Smart MPPT control method to maximize the power generated from PV systems diagnosed by ANFIS

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Abstract
The fluctuation of the environment in the PV system area directly penetrate to the converter that use to control the voltage and current of the PV system cause converter should have the high-efficiency control method. MPPT is one of the most popular methods used to control the inverter for providing energy to load and battery effectively. Therefore, this article proposed the methods to reduce power loss from the impact of converter penetration using the ANFIS model. ANFIS model was used to analyze any factor that affects MPP tracking (MPPT) and select the appropriate control signal to control MPPT. For validating the results, the proposed method was compared with the traditional converter control method. The simulation results showed that the proposed method could significantly reduce the power loss of the PV system more than the conventional method.

Keywords: *MPP tracking, ANFIS, PV systems, inverter*

1 Introduction
Photovoltaic (PV) system installations in the world are increasingly interesting to a high rate due to increased utility electric costs and incentives offered by governments. In 2018, the installed capacity of PV systems for electricity generation reached approximately 512 [1]. For grid-connected PV systems, two power conversion methods can be used: (1) two-stage conversion and (2) single-stage conversion systems. Two-stage conversion system includes a DC/DC converter that the MPPT algorithm is applied to this converter and DC/AC conversion is made by an inverter. To improve the efficiency as well as cost reduction of the system, the DC/DC converter can be removed and use only the inverter in the system. As a result, either MPPT or DC/AC conversion is made by the inverter. Usually, the efficiency of the single-stage conversion system is about 4-10% more than two-stage conversion [2].

Applying the MPPT algorithm into the inverter may complicate the control methods because both MPPT and grid current controllers in the inverter is designed to work together appropriately. However, the use of this structure attracts more attention because advancement in power electronics and microcontrollers increasingly [3-6]. Normally, PV systems track the MPP (MPP) of the PV systems to generate maximum available solar energy. However, PV systems may also have to follow commands to control the amount of real power output certainly or to maintain frequency in a range of regulation. In order to work in quite dynamic system conditions, PV systems need to perfectly switch between fixed real power control mode and MPP Tracking (MPPT) mode. The two factors that determine the performance of the MPPT controller are the control period of the MPPT controller and the magnitude of the perturbation voltage. In other words, The MPPT perturbation voltage that is set for large makes the MPP able to be reached rapidly when the irradiation and temperature changes. But, in the steady-state where the irradiation and temperature do not change, the controller of PV array unnecessary to oscillates greatly around the MPP. On the other hand, if the perturbation voltage is set to a small value, the output power of the PV module will oscillate at a small value near the MPP in the steady-state where the insolation does not change, and the power generation amount can be maintained stably. However, if the insolation frequently changes like cloudy days with lots of clouds, the MPP cannot be followed up in advance, and it causes a large loss in power generation [7][8]. On the other hand, the MPPT control period which is set for short, makes the dynamics of the MPPT controller be accelerated even though the perturbation voltage is set to a small value. But too short, the MPPT control period does not contribute to the improvement of the MPPT performance and only consumes the MPPT facility cost or the controller time resources.

Accordingly, this paper proposes a high-performance control strategy OF MPPT to work together with the current injection to the grid in the single-stage PV systems. For MPPT, the Adaptive Neuro-Fuzzy Inference System algorithm was used to track the MPP. This algorithm used the relation between irradiance temperature current and voltage to maximize the speed of dynamic response of the MPPT algorithm. Also, an improved direct power control (DPC) method is used to control the injected active and reactive power to the grid. To validate the results of the proposed method, the proposed method was compared with MPPT conventional method that is perturb & observe. All of the simulations was done in MATLAB/Simulink program.

2 System Configuration

The configuration of the proposed system is shown in Figure 1. A single-stage system is proposed for a grid-connected photovoltaic system. The PV system under discussion that adopts the single-stage single-phase grid-connected inverter structure consists of PV array, inverter, and transformer. In the PV grid-connected control, the algorithm of tracking the maximum power point is adopted to improve the utilization efficiency of PV cells, and proper inverter control strategy is selected to raise the power quality of the AC side grid connection.

