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doi:10.15199/48.2022.08.27

Design and Implementation of MPPT Fuzzy Logic Controller for Inverter Connected to Water Pump

Abstract*. At present, renewable energy sources such as Photovoltaic (PV) are prevalent because the energy sources are unlimited and free of emissions. One example of its application is as a supply for water pumps. In this application, the value of the power produced by solar cells is very influential, because of the more optimal the power generated by solar cells, the more optimal the water that can be pumped by this water pump. However, PV is a non-linear energy source whose output power changes depending on irradiance and ambient temperature. Therefore we need a method to optimize the power released by the PV. This method is called MPPT (Maximum Power Point Tracking). Using MPPT with conventional algorithms such as Perturb and Observe (P&O) has a slow response and oscillations when in maximum power. In this study, an MPPT will be designed with the Fuzzy Logic Controller (FLC) algorithm to accelerate the system's response to load changes and reduce oscillations that occur when maximum power is available. From the results of research that has been done so as to get the MPPT FLC energy efficiency results with irradiation changes of 98.9% (simulation) or 97.62% (implementation) and load changes of 98.8% (simulation) or 96.51% (application). The use of MPPT FLC, when connected to a Water Pump, has an average total water flow more than without MPPT with a ratio of 1.58: 1 so that the use of MPPT with the FLC algorithm produces better response and energy efficiency.*

Streszczenie. Obecnie dominują odnawialne źródła energii, takie jak fotowoltaika (PV), ponieważ źródła energii są nieograniczone i wolne od emisji. Jednym z przykładów jego zastosowania jest zasilanie pomp wodnych. W tej aplikacji bardzo ważna jest wartość energii wytwarzanej przez ogniwa słoneczne, ponieważ im bardziej optymalna moc wytwarzana przez ogniwa słoneczne, tym bardziej optymalna jest woda, którą ta pompa może przepompować. Jednak fotowoltaika jest nieliniowym źródłem energii, którego moc wyjściowa zmienia się w zależności od natężenia promieniowania i temperatury otoczenia. Dlatego potrzebujemy metody optymalizacji mocy uwalnianej przez PV. Ta metoda nazywa się MPPT (Maximum Power Point Tracking). Używanie MPPT z konwencjonalnymi algorytmami, takimi jak Perturb i Obserwacja (P&O), ma powolną reakcję i oscylacje przy maksymalnej mocy. W tym badaniu MPPT zostanie zaprojektowany z algorytmem Fuzzy Logic Controller (FLC), aby przyspieszyć reakcję systemu na zmiany obciążenia i zredukować oscylacje, które występują, gdy dostępna jest maksymalna moc. Z wyników badań przeprowadzonych w celu uzyskania wyników efektywności energetycznej MPPT FLC przy zmianach napromieniowania 98,9% (symulacja) lub 97,62% (wdrożenie) i zmianach obciążenia 98,8% (symulacja) lub 96,51% (aplikacja). Użycie MPPT FLC, po podłączeniu do pompy wodnej, ma średni całkowity przepływ wody większy niż bez MPPT ze stosunkiem 1,58:1, dzięki czemu użycie MPPT z algorytmem FLC zapewnia lepszą reakcję i wydajność energetyczną. (***Projekt i wdrożenie sterownika MPPT Fuzzy Logic dla falownika podłączonego do pompy wodnej***)

Keywords: Photovoltaic, Water Pump, MPPT, Fuzzy Logic Controller
Słowa kluczowe: zasilanie fotowoltaiczne, pompa wodna, falownik

Introduction

Along with technological advances and the rapid growth of population, the energy demand from year to year increased, but inversely proportional to thin out fossil resources. Besides, the use of Energy with fossil resources produces carbon emissions that negatively impact the environment. So much research that aims to finding and maximizing Alternative Energy. The center of attention of the general public is Photovoltaic (PV) because PV can convert sunlight energy into clean electricity without pollution and unlimited resources. In the future, solar energy will become one of the essential sources of Energy, more than 45% of the population in the world will start using PV as a producer of electrical energy [1]. Therefore need special equipment to reduce costs and can increase the power generated by PV.

Basically, PV is a natural non-linear power source with a characteristic curve of I-V or P-V that is very dependent on irradiance and temperature. To increase the PV output power and efficiency to the maximum so that the P-V characteristic curve must be able to reach the maximum point or called the Maximum Power Point (MPP). One way to keep PV at the MPP point is to use an algorithm controlled converter called Maximum Power Point Tracking (MPPT) [2]. The algorithm on the MPPT will control the converter so it can condition the working voltage on the PV to always be at its maximum powerpoint. The most common type of MPPT algorithm is the Perturb and Observe (P&O) method because it is rather simple and the control is easy but inefficient in terms of time and has significant losses. The disadvantage of this method is that when a steady-state condition, the output power's value oscillates around the peak power point so that it has significant losses. The P&O method cannot release the maximum power when changes in weather are swift. One application that can be utilized from PV is Solar Water Pump [3]. This system is often used as a solution to fulfil water needs in areas that do not have access to electricity by utilizing water pumps that are connected to PV. Solar Water Pump itself works based on the power generated from PV. The more maximum the power generated by PV, the higher the flow of water that can be pumped.

