

## Design intelligent maximum power point tracking for photovoltaic at Universitas Airlangga

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### ABSTRACT

Rooftop photovoltaic (PV) plant is one of the independent electricity that is favorable in recent years. Rooftop PV plant can be used as the source of smart building as well as fast charging station. Although rooftop PV plant could provide clean and sustainable energy from solar, they also come with disadvantages in terms of intermittent power output. This intermittent power output is due to the uncertainty of the source. To tackle this problem, maximum power point tracking method is essential. Maximum power point tracking (MPPT) method can be used to extract maximum power from the solar cell in all conditions. This paper proposes an intelligent method for designing DC-DC MPPT based on fruit fly optimization (FFO) on realistic rooftop PV plant. Practical rooftop PV plant in Universitas Airlangga is employed as the testing system. The proposed method's efficacy is evaluated using time domain simulation. According to the simulation results, the proposed method can significantly extract power from PV.

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## 1. INTRODUCTION

Integration of renewable based power plant has increased significantly over the years due to the development of power electronic devices [1]. Renewable based power plants such as wind power plant and photovoltaic (PV) power plant are already integrated to the existing grid [2]–[4]. Countries such as the United States, Australia, Europe, China, and Japan have integrated renewable energy plants into their power grids [5]. Among numerous types of renewable power plants, PV generations are becoming more popular due to the rapid development of semiconductor materials [6]. PV generation could provide the grid with clean and sustainable energy. They do, however, have drawbacks in terms of uncertain power output as well as low inertia characteristics [7], [8]. Furthermore, to generate large amount of electricity, PV power plants need a large amount of space. Hence, it is hard to develop PV generation in a small area or in densely populated area. However, this problem can be handled by installing PV generations in the rooftop of the building itself. This method is usually called as rooftop PV generation [9].

Rooftop PV generation is widely used in developed countries such as Australia, US, Europe, and Canada [9]. A developing country such as Indonesia is currently adopting a similar approach by installing rooftop PV generation. Although rooftop PV generation could handle the problem of small area and densely

populated area, the handicap of PV generation is still there. To tackle this problem, a method for extracting maximum power from PV generation is essential. This method is generally known as maximum power point tracking (MPPT) [10]. This paper presented a method for optimally design a MPPT of rooftop PV generation at Universitas Airlangga. An intelligent method based of fruitfly algorithm is used in this paper.

The remainder of the paper is structured as follows: section 2 introduces the basic theory of PV, MPPT, and Proportional and Integral (PI) controllers. Furthermore, system identification, fruitfly algorithm and how to design MPPT based fruitfly algorithm are also illustrated in section 2. Simulation results are described in section 3. Section 4 highlights the contribution and conclusions of the paper.

**2. RESEARCH METHOD**

**2.1. Maximum power point tracking**

Maximum power point tracking, abbreviated as MPPT, is a method used in PV systems to ensure that the PV system produces the maximum amount of power. MPPT is not a mechanical tracking system that changes the position of the PV module to face the sun so that it receives the most energy from the sun. MPPT is an electronic system that contains an algorithm for tracking the maximum power points that a PV can produce. The I-V and P-V characteristic curves show that the work of a PV is not linear, but rather varies dynamically in response to changes in the value of sunlight intensity on the PV surface and the temperature on the PV surface [11]. Figure 1 shows the I-V and P-V curve for maximum power point.

