# ANFIS Based MPPT Design for Rooftop Solar Panels Connected to Single Phase Power Grid

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**Abstract.** The Indonesian government targets Indonesia to have zero emission energy by 2050. Solar energy is one solution to this target. The issuance of the Minister of Energy and Mineral Resources Regulation Number 26 of 2021 concerning Rooftop Solar Power Plants opens up opportunities for increasing the capacity of the energy mix from solar energy. However, solar power plants have weaknesses such as low efficiency of solar modules and non-linear power output of the module. This study proposes ANFIS MPPT design as a reference to obtain the maximum power that can be given to a rooftop solar panel system connected to a single-phase grid. The network voltage level is 220 V rms. This study uses 800-pairs dataset for input and output. The inputs of the ANFIS MPPT are radiation and temperature, and the output is reference voltage. The results by using Simulink simulation show that changes in irradiation are followed by changing in the power output of rooftop solar panels. For a load of 5 + j2 kVA, at high irradiation the rooftop solar panels provide greater current to load than at low irradiation. The current from the grid flows to the load based on difference between the load current and current from the rooftop solar panels.

**Keywords:** rooftop solar panels · ANFIS · MPPT · GRID · single phase

## 1 Introduction

Solar energy is clean energy. Solar energy is one of the renewable energy sources for electricity generation. The Indonesian government is targeting a zero-emission energy system by 2050. The contribution of solar power generation will experience a massive increase from only 0.05% in 2020 to 24% in 2030 [1]. This government target is supported by the abundant solar energy sources in Indonesia. Based on Indonesia Energy Outlook 2019, the potential for solar energy in Indonesia is 207.8 GWp [2]. West Nusa Tenggara (NTB) has an area of 19769.00 km2. Based on regional statistics of solar resources and PVOUT calculated from the long-term average based on the period 1994/1999/2007 to 2018, the specific photovoltaic power output is in the range of 3.09–4.78 kWp. Direct normal irradiation potential is between 2.32–5.49 kWh/m2, with PV module installation slope between 9–14 degrees [3]. This condition brings hope for the use of rooftop solar panels as solar power plants to support the Indonesian government's target. This


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government policy is also supported by the Minister of Energy and Mineral Resources No. 26 of 2021 concerning Rooftop Solar Power Plants. In accordance with chapter 5 paragraph 1, it is stated that “The capacity of the rooftop PV mini-grid system is limited to a maximum of 100% (one hundred percent) of the connected power of PT. PLN (Persero) [4].

Solar power plants are connected to the electric power grid require quite complex equipment such as: Solar modules, inverters, AC breaker panels, and import-export kWh meters [5]. This causes the investment costs for solar power plants to be quite expensive. In addition, solar modules as the main component for converting solar energy into electrical energy have non-linear characteristics and low efficiency between 12–18% [6]. The nonlinearity of the solar module causes the module output power to vary depending on the load is being served. To get the maximum power output, the module voltage must be controlled by tracing the voltage at the maximum power point. This tracing method is known as Maximum Power Point Tracking (MPPT).

The development of soft computing brings considerable and important changes in equipment control to achieve certain goals. Soft computing applied to the MPPT technique includes: Fuzzy logic control MPPT, artificial neural network (ANN) technique, adaptive neuro-fuzzy inference system (ANFIS) technique, and differential evolution and genetic algorithm [7]. The ANFIS technique can be a solution to obtain membership functions and fuzzy rules from the MPPT fuzzy logic control method. Because the ANN technique is able to reduce the fuzzy rule errors in ANFIS compared by trial-and-error method. Moreover, the ANFIS parameters are optimized automatically. The ANFIS technique has provided many solutions for improving MPPT control performance on stand-alone PV systems [8–12]. In addition to MPPT control, the ANFIS technique is also very robust for power system stability control [13–17]. In grid-connected PV systems, the ANFIS MPPT design involves a DC-DC converter such as a buck converter [18], and boost converter [19].

