Chapter 5

Fuzzy Controller-Based MPPT of PV Power System

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Additional information is available at the end of the chapter

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Abstract

The power demand has been increasing day by day due to population growth, new industrial development, etc. Meeting power demand is one of the challenge factors for fossil fuel-based power generation alone as well as the environmental issue of carbon footprint. Consequently, there is a need to concentrate on alternate energy sources to meet the power demand. In this chapter, the photovoltaic (PV) cell operation under various weather conditions is analysed, and based on the performance, the MPPT controller is developed by using fuzzy logic controller. The proposed system has been modelled in MATLAB environment, and the system performance has been analysed. Finally, the simulation results are evaluated and compared with IEEE 1547 standard for proving the effectiveness of the proposed system.

Keywords: MPPT, fuzzy, PV, MATLAB

1. Introduction

The maximum power point tracking (MPPT) plays a major role in photovoltaic (PV) power system. The PV power generation changes with respect to sun light irradiance and temperature [1]. Nowadays, many researches develop different MPPT techniques for improving the MPP in PV system. There are two major classifications such as indirect and direct MPPT controllers [2]. The indirect MPPT techniques are used for offline analysis of PV system performance, while the direct MPPT techniques are used to measure PV voltage and PV current during online condition. In this chapter, the direct method has been developed by using fuzzy logic controller to track the MPP of PV system [3]. This method is very robust and easy; meanwhile, no mathematical model is required for designing the controller. In this chapter, MPPT algorithm has been tested with numerical simulation in MATLAB environment, and the PV performance at constant and variable irradiance as well as temperature has been analysed [4].

2. Mathematical modelling of PV system

The following mathematical models of electrical characteristics are considered to design 20 kW photovoltaic module and simulated using MATLAB environment:

2.1. Open-circuit voltage

The open-circuit voltage, V_{OC}, is the extreme voltage offered from a PV cell, and this happens at zero current. The open-circuit voltage links to the amount of forward bias on the PV cell due to the bias of the PV cell junction with the light-generated current [5, 6]:

$$V = \frac{NKT}{Q} \, in \frac{I_L - I_o}{I_o} + 1 \text{ Volt} \tag{1}$$

where V is the open-circuit voltage, N is diode ideality constant, K is the Boltzmann constant (1.381*10^-23 J/K), T is temperature in Kelvin, Q is electron charge (1.602*10^-19 c), IL is the light-generated current same as Iph (A), and Io is the saturation diode current (A).

2.2. Light-generated current (radiation)

$$\mathrm{I_L} = \frac{\mathrm{G}}{\mathrm{G_{ref}}} * \left(\mathrm{I_{Lref}} + \alpha_{\mathrm{Isc}}\left(\mathrm{T_c} - \mathrm{T_{c\,ref}}\right)\right) \tag{2}$$

where G is the radiation (W/m^2), Gref is the radiation under standard condition 1000 W/m^2, ILref is the photoelectric current under standard condition 0.15 A, TCref is module temperature under standard condition 298 K, αISC is the temperature coefficient of the short-circuit current (A/K) = 0.0065/K, and IL is the light-generated current (radiation).

2.3. Reverse saturation current

$$\mathrm{I_o} = \mathrm{I_{or}} * \left({}^{\mathrm{T}}\!/\mathrm{T_{ref}} \right)^3 \exp\left(\left(\frac{\mathrm{QE_g}}{\mathrm{KN}}\right) * \left(\frac{1}{\mathrm{T_r}} - \frac{1}{\mathrm{T}}\right)\right) \tag{3}$$

$$\mathrm{I_{orn}} = \frac{\mathrm{Isc}}{\exp^{\left(\mathrm{V_{ocn}}/\mathrm{NV_{tn}}\right)}} \tag{4}$$

where Io is the reverse saturated current, Ior is the saturation current, N is the ideality factor 1.5, and Eg is the band gap for silicon 1.10 eV.

2.4. Short-circuit current

Ish = IL. It is the extreme value of the current produced by a PV cell. It is formed by the short circuit-situation: V = 0.

$$\mathrm{I_{sh}} = \mathrm{I_L} - \mathrm{I_o}\left(\left(\exp^{\left(\mathrm{Q}\frac{\mathrm{V - IR_s}}{\mathrm{NKT}}\right)} - 1\right)\right) \tag{5}$$

2.5. Irradiation

G = radiation W/m^2 (**Figures 1** and **2**).

