An Intelligent MPPT Technique for a Three-Stage Battery Charge Controller for Standalone System

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Abstract This paper presents a comparative analysis between two different MPPT algorithms for a 3-stage battery charge controller (BCC) using a standalone system. A DC–DC buck converter is used as a step-down converter. Two different algorithms are used to extract the maximum power from solar PV panel. The maximum power from the solar photovoltaic panel is extracted using a conventional approach of Perturbation and Observation, as well as an intelligent MPPT technique called Fuzzy logic control. A battery charge controller (BCC) is used to charge the battery by using three different stages of the charging strategy. The different stages of charging incorporate Stage1—Bulk charging, Stage2—Absorption charging and Stage3—Float charging stage. The overall performance of the model is measured in terms of MPP tracking, lead-acid battery charging and controller efficiency. The output shows that the MPPT charge controller can track the MPP within 0.5 s regardless of solar irradiation variation. The concept of charging the battery in stages is implemented. The efficiency of the battery charge controller is attained up to 98.86% with a Fuzzy logic controller.

Keywords Fuzzy logic controller (FLC) · Perturb and observe (P&O) · Battery charge controller (BCC)

1 Introduction

Over the last few years, researchers from all over the world have been working furiously in the renewable energy area to provide clean and eco-friendly energy. Because PV systems depend on sunlight to create electricity, they can only be used during the day when sunlight is present. Therefore, one of the alternatives to store energy is batteries. As a result, the solar photovoltaic charge controller plays a very important role in allowing this solution to be possible. The MPP charge controller for solar photovoltaics is made up of a BCC and an MPP tracker. MPPT controller extracts the maximum amount of power from the solar photovoltaic panel and transfers it to the

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BCC. The battery is charged using a multi-stage charging process. To avoid damage from excessive charge gassing and overheating issues, this procedure is utilized to charge the battery. In this research paper, MPPT performance is evaluated in terms of tracking time and tracking efficiency with two different MPPT algorithms.

2 Methodology

This model is comprised of a solar photovoltaic panel, a buck converter, a battery and an MPPT charge regulator system. Figure 1 gives an outline of the solar PV MPPT battery charge control system configuration. The block of the MPPT charge control system contains a P&O MPPT algorithm as well as a 3-stage charge regulator for lead-acid batteries. For the implementation of an intelligent technique in solar PV battery charge control system Fuzzy logic is also implemented with 3-stage charge regulators with lead-acid battery. This system configuration is fit to charge a battery of 48 V from the 2-kW solar photovoltaic power source.

2.1 *Solar PV System*

The SPV system's efficiency and output power are entirely dependent on PV array configurations and different weather conditions such as sun irradiation and temperature changes. The work in this study is based on a constant temperature of 25 °C and variable solar irradiations of 600–1000 W/m^2 (Table 1).

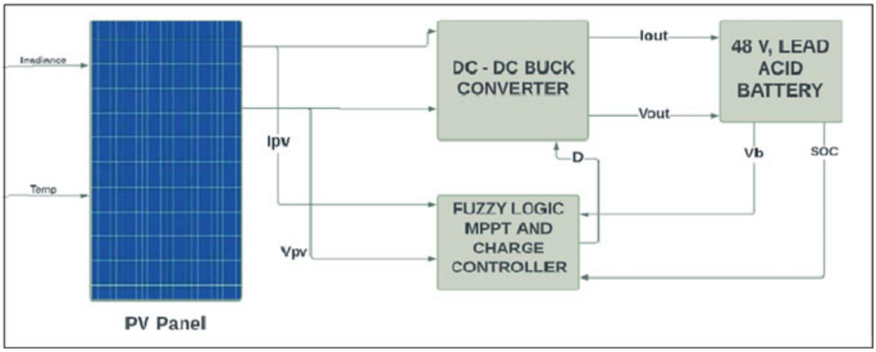

Fig. 1 MPPT system configuration block diagram

Table 1 Solar PV panel parameter specifications

Measuring parameter	Values
Maximum power (P_m)	250 W
Maximum current (I_m)	8.1 A
Maximum voltage (V_m)	30.9 V
Short circuit current (I_{sc})	60 A
Open circuit voltage (V_{oc})	36.6 V
Number of cells in parallel (N_p)	2
Number of cells in series (N_s)	4