This research is an ANFIS MPPT design on a PV system that is connected to the grid via an inverter in the form of Simulink simulation. The output of the PV system is directly connected to the inverter and the inverter is controlled by the inverter control based on, first: the difference between the reference voltage (ANFIS MPPT output) and the PV voltage, and secondly: the grid voltage. The PV system under study is rooftop solar panels.

## 2 Data and Method

The ANFIS-based MPPT design steps for rooftop solar panels include: Creating training data for ANFIS, then training ANFIS using the data, testing ANFIS for various irradiation and temperature variations, and finally applying ANFIS MPPT to a rooftop panel system connected to the electricity grid.

### 2.1 Dataset for ANFIS Training

The dataset was obtained from a solar panel model simulation using Simulink version 8.5 (R2015a). The solar panel is modeled using a PV array with a capacity of 3500 W.

**Table 1.** Specification of Trisna Solar TSM-250PA05.08 [20].

| Module data | Example |
|---|---|
| Maximum Power (W) | 249.86 |
| Cell per module (Ncell) | 60 |
| Open circuit voltage $V_{oc}$(V) | 37.6 |
| Short-circuit current $I_{sc}$ (A) | 8.55 |
| Voltage at maximum power point $V_{mp}$ (V) | 31 |
| Current at maximum power point $I_{mp}$ (A) | 8.06 |
| Temperature coefficient of $V_{oc}$ (%/deg.C) | −0.35 |
| Temperature coefficient of $I_{sc}$ (%/deg.C) | 0.06 |

The solar module in this research is Trina Solar TSM-250PA05.08 with dimensions of width: 99.20 cm, height: 165.00 cm and weight: 18.60 KGS. The module specifications are in Table 1.

The solar panel consists of 14 solar modules connected in series to produce 3500 Wp of power. The dataset for training is 2 input data, namely solar irradiation and temperature, 1 output data, namely voltage at the maximum power point. To get the voltage ($V_{mp}$) at the maximum power point, the solar panel is loaded with a variable load value. The number of datasets for training is 800 data with data ranges for irradiation and temperature are 10–1000 W/m2 and 25–95 °C, respectively.

### 2.2 ANFIS Structure for MPPT

This research uses ANFIS based on Takagi-Sugeno Fuzzy Inference System (FIS). The solar irradiation and temperature inputs consist of 7 gaussmf type membership functions each, and 1 linear output for $V_{mp}$. ANFIS structure is shown in Fig. 1(a).

The results of the solar panel ANFIS training are shown in Figs. 1(c) and 1(d) for the irradiation and temperature irradiation membership functions, respectively. Figure 1(b) is control surface for input-output an ANFIS based MPPT to obtain voltage at the maximum power point ($V_{mp}$).

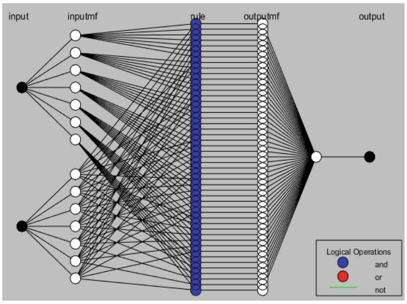
### 2.3 Testing the Output of MPPT Based on ANFIS

The results of the ANFIS-based MPPT training were tested with various inputs of irradiation and temperature. The ANFIS MPPT output ($V_{ref}$) is compared with the voltage ($V_{mp}$) at the maximum power point to get the quality of ANFIS MPPT training.

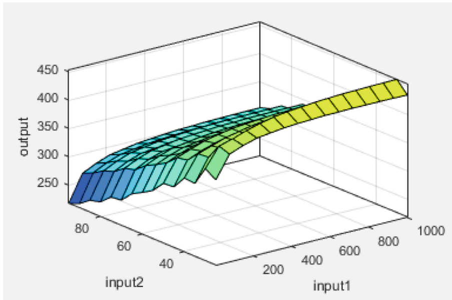
### 2.4 ANFIS MPPT for Grid Connected Rooftop Solar Panels

MPPT ANFIS is applied to a grid-connected rooftop solar panel in a single-phase electrical system. Single line diagram of the system is shown in Fig. 2.