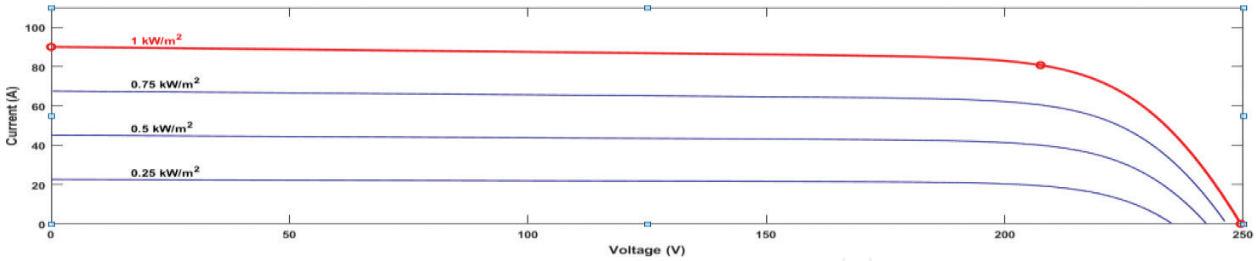

Figure 1. PV—Voltage vs. current characteristics.

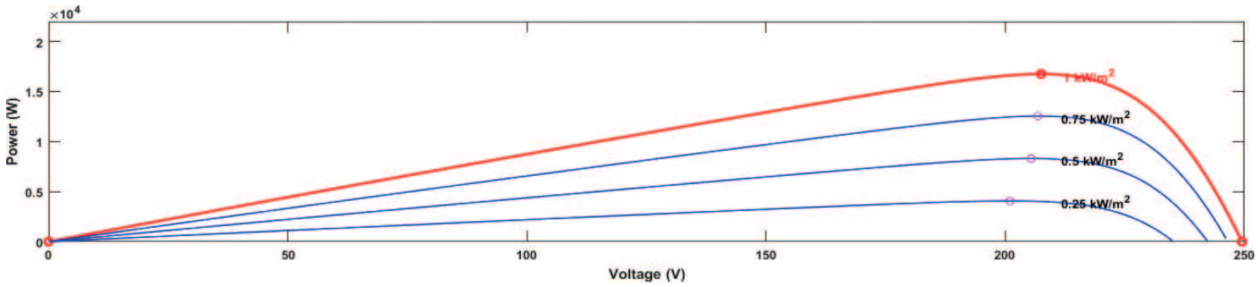

Figure 2. PV—Power vs. voltage characteristics.

3. Maximum power point tracking (MPPT) for photovoltaic system

Renewable energy sources play an important role in meeting consumer power demand due to their abundant availability and lesser impact on the environment [5]. The main hurdle in PV energy expansion is the investment cost of the PV power system implementation. PV energy generation is not constant throughout the day due to the changes in weather. The efficiency of power generation is very low (the range of efficiency is only 9–17% in low irradiation regions). Therefore, MPPT technologies have an important role in PV power generation for optimal power generation at various weather conditions.

In this chapter, we have discussed and analysed fuzzy logic controller-based MPPT controller for 20 kW PV system.

The proposed fuzzy-based MPPT block diagram is shown in **Figure 3**. **Figure 4** presents the structure of the fuzzy controller that has two inputs and one output. The fuzzy membership function has been designed by trapezoidal method for both input and output membership values. The defuzzification of proposed fuzzy controller has been used for centre of gravity. The MPPT fuzzy controller has two inputs such as PV voltage and PV current shown in **Figures 5** and **6**, respectively. The MPPT fuzzy controller generates a duty cycle based on input of fuzzy controller and is fed into boost converter shown in **Figure 7**. Finally, the fuzzy interference rules are designed based on changes in PV voltage

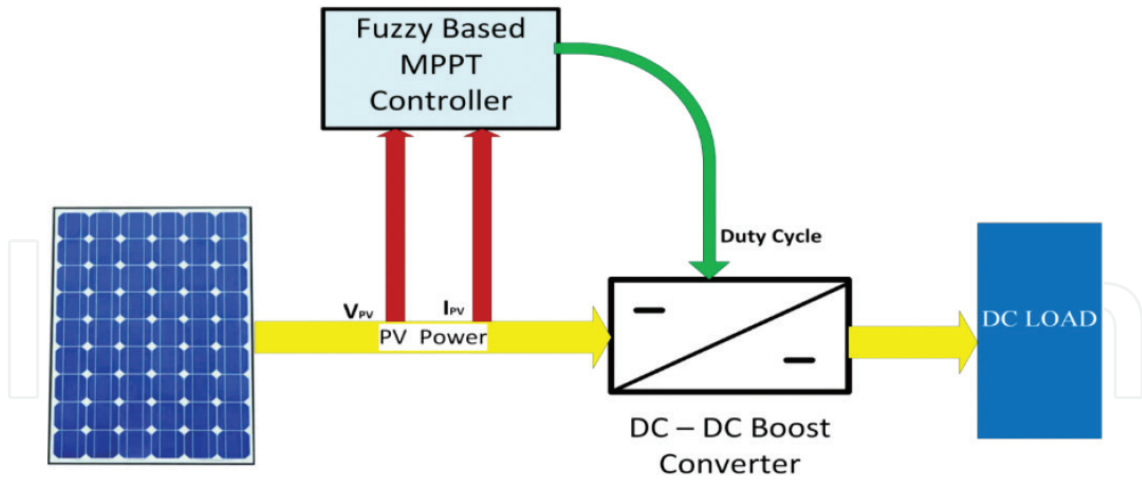

Figure 3. PV—MPPT block diagram.