2.2 Buck Converter

A buck converter is used in this model because the voltage of the solar PV panel is higher than the voltage of the battery. Therefore, a buck converter is used to reduce the PV panel's voltage while sustaining power transfer to the battery. The buck converter's design equation can be obtained from Eqs. (1) to (4).

$$D = \frac{V_{out}}{V_{in}} \tag{1}$$

$$R_{in} = \frac{R_{load}}{D} \tag{2}$$

$$I_L = \frac{V_{in} D(1 - D)}{fswL} \tag{3}$$

$$V_C = \frac{V_{in} D(1 - D)}{8Lf2C} \tag{4}$$

where D represents the buck converter's duty cycle, R_{in} represents the input resistance, I_L represents the inductor ripple current and V_C represents the buck converter's output capacitor voltage (Table 2).

Table 2 Parameter specification of the buck converter

Parameters	Values
Value of the capacitor, C	1000 Uf
Value of the Inductor, l	10 Mh
Input voltage of the converter, V_{in}	120 V
Switching frequency of converter, F_s	1000 Hz
Duty cycle of the converter, D	0.4
Capacitor ripple voltage, dV_c	2.3 Nv
Inductor ripple current, di_l	0.288 Ma

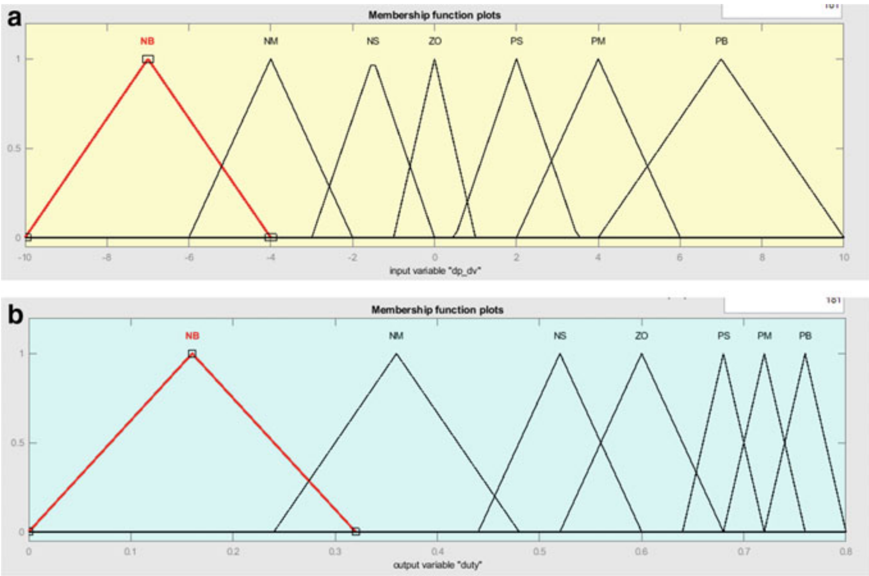

Fig. 2 **a** Input MF dp_dv. **b** Ouput MF 'duty cycle'

2.3 MPPT Algorithm–Fuzzy Logic Controller

To deal with non-linearity, imprecise input and exact output in an inaccurate system model, an MPPT–FLC is used. A fuzzy logic controller can be designed in three steps. Fuzzification is the initial stage, and it is used to convert crisp input into a linguistic variable. The inference system, which consists of a rule base, is the second step, and defuzzification, which converts the fuzzy output into crisp output, is the third step. Membership functions include Neg. Big (NB), Neg. Medium (NM), Neg. Small (NS), Zero (ZO), Pos. Small (PS), Pos. Medium (PM), and Pos. Big (PB) are used for both input error and change in error (Figs. 2 and 3).

