A Modified Firefly Algorithm for Maximum Power Point Tracking (MPPT) Using Sepic Converter Under Shading Condition

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Abstract. This paper presents a method that modify firefly algorithm method, the existing firefly algorithm method uses the principle of spreading several duty cycles which are later compared to each power gain from the spread and the best one is taken. In this proposed method, the firefly algorithm computation is being simplified and combined with perturb and observe control so the time to reach the global maximum power is reduced and the output power is not fluctuating. To control the output power the SEPIC Converter topology is used. To ensure the maximum power generated, the duty cycle of the SEPIC Converter is adjusted using modified firefly algorithm control. Then it will be compared with existing firefly algorithm and perturb and observe control to verify the proposed method is faster and not fluctuating.

Keywords - *solar module, firefly algorithm, perturb and observe, maximum power point tracker, sepic converter*

1 Introduction

As time goes by, the demand for electricity is increasing while fuels such as coal, gas and petroleum are getting higher in price and are also not environmentally friendly. Therefore, renewable energy was developed, one of which is solar energy. Solar modules are used to generate solar energy due to low maintenance costs and are also environmentally friendly.

Various researches are conducted to produce solar electric energy that is superior in performance, reliability and energy efficiency. To create superior solar energy there are things that need to be considered, namely the efficiency of solar modules which is low so that a lot of energy loss is wasted.

Some literature shows many methods of MPPT to find the maximum power to increase its efficiency. There are Perturb and observe (P&O) method, Fuzzy Logic, Neural Network and also other MPPT methods. The most widely used method in MPPT is P&O because it is easy to implement on the system, but this

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method has power output results that cannot be constant (fluctuating) so that the results are not accurate. This fluctuating level can be reduced but will make the power output inaccurate. the time to reach maximum power is getting longer. Artificial intelligent methods can find the maximum power value with a high level of precision, such as fuzzy logic, artificial neural network and also nature-inspired algorithms such as firefly algorithm (FA) , particle swarm optimization (PSO). Fuzzy logic when applied to this system, the level of accuracy depends on the knowledge of the programmer when designing the membership function and rule base. While MPPT using neural network requires data for the learning process, so the data needed will be very much because the power generated also depends on temperature and irradiance.

Therefore, a method inspired by nature is offered, namely the firefly algorithm (FA), Xin-She Yang. Firefly algorithm is an artificial intelligence method that can find the maximum power value with a shorter time to achieve convergence time with a high level of accuracy.

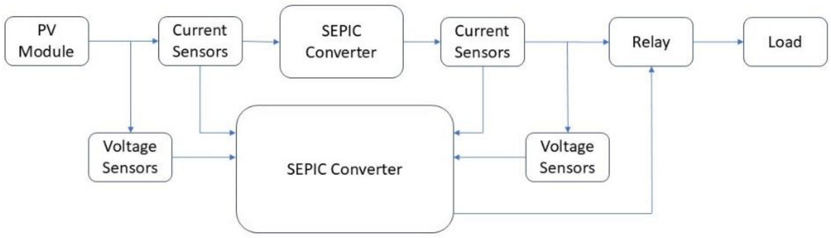

Figure 1. Block Diagram System

In this design with a block diagram as in Figure 1, testing has been carried out on the solar module system, SEPIC Converter is used in the process of transferring energy from the solar module to the load. The voltage regulation on the solar module is determined based on the amount of duty cycle used, the duty cycle is obtained by spreading several variations of the duty cycle, then the voltage and current will be obtained at each distribution, so that the power value of the solar module will be obtained. After that, it will be compared between all the duty cycle distributions which is the most optimal power, then the duty cycle will be used in the SEPIC Converter so that the power output on the solar module is optimal. This method is used to increase the efficiency of solar modules with a high level of precision. To see its success, this method will be compared with the regular firefly algorithm method also with Perturb and Observe method which is the most widely used method in this system, so this comparison is very helpful in the research process, because by comparing the two we can see where the advantages and disadvantages of the methods offered.

2 System Description

2.1 SEPIC Converter For MPPT

SEPIC (Single Ended Primary Inductor Converter) converter can function as raising the voltage and lowering the voltage of the input voltage. The polarity between the input voltage and the output is the same. The SEPIC converter circuit is shown in Figure 2. SEPIC converters can operate in continuous conditions and discontinuous conditions.