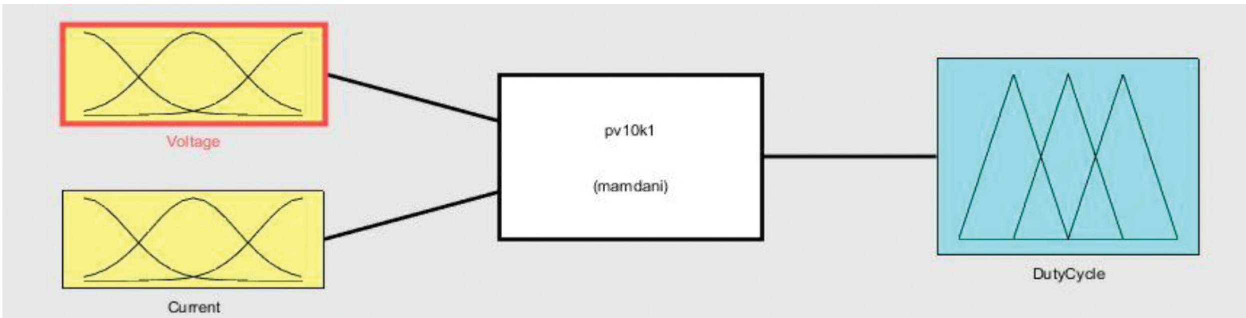

Figure 4. Fuzzy controller structure for MPPT of PV system.

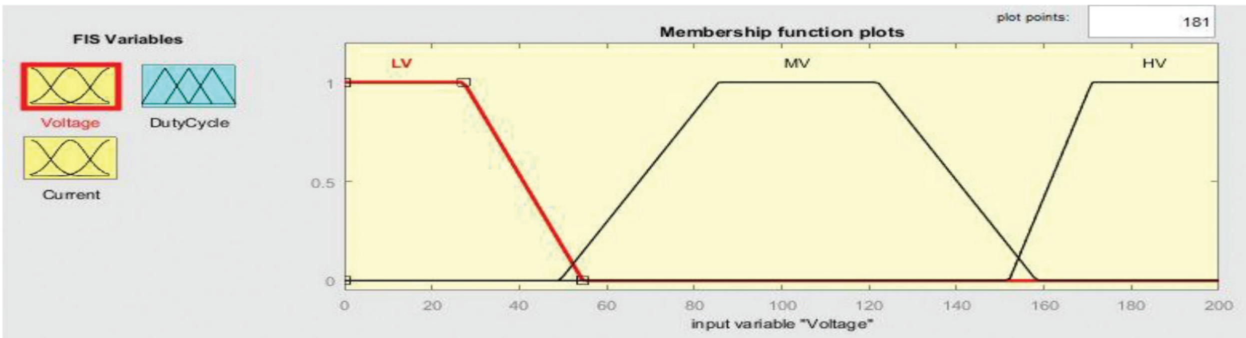

Figure 5. Fuzzy input membership function (voltage) for MPPT of PV system.

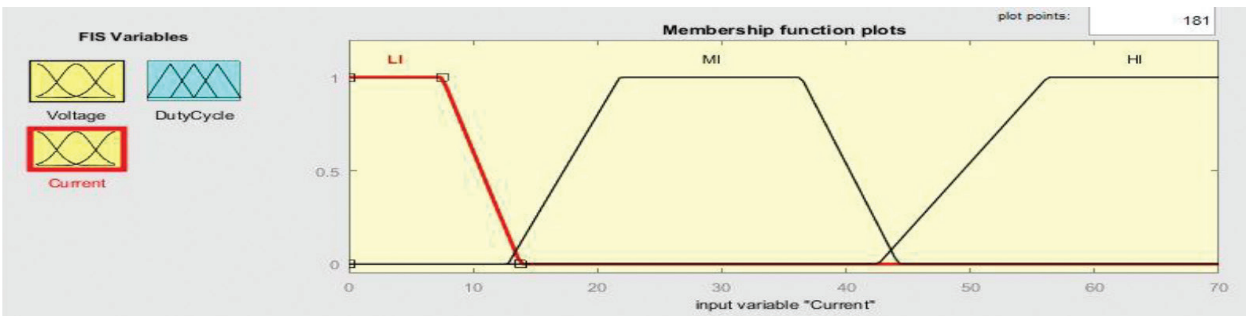

Figure 6. Fuzzy input membership function (current) for MPPT of PV system.