2.4 MPPT Algorithm–Perturb and Observe

Many industrial solar Photovoltaic charge controllers use the P&O MPPT because of the ease with which it can be tracked and implemented. This MPPT algorithm measures the PV array's maximum power and delivers a duty cycle proportional to that power to the battery charge controller.

ΔP \ ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig. 3 Fuzzy logic controller rule base

3 Results and Discussion

For performance analysis, the maximum power point battery charge regulator for the standalone PV system model was successfully implemented. A user-defined method with variable steps is used to configure the Simulink model. This system configuration is fit to charge a battery of 48 V from a 2-kW solar photovoltaic power source also controlling the charging by utilizing a 3-stage battery charging technique. This model gives the overall efficiency up to 98.86% which is similar to some top-of-the-line business solar photovoltaic maximum power point trackers for charge controllers (Fig. 4).

3.1 Performance of the Solar PV Panel

Figure 5a Shows the comparative analysis between the output current of the PV panel with P&O and FLC-based MPPT algorithm. With FLC smooth DC output current is obtained whereas there is some disruption in output current in P&O.

Figure 5b Shows the comparative analysis between output voltage obtained from the PV panel with P&O and FLC. In each step, FLC has less oscillations, faster response time and precise tracking as compared with the P&O MPPT algorithm.

Figure 5c Shows the comparison b/w maximum output power obtained from the PV panel. Both P&O and FLC MPPT effectively track the maximum power as shown in Fig. 5c. A fuzzy logic controller must be chosen over the P&O controller for practical application because of its superior performance. As a result, the FLC has higher performance and is closer to the P&O.

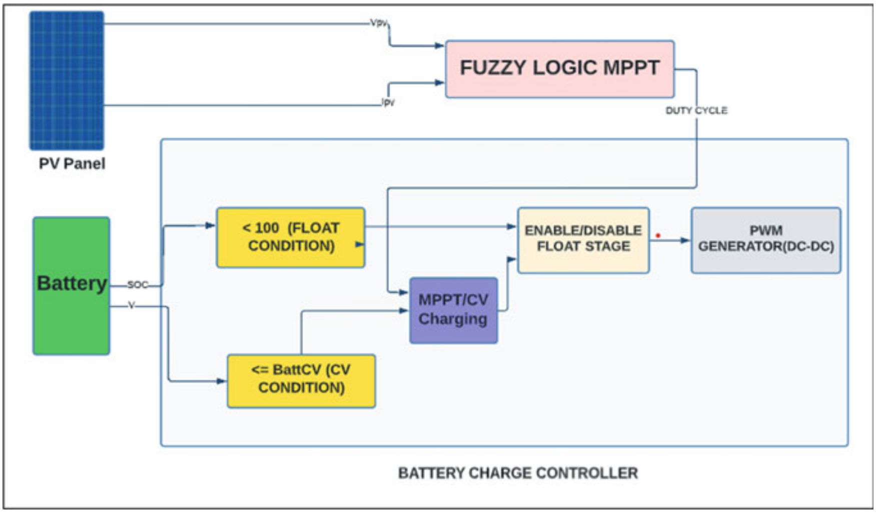

Fig. 4 Block diagram of a battery charge controller with FLC

3.2 Performance of the Lead/Acid Battery

Figure 6a shows the battery's output current with P&O and FLC MPPT algorithm. With FLC smooth DC output current is obtained whereas with P&O there is a lot of oscillations in output current is obtained.

Figure 6b shows the comparative analysis between output voltage of the battery with P&O and FLC MPPT algorithm.

Figure 6c shows the comparison between SOC of the battery. SOC obtained with FLC is higher than the SOC obtained from the P&O MPPT algorithm (Table 3).