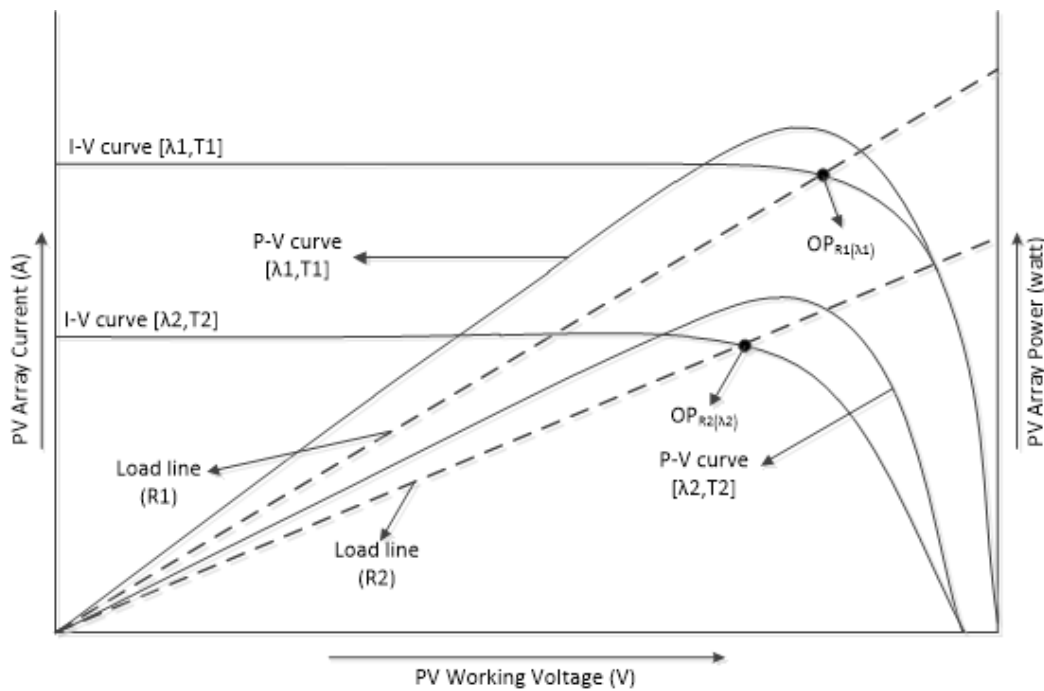


Figure 1. I-V and P-V curve

In Figure 1 there are 2 maximum working points (MPP), namely *OPR1* and *OPR2*. The operating point of *OPR1* is the value of MPP at irradiation condition ( $\lambda_1$ ) and temperature ( $T_1$ ) for load ( $R_1$ ). Furthermore, *OPR2* is the value of MPP in irradiation condition ( $\lambda_2$ ) and temperature ( $T_2$ ) for load ( $R_2$ ). Moreover, If the irradiation changes from  $\lambda_1$  to  $\lambda_2$  and the temperature changes from  $T_1$  to  $T_2$  then the I-V and P-V curves shift from curves ( $\lambda_1, T_1$ ) to curves ( $\lambda_2, T_2$ ). To achieve the MPP condition, the load must change from  $R_1$  to  $R_2$  so that the system works in MPP conditions [12].

**2.2. Dynamic Model of DC-DC Converter**

The DC/DC boost converter increases the output voltage from a certain input voltage level by controlling the “ON” and “OFF” duration of the power switch. The duty cycle  $d$  denotes the interval when the switch is “ON” and  $d'=1-d$  is the interval for which it is “OFF”. The averaged state space equation of

DC/DC boost converter over one period is obtained by combining the dynamic equations during “on” and “off” states. The complete state equation of DC/DC boost converter as given in (1) [13].

$$\dot{x} = \{A_1 d + A_2(1-d)\}x + \{B_1 d + B_2(1-d)\}u$$

$$\begin{bmatrix} \dot{i}_b \\ \dot{i}_s \\ \dot{v}_b \end{bmatrix} = \begin{bmatrix} -\frac{(1-d)(R_{Lb}+R_{Cb})}{L_b} & \frac{(1-d)R_{Cb}}{L_b} & -\frac{(1-d)}{L_b} \\ \frac{(1-d)R_{Cb}}{L_s} & -\frac{(1-2d)R_{Cb}}{L_s} & \frac{1}{L_s} \\ \frac{(1-d)}{C_b} & -\frac{1}{C_b} & 0 \end{bmatrix} \begin{bmatrix} i_b \\ i_s \\ v_b \end{bmatrix} + \begin{bmatrix} \frac{1}{L_b} \\ 0 \\ 0 \end{bmatrix} v_g \quad (1)$$

Where state variables of DC/DC converter are consisting of input current ( $i_b$ ), output current ( $i_s$ ) and output DC/DC voltage which is similar to capacitor voltage ( $v_b$ ).  $R_{Lb}$  and  $R_{Cb}$  represent internal resistance of inductor ( $L_b$ ) and capacitor ( $C_b$ ) of boost converter. Input variable of the DC/DC converter is represented by  $v_g$ . While, an additional interface inductor ( $L_s$ ) is considered to provide connection between DC/DC converter with other power electronic devices such as DC/AC inverter in the proposed two-stage PV system [14].