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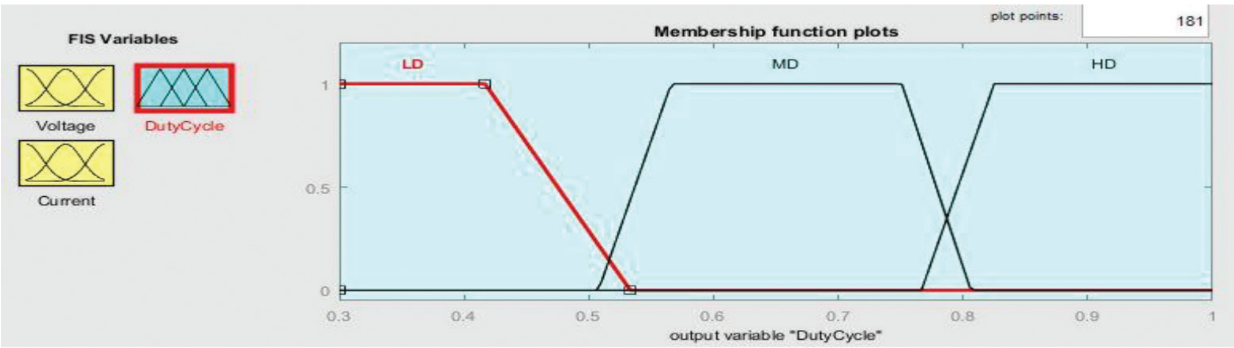

Figure 7. Fuzzy output membership function (duty cycle) for MPPT of PV system.

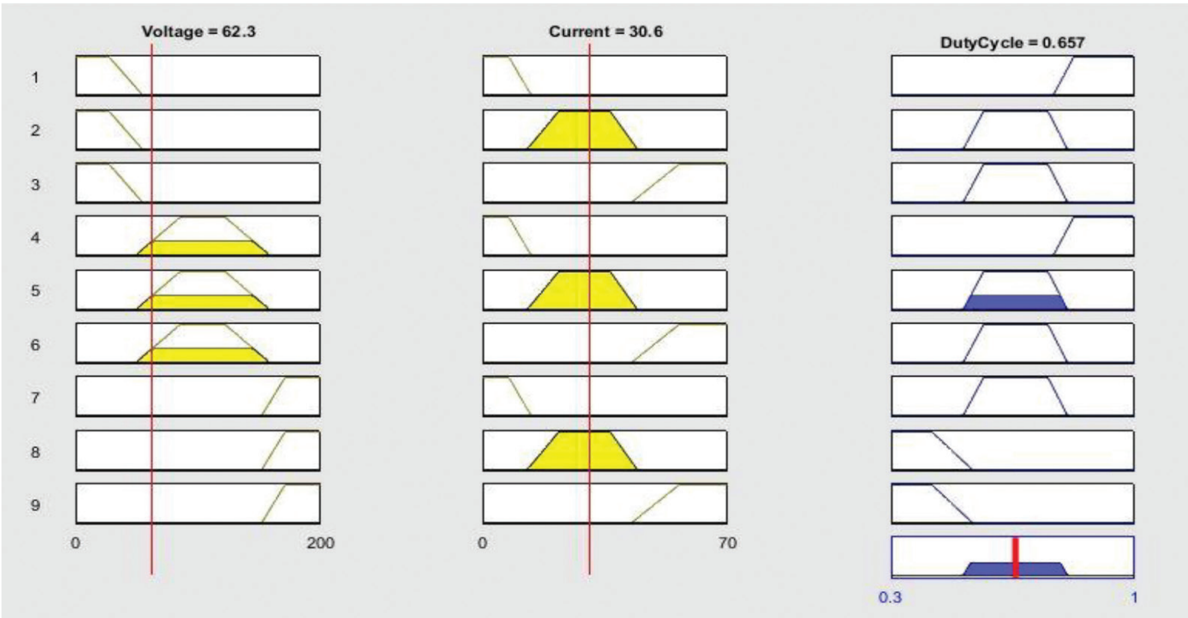

Figure 8. Fuzzy rules for MPPT of PV system.