4 Conclusion

In this paper, a complete simulation for a solar photovoltaic MPPT charge regulator model is carried out effectively in MATLAB. This accomplished the overall efficiency up to 98.86% which is similar to some top-of-the-line business solar photovoltaic Simulink. A fuzzy logic technique-based MPPT controller, P&O-based MPPT tracking algorithm, DC–DC step-down converter and 3-stage battery charge regulator are demonstrated. This system configuration is fit to charge a battery of 48 V from a 2-kW solar photovoltaic power source also controlling the charging by utilizing a 3-stage battery charging technique with maximum power point trackers for charge controllers. This MATLAB-Simulink system model introduced can be easily modified to match the needs of any modern Maximum power point charge controller having a similar configuration. According to the simulation, the PV system can give

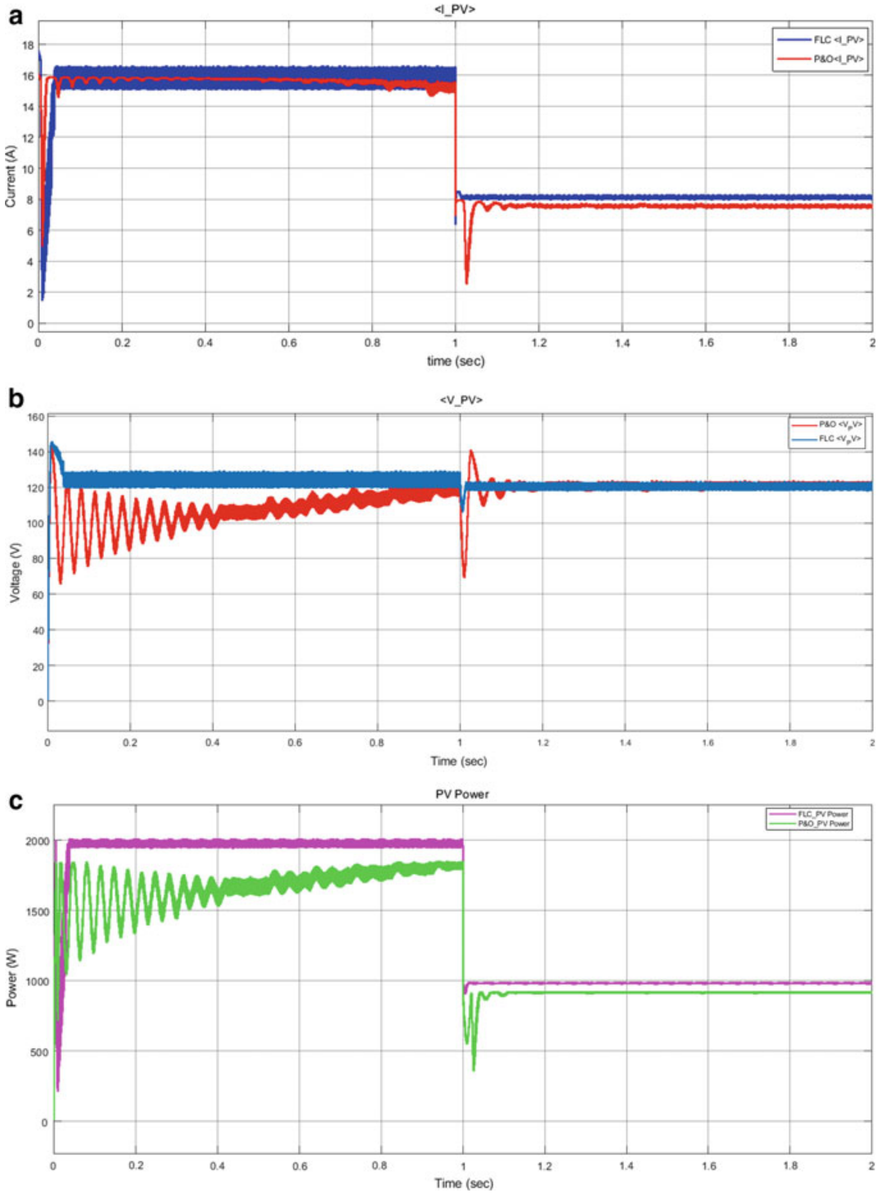

Fig. 5 **a** The output current of the PV panel with P&O and FLC. **b** The output voltage of the PV panel with P&O and FLC. **c** Maximum power of the PV panel with P&O and FLC