### 2.3. PI controller

PI controller is a controller to determine the precision of a control system with the characteristics of feedback on the system. The PI controller consists of two control procedures. These procedures are proportional (P) and Integral (I) [15]. Proportional controller works as a gain of the signal error. The application of proportional controller has various limitations due to the non-dynamic nature of the controller. However, in simple basic applications, the proportional controller can improve the transient response, Especially the rise and settle times. The output of a proportional controller is proportional to the magnitude of the error signal.

The purpose of integral controller is to create a system with a zero steady-state error. If a controller does not have an integrator element, the proportional controller cannot guarantee to have a system output with a zero steady state error. When the steady state error value approaches zero, the integral control effect is getting smaller. The integral controller can eliminate steady state error, but improper selection of integral controller parameter ( $K_i$ ) can cause system instability. Utilizing a very high  $K_i$  value can cause the output to oscillate as it increases the order of the system [16]. The integral controller output is a continuous sum of input fluctuations. When the error signal does not change, the integral controller maintains the output state as it was before the change in the input data [17].

### 2.4. Fruit Fly Optimization

Fruit fly optimization (FFO) is an optimization method inspired by the behavior of a fruit fly. Pan first proposed this algorithm in 2011 [18]. Fruit flies outperform other species in terms of olfaction and vision. Fruit flies can detect food from 40 kilometers away [19]. According to the smell, the fruit fly moves toward the food. They could also use their vision to get to their food [20].

FFO has two critical steps: the smell step and the vision step. During the smell phase, the fruit flies use their smelling ability to move toward the food. The vision phase begins when they are close to their food [21]. This second step is used to locate nearby food. This process will be repeated by the fruit flies until they find food. The FFO step can be described mathematically as follows [22].

- Initialization of parameters (number of particle, number of iteration).
- Initialization of the particle's initial position.
- Use smell sensing to update the location. (2) and (3) describe the mathematical representation of smell sensing (3).

$$X_i = X_{axis} + RandomValue \quad (2)$$

$$Y_i = Y_{axis} + RandomValue \quad (3)$$

- Determine the fly's distance from the origin as well as the smell concentration judge value (S). In (4) and (5) can be used to describe the mathematical representation of these procedures (5).

$$Dist_i = \sqrt{X_i^2 + Y_i^2} \quad (4)$$

$$S_i = 1/Dist_i \quad (5)$$

- e. Determine the value of smell concentration using (6).

$$Smell_i = Function(S_i) \quad (6)$$

- f. Identify the best fly by using (7).

$$bestSmell\ bestIndex = \max(Smell) \quad (7)$$

- g. Use (8), (9) and (10) to save the best concentrate value and the best location of fruit flies (10).

$$Smellbest = bestSmell \quad (8)$$

$$X_{axis} = X(bestIndex) \quad (9)$$

$$Y_{axis} = Y(bestIndex) \quad (10)$$

- h. Repeat steps c–f until the algorithm meets the specified criterion.

## 2.5. System Identification using MATLAB

In this paper, the rooftop PV generation is already installed in the Nanizar building at Universitas Airlangga as shown in Figure 2. Hence, it is not easy to simulate the power plant, as all of the parts were obtained directly from the manufacturer. The total generating capacity of this PV generation 1 kW. Hence in this research, system identification toolbox is used to capture the dynamic model of DC-DC converter of PV generation. For this study, the power output of solar cell in both mono and poly solar cell is used as the input. Furthermore, the output of this study is power output from solar charge controller for both solar cell type.