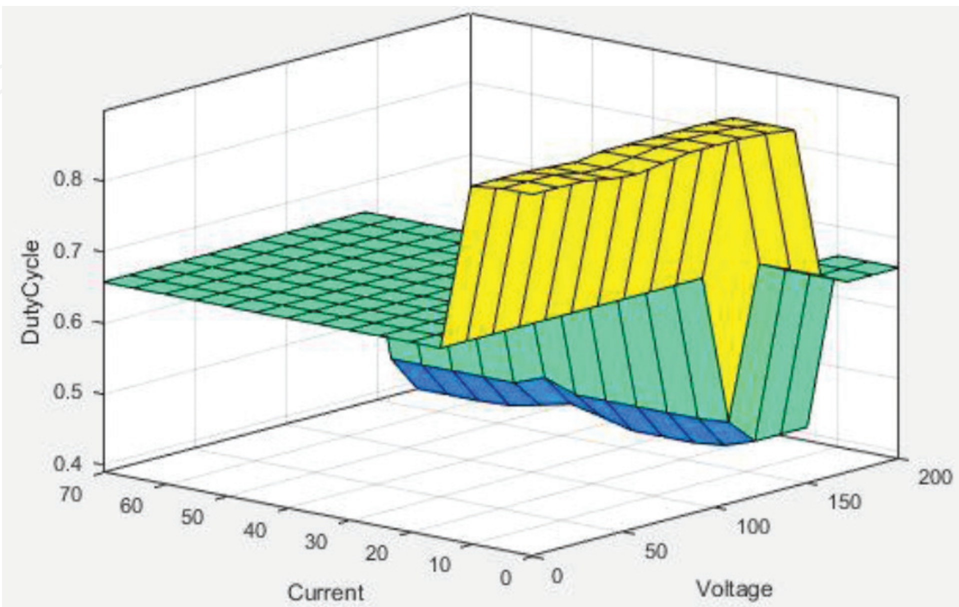

Figure 9. Fuzzy surface structure for MPPT of PV system.

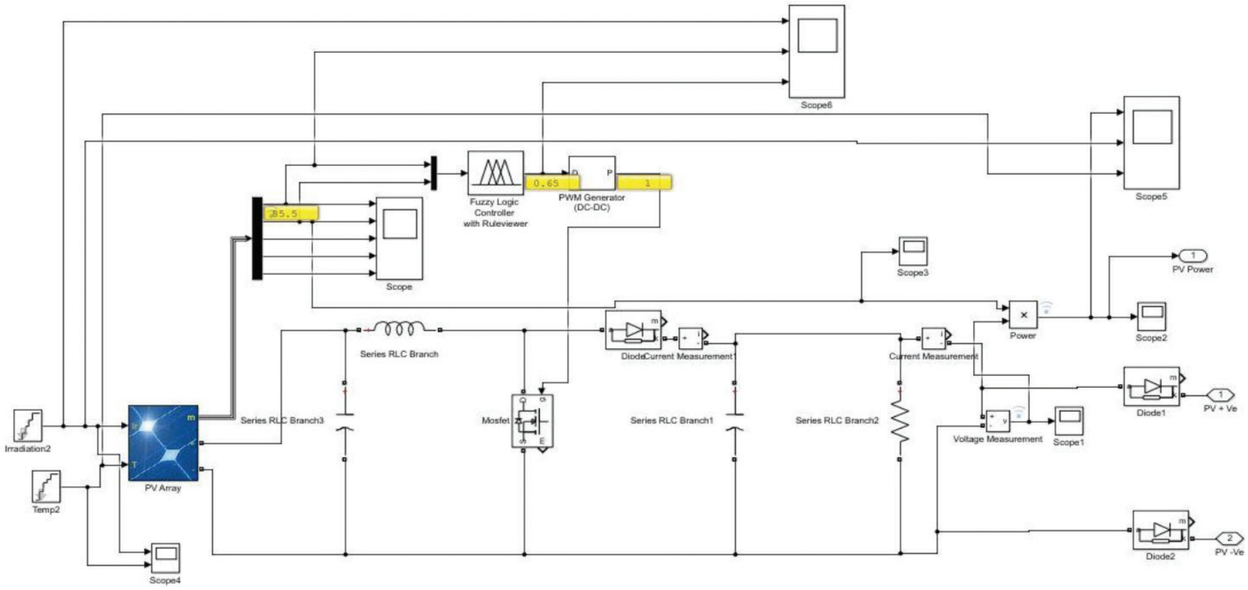

Figure 10. Fuzzy simulation model for MPPT of PV system.

and current under various weather conditions as shown in **Figure 8**, and then the surface view of fuzzy rules is presented in **Figure 9**. The above designed fuzzy controller has been implemented in MATLAB simulation of 20 kW PV system and its boost converter as shown in **Figure 10**.