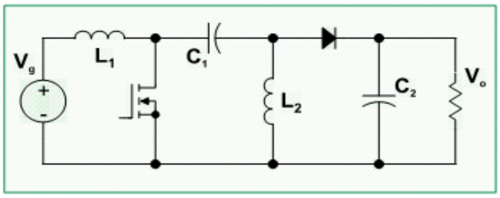

Figure 2. Sepic converter circuit

The working arrangement for the SEPIC converter circuit in continuous condition is shown in Figure 3 when the switch is on for t1, the voltage enters and is stored to inductor L1 and the other inductor L2 stores energy from capacitor C1. During the switch on, capacitor C2 does not get energized because the diode is in reverse condition. In Figure 4 when the switch is off for t2, diode D is in forward condition so the energy stored in both inductors is transferred to the load and also charging capacitor C2.

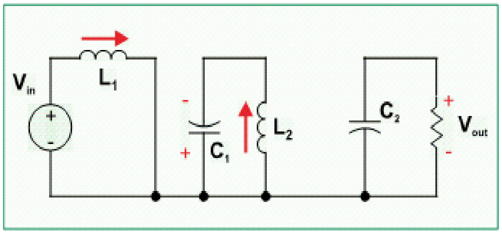

Figure 3. Switch ON condition

The voltage on capacitor C1 is the same value as the voltage on the source

$$V_{c1} = V_s \tag{1}$$

The voltage of inductor L1 is obtained from the following equation

$$V_{L1} = V_s = L_1 \frac{di_L}{dt} (V) \tag{2}$$

Change in current of inductor L1

$$\frac{di_L}{dt} = \frac{\Delta i_L}{DT} = \frac{V_S}{L1} \quad (3)$$

$$\Delta i_{L1(Closed)} = \frac{V_S DT}{L1} (A) \quad (4)$$

The voltage of inductor L2 is obtained from the equation

$$-V_{L2} = V_{C1} = L_2 \frac{di_L}{dt} (V) \quad (5)$$

Change in current of inductor L2

$$\frac{di_L}{dt} = \frac{\Delta i_L}{DT} = \frac{-V_{C1}}{L2} \quad (6)$$

$$\Delta i_{L2(Closed)} = \frac{-V_{C1} DT}{L2} (A) \quad (7)$$

Nomenclature :

D = *duty cycle*
V_{c1} = Voltage on Capacitor C_1 (V)
V_{L1} = Voltage on Inductor L_1 (V)
V_{L2} = Voltage on Inductor L_2 (V)
V_s = Source Voltage (V)
Δi_{L1} = Change in inductor current L_1

When the switch is off, the voltage on inductor L2 is equal to the output voltage value as shown in Figure 4.

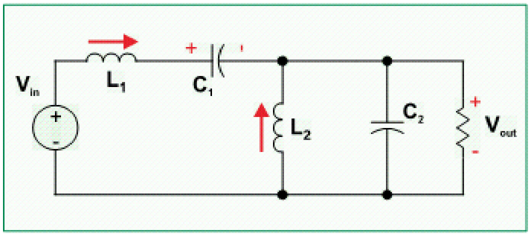

Figure 4. Switch OFF condition

From the equation, the duty cycle is obtained

$$V_O = \frac{V_S D}{(1-D)} (V) \quad (8)$$

$$D = \frac{V_O}{V_S + V_O} \quad (9)$$

Nomenclature :

Vo = Voltage Output (V)

$\Delta i_{L1(Open)}$ = Change in current of inductor L1 when the switch is ON

$\Delta i_{L1(Closed)}$ = Change in current of inductor L1 when the switch is OFF

Calculation of SEPIC converter under continuous conditions:
Determine the duty cycle

$$D = \frac{V_O + V_D}{V_{IN} + V_O + V_D} \quad (10)$$

2.2 P&O Algorithm for MPPT

Maximum Power Point Tracker (MPPT) is a method to find the maximum power point (MPP) from the voltage power characteristic curve of solar panels in order to take the nominal duty cycle value, so that the converter can deliver maximum power from solar panels to the load. Perturb and Observe (P&O) algorithm is one of the conventional MPPT methods that is very cheap and easy to implement. This MPPT design requires two parameters to determine the slope, namely the converter input voltage (Vin) and the converter input current (Iin).

$$P_{in}(n) = V_{in}(n) \; x \; I_{in}(n) \quad (11)$$

From these two parameters obtained Power (Pin), and voltage (Vin), then compared with the previous data reading parameters, namely Pin (n-1) & Vin (n-1).

