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Using PV Fuzzy Tracking Algorithm to Charge Electric Vehicles

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ABSTRACT

Due to the possible shortage of oil and gas, increasing the number of cars, global warming, air pollution, and outages, there is a special need for renewable energy sources and electric vehicles (EVs). The new battery-electric vehicles BEVs can be charged by the power grid. However, the existing fossil fuel power plant cannot provide enough power for this purpose, and the only choice is renewable energy sources (RECs). Comparing RECs, solar energy is abundant and accessible in any part of the world. Needless to state that a maximum power point tracking (MPPT) system is required in order to extract maximum power from solar modules. In this paper, a charging strategy is proposed via using a solar system, a boost converter, and a fuzzy tracking algorithm. The main research contribution of the presented paper is to charge an EV without putting stress on the power grid. The effectiveness of this approach is demonstrated by the MATLAB Simulink and LTSPICE results.

1. Introduction

Solar energy is a plentiful supply of energy that anyone implementing on their rooftop may generate and use electrical energy to meet their needs [1]. Because the sun radiation changes during the day and during cloudy conditions, the output of solar PV varies as well [2, 3]. The only way that can increase the efficiency of the solar system is to use Maximum Power Point Tracking [4]. Solar energy may be harnessed in a variety of ways, depending on our needs [5]. One of the most important parts in which solar energy can be utilized is for charging electric vehicles [6, 7]. Nowadays, there are quite a few EVs that can be fed by the power grid [8]. However, because of the shortage of power and fossil fuel, the best and the only option is the usage of renewable energies such as solar energy [9, 10]. Fig. 1 shows the proposed topology of this paper, which includes solar panels, a boost converter, a fuzzy tracking controller, a DC bus, and electric vehicle batteries.

As can be seen between the solar panels and EV batteries, there is a special need for a DC-DC converter to do the MPPT part of the system [11-13]. By using output voltage and current, the fuzzy controller is able to adjust the duty ratio of the pulse wide modulation signal, which controls the switching of the boost converter [14-16]. In recent years, some research has been done on using solar energy and DC-DC converters for charging electric vehicles. In [17], the authors propose an optimization method to utilize the effect of solar and two separated batteries on EV. In [18], the author shows that Toyota City's new solar charging system combines a solar power storage unit with a commercial charging station. Toyota City has erected solar-powered charging stations to encourage the use of environmentally friendly automobiles such as plug-in hybrid electric vehicles. In [19], the author examines the effect of the number of PV cells and the vehicle surface cover on the outputted power. The battery state of charge is maintained and monitored based on these factors and taking into consideration the vehicle situation and location in order to define the optimum approach and the highest yield factor in relation to this source of energy. In [20], the charging station will function as a grid-connected solar power plant. The author also mentions that in most cases, a transformer is used to feed low voltage solar power to the grid. The main goal of the research is to lower the overall cost, size, and power losses of the system. The paper structure is Introduction, Solar system, Boost converter, Fuzzy tracking techniques, Simulation results and conclusion.

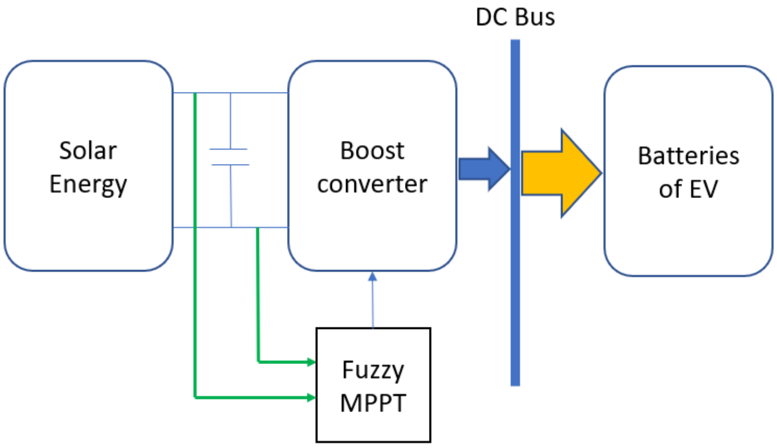


Fig. 1. Proposed topology

2. Solar System

A solar cell is the very basic component of a PV system. To specify the behavior of a solar cell, one-diode and two-diode circuits are often utilized [21]. In Fig. 2, a one-diode circuit model of a PV cell has been indicated.