4. MPPT results and discussion

The developed fuzzy logic controller has been tested and simulated in MATLAB environment, and the fuzzy controller performance under various weather conditions such as variable irradiance (1000, 750, 500 and 250 W/m^2) and temperature (20, 25, 30, 32 and 35°C) was analysed. The simulated results are analysed in the above conditions. **Figure 11** represented PV boost converter output voltage at various irradiance. **Figure 12** represented PV boost

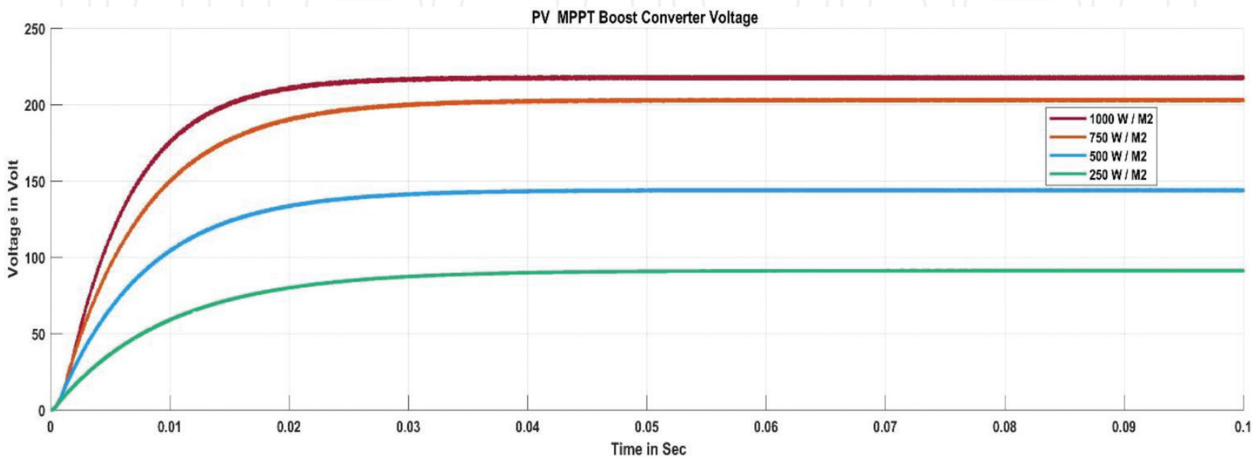

Figure 11. Fuzzy-based 20 kW PV system output voltage at various irradiance.

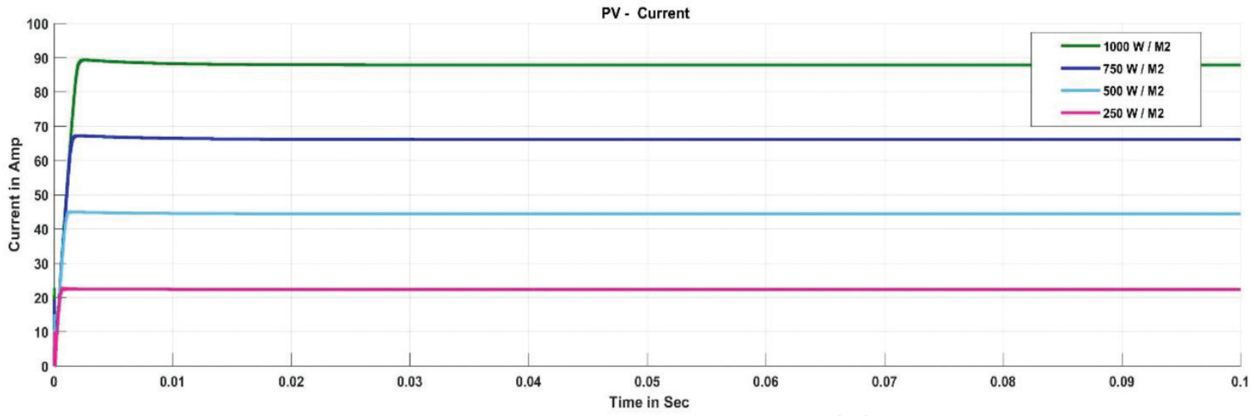

Figure 12. Fuzzy-based 20 kW PV system output current at various irradiance.

