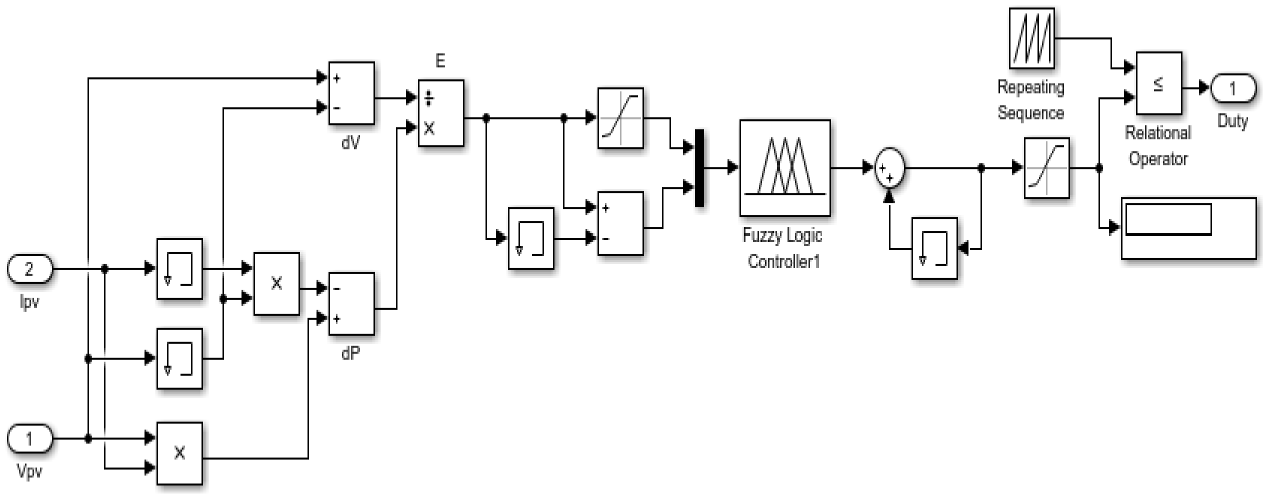
3.1 Adaptive Neuro-Fuzzy Inference System based MPPT

Simulations were carried out with variations in irradiation values, namely at 1000 W/m^2, 500 W/m^2, dan 400 W/m^2 with a PLIMIT value of 150 Watts. Figure 11 (a) is a simulation circuit for the MPPT system, while Figure 11 (b) is a circuit for the MPPT-ANFIS control. MPPT-ANFIS control will then be compared with a system without MPPT control to find out the performance of MPPT control in improving the efficiency of using solar panels. The system without control will run with a constant duty cycle of 38.2%.



(a) Simulink Block of MPPT System

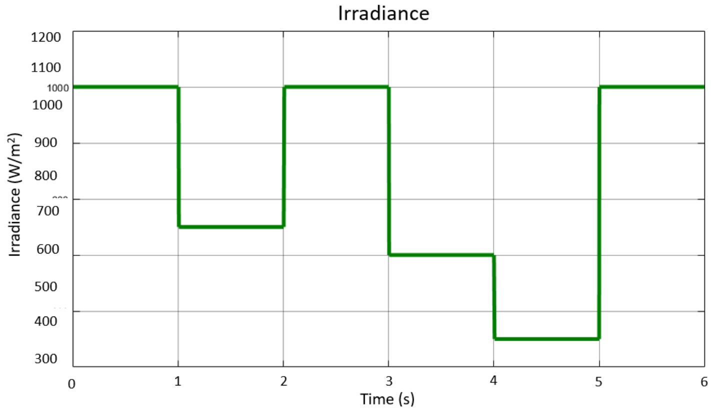
(b)



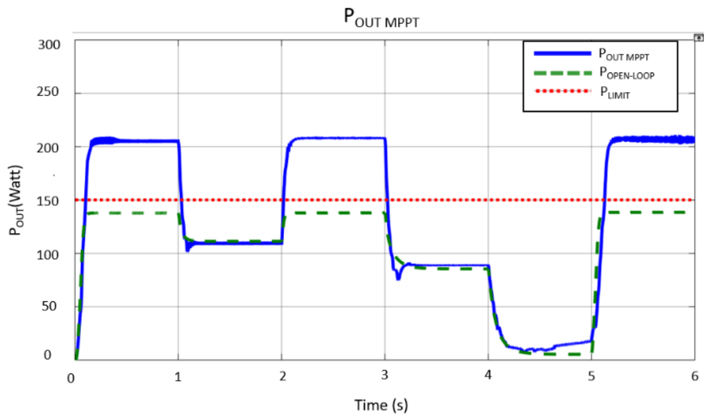
(c) Control Block of MPPT-ANFIS System

Figure 11. ANFIS Based Maximum Power Point System

The results of Figure 12(a) simulation showed changes in irradiation received by solar panels. While the straight line in Figure 12(b) is the output power response when the MPPT control works, the dotted line is the output power when open-loop or without MPPT, and the square dotted line is the PLIMIT value or limit power.