Figure 2. Nanizar building from google map

Then the input and output data are fed into the system identification toolbox. The next step is to choose the poles and zeros of the identified system. In this paper 2 zeros and 2 poles were used so that the dynamic model of the system can be captured in more detail. After the input and output, poles and zeros are determined, the toolbox will automatically identify the system model as well as the percentage similarity between the identified model and the real plant. As the PV generation consists of mono and poly solar cell, it is essential to Model both of them separately. From the results it is found that for poly the percentage similarity is 91%. While for mono the percentage similarity is 85%. Figures 3 and 4 depict the graphical User Interface (GUI) system identification in Matlab for poly and mono DC-DC converter.

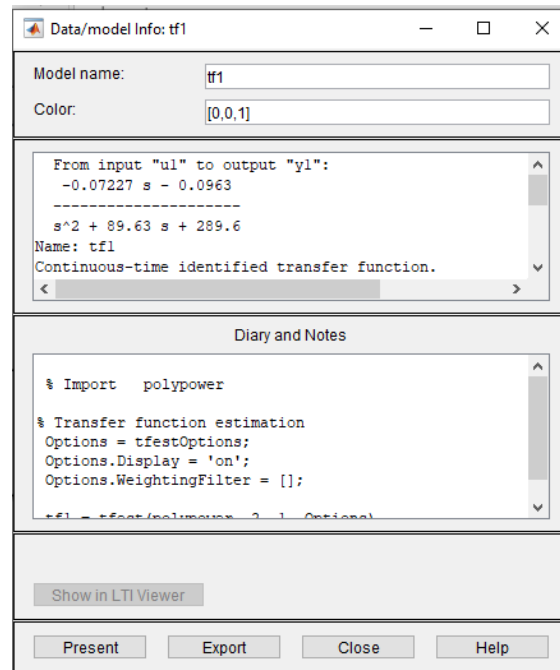


Figure 3. Poly solar cell DC-DC converter dynamic model

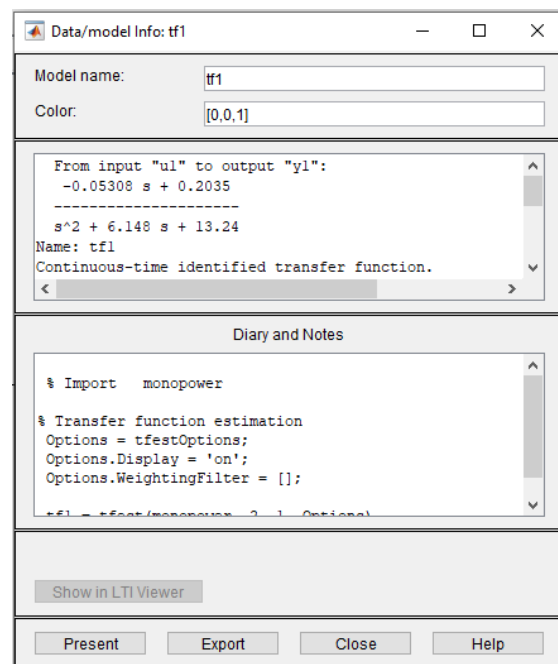


Figure 4. Mono solar cell DC-DC converter dynamic model

## 2.6. Tuning PI controller using FFO

This section focuses on the procedure of designing PI controller as MPPT controller based on FFO. The dynamic system is Model in simulink while the FFO is coded in MATLAB. Furthermore, the objective function of the FFO is to reduce the error of rooftop PV plant output. In (11) can be used to calculate the objective function of FFO [23]–[25].

$$E = \int_0^{time} t|e(t)|dt \quad (11)$$

The procedure of designing PI controller based of FFO for MPPT controller includes the following steps:

- Collect the input and output of Rooftop PV plant.
- Use the real input and output data from rooftop PV plant as the input and output of system identification toolbox.
- Do the system identification and used second order representation for the poles and zeros.
- Find the dynamic model of realistic rooftop PV plant and put the model into simulink (make sure the similarity percentage is more than 75% otherwise back to step 1).
- Add PI controller between the error detector output and system input.
- Begin the FFO by setting the number of fruit flies, iterations, and optimized parameters.
- As the initial position, generate a random position of fruit flies.
- Use smell sensing to update the location.
- Determine the fly's distance from the origin and the smell concentration.
- Determine the smell concentrate value.
- Using the objective function, find the best fly.
- Save the best concentration value and fruit fly location.
- Repeat steps 8 and 9 until the algorithm meets the criterion (can be iteration or minimum objective function).
- Print the results ( $K_p$  and  $K_i$  value).