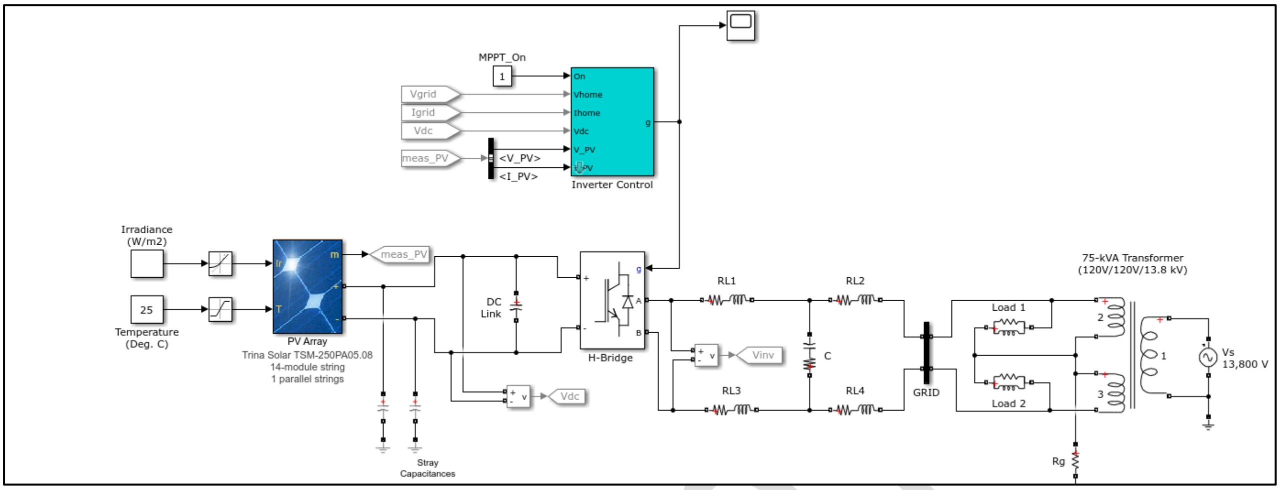

Figure 1. System Configuration of grid-connected photovoltaic single-stage system system

2.1 PV Array

PV array characteristics and its mathematic model will be described in this section. A PV array is composed of PV cells connected in series and in parallel to achieve the desired DC power and DC voltage input for an inverter system. The DC power of PV array vs. voltage characteristics at different solar irradiation levels and temperatures are shown in Figure 2 and 3, respectively.

Three characteristic operation points for the PV system:open circuit, MPP and short circuit are shown in Figure 1. I_{sc} is the short circuit current; V_{oc} is the open-circuit voltage; V_{MPP} and I_{MPP} are voltage and current at the MPP, respectively. The corresponding mathematical equation is given in Eq. (1) [9][10].

$$I = I_{sc} - I_0\left[exp\left(\frac{q(V+IR_S)}{N_s kTa}\right) - 1\right] - \frac{V+IR_S}{R_{sh}} \qquad (1)$$

Where I_{pv} and I_0 are the PV and the diode saturation currents, respectively. N_s is the number of cells connected in series for greater output voltage, k is the Boltzmann constant (1.3806503×10-23 J/K), T (Kelvin) is the temperature of the p-n junction of the diode, and q (1.60217646×10-19C) is the electron charge. R_s and R_{sh} are the equivalent series and shunt resistances of the array, respectively, and a is the diode constant factor, which is usually chosen to be in the range of $1 \le a \le 1.5$ [10]. the module under standard testing conditions of 1000 W/m^2 at 25 ◦C are given in Table I [11]