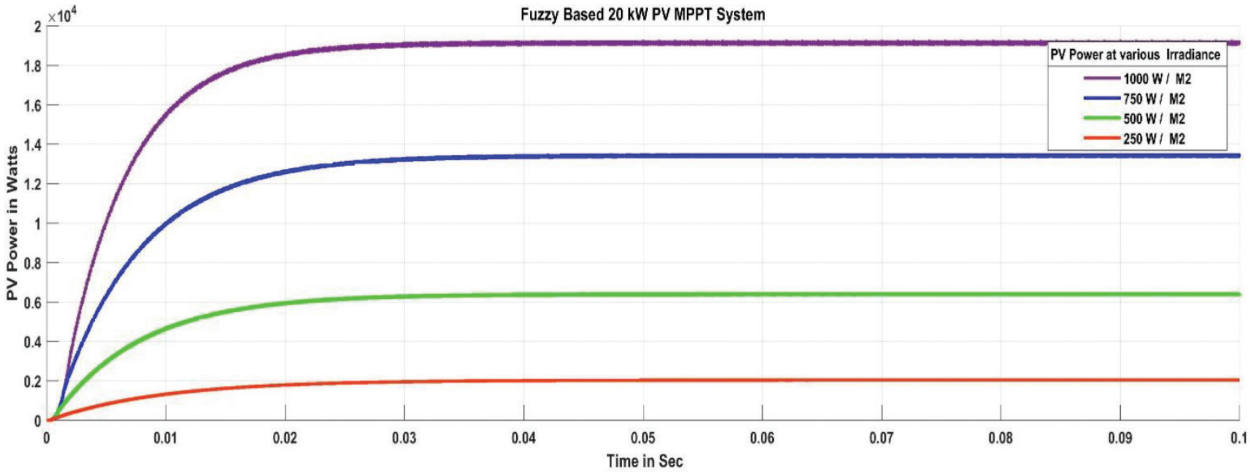

Figure 13. Fuzzy-based 20 kW PV system output power at various irradiance.

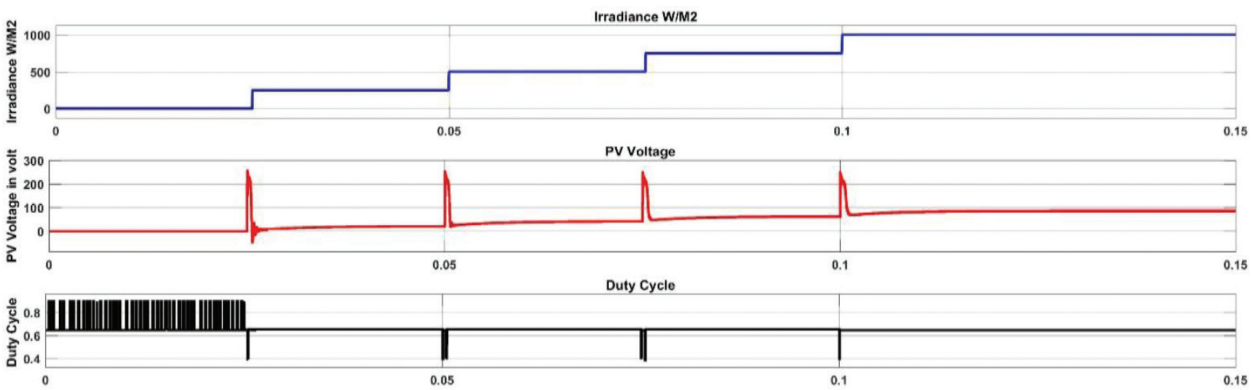

Figure 14. Duty cycle generation at various weather conditions.

converter output current at various irradiance. **Figure 13** represented PV boost converter output power at various irradiance. The fuzzy controller output signal of boost converter duty cycle is analysed at various weather conditions shown in **Figure 14**. The proposed MPPT system has been analysed in two different cases such as Case 1 (constant temperature and