Therefore, to maximize solar panels, so need MPPT control based on the Fuzzy Logic Controller (FLC) with fast response and can adjust to the environment so that the PV output power can be utilized to the maximum [4]. This research will be studied about FLC-based MPPT on objects with non-constant irradiance, changing loads, and comparisons between the algorithms used in MPPT.

Basic Theory

A. Photovoltaic (PV)

The Photovoltaic (PV) is a device that can convert energy from light into electrical energy in the form of voltage and direct current (DC). PV is generally made of semi-conductor or polymer materials. The technology used is very closely related to the solid-state technology used in making transistors, diodes and other semiconductor devices. This material has the characteristic of being able to produce an electric current by releasing the outer electrons from an atom using energy taken from photons that have a wavelength of no more than 1.11 μm [5].

PV is a current source, which has an output power that depends on the intensity of sunlight and ambient temperature. The greater intensity of sunlight, the current flowing from the solar panel will be large and inversely proportional to the temperature. In its application PV never works using only one cell, so in its application PV cells are arranged and configured into a PV module. In a PV module there are 36 cells arranged in series, so they can produce more energy. PV systems can be divided into two categories, including stand-alone and grid-connected systems. For stand-alone systems, PV is directly connected to the load without being connected to electricity from PLN, so the circuit is simpler.

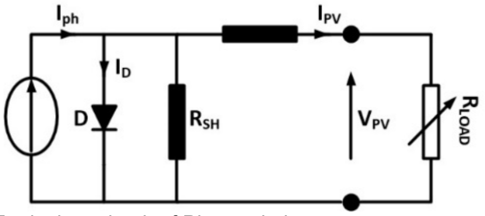

Fig. 1. Equivalent circuit of Photovoltaic

Current sources produce electrical output (Iph) when exposed to light. In non-ideal PV modeling, there are series (Rs) and parallel (Rsh) resistive components. Series resistance causes a voltage drop and parallel resistance represents a leakage current that is heading towards the ground. [6]

(1) $I = \frac{[Isc+Ki(T-298)]}{1000}\beta - Is\left(e^{\frac{q(V+RsI)}{AkT}} - 1\right) - \frac{V+IRs}{Rsh}$

Where: Is = Diode saturation current (A); q = Charge electron (1.602 x 10-19C); V = Voltage of Photovoltaic (V); Rs = Resistance series (Ω); A = Factor ideality P-N junction; k = A constant Boltzman (1.38 x 10-23 J/K); T = Temperature (K)

With the above equation, PV has certain current and voltage relationship characteristics. The relationship between current and voltage characteristics is described in the form of a curve. In addition there is also a relationship between power and voltage as shown in Figure 2. Based on the resulting characteristic curve, it appears that the maximum peak value of the PV can change according to the irradiation value.

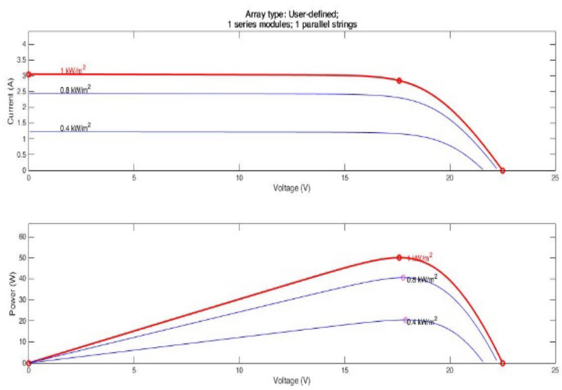

Fig. 2. Characteristic Curve of Photovoltaic

B. Maximum Power Point Tracking (MPPT)

Making renewable energy technology has increased rapidly in recent years which is to meet the world's increasing electricity needs. Therefore, almost all countries try to implement energy saving programs, namely by using renewable energy, one example is the use of solar energy. To apply it into an electrical energy, solar energy is processed using a tool that is photovoltaic (PV).
However, the efficiency generated from PV is still very low at 18% - 20% and is strongly influenced by irradiation and ambient temperature. This is because PV is a non -liner energy source. Therefore we need a method so that the power generated by PV is always maximal or at the MPP (Maximum Power Point) point [6].

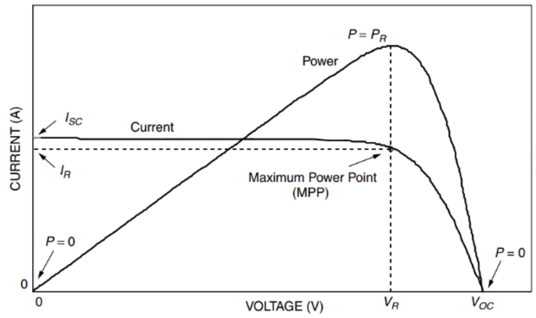

Fig. 3. Curve of Maximum Power Point (MPP)

MPPT is divided into two types namely Conventional MPPT and intelligent MPPT. Conventional MPPT is a suitable method to use when the irradiances are unchanged or uniform. This method is simple and easy to use but cannot be used during partial shading conditions. Conventional MPPT methods include Perturb and Observe (P&O), Hill Climbing, Incremental Conductance, short circuit current, open circuit voltage, and ripple correlation control. Furthermore, MPPT intelligence is a method based on artificial intelligence that is able to work during partial shading conditions. MPPT intelligent methods include Fuzzy Logic Controller (FLC), Artificial Neural Network (ANN), Particle Swarm Optimization (PSO), and Genetic Algorthm [7].