### 3. RESULTS AND DISCUSSION

This paper considers the 1 kW practical rooftop PV plant in Nanizar building Campus C Universitas Airlangga to show the effectiveness of the proposed method. The test system consist of two types of solar cell: polycrystalline and monocrystalline as shown in Figures 5 and 6. The capacity of each solar cell type is 500 watt. Both solar cell types are connected with different DC-DC conveter. The DC-DC converter is modeled as a linear model as described in section 3.

To investigate the performance of the system, three case studies were considered. The first and second case study focus on comparing the proposed method with conventional method. Time domain simulation was used in these cases study. Finally, the system are tested using random input to simulated uncertainty of solar radiation. Table 1 illustrates the tuned PI controler for poly and mono solar cell.



Figure 5. 500 WP poly solar cell



Figure 6. 500 WP mono solar cell

Table 1. PI value for poly and mono solar cell

Index	Kp	Ki
Poly	690	2790.8
Mono	21	84

**3.1. Case study 1**

In this case, there are two input references. The initial value of the input is 500 watt step input, while the the final value of the input is 1,000 watt step input. The purpose of this assesment is to investigate how the controller reacts when the input is not constant. Figure. 7 shows the dynamic response of DC-DC for poly cell. Moreover, Figure. 8 illustrates the dynamic response of DC-DC for mono cell. Tables 2 and 3 show the detailed features of Figures. 7 and 8.

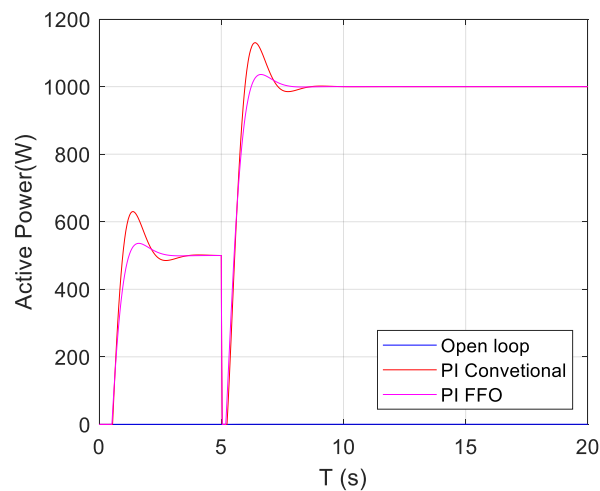


Figure 7. DC-DC converter output of poly solar cell for two reference input

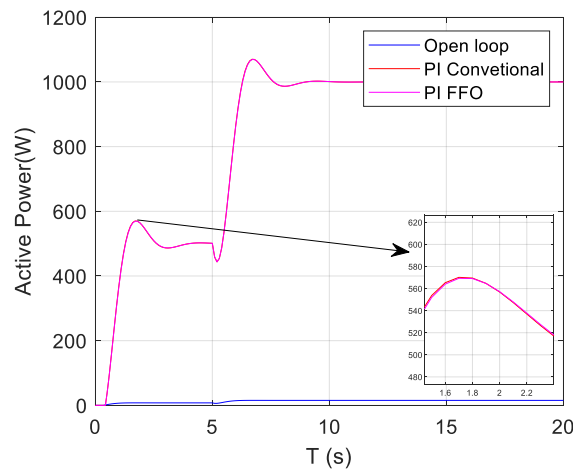


Figure 8. DC-DC converter output of mono solar cell for two reference input

Table 2. Detailed features of Figure 7

Index	Overshoot (watt)	Settling time (second)	Final value (watt)
Open loop	3.525	3	2.8
Conventional	630.2	7	500
Intelligent based	536	6.1	500

Table 3. Detailed features of Figure 8

Index	Overshoot (watt)	Settling time (second)	Final value (watt)
Open loop	1.2281	8	0.333
Conventional	570	7	1,000
Intelligent based	569	6	1,000

Similar with the first case study, the best response is provided by DC-DC with the proposed method. Hence, it can be stated that the proposed controller could handle the variation of the input signal (variation of power output from solar cell). In addition the proposed controller manage to find the steady state value similar with the reference input. Hence it can be stated that the system have zero error steady state.