(a) Irradiation Variation



(b) Output Power of Non-MPPT System Compared with ANFIS based MPPT System and P_{LIMIT}
Figure 12. Output Power Response of MPPT-ANFIS on Variable Irradiance

Table 2. Comparison of Output Power on Non-MPPT system and ANFIS based MPPT System

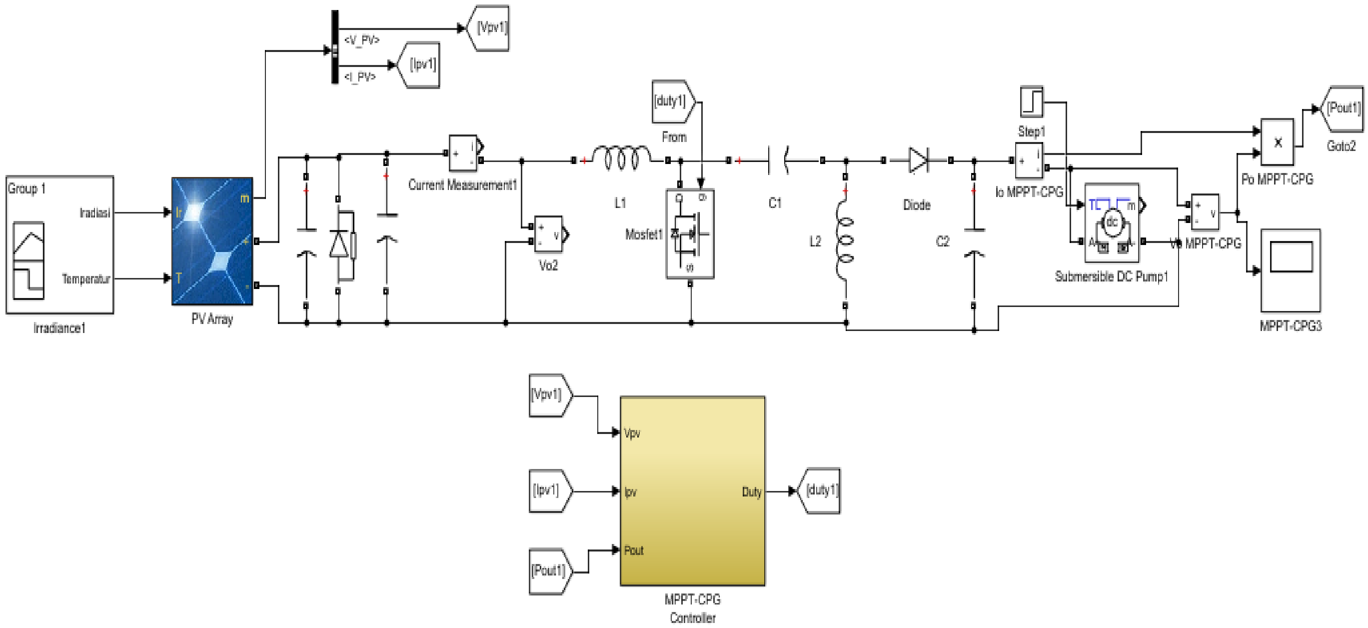
P_{LIMIT} (Watt)	Irradiance (W/m^2)	$P_{OUT\ NON\text{-}MPPT}$ (Watt)	$P_{OUT\ MPPT}$ (Watt)	$V_{OUT\ MPPT}$ (Volt)
150	1000	137.9	208.6	12.97
	500	111.3	115.8	9.54
	1000	137.9	208.6	12.97
	400	85.48	91.62	8.46
	100	5.65	17.26	3.712
	1000	137.9	208.6	12.97
Average of $P_{OUT\ NON\text{-}MPPT}$ (Watt)				102.68
Average of $P_{OUT\ MPPT}$ (Watt)				141.75
Increased Efficiency with MPPT $= \frac{P_{OUT\ MPPT}}{P_{OUT\ NON\ MPPT}} \times 100\%$				38.05%