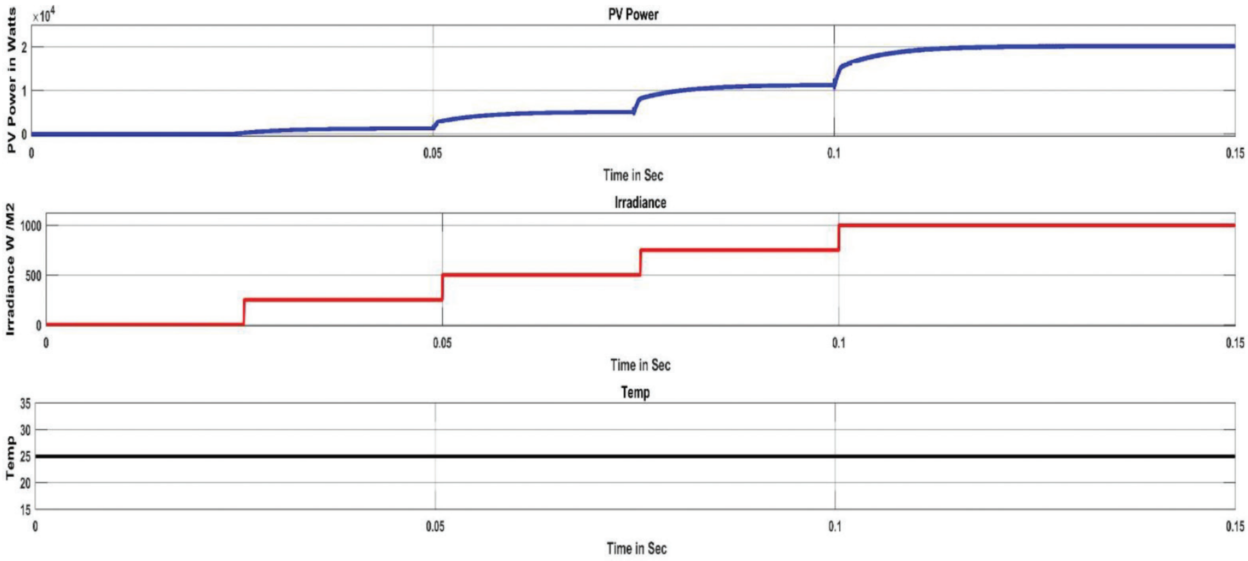

Figure 15. Analysis of the PV system performance at constant temperature.

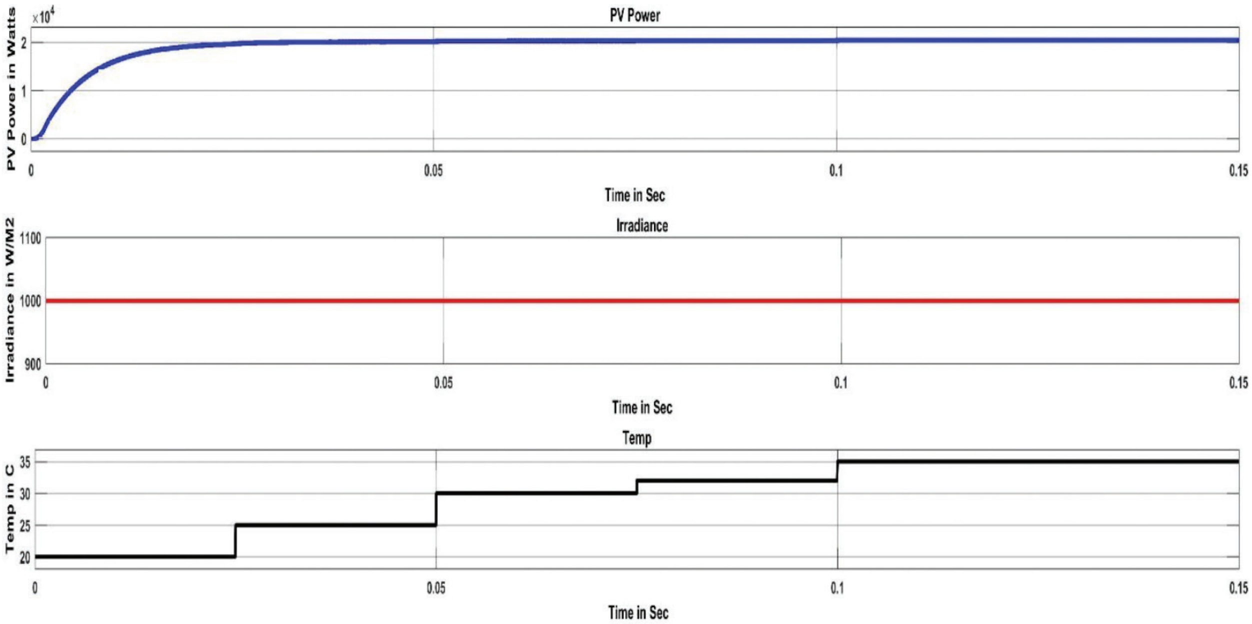

Figure 16. Analysis of the PV system performance at constant irradiance.

variable irradiance shown in **Figure 15**) and Case 2 (constant irradiance and variable temperature shown in **Figure 16**).

5. Conclusion

This paper deals with grid integration of PV power system with intelligent controller-based energy management to improve the power quality. The above objectives are achieved by modelling of mathematical design of PV system and simulating PV system

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at various weather conditions with fuzzy-based MPPT system. The fuzzy-based energy management system is developed and tested under various power demands, and then operation of battery charging and discharging is analysed. Finally, the proposed objective of grid integration of PV system is simulated in MATLAB, and system performance under various operating conditions is analysed. The improvement of power quality simulation results is compared with 1547 standard and proves the effectiveness of the proposed system.

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