The results of the comparison were obtained ΔP and ΔV

$$\Delta V = V_{in}(n) - V_{in}(n-1) \quad (12)$$

$$\Delta P = P_{in}(n) - P_{in}(n-1) \quad (13)$$

And the result of dividing ΔP and ΔV will be called the slope.

$$\text{Slope} = \frac{\Delta P}{\Delta V} \quad (14)$$

As shown in Figure 5, there are 3 types of points in 3 positions. To the left of the peak dP/dV > 0, at the peak of the curve dP/dV = 0 and to the right of the peak dP/dV <0.

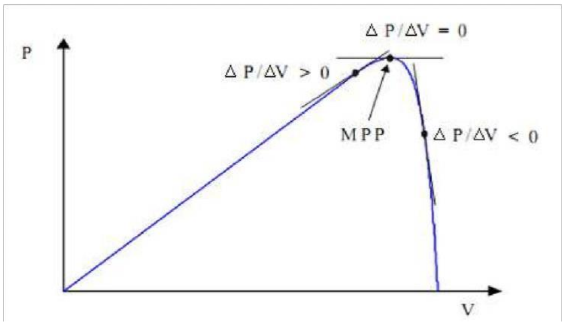

Figure 5. Different ΔP/ΔV positions on the solar cell power curve

To the left of MPP, the power change versus voltage change dP/dV>0, while to the right, dP/dV 0, it is known that perturbation is done to move the PV working voltage forward towards MPP. If dP/dV, then the change in the working point directs the PV away from MPP. Then the P&O algorithm reverses the direction of perturbation. The flowchart of the P&O algorithm is shown in Figure 6.

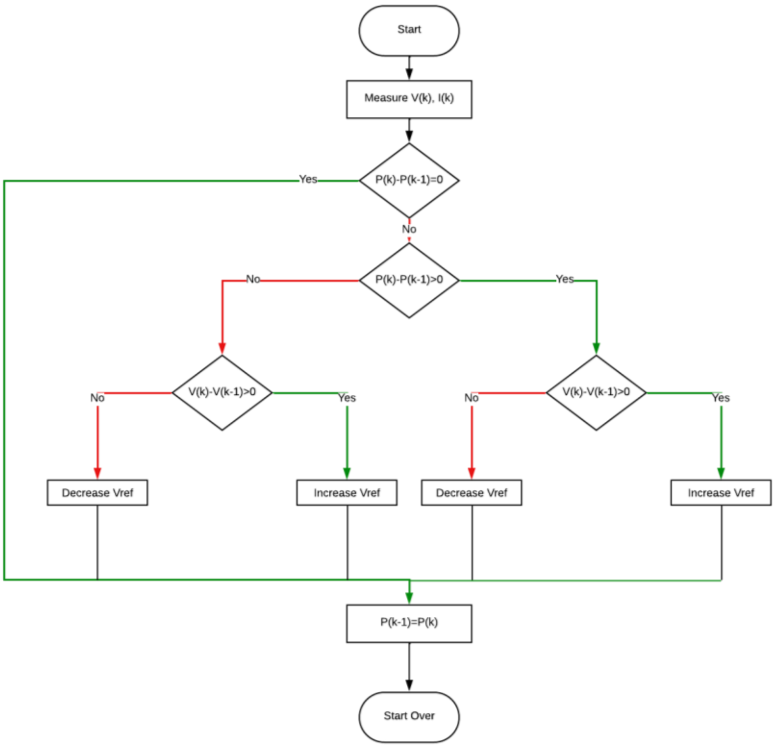

Figure 6. Flowchart of the Perturb & Observe (P&O) algorithm

2.3 Firefly Algorithm for MPPT

Xin-She Yang wrote down three ideal rules to make it easier to understand the firefly algorithm, namely:

1. All fireflies are unisex, so one firefly will be attracted to another firefly
2. Attraction is proportional to the brightness of the firefly light, fireflies with low light levels will be attracted and move towards fireflies that have higher brightness levels, the brightness of the firefly light will decrease with time and the absorption of light due to air factors.
3. The intensity of firefly light is determined by the objective function value of the given problem. For maximization problems, the light intensity is proportional to the objective function value.

In the simplest case of a maximal optimization problem, the luminance I of the firefly at location x can be written I(x) ∞ f(x). However, the attraction β is relative, judging from a firefly to another firefly. Thus, β will change the magnitude of rij between firefly i and firefly j. Light intensity decreases with distance from the source, and light is also absorbed in the medium (air), so the attraction varies with the absorption rate.