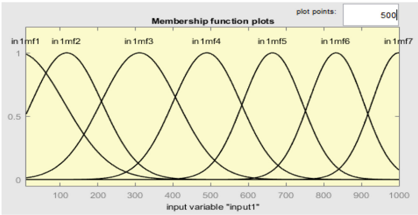
The inverter is a component for converting DC voltage from rooftop solar panels to AC voltage. The inverter is controlled by the inverter control. The inverter control gets



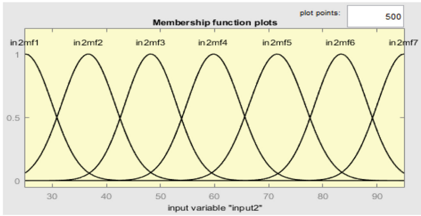

a. MPPT structure.




b. Control surface.




c. Irradiation membership function.




d. Temperature membership function.

**Fig. 1.** MPPT based on ANFIS.

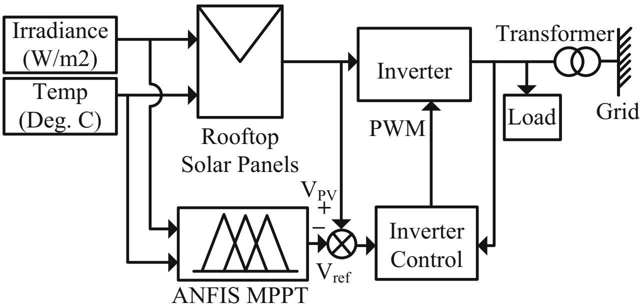



**Fig. 2.** Grid-connected rooftop solar panels single line diagram.

two inputs, first: The difference between the voltage ($V_{ref}$) and the solar panel voltage ($VPV$), the second input is the magnitude of the grid voltage. The electrical load in the study was 5 + j 2 kVA. The transformer capacity is a 100 kVA transformer, rated voltage (220/380) V/20 kV.

The formula for calculating the current in the load can be written as follows:

$$I = \left(\frac{S}{V}\right)^{*} \tag{1}$$

where S and V are complex power and voltage, respectively.

$$I_{rms} = |I| \tag{2}$$

The current flowing to the load is the current from the rooftop solar panels and the grid, it can be written:

$$I_{load} = I_{RSP} + I_{Grid} \tag{3}$$

where $I_{RSP}$ and $I_{Grid}$ are the currents from the rooftop solar panels and from the grid, respectively.

## 3 Result and Discussion

The dataset was obtained from the Simulink simulation using the circuit shown in Fig. 3. The result of running Simulink was a variation of voltage, current, and power at a given load. The simulation results were plotted to produce a graph of the relationship between the output power and the solar panel voltage. Figure 4 was the result of the plot of power against voltage for 1000 W/m$^2$ irradiation and temperature on 25 °C.

The maximum power under these conditions was 3497.03 Watts and the voltage ($V_{mp}$) at the maximum power point was 434.6 V. The comparison results of the ANFIS MPPT output ($V_{ref}$) to the voltage ($V_{mp}$) at the maximum power point for several variations of irradiation at 25 °C are shown in Table 2.

Table 2 shows that the difference in output reference voltage ($V_{ref}$) of ANFIS MPPT to $V_{mp}$ is quite small, the maximum error is at 100 W/m$^2$ irradiations and the minimum is at 500 W/m$^2$ with an average of 0.09%.

Simulink simulations were carried out for ANFIS MPPT on rooftop solar panels connected to a single-phase electricity grid. In this simulation, solar panels are assumed in various irradiations. The irradiation is also assumed increased and decreased gradually in the form of a ramp at a constant temperature (25 °C). The Irradiation is taken on 250, 750, 500 and drops to 0 W/m$^2$ within 1.2 s. The irradiation changes with a slope of ± 8000. The graph of the change in irradiation is shown in Fig. 5.