C. Algorithm Perturb and Observe (P&O)

The P&O algorithm is one of the methods that is often used in the use of MPPT because of its simple application and low implementation costs. The working principle of the P&O algorithm is to change the duty cycle of the converter used. Decision making is based on two things namely changes in power and voltage. Then the system compares the current power calculation with the previous one to determine the next duty cycle setting [8]. By changing the duty cycle of the converter causes an increasing or decreasing in voltage and power values so that the MPP point can be found by knowing the system is operating in the left or right area of the MPP point. The flowchart of the P&O algorithm can be seen in Figure 4.

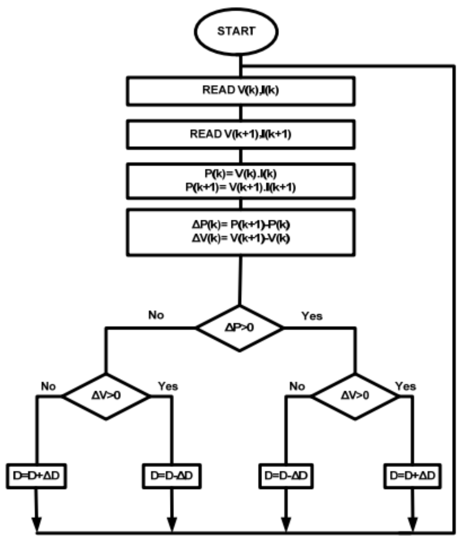

Fig. 4. Flowchart of Algorithm P&O [2]

D. Algorithm Fuzzy Controller (FLC)

Fuzzy logic has various applications, especially in the use of renewable energy. One application that can be used as fuzzy logic is as a controller to get the maximum output power output issued by PV with changing irradiance conditions and varying temperatures.

In this study MPPT used the FLC method because this method has a speed in approaching the maximum point and a little oscillation when in a steady state. This is very easy to implement because fuzzy logic does not require complicated mathematical modeling but the resulting value is quite competent with varied inputs [9].

Fuzzy Logic Controller (FLC) algorithm can be classified into three stages, namely Fuzzification, Inference Engine, and defuzzification [10]. The components and general architecture of the FLC are shown as Figure 5.

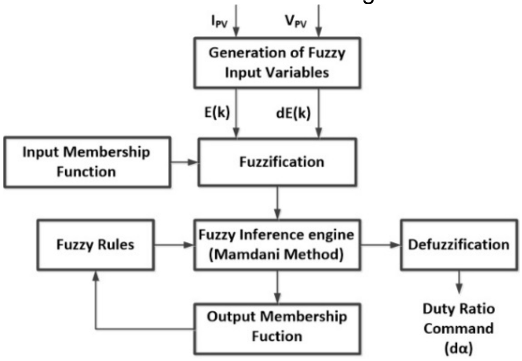

Fig. 5 Basic Architecture of Fuzzy Logic Controller

i. Fuzzification

In the fuzzification process the input variables in the form of numerical values (crisp) will be transformed into linguistic variables based on membership functions as Figure 6.

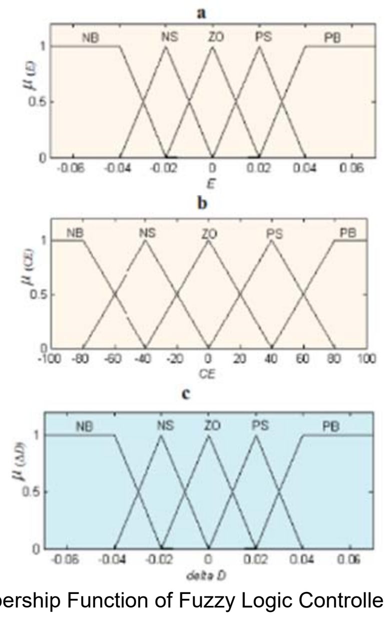

Fig. 6. Membership Function of Fuzzy Logic Controlle

At this stage two criteria of input values that used as controllers can be determined, namely error or E (k) and change of error or CE (k). The values of the variables E (k) and CE (k) can be seen from the equation below,

(2) $$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)},,$$
$$CE(k) = E(k) – E(k-1)$$

ii. Inference Engine

The Inference Engine accepts the results of the calculation process in fuzzification and produces a value that will be processed into a linguistic variable based on the membership function. The membership function that we will use in the MPPT process consists of five members, namely PB (positive big), PS (positive small), ZO (zero), NS (negative small), and NB (negative big). After being converted to linguistic variables, the membership function of the output will be determined based on fuzzy rules (rule based fuzzy). The method used to formulate fuzzy rules can be calculated or sought based on the expertise and experience of people who have studied this system.