The simple form of the variation of light intensity I(r) inversely proportional to the square of the distance can be written as follows:

$$I(r) = \frac{I_s}{r^2} \tag{15}$$

where Is are the intensity of the source. For a given medium with a fixed light absorption coefficient γ, the light intensity I varies with distance r.

$$I = I_0 e^{-\gamma r} \tag{16}$$

where I0 is the initial light intensity. To avoid the value of r = 0 in the Is/r2 equation, the combined effect of the inverse square ratio of distance and absorption can be approximated by a Gaussian shape.

$$I(r) = I_0 e^{-\gamma r^2} \tag{17}$$

The firefly's attraction is proportional to the light intensity seen from the neighboring firefly. We can now define the attraction β of a firefly by the equation

$$\beta = \beta_0 e^{-\gamma r^2} \tag{18}$$

where β0 is the attraction at the time r = 0. Since it is faster to calculate 1/(1+r2) than the exponential function, the above formula can be approximated by

$$\beta = \frac{\beta_0}{1+\gamma r^2} \tag{19}$$

If the firefly located at x'=(x'1, x'2, . . . , x'n) is brighter than the firefly located at x=(x1, x2, . . . , xn), the firefly located at x will move towards x'. Updating the location of the firefly located at x can use the following equation:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_i - x_j) + \alpha \varepsilon_i^t \tag{20}$$

The last term is the random term with α being a randomized parameter with $0 \leq \alpha \leq 1$ and ε being a vector of random values, while the second term is the attraction of x to x'.

$$r_{ij} = \sqrt{\left(x_{i-x_j}\right)^2} \tag{21}$$

The algorithm of FA can be summarized as follows:

1. Create a random solution set, { x1 , x2 , ... , xn}
2. Calculate the intensity of each solution member, { I1 , I2 , ..., In}
3. Move each firefly i towards another firefly that is brighter, and if there are no more brighter ones, move randomly.
4. Update the solution set.
5. Stop if it has met the desired optimization criteria, if not then return to step two.

The flowchart of the firefly algorithm method is shown in Figure 7.

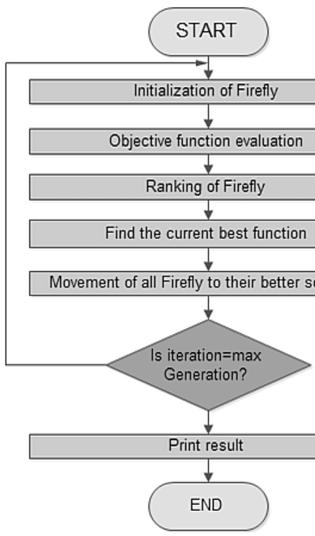

Figure 7. Firefly Algorithm Flow Chart.

2.4 Modified Firefly Algorithm for MPPT

On this paper we proposed modified firefly algorithm method by modifying firefly algorithm and combining it with perturb and observe method. The firefly algorithm is modified by changing the 20 equation to obtain firefly coordinates.

The regular firefly algorithm compares the light intensity for each firefly to the other firefly to obtain the brightest firefly. And the modified firefly compares the light intensity to the brightest firefly by multiplying the average of all fireflies light intensity, so the movement of the firefly is more efficient. So the computation of the objective function is faster than the regular firefly algorithm. The figure 8 below is the flowchart of the proposed method.