Table 2 shows output power response data when a system without MPPT and a system with MPPT control is working. The simulation results show that the use of MPPT-ANFIS control can increase the efficiency of using solar panels by 38.05%. When the irradiation point is 400 W/m^2 and the system is running without MPPT control, the output power of the converter is 85.48 Watts. Meanwhile, when the MPPT control will work to get the optimal input power value that can produce solar panels to supply at a load of 91.62 Watts at 8.46 Volts. When the irradiation point is 100 W/m^2 and the system is running without MPPT control, the output power of the converter is 5.65 Watts. Meanwhile, when the MPPT control will work to get the optimal input power value that can produce solar panels to supply at a load of 17.26 Watts at 3.712 Volts. When the input irradiation value is 500 W/m^2 the output power of the system without control is 111.3 Watts and the system with MPPT control is 115.8 Watts at 9.54 Volts. When the irradiation value is 1000 W/m^2, the output power generated by SEPIC Converter when without MPPT is 137.9 Watts and when the MPPT control is run, the output power is 208.6 Watts at.12.97 Volts.

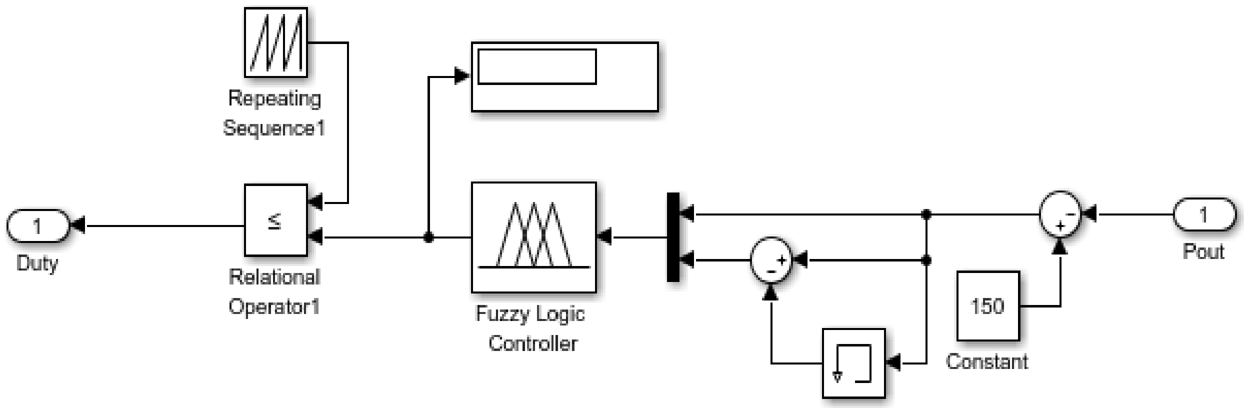
The simulation results shown that even with a low solar irradiation value of 100 W/m^2, the system was still able to supply a submersible dc pump. However, if the irradiation value is 1000 W/m^2 the power generated exceeded the load requirement of 150 Watts at 11 Volts. Therefore, it is necessary to limit the output power of the SEPIC Converter with the use of MPPT control so that there is no overvoltage disturbance in the load.

3.2 A Modified Adaptive Neuro-Fuzzy Inference System based MPPT-CPG

To avoid the output power exceeding 150 Watts, a CPG mode control is added. CPG mode works when the solar panel output power is more than the limited power, thus avoiding overvoltage interference. Simulations were carried out with irradiation conditions of 1000 W/m^2, 500 W/m^2 and 400 W/m^2 with a P_{LIMIT} value of 150 Watts. Figure 13 (a) is a simulation circuit for an MPPT system integrated with CPG control, while Figure 13 (b) is a circuit for CPG-ANFIS control.