iii. Defuzzification

In the process of defuzzification, the outcome of the Inference Engine process in the form of linguistic variables will be converted back into a numeric value (crisp). In general, defuzzification consists of two algorithms, the Center of Area (COA) and the Max Criterion Area (MCA). However, most of the methods used in the defuzzification process are COAs which are a combination of the total fuzzy set. The center of gravity (ΔD) can be searched by the following equation,

(3) $$\Delta D = \frac{\sum_{j=1}^{n} \mu(\Delta Dj).\Delta Dj}{\sum_{j=1}^{n} \mu(\Delta Dj)}$$

The results of fuzzy logic output where the change in duty cycle ΔD (k) which has been calculated through the above equation and scaled by the addition of S so as to produce the actual value of duty cycle D (k) through the equation,

(4) $$D(k) = D(k-1) - S\Delta D\ .\Delta D\ (k)$$

E. Boost Converter

MPPT has two important components to reach the maximum point, the controller algorithm and the DC-DC converter. In the selection of DC-DC converters must consider several factors including the input and output power flow, cost, flexibility, and response to PV characteristics. At this MPPT will use a Boost Converter. This converter is able to provide higher output voltages compared to the input voltage [11]. In its use the converter uses a switching system to regulate the duty cycle by giving a PWM signal (pulse width modulation).

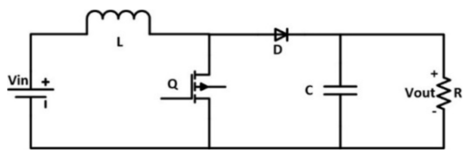

Fig. 7. Boost Converter Circuit

The boost converter output voltage values can be found by the equation:

(5) $$V_O = V_S\ (\frac{1}{(1-D)})$$

Inductor value by declaring the value of L according to the desired value of ΔI_L, the equation is obtained,

(6) $$L = \frac{V_S DT}{\Delta I_L} = \frac{V_S D}{\Delta I_L f}$$

Capacitance values can be found by the equation:

(7) $$C = \frac{D}{R(\frac{\Delta V_O}{V_O})f}$$

F. Inverter One Phase

Inverter is a circuit that converts direct voltage (DC) signals to alternating voltage (AC). The inverter voltage source can be a battery, solar panel, dry battery and or other DC voltage source. While the output of the inverter is AC voltage of 220 V or 110 V with an output frequency of 50Hz or 60Hz. Basically, the inverter is a device that makes the voltage alternating from the voltage in the same direction by the formation of voltage waves. But the voltage wave formed by the inverter is not a sinusoidal wave, but a square wave. The AC voltage is formed using two pairs of switches. For the configuration of inverters commonly used are the type of halfbridge inverter and fullbridge inverter [12].

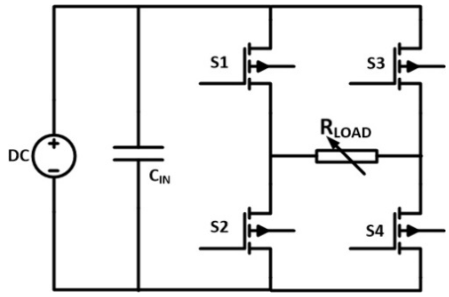

Fig. 8. Inverter Fullbridge of One Phase Circuit

G. Water Pump

A water pump is an electronic device that is driven by a single phase Induction Motor. Single phase induction motor is one type of motor that works by using a single phase alternating current (AC) as the source of its stator coil. Single-phase Induction Motor has a different working principle with a three-phase Induction Motor, where three-phase AC motors have three turns on the stator that function to produce a rotating field and induction and torsion interaction occur in the rotor. Whereas the single phase induction motor has two stator windings, the main phase winding and the auxiliary phase winding.

The ability of water pumps in issuing water discharge can be explained using the affinity law which shows the mathematical relationship between variables in the water pump [13]. With the value of the diameter of the impeller considered constant, then the equation of the law of affinity can be written as follows:

(8) $$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

(9) $$\frac{H_1}{H_2} = \left(\frac{N_2}{N_1}\right)^2$$

Where: Q = Debit (GPM); H = Total head (ft); N = Speed of Pump (RPM)

While the magnitude of the torque value will be proportional to the square of the speed as in the following equation,

(10) $$\frac{\tau_2}{\tau_1} = \left(\frac{N_2}{N_1}\right)^2$$

Design of Simulation System

A. A Block Diagram System

In this study, the simulation of the MPPT system with the Fuzzy Logic Controller (FLC) algorithm that uses the SIMULINK application available in MATLAB 2015a software. The overall system simulation includes solar panels, boost converters, single phase inverters and water pumps as shown in Figure 9.

The boost converter here will be operated as a voltage controller to produce maximum power from the MPPT system using the Fuzzy Logic Controller algorithm.