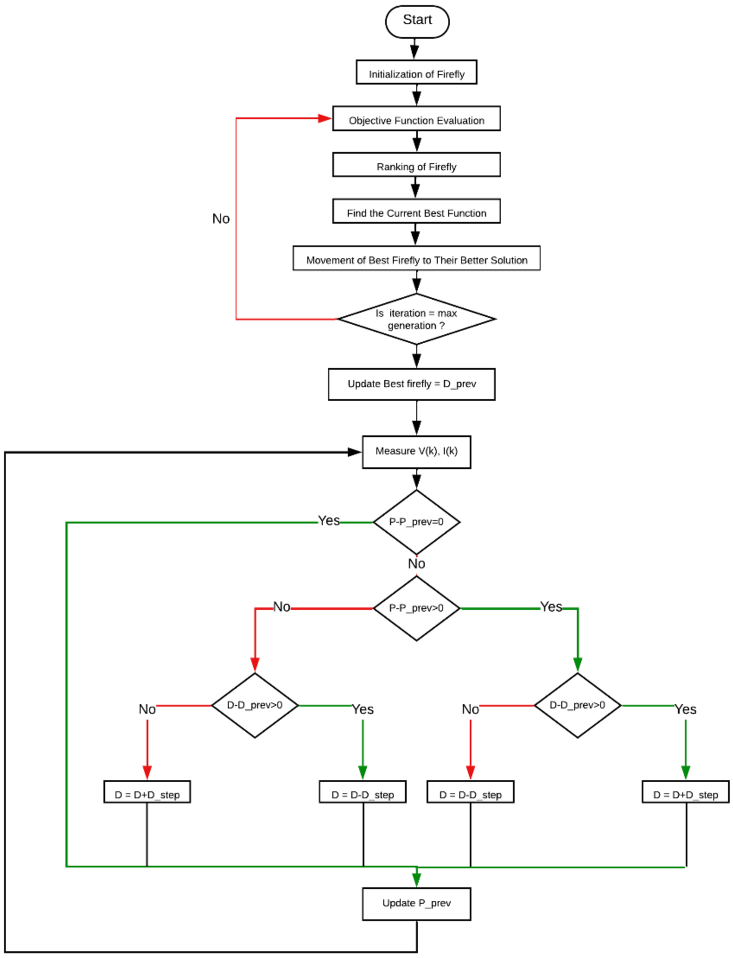

Figure 8. Modified Firefly Algorithm Flow Chart

3 Analysis and Experimental Result

3.1 SEPIC Converter Testing

SEPIC Converter testing aims to determine the function of the SEPIC Converter as a dc-dc converter and to determine the response of the converter to changes in duty cycle and the performance of the converter by looking at the efficiency value. The testing circuit is shown in Figure 9

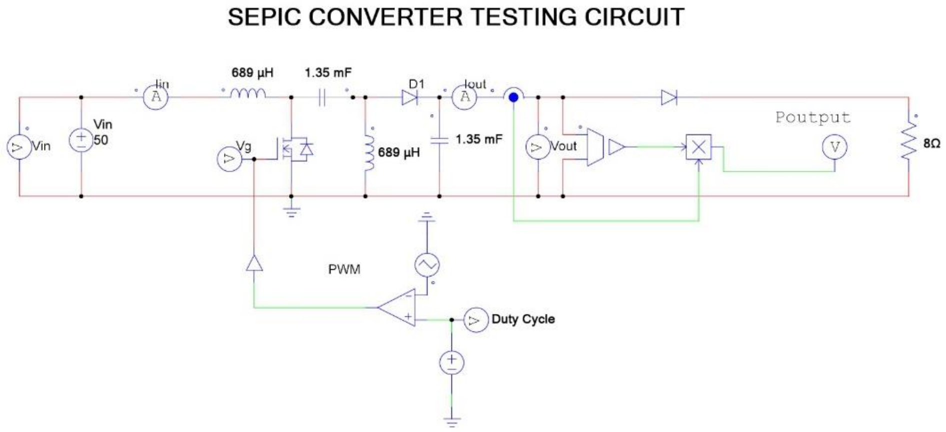

Figure 9. SEPIC Converter Testing Circuit

This test is done to validate the converter is working properly, the input voltage varies from 30 - 60 V and a resistive load. As for the duty cycle value, it will be varied from 30% to 45%. And the result shows that the efficiency is nearly reach 100% as shown in Table 2.

Table 1. SEPIC Converter Testing Results

No	Duty Cycle	V_{in} (V)	I_{in} (A)	V_{out} (V)	I_{out} (A)	P_{in} (VA)	P_{out} (VA)	Efficiency (%)
1	0.3	30	0.70	12.85	1.60	21.00	20.56	97.90%
		40	0.93	17.14	2.14	37.52	36.68	97.76%
		50	1.16	21.43	2.68	58.40	57.43	98.34%
		60	1.38	25.70	3.21	82.80	82.50	99.63%
2	0.4	30	1.86	20.00	2.49	55.80	49.96	89.53%
		40	2.30	26.70	3.33	92.00	88.91	96.64%
		50	3.36	33.30	4.19	168.00	139.53	83.05%
		60	3.38	40.00	4.99	202.80	199.60	98.42%
3	0.45	30	2.50	24.50	3.06	75.00	74.97	99.96%
		40	3.60	32.70	4.10	144.00	134.07	93.10%
		50	4.10	41.00	4.96	205.00	203.36	99.20%
		60	5.08	49.00	6.13	304.80	300.37	98.55%

3.2 MPPT Testing on Several Methods

3.2.1 Perturb and Observe Algorithm for MPPT Testing

Figure 10 is the result of the power response from the P&O method, which works if the current power output is greater than the power output before, then the duty cycle value will be increased and vice versa if the current power output value is lower than before then the duty cycle value will be. The maximum output power is 400 W and it takes 0.16 seconds to reach this state, but it had fluctuating power output and duty cycle between 0.4 to 0.7 results that can affect switching component, the duty cycle result is shown in figure 11 below.