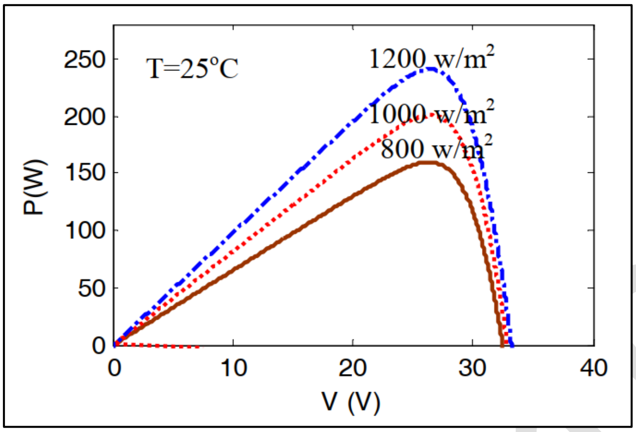

Figure 2. Voltage and power curve at temperature = 25 °C in different irradiance

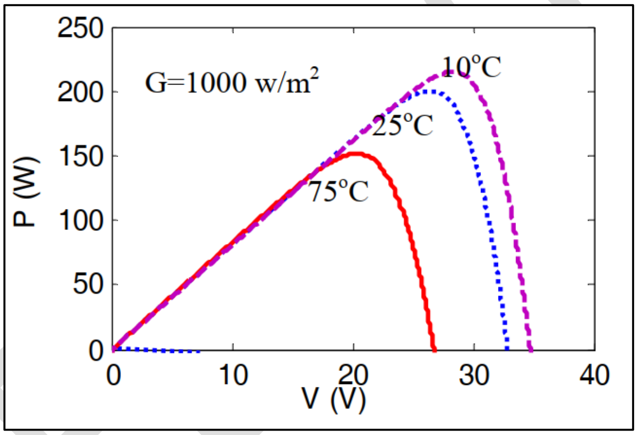

Figure 3. Voltage and power curve at irradiance = 1000 W/m² in different temperature

Table I PV module parameters [11]

Parameters	Values
Maximum power point (MPP)	115 W
Voltage at MPP (V_{MPP})	17.1 W
Current at MPP (I_{MPP})	6.7 A
Open circuit voltage (V_{OC})	21.8 V
Short circuit voltage (I_{SC})	7.5 A
Temperature efficiency of I_{sc}	0.065 %/°C

2.2 Inverter

The Universal Bridge block allows simulation of converters using both naturally commutated (or line-commutated) power electronic devices (diodes) and forced-commutated devices (IGBT). A number of bridge arms Set to 2 to get a single-phase converter. Snubber resistance (Rs) is Set to inf to eliminate the snubbers from the model. Snubber capacitance (Cs) is set to inf for getting a resistive snubber. Internal resistance (R_{in}) of the selected device is 10^{-3} Ω. Forward voltages (device V_f, diode V_{fd}) This parameter is available when the selected Power electronic device is IGBT/Diodes. Forward voltages, in volts (V), of the forced-commutated devices (IGBT) and of the antiparallel diodes. The default is zero. The gate input (g) for the controlled switch devices. The pulse ordering in the vector of the gate signals corresponds to the switch number indicated in the six circuits shown in the Description section. For the diode and thyristor bridges, the pulse ordering corresponds to the natural order of commutation. For all other forced-commutated switches, pulses are sent to upper and lower switches of phases A and B.

2.3 Inverter controller

To effectively ensure the stable grid-connected current and achieve single-phase balance, the control strategy of suppressing the negative sequence current may be adopted [12-13]. This control algorithm maintains the single-phase balance by regulating the AC side negative sequence current component to be zero and ensures the AC side only contains the positive sequence current component. The inverter control block diagram is shown in Figure4, in which the computational equation of d, q reference current values of current inner loop Considering the actual conditions, the inverter is connected into the power grid with the power factor, and now the reactive power is zero. Thus, in the program design, the power calculation may be removed, while the outer loop directly sets the positive sequence d axle current instruction value. After grid voltage sags, reactive compensation is realized through reactive positive sequence q axle current setting, i.e., the voltage outer loop may adopt the outer loop setting [14]. And the MPPT is the method to estimate V_{dc} for V_{dc} regulator to maximize the power of the PV array system.