The output power response of the rooftop solar panel and the reference voltage ($V_{ref}$) of the ANFIS MPPT are shown in Figs. 6(a) and 6(b), respectively. Figure 6(b) shows

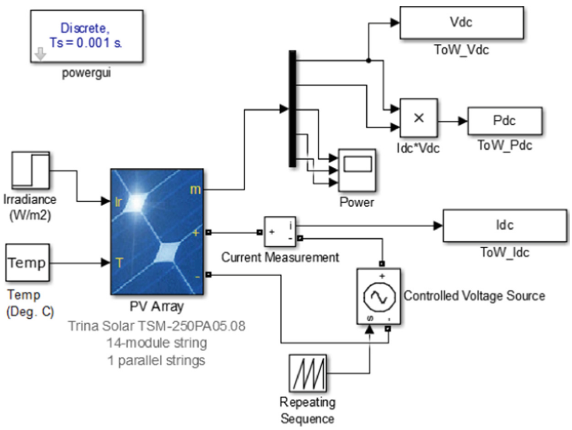



**Fig. 3.** Rooftop solar panel simulation for dataset.

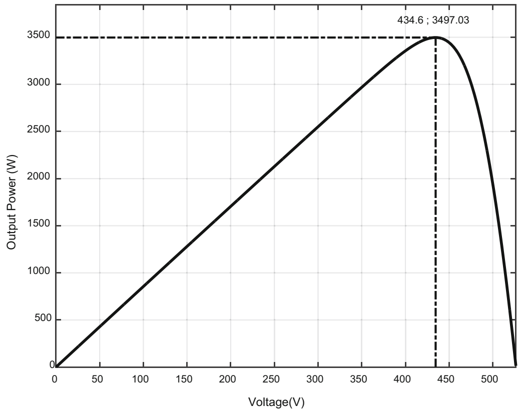



**Fig. 4.** Rooftop Solar Panels Characteristic 3500 W.

**Table 2.** Vref vs $V_{mp}$ at the maximum power point.

| Irradiance (W/m2) | $V_{mp}$ (V) | $V_{ref}$ (V) | Error (%) |
|---|---|---|---|
| **100** | **410.02** | **411** | **0.24** |
| 200 | 421.40 | 422 | 0.14 |
| 300 | 427.24 | 427 | 0.06 |
| 400 | 430.76 | 431 | 0.06 |
| **500** | **432.96** | **433** | **0.01** |
| 600 | 433.84 | 434 | 0.04 |
| 700 | 434.72 | 435 | 0.06 |
| 800 | 434.692 | 435 | 0.07 |
| 900 | 434.69 | 435 | 0.07 |
| 1000 | 434.60 | 434 | 0.14 |
| | | Min. | 0.01 |
| | | Max. | 0.24 |
| | | Avg. | **0.09** |

the fluctuation of the reference voltage ($V_{ref}$) to produce the maximum output power of a tap solar panel based on irradiation. Figure 6(a) shows the output power of the rooftop solar panels following the change in irradiation. The higher the irradiation, the greater the power output of the rooftop solar panels, and vice versa.

Figure 7(a) is the grid voltage (AC) generated by the inverter. The nominal grid voltage is 220 V rms. Under load conditions, the grid voltage is less than the nominal voltage of 220 V rms and fluctuates due to changes in irradiation. Voltage drop on the grid is not less than 10% of the nominal voltage. The lowest grid voltage from the simulation results is 219.25 V rms. Figure 7(b) is the current absorbed by the load. The load current can be calculated from the load power of 5 + j2 kVA divided by the grid