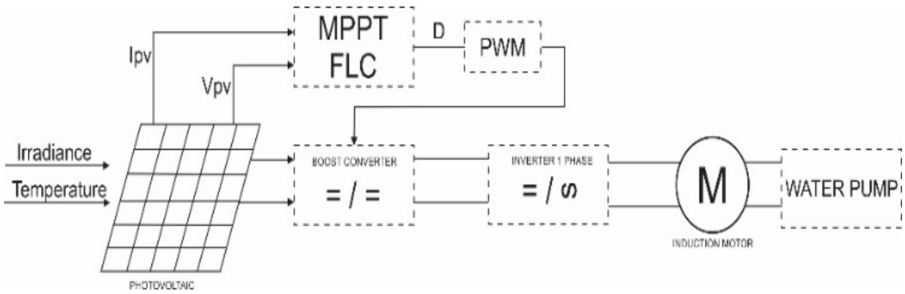

Fig. 9. Block System of MPPT for Inverter supply to connected Water Pump

B. Parameter of Algorithm Fuzzy Logic Controller

MPPT system with FLC algorithm has two inputs namely Error or E (k) and Delta Error or CE (k). E (k) is the ratio of the change in the value of the PV output power with the change in the PV output voltage at each time. Whereas CE (k) is a change from Error every time.

The input value E (k) shows the change in the point where it is located on the left or right of the MPP on the characteristic curve P-V. The value of E (k) will be large when the operating point is far from the maximum operating point and the value will get smaller if it is approaching the maximum operating point or the value of E (k) must be close to 0. While CE (k) indicates a shift in the direction of tracking power towards maximum point, where if the value is negative then the tracking power leads to the right and if the value is positive then the tracking power leads to the left.

To find out the value of E (k) and CE (k), it can first be simulated using the P&O algorithm. Previously in equations (2) and (3), it is known that the values of E (k) and CE (k) can be found using the parameters Power and Voltage. From the simulation results that have been carried out, obtained an average E (k) value of 5. And for CE (k) get a relatively smaller value than the value of CE (k). Therefore to form an interval from fuzzyfication, the value E (k) with interval [-5,5] and CE value (k) with interval [-5,5].

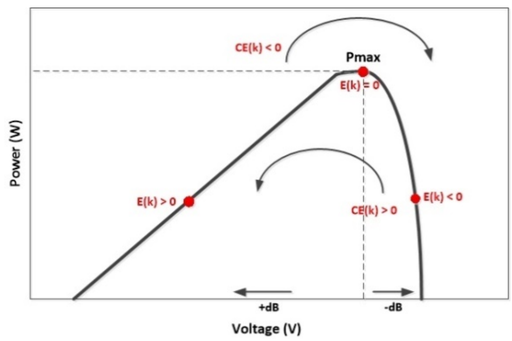

Fig. 10. Work principle of MPPT FLC

The membership functions of E (k) and CE (k) in the fuzzification process are as follows:

PB (Positive Big) : [2 4 5 8]
PS (Positive Small) : [0 2 4]
ZO (Zero) : [-2 0 2]
NS (Negative Small) : [-4 -2 0]
NB (Negative Big) : [8 -5 -4 -2]

The choice of membership function depends on the experience and expertise of the user in learning and using this system. Triangles and trapezoid (shoulder) shapes are common shapes that are often used in fuzzy modeling because they produce the best value and are easy to implement. In addition, the selection of the shape of the triangle and trapezoid (shoulder) because it is easier in mathematical calculations compared to using other shapes such as the curve s or bell shape.

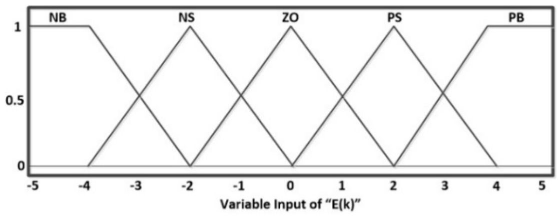

Fig. 11. Membership Function Variable of E(k)

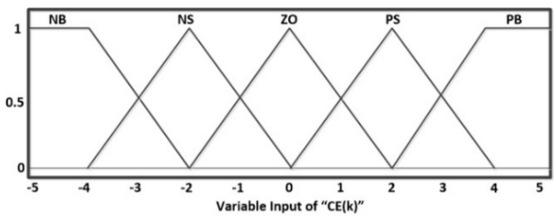

Fig. 12. Membership Function Variable of CE(k)

After the Fuzzyfication process is complete, the fuzzy value will be linked through a fuzzy rule (rule based system). The fuzzy method used is the Mamdani method because the output of the fuzzy process is in the form of a number not in the form of an equation. This rule contains a rule that explains the condition of the input.

TABLE I . Rule Table of Fuzzy

E(k)/CE(k)	PB	PS	ZO	NS	NB
PB	PB	PB	PB	PB	PB
PS	PB	PS	PS	ZO	ZO
ZO	PS	PS	ZO	NS	NS
NS	ZO	ZO	NS	NS	NB
NB	NB	NB	NB	NB	NB

The FLC MPPT system uses 25 Fuzzy rules that have been designed according to Table I, where the making of fuzzy rules considers two input values, E (k) and CE (k). Fuzzy rules are calculated so that the condition of the system is always at the maximum point. So that when the value of E (k) gets bigger, the change in duty cycle will also be greater or when the value of E (k) gets smaller (close to the value of 0), the change in duty cycle will get smaller and try to reach a maximum point so that it reduces oscillation during steady state.