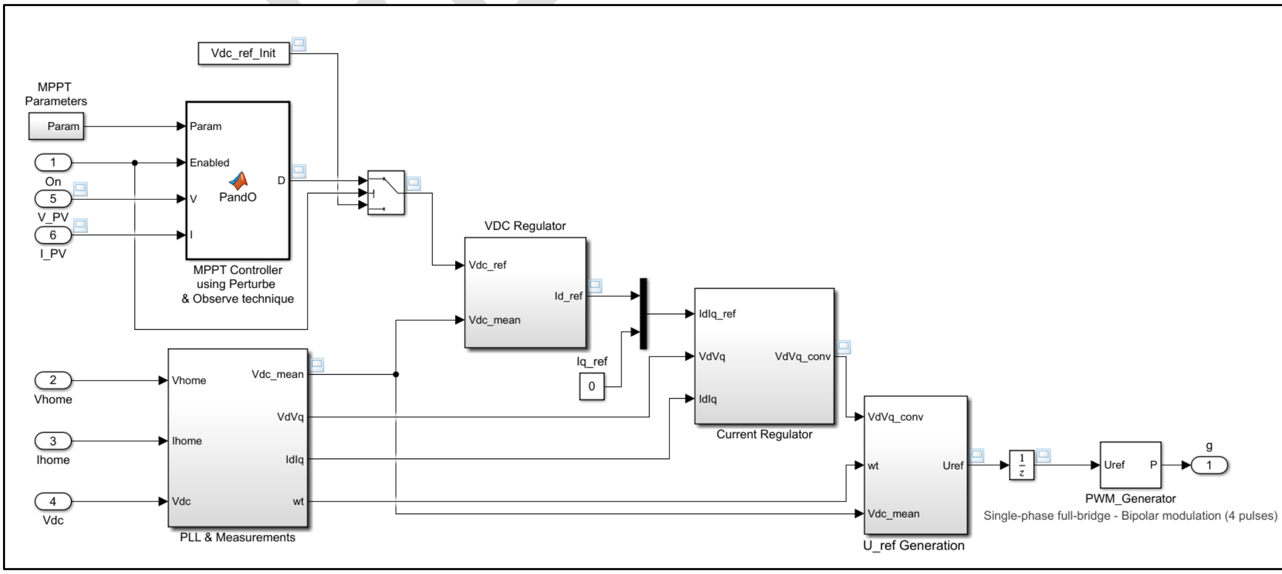

Figure 4. Inverter control diagram

3 MPPT Control Methods

The output PV power has a maximum dependent on the atmospheric conditions. To convert the energy available with the best performance, it is essential to work around an optimal operating point corresponding to the maximum power delivered by the PV array. In the paper, the Perturb and Observe the MPPT control method was simulated to validate the results with the proposed method that is the ANFIS MPPT control method.

3.1 Perturb and Observe

P&O or the hill-climbing method is the widely used technique to track MPP. It perturbs the operating point and observes the difference in power before and after perturbation. The power is calculated using current and voltage sensors. If a power difference is positive, the direction of perturbation remains the same; otherwise, it is reversed. Therefore, this algorithm always keeps tracking back and forth even after reaching the MPP, which results in power oscillations around MPP. As discussed, oscillations can be controlled by reducing the step size which will increase the time to track MPP. Figure 5 shows the basic idea of P&O MPPT. A time delay in perturbation is required to settle transients of the circuit [15].

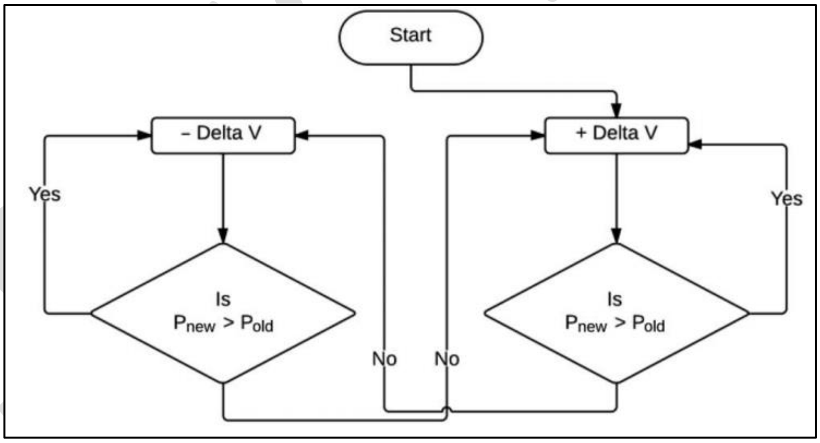

Figure 5. basic idea of P&O MPPT

3.2 ANFIS

ANFIS is an integration of the interpretability of the Fuzzy Inference System (FIS) with the adaptability of a neural network [16], makes the fuzzy system more systematic and less relying on expert systems [17]. Through the ANFIS approach, FIS not only take linguistic rules but also learn and train by numerical data through the neural network's learning algorithm [18].