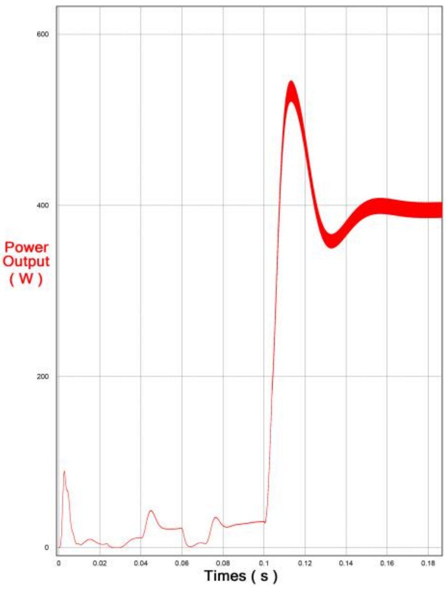

Figure 10. MPPT Power Graph with P&O Method

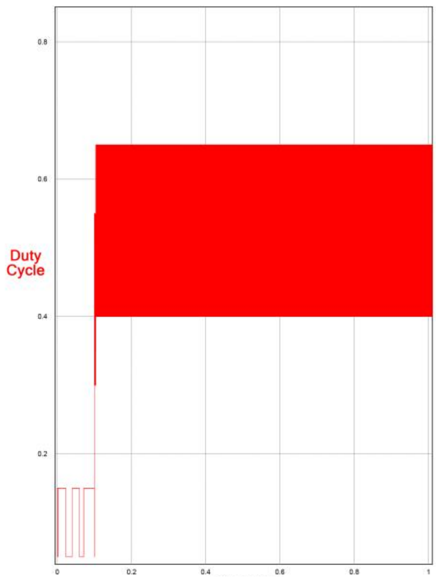

Figure 11. Duty Cycle of P&O Method

3.2.2 Firefly Algorithm for MPPT Testing

This method uses a random process after which an evaluation process is carried out by comparing the current power results with the previous power results. Then from the results of this comparison can be determined the maximum power in the solar cell called PGbest.

The following is the result of the Firefly Algorithm method test response to find the maximum power can be seen in Figure 14. The output power reached 400 W and the duty cycle value is 0.44 but it takes 2.8 seconds to reach divergence state as we can see in figure 15. The voltage response and current response can be seen in figure 16 and figure 17.