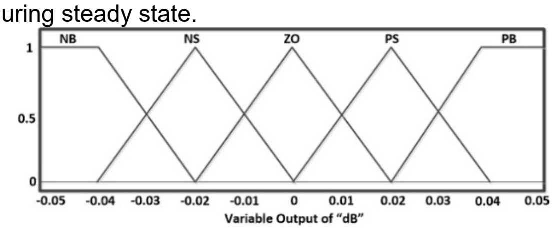

Fig. 13. Membership Function Variable of dB

The results obtained from this fuzzy rule are the value changes in the duty cycle ratio which is entered into the DC-DC converter. The change in duty cycle ratio is set at 0.05 to produce a small oscillation. Changes to the duty cycle ratio in the membership function can be seen in Figure 13.

C. Design of Boost Converter

In designing a converter, what needs to be done is to determine the value of electrical parameters that will be used such as the value of the input voltage (Vin), output voltage (Vo), switching frequency (fs), power (P), inductor current ripple, capacitor voltage ripple. Determination of these parameters must also consider the availability of components on the market and the availability of supporting equipment in the laboratory. The purpose of determining the parameter values is to be a reference in determining the components to be used.

TABLE II. Design Specification of Converter

Parameter	Nilai
Voltage Input (V_{in})	17.6 V
Voltage Output (V_o)	30 V
Power Output (P_o)	50 Watt
Frequency Switching (f_s)	20 kHz
Current inductor ripple	0.5A
Voltage capacitor ripple	1.5V

Simulation Results And Data Analysis

A. Simulation with Different Irradiance and Constant Load

The simulation uses two PV modules which are arranged in parallel with different irradiations and with a constant load. The selection of PV modules considers the implementation in the ITS Electrical Energy Conversion laboratory. The temperature in the PV is assumed constant at 25°C. In this simulation a comparison of the use of the Perturb and Observe (P&O) algorithm with the MPPT Fuzzy Logic Controller (FLC) with parameters compared is the amount of power and energy efficiency obtained.

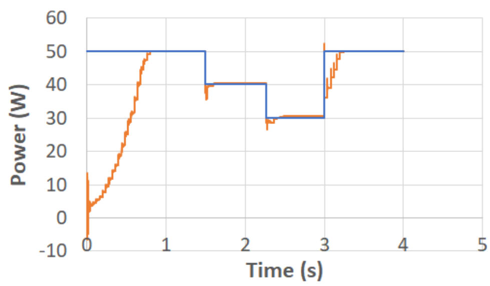

Fig. 14. Power Graph of different irradiance using FLC algorithm

Irradiation is changed from 1000 W / m^2 to 800 W / m^2 at 1.5 seconds then irradiation is lowered back to 600 W / m^2 at 2.25 seconds and finally increased to 1000 W / m^2 at 3 seconds. Changes in irradiation are done to test the MPPT algorithm can run well in down or up conditions.

In the MPPT with the FLC algorithm the total energy produced is 151,867 Joules. When viewed from the PV characteristic curve, the total overall energy that can be produced by PV is equal to 153,545 Joules. If the PV is using MPPT the FLC algorithm has an energy efficiency of 98.9% or an energy loss of 1.1%.

B. Simulation With Constant Irradiance and Different Load

In the following simulation the load changes with the PV test conditions (Irradiation W/m2 and temperature 25°C) so that the maximum PV output power is 100.3W. The load used for testing changed loads is to use resistors that change the resistance value. The load starts at 17.9 Ω then at the 2 second the load is reduced to 13 Ω, and finally the load is reduced to 9 Ω at 3 seconds.

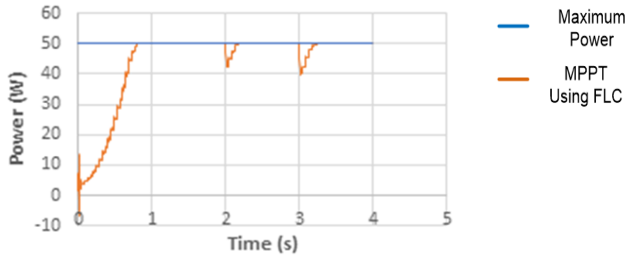

Fig. 15. Power Graph of different load using FLC algorithm

Furthermore testing using the MPPT FLC algorithm, the MPP point can be achieved with a faster tracking time compared to P&O. The power generated by PV when in a steady state with less insulation. The energy generated using the FLC algorithm is 176,274 Joules. The energy efficiency that can be achieved from this algorithm is 98.8% and the amount of energy lost is only 1.2%.

C. Simulation system of MPPT Fuzzy Logic Controller for Inverter Supply to Connected Water Pumpp

When the system uses MPPT it can be seen that the output power of the PV is able to reach the MPP point even though it is burdened by a water pump. Shown in Figure 16 and Figure 17 is the power output of PV when connected MPPT and without MPPT. When using MPPT, the total flow of water produced is more than without using MPPT which is 1.3 liters or shown in Figure 18. This is because the incoming power to the water pump is greater when using MPPT. In this condition the maximum energy that can be produced by PV is 354.51 Joules. The use of MPPT with the FLC Algorithm can produce energy in the amount of 337.26 Joules, so the energy efficiency obtained is 95.13% and the energy loss from the system is 4.87%.