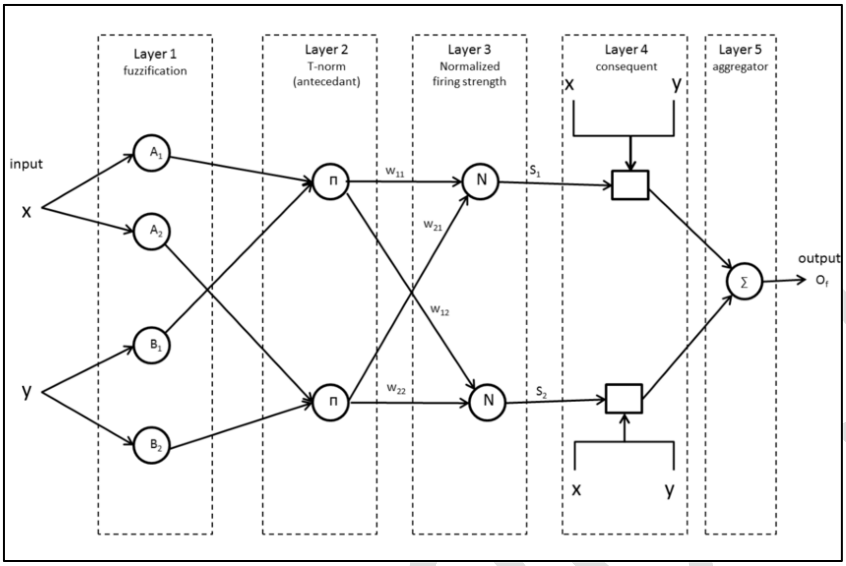

Figure 6. ANFIS model

ANFIS model can simulate and analyze the mapping relation between inputs and output data through a hybrid learning algorithm to determine the optimal distribution of membership functions [19]. Parameters of the equivalent FIS are optimized through a hybrid learning algorithm using input-output data sets. ANFIS's architecture, which considers two inputs and a single output, as shown in Figure 6, is based on fuzzy if-then rules of Takagi-Sugeno type [20-21].

In this paper, the ANFIS model was used to estimate dc voltage and send it to the V_{dc} regulator for tracking MPP of the PV array system. ANFIS model including 2 parts: input and output. Inputs of the ANFIS model include temperature irradiance and V_{dc}(previous). The output of the ANFIS model includes V_{dc}. After V_{dc} estimated that data would send to the V_{dc} regulator to regulate the DC voltage to track MPP following Figure 4.

4 Simulation and Results

In order to validate the proposed ANFIS MPPT, simulation is performed under dynamic weather conditions. The irradiance and P_{dc} from the PV array system that used to simulate are shown in Figure 6.