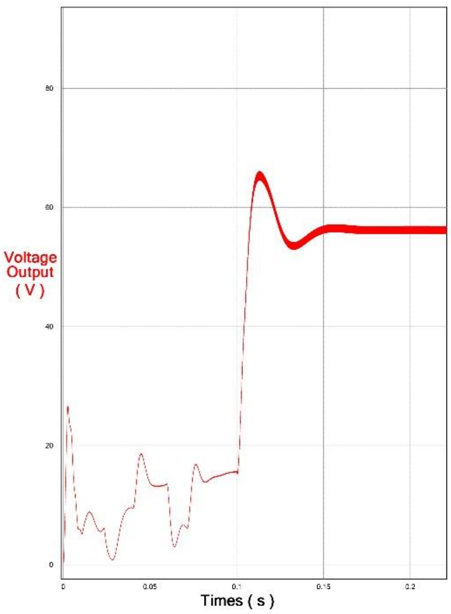

Figure 12. Voltage Graph with P&O Method

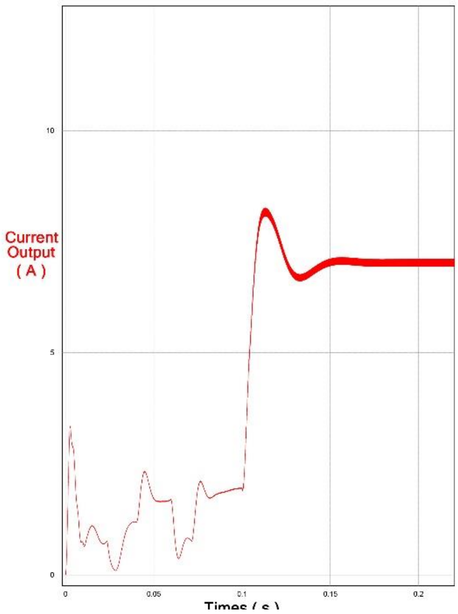

Figure 13. Current Graph with P&O Method

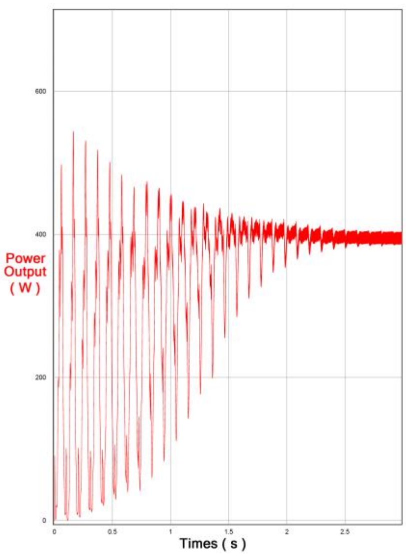

Figure 14. MPPT Power Graph with Firefly Algorithm Method

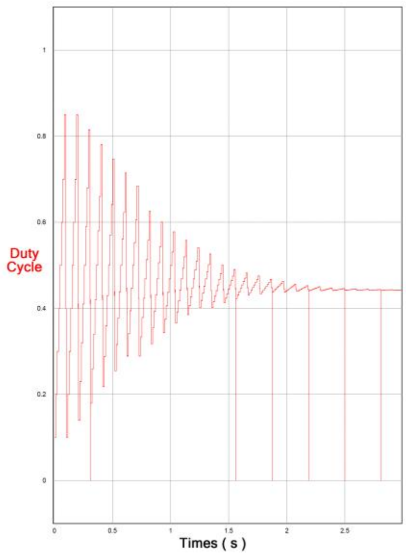

Figure 15. Duty Cycle of Firefly Algorithm Method

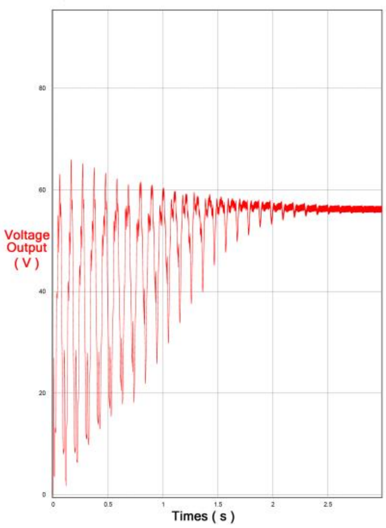

Figure 16. Voltage Graph of Firefly Algorithm Method

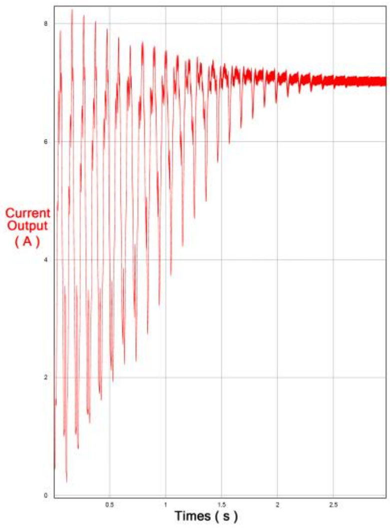

Figure 17. Current Graph of Firefly Algorithm Method

3.2.3 Modified Firefly Algorithm for MPPT Testing

This proposed method modifies firefly algorithm by comparing each of firefly to the average value from all of the firefly that has been spread before so it doesn't compared one by one and move closer to each firefly. This made the firefly to reach the convergence state faster and didn't trapped in local maximum power. And then it will be combined with P&O method for MPPT Testing. The result is shown in figure 18. The output power is found faster than the regular firefly algorithm and solved the fluctuation on P&O method.

The maximum power output reached 400 W and the duty cycle value is 0.44 with the total time to reach divergence is 0.75 seconds. It is four times faster than the regular firefly algorithm.

3.2.4 Comparison

From three methods (P&O, Firefly Algorithm and Modified Firefly Algorithm) that are being simulated the result of the power, voltage, current tracking speed and efficiency can be seen in table 3.