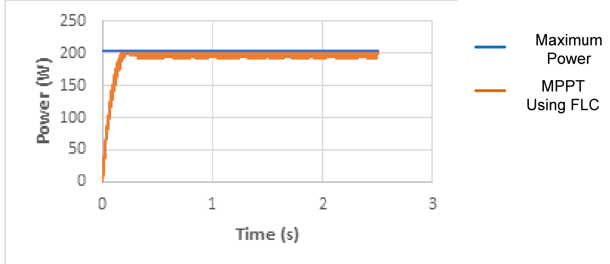

Fig. 16. Power of PV that connected Water Pump with MPPT FLC

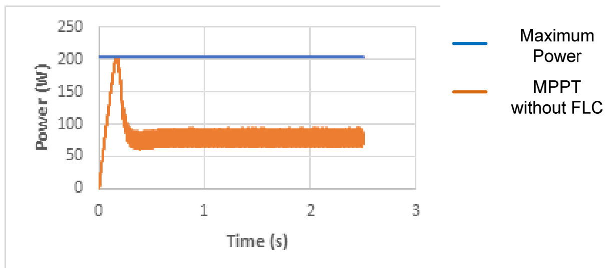

Fig. 17. Power of PV that connected Water Pump without MPPT

Whereas when the system does not use MPPT or shown in Figure 17 the power is not able to reach the MPP point so there is a lot of energy lost. By using a system without MPPT, the total flow of water generated from the pump is 0.9 liters. In conditions of use without energy that can be produced by the system that is equal to 146.98 Joules, so the energy efficiency obtained is 41.46% and the energy lost from the system is 58.54%.

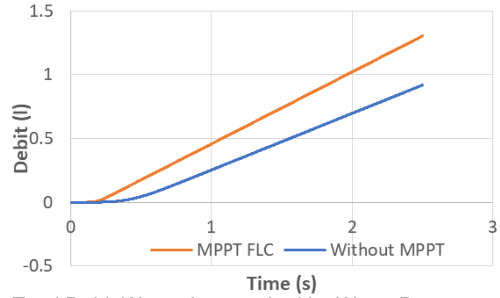

Fig. 18. Total Debit Water that resulted by Water Pump

D. Characteristic PV Curve

The PV characteristic curve needs to be obtained for knowing some parameters such as maximum power (Pmpp), optimal voltage (Vmpp) and, optimal current (Impp). The way for getting the PV characteristic curve is by connect PV with a variable resistor where on this final project uses rheostat 25Ω. Rheostat is shifted from the maximum R value to the minimum R. During change R value is the value of the current and voltage read by the sensor saved to logger. The PV characteristic curve is found in various kinds of irradiation and with an ambient temperature of 31°C with cell temperatures reaching 53°C. This is what causes PV cannot work according to nameplate.

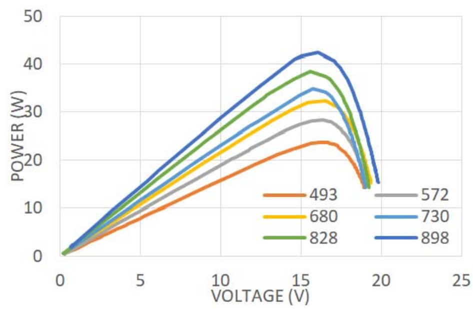

Fig. 19. Characteristic curve of Power and Voltage PV

E. Testing of MPPT Different Irradiance and Constant Load

Irradiation testing is done in two ways, namely by covering the plastic and shifting the angle of the PV. The first is testing the irradiation changes by covering the plastic. Testing is done by measuring the PV power under normal conditions, then the PV is covered with two layers of plastic evenly to reduce irradiation at 70 seconds then the PV is covered again by adding three layers of plastic evenly at 140 seconds. After that at 210 seconds the plastic layer covering the PV removed with the remaining two plastic layers and at 280 seconds the entire plastic layer is removed. This test is done at 13.00 WIB.

The graph shows that the irradiation value starts from 680 W/m^2 with the power according to the characteristic curve of 32.3 W, then the irradiation is reduced to 572 W/m^2 with a power of 28.3 W then the irradiation returns to 492 W/m^2 with a power of 23.3 W and then the irradiation is again increased to 572 W/m^2 and finally increased again to 680 W/m^2. This test is carried out to observe the MPPT response when the irradiation rises or falls. The total energy that can be produced from the system is 1642,287 Joules.

The first test was carried out using the P&O algorithm. This algorithm can respond to decreases and increases in various irradiations. However, it can be seen in Figure 20 that the initial tracking to reach the MPP point takes a long time and there is oscillation when the maximum power has been reached. In addition, when using MPPT P&O for a long time makes the isolation of this MPPT even greater and results in considerable energy loss. This is because the

MPPT P&O cannot respond well when changes in irradiation vary and the resulting duty cycle also experiences a significant increase or decrease. In testing using the MPPT P&O algorithm the total energy is 1483.61 Joules or the resulting energy efficiency is 90.69%.