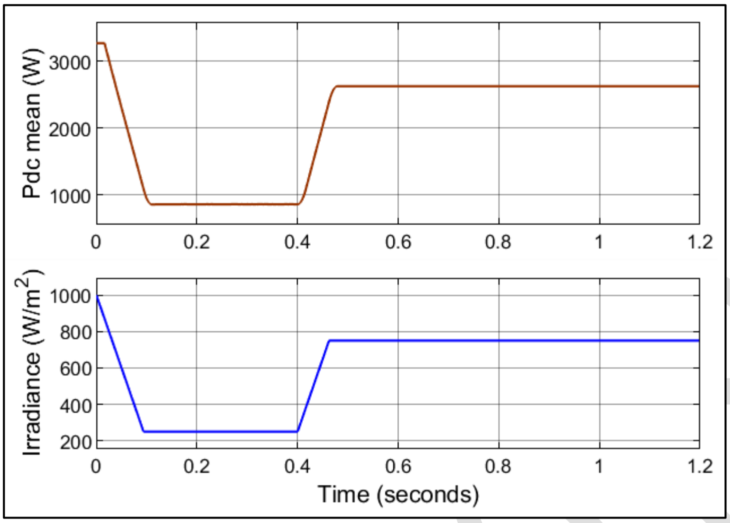

Figure 6. The base irradiance and P_{dc} from PV array system

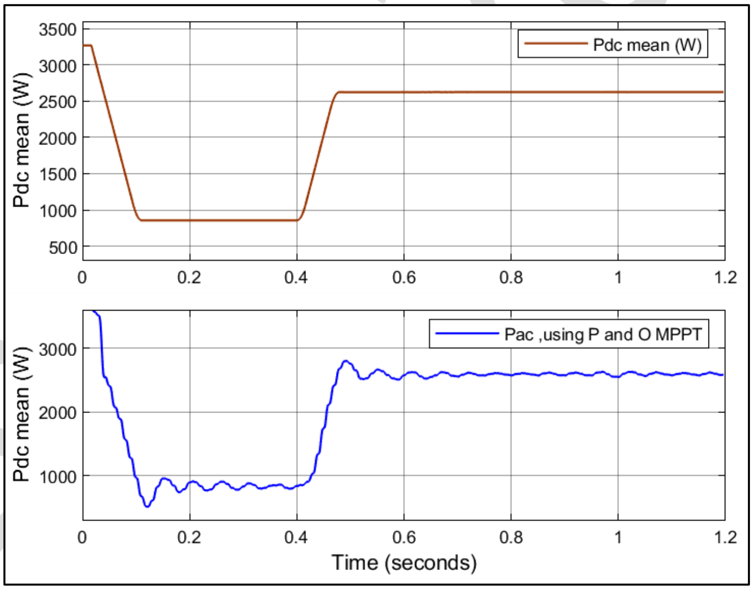

Figure 7. The P_{ac} that used to track MPP by P&O method and P_{dc} from PV array system

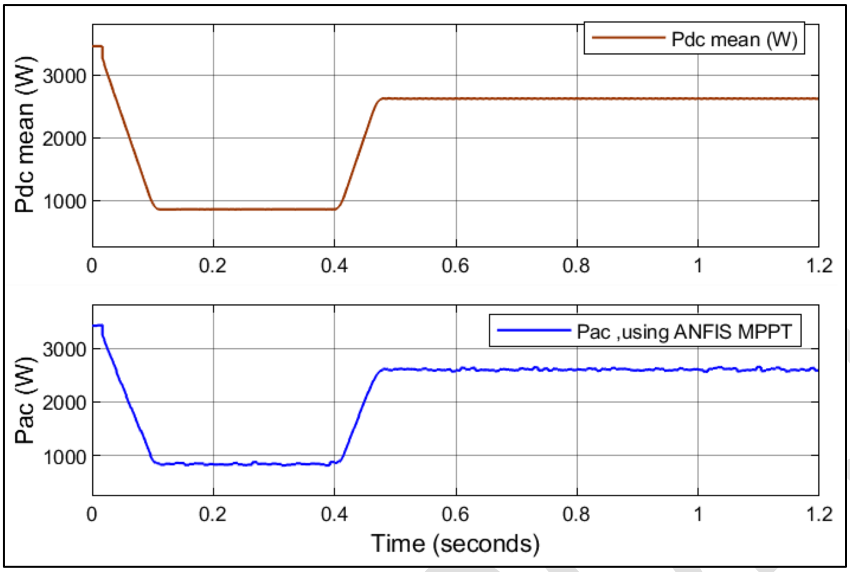

Figure 8. The P_{ac} that used to track MPP by ANFIS method and P_{dc} from PV array system

From the simulation results, Figure 7 shows that P&O MPPT can track, but the AC power has a little bit fluctuation because P&O can't effectively track V_{dc}. For the proposed method, the ANFIS model was used to track MPP to reduce power loss when power was changing to the grid. The simulation results in figure 8 show The AC power from the proposed method can track MPP more effectively than the conventional method that is P&O MPPT significantly because the ANFIS model can estimate the dc voltage by the relation between input and output better than P&O that increase or decrease the voltage in linear.

5. Conclusion

This paper has proposed a new method to track MPP. The proposed method used the ANFIS model to track MPP. For verifying the efficiency of the proposed method, the proposed method was compared with the conventional P&O MPPT technique in MATLAB/Simulink program. The simulation results showed the proposed method could track MPP more effectively than P&O MPPT technique because the ANFIS model in the proposed method can track the voltage more effectively than P&O, especially the high power fluctuated period.

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