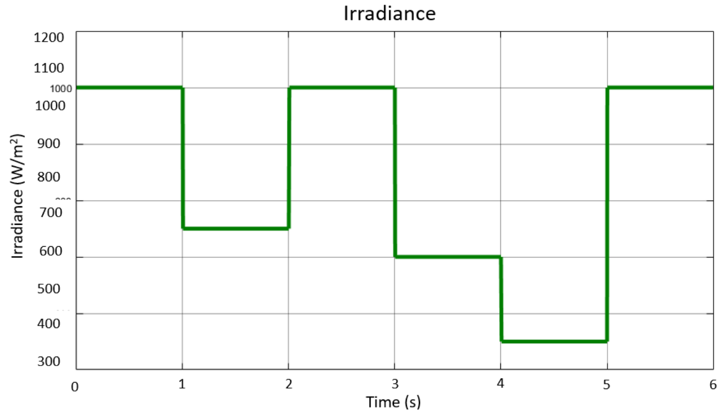
(a) Simulink Block of MPPT-CPG System



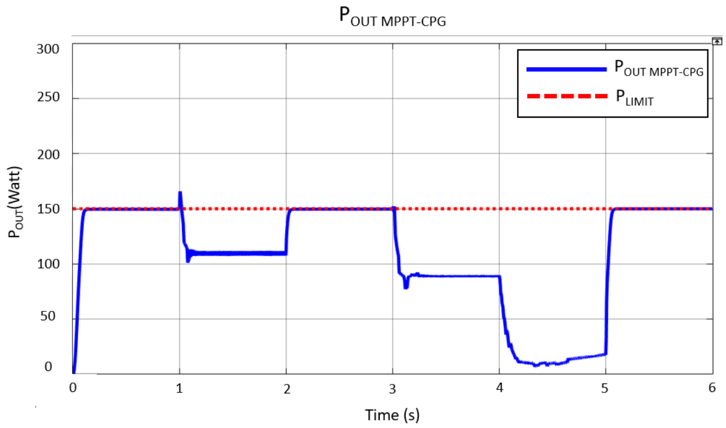
(b) Control Block of CPG-ANFIS System

Figure 13. ANFIS Based Maximum Power Point-Constant Power Generation System

The simulation results Figure 14(a) shows the change in irradiation received by the solar panel. While the straight line in Figure 14(b) is the output power response when the MPPT-CPG control combination works and the dotted line is the PLIMIT value or limit power.



(a) Irradiation Variation



(b) Output Power of ANFIS based MPPT Compared with P_{LIMIT}

Figure 14. Output Power Response of MPPT-CPG ANFIS on Variable Irradiance

Table 3. ANFIS based MPPT-CPG Simulation Results

P_{LIMIT} (Watt)	Irradiance (W/m^2)	$P_{OUT\ MPPT-CPG}$ (Watt)	$V_{OUT\ MPPT-CPG}$ (Volt)
150	1000	149.9	11
	500	115.8	9.54
	1000	149.9	11
	400	91.62	8.46
	100	17.26	3.712
	1000	149.9	11

Table 3 shows the output power response data when the MPPT-CPG control is working. From the simulation results, when the irradiation value is 400 W/m^2 and 500 W/m^2, then the MPPT control will work to get the maximum input power value that can be generated by solar panels to supply the load, when the input irradiation is 100 W/m^2 power used to supply the load is 17.26 Watt. When the input irradiation is 400 W/m^2 power used to supply the load is 91.62 Watt. When the input irradiation value is 500 W/m^2, the power used to supply the load is 115.8 Watt. When the irradiation is 1000 W/m^2, the CPG mode works to limit the output power value of the SEPIC Converter so that it does not exceed the load requirement, namely with an output power of 149.9 Watts at 11 Volts. Due to the pump's ability to operate at a minimum power of 2.66 Watts, the system created can supply submersible DC pumps even at an irradiation value of 100 W/m^2.

The simulations results show that, under high irradiation conditions, CPG control can be used to limit the power supplied to the submersible dc pump in accordance with load needs, allowing the system to avoid overvoltage interference while MPPT control is able to supply a submersible dc pump with the most optimal power that can be produced by solar panels.

4. Conclusion

The ANFIS MPPT-CPG control created aims to limit power so that it does not exceed load needs and avoid overvoltage disturbance. MPPT control on the system works when the PV output power is smaller than the load required power to provide the most optimal supply to the load. While CPG mode works when the PV output power is greater than the specified load power to limit the output power of the converter so as not to exceed the need. The results of simulations that have been done, the MPPT mode can supply submersible dc pumps under low irradiation conditions and boost the efficiency of solar panel use by up to 38.05%. The ANFIS MPPT-CPG system can produce the optimum amount of power generated by solar panels while limiting supply power to 150 Watts at 11 Volts to avoid overvoltage disturbance.