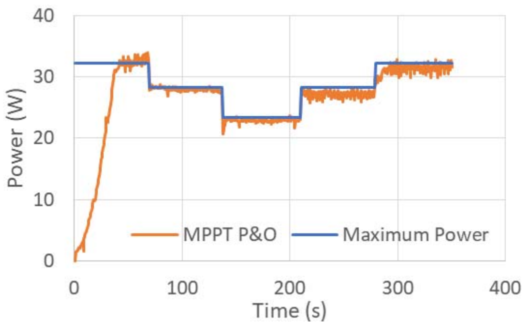

Fig. 20. Power Graph of different irradiance using P&O algorithm

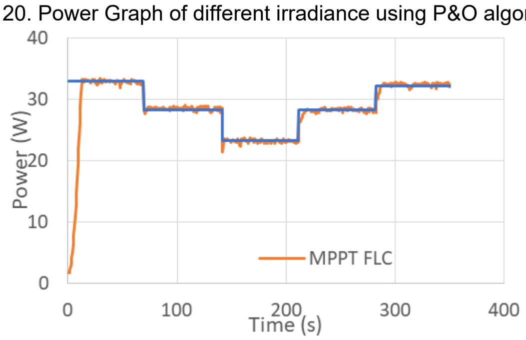

Fig. 21. Power Graph of different irradiance using FLC algorithm

Subsequent testing uses the FLC algorithm. This algorithm can respond to decreases and increases in various irradiations. It can be seen in Figure 21 that the initial tracking to reach the MPP point has a very fast response compared to the P&O algorithm and oscillation when the steady state conditions are much less. In testing using the MPPT FLC algorithm the total energy is 1603,234 Joules or the resulting energy efficiency is 97.62%.

F. Testing of MPPT Constant Irradiance and Different Load

This test is done by changing the load to determine whether the MPPT algorithm can still be in the MPP condition. Load change is done by changing the resistance of the load using the rheostat. Load change starts from large resistance to small resistance. For the initial load the resistance is made with a full load condition of 18Ω, then at the 70th second it drops to 13 Ω and the last change at the 110th second is reduced to 9 Ω. The value of the resistance change is chosen based on the range of duty cycle values so that it can maintain power at its maximum point. The experiment was conducted at 11.00 WIB with irradiation of 830 W / m^2.

The first MPPT test was using the P&O algorithm. If based on the simulation that has been done, the power produced tends to be constant and will always be at the MPP point and there is a change in the value of the duty cycle in order to keep the power at its maximum point. The power that can be produced by PV in this condition is 39.2 W or the total energy that can be produced by PV is 356,712 Joules.

The next test is MPPT with FLC algorithm. It can be seen in Figure 22, using the FLC tracking power algorithm when load changes are faster and oscillations when the steady state conditions are smaller than using the P&O algorithm. MPPT response with the FLC algorithm when there is a change with a decrease in load to 13Ω takes 7.22 seconds, whereas when a decrease in load to 9Ω takes 3 seconds to reach the MPP point. Total Energy generated using the FLC algorithm is 344,295 Joules or has energy efficiency, i.e. 96,517%. So that the load changes in the FLC algorithm run better and faster than the P&O algorithm.

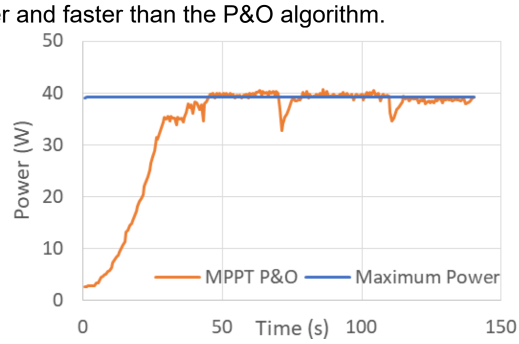

Fig. 22. Power Graph of different load using P&O algorithm

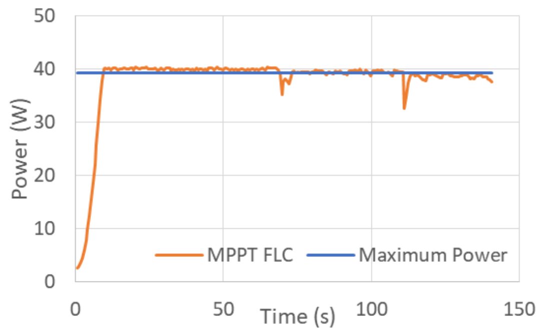

Fig. 23. Power Graph of different load using FLC algorithm

Conclusion

From the simulation results and tests obtained, the results show that the use of MPPT with the FLC algorithm has better efficiency than the use of MPPT with the P&O algorithm, both for changes in irradiation and changes in load. When the MPPT FLC is connected to the water pump it has a greater energy efficiency than it is not connected with the MPPT. In addition, the total average water flow generated when connected to the MPPT FLC is greater with a ratio of 1.58: 1.

Suggestions for future research are MPPT testing can be done using a PV simulator so that the results obtained are more optimal. Furthermore, the implementation is expected to use current and voltage sensors with higher accuracy and the microcontroller used must have a faster clock reading so that the algorithm reading is also faster.

Acknowledgements

The Author thanks to Institute Teknologi Sepuluh nopember and Shipbuilding Institute of Polytechnic Surabaya which support to finish this paper.

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