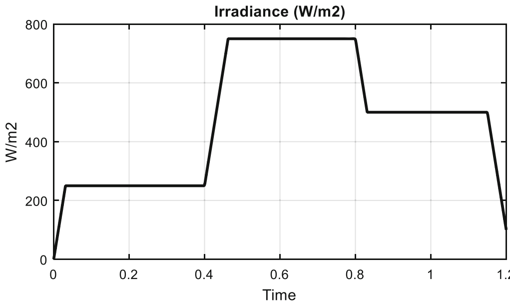
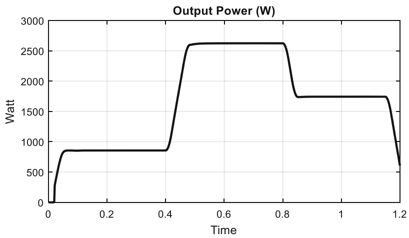
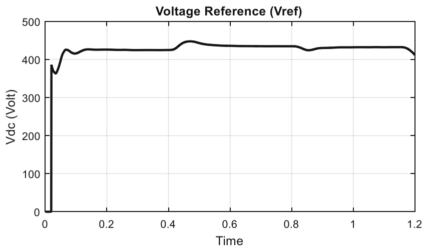



**Fig. 5.** Irradiation change (W/m$^2$).

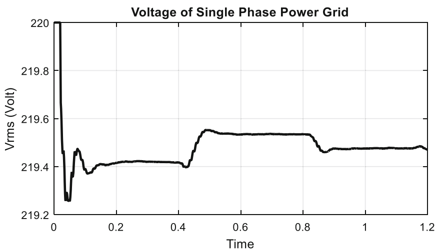



a. Rooftop solar panel output power.

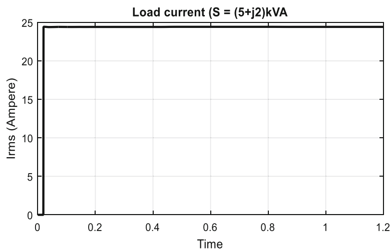



b. Output reference voltage.

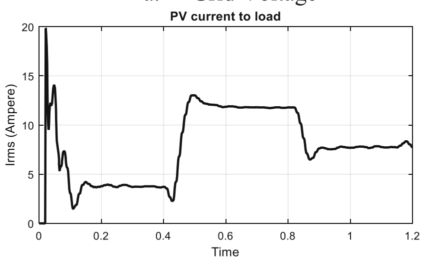
**Fig. 6.** Rooftop solar panel output power response due to $V_{ref}$ at certain irradiation.



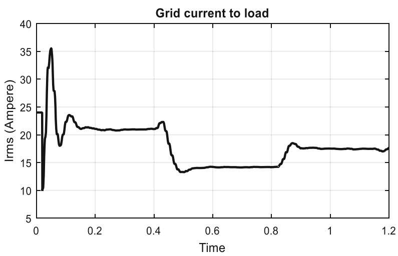

a. Grid Voltage




b. Load current




c. Current delivered by rooftop solar panels to the load




d. Current supplied by grid to the load

**Fig. 7.** Power grid side.

voltage. Equations (1) and (2) are used to calculate the current in the load as follows:

$$I = \left( \frac{(5 + j2)10^3}{220} \right)^* = (22.7273 - j9.0909)\,A$$

$$I_{rms} = |22.7273 - j9.0909| = 24.4780\,A$$

This result is in accordance with the load current value shown in Fig. 7(b). The simulation results show that the current at the load is supplied from 2 sides, from the solar panels rooftop and the grid, as shown in Figs. 7 (c) and (d), respectively. The sum of the load currents is equal to the current from the rooftop solar panels plus the current from the grid, the condition is in accordance with Eq. (3). At low irradiation, rooftop solar panels provide a lower current than at high irradiation. The current shortage for the load is supplied from the grid.

## 4 Conclusion

ANFIS MPPT is trained using the characteristics of rooftop solar panels to obtain a reference voltage (voltage at the maximum power point). The difference between the reference voltage and the solar panel rooftop voltage at a certain irradiation is used as a control inverter. Rooftop Solar Panels can provide maximum power to the load according to the received irradiation. A load current of 24.4780 A rms is supplied with fluctuating quantities from two sides (rooftop solar panels and grid) depending on the irradiation received by the rooftop solar panels.

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