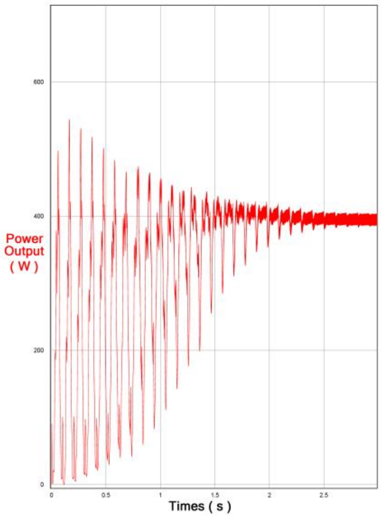

Figure 18. MPPT Power Graph of Modified Firefly Algorithm

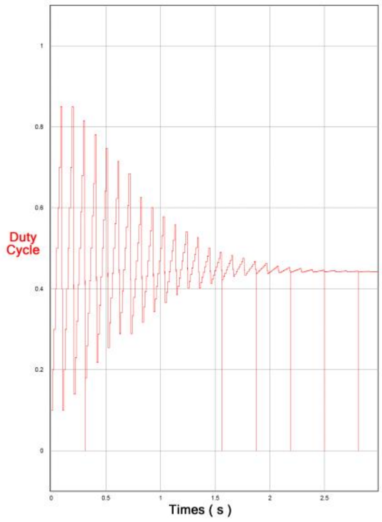

Figure 19. Duty Cycle of Modified Firefly Algorithm Method

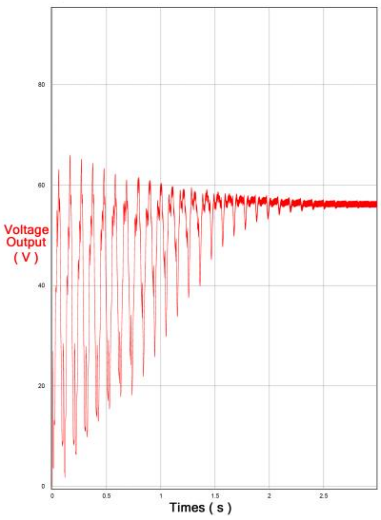

Figure 20. Voltage Graph of Modified Firefly Algorithm

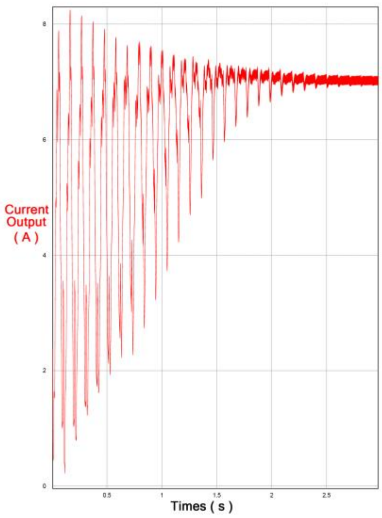

Figure 21. Current Graph of Modified Firefly Algorithm

Table 2. Comparison Table

Conditions	Tracking Method	Power (W)	Voltage (V)	Current (A)	Tracking Speed (s)	Maximum Power (W)
1000 W/m^2 and 25^o	P&O	401.92	56.76	7.09	0.20	403.47
	FA	401.92	56.72	7.09	2.39	402.09
	MFA	401.92	57.56	7.10	0.69	408.65
Shading 1000 to 500 W/m^2 and 25^o	P&O	201.93	29.46	3.68	0.20	108.42
	FA	201.93	32.23	4.03	0.05	129.89
	MFA	201.93	32.35	4.03	0.04	130.40
Shading 500 to 1000 W/m^2 and 25^o	P&O	401.92	56.85	7.09	0.10	403.11
	FA	401.92	56.78	7.09	0.09	402.58
	MFA	401.92	56.98	7.11	0.08	405.15

From the table above we can ensure that Modified Firefly Algorithm (MFA) had faster tracking speed than the existing firefly algorithm. Altough P&O tracking speed is faster at the beginning but when it comes to shading condition MFA is faster than regular firefly algorithm and P&O. Beside that P&O duty cyle is too fluctiative than MFA and FA.

4 Conclusion

In this paper, the algorithm proposed is modified firefly algorithm to find the maximum value of solar panel. The algorithm used has a shorter time to reach convergence when compared to methods that are often used in MPPT systems are the P&O method and compared to existing firefly algorithm method. From the results obtained, the proposed method used can find the maximum power value of the solar module accurately four times faster than the regular firefly algorithm and the duty cyle are steady compared to the P&O method which has fluctuating duty cycle value results that can affect the switching component.

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