**3.2. Case study 2**

In the second case study, the uncertainty analysis of the power output from solar cell is conducted. The uncertainty power output from solar cell is presented by random input to the DC to DC converter. The random input are random signal input from the Simulink library. Figures 9 and 10 illustrate the dynamic response of DC-DC power output from mono and poly solar cells.

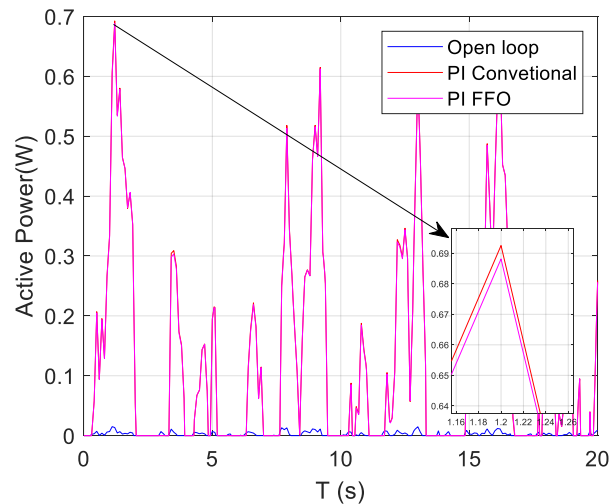


Figure 9. Active power response of DC converter for mono solar cell

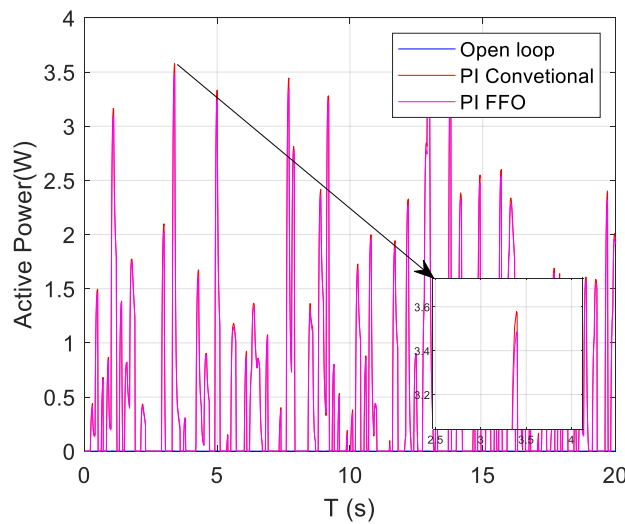


Figure 10. Active power response of DC converter for poly solar cell

It is observed that the proposed controller could provide better performance compared to the conventional controller indicated by the small fluctuation of the response. It is happened because the proposed controller can provide optimal control signal to the DC-DC converter. This optimal signal can make DC-DC converter track the MPP of the PV. Hence, it can be stated that the proposed method could handle the uncertainty of the sources.



#### 4. CONCLUSION

This paper proposes an intelligent design of MPPT for practical rooftop PV generations using FFO. The system plan is DC-DC converter of PV generations. The dynamic model of DC-DC converter is constructed using a system identification toolbox in matlab. PI controller is used as the MPPT controller. From the simulation results it is noticed that designing a PI controller using FFO could enhance the performance of the DC-DC converter for producing an active power. It is indicated by the less overshoot and fastest settling time compared to the conventional PI controller. It is also found that, by using PI controller, the DC-DC converter can extract the maximum power from the solar cell. Further research need to conducted by identifying the dynamic representation of PV generations (from irradiance to AC load power) to conduct full study of designing PV generation controller.

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