Notation

V_{IN} : Input Voltage of SEPIC Converter
$f_{switching}$: Switching Frequency
V_{OUT} : Output Voltage of SEPIC Converter
L : Inductor
C : Capacitor
Wp : Wattpeak
R_{LOAD} : Resistor Value of Load
P_{OUT} : Output Power

Acknowledgment

Thank you to the Politeknik Elektronika Negeri Surabaya, which has become a place for researchers to develop this journal research. Hopefully, this research can make a major contribution to the advancement of technology in Indonesia.

References

[1] M. Senthil Kumar, P. S. Manoharan, and R. Ramachandran, "Modelling and simulation of ANFIS-based MPPT for PV system with modified SEPIC converter," 2019. http://dx.doi.org/10.1504/IJBIDM.2017.10007894
[2] U. H. al Rasyid, Politeknik Elektronika Negeri Surabaya, Institute of Electrical and Electronics Engineers. Indonesia Section, and Institute of Electrical and Electronics Engineers, *A Modified MPPT Algorithm Using Incremental Conductance for Constant Power Generation of Photovoltaic Systems*.
[3] S. Shabaan, M. I. Abu El-Sebah, and P. Bekhit, "Maximum power point tracking for photovoltaic solar pump based on ANFIS tuning system," *Journal of Electrical Systems and Information Technology*, vol. 5, no. 1, pp. 11–22, May 2018. https://doi.org/10.1016/j.jesit.2018.02.002
[4] Y. Yang, H. Wang, F. Blaabjerg, and T. Kerekes, "A hybrid power control concept for PV inverters with reduced thermal loading," *IEEE Transactions on Power Electronics*, vol. 29, no. 12, pp. 6271–6275, 2014. https://doi.org/10.1109/TPEL.2014.2332754
[5] Reza Iskharisma Yuwanda, Eka Prasetyono, and Rachma Prilian Eviningsih, *Constant Power Generation Using Modified MPPT P&O to Overcome Overvoltage on Solar Power Plants*. 2020 International Seminar on Intelligent Technology and Its Applications (ISITIA), 2020. https://doi.org/10.1109/ISITIA49792.2020.9163685
[6] F. R. Hasan, E. Prasetyono, and E. Sunarno, "A Modified Maximum Power Point Tracking Algorithm Using Grey Wolf Optimization for Constant Power Generation of Photovoltaic System," 2021. https://doi.org/10.1109/AIMS52415.2021.9466050
[7] R. I. Navarro, "Study of a neural network-based system for stability augmentation of an airplane Annex 1 Introduction to Neural Networks and Adaptive Neuro-Fuzzy Inference Systems (ANFIS)," 2013.
[8] D. Karaboga and E. Kaya, "Adaptive network based fuzzy inference system (ANFIS) training approaches: a comprehensive survey," *Artificial Intelligence Review*, vol. 52, no. 4. Springer Netherlands, pp. 2263–2293, Dec. 01, 2019. https://doi.org/10.1007/s10462-017-9610-2
[9] Daniel W. Hart, "Power Electronics".
[10] L. M. Septya, I. Sudiharto, S. N. Dwitya, O. Asrarul Qudsi, and E. Sunarno, "Design and Implementation Soft-switching MPPT SEPIC Converter Using P&O Algorithm," in *E3S Web of Conferences*, Jun. 2018, vol. 43. https://doi.org/10.1051/e3sconf/20184301010
[11] Soedibyo, Budi Amri, and Mochamad Ashari, *The comparative study of Buck-boost, Cuk, Sepic and Zeta converters for maximum power point tracking photovoltaic using P&O method*. Int. Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), 2015. https://doi.org/10.1109/ICITACEE.2015.7437823
[12] G. Sharp and A. Emanuel, "Sepic Converter Design and Operation."
[13] S. Necaibia, M. S. Kelaiaia, H. Labar, A. Necaibia, and E. D. Castronuovo, "Enhanced auto-scaling incremental conductance MPPT method, implemented on low-cost microcontroller and SEPIC converter," *Solar Energy*, vol. 180, pp. 152–168, Mar. 2019. https://doi.org/10.1016/j.solener.2019.01.028
[14] A. Faruq, A. Marto, N. K. Izzaty, A. T. Kuye, S. F. Mohd Hussein, and S. S. Abdullah, "Flood Disaster and Early Warning: Application of ANFIS for River Water Level Forecasting," *Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control*, pp. 1–10, Feb. 2021. https://doi.org/10.22219/kinetik.v6i1.1156
[15] Anang Tjahjono, Ony Asraul Qudsi, Novie Ayub Windarko, Dimas Okky Anggriawan, Ardyono Priyadi, and Mauridhi Hery Purnomo, *Photovoltaic Module and Maximum Power Point Tracking Modelling Using Adaptive Neuro-Fuzzy Inference System*. Makassar International Conference on Electrical Engineering and Infonnatics (MICEEI), 2014. https://doi.org/10.1109/MICEEI.2014.7067301
[16] N. I. Mufa'ary, I. Sudiharto, and F. D. Murdianto, "Comparison of FLC and ANFIS Methods to Keep Constant Power Based on Zeta Converter," *INTEK: Jurnal Penelitian*, vol. 8, no. 1, p. 21, Jul. 2021. http://dx.doi.org/10.31963/intek.v8i1.2701
[17] D. Mlakić and S. Nikolovski, "Anfis as a Method for Determinating MPPT in the Photovoltaic System Simulated in Matlab/Simulink," 2016. https://doi.org/10.1109/MIPRO.2016.7522301
[18] N. Walia, H. Singh, and A. Sharma, "ANFIS: Adaptive Neuro-Fuzzy Inference System-A Survey," 2015. http://dx.doi.org/10.5120/ijca2015905635