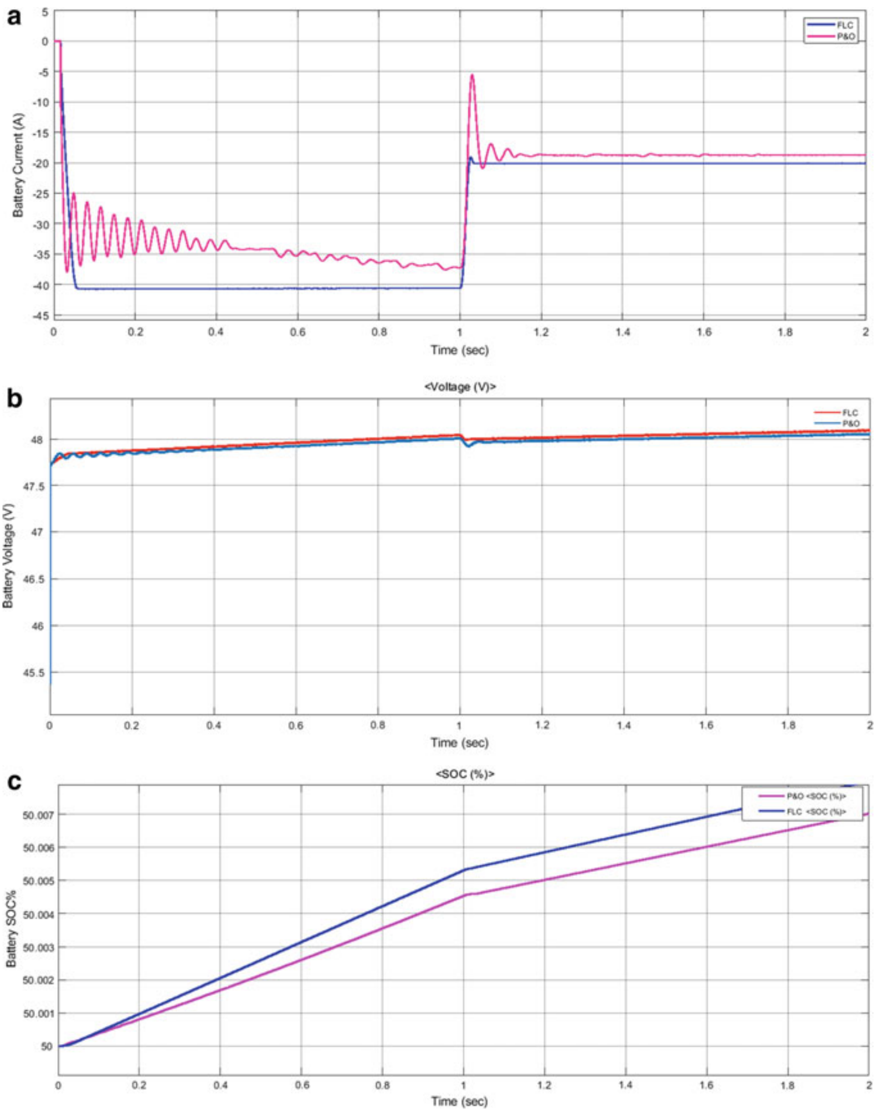

Fig. 6 **a** Battery's output current with P&O and FLC. **b** Battery's output voltage with P&O and FLC. **c** SOC of the battery with P&O and FLC

the maximum power with both MPPT controllers. Fuzzy MPPT, on the other hand, outperforms standard controllers when it comes to nonlinear systems. When MPP is detected, it has the capacity to reduce perturbed voltage. In contrast to the traditional MPPT, where the output power fluctuates about MPP, this activity saves a more consistent outcome power.

Table 3 Comparative analysis using FLC and P&O MPPT techniques

Parameter	P&O	FLC
The efficiency of the controller	98.85%	98.86%
Ripple in output voltage (SPV)	High	Low
Ripple in output current (SPV)	High	Low
Ripple in output power (SPV)	High	Low
State of charge (battery)	50.06	50.07
Output current (battery)	Fluctuating	Smooth DC
Ripple in output voltage (battery)	Negligible	Negligible
Control strategy	Voltage control	Intelligent control

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