[19] Yuan-Ting Chu, Li-Qiang Yuan;, and Hsin-Han Chiang, "ANFIS-based Maximum Power Point Tracking Control of PV Modules with DC-DC Converters," 2016. https://doi.org/10.1109/ICEMS.2015.7385123

[20] J. K. Shiau, Y. C. Wei, and B. C. Chen, "A study on the fuzzy-logic-based solar power MPPT algorithms using different fuzzy input variables," *Algorithms*, vol. 8, no. 2, pp. 100–127, 2015. https://doi.org/10.3390/a8020100

[21] V. Govinda Chowdary, V. Udhay Sankar, D. Mathew, C. Hussaian Basha, and C. Rani, "Hybrid Fuzzy Logic-Based MPPT for Wind Energy Conversion System," in *Advances in Intelligent Systems and Computing*, 2020, vol. 1057, pp. 951–968. https://doi.org/10.1007/978-981-15-0184-5_81

[22] A. M. Noman, K. E. Addoweesh, and A. I. Alolah, "Simulation and Practical Implementation of ANFIS-Based MPPT Method for PV Applications Using Isolated Ćuk Converter," *International Journal of Photoenergy*, vol. 2017, 2017. https://doi.org/10.1155/2017/3106734

[23] A. Sangwongwanich, Y. Yang, and F. Blaabjerg, "High-performance constant power generation in grid-connected PV systems," *IEEE Transactions on Power Electronics*, vol. 31, no. 3, pp. 1822–1825, Mar. 2016. https://doi.org/10.1109/TPEL.2015.2465151

[24] M. P. Zala, P. H. Pandya, K. N. Odedra, D. P. Patel, and L. Engineering College, "Active Power Control of PV System in MPPT and CPG Mode," 2017. https://doi.org/10.29007/3f21

[25] Ariya Sangwongwanich, Yongheng Yang, Frede Blaabjerg, and Huai Wang, *Benchmarking of Constant Power Generation Strategies for Single-Phase Grid-Connected Photovoltaic Systems*. IEEE, 2016. https://doi.org/10.1109/APEC.2016.7467899

[26] Levon Gevorkov, Anton Rassõlkin, Ants Kallaste, and Toomas Vaimann, *Simulink Based Model for Flow Control of a Centrifugal Pumping System*. International Workshop on Electric Drives: Optimization in Control of Electric Drives (IWED), 2018. https://doi.org/10.1109/IWED.2018.8321399

[27] A. Swandi, S. Rahmadhanningsih, S. Viridi, and I. M. Sutjahja, "Trial of DC Submersible Pump 12 Volt 50 Watt with Solar Power and Relationship between Water Discharge and Storage Height," *JPSE (Journal of Physical Science and Engineering)*, vol. 6, no. 2, pp. 61–67, Jul. 2021. https://dx.doi.org/10.17977/um024v6i22021p061

[28] F. Alkarrami, T. Iqbal, K. Pope, and G. Rideout, "Dynamic Modelling of Submersible Pump Based Solar Water-Pumping System with Three-Phase Induction Motor Using MATLAB," *Journal of Power and Energy Engineering*, vol. 08, no. 02, pp. 20–64, 2020. https://doi.org/10.4236/jpee.2020.82002