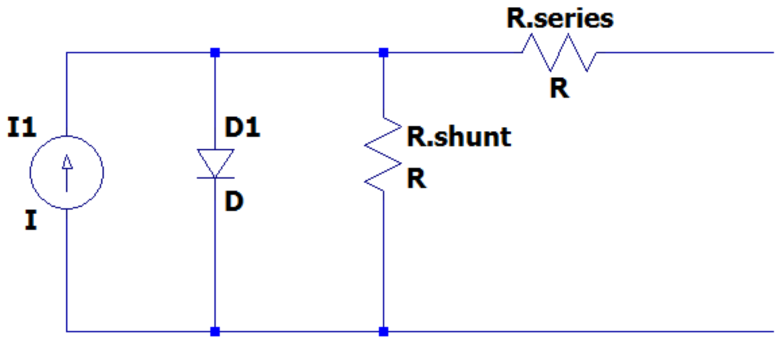


Fig. 2. A one-diode circuit of a PV cell

The PV model in Fig. 2 includes a current source due to the sun radiation and a parallel-connected diode, which represents the P-N connection of the semiconductor. The series and parallel resistance respectively, must be very low and very high in order to lower the losses of the model [22]. The one-diode circuit presented in this paper has more accuracy and is less influenced by temperature compared to a double-diode one [23]. The solar V-I and P-V curves are impacted by the sun radiation and ambient temperature, which are modeled as follows [24].

$$I_1 = \left[I_{SC} + K \left(T - T_{REF} \right) \right] \frac{S}{1000} \quad (1)$$

$$I_{RS} = \frac{I_{SC}}{\left[\exp\left(\frac{qV_{OC}}{N_S KAT} \right) - 1 \right]} \quad (2)$$

$$I_S = I_{RS} \left(\frac{T}{T_{REF}} \right)^3 \exp\left[\frac{qE_g \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)}{KA} \right] \quad (3)$$

Where I_{SC} is the short-circuit current of the cell, T is the temperature of the solar cell, $T_{REF} = 273$ and S is the sun irradiation, $S_{ref} = 1000\ w/m^2$, K is the Boltzmann constant, $K = 1.23 \times 10^{23}$, V_{OC} is the open-circuit voltage and N_s is the number of series cells. Fig. 3 shows the I-V and P-V curves with the highest sun radiation and the most suitable ambient temperature. The open-circuit voltage in the proposed system is 64 volts, the short-circuit current is equal to 6 A, and the maximum power which can be achieved is 300 watts.

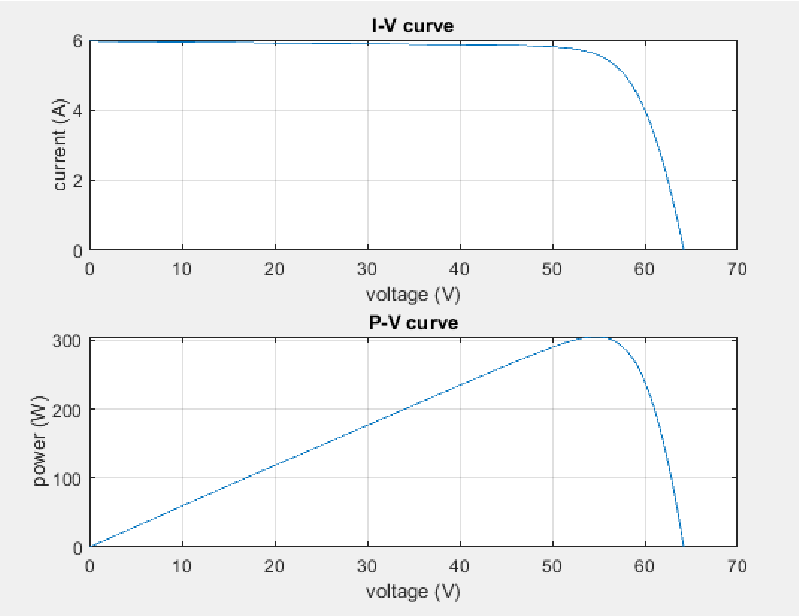


Fig. 3. I-V and P-V curves

In order to use MPPT in a solar cell, a DC-DC converter is required. In this paper, a boost converter is utilized for this purpose which is illustrated in the next section.

3. Boost Converter

The output voltage of the solar system is low and needs to be boosted equally to the amount of the DC bus, which is used for charging EVs [25]. In this regard, a boost converter is utilized between the solar modules and the DC bus [26]. In Fig. 4, the conventional topology for the step-up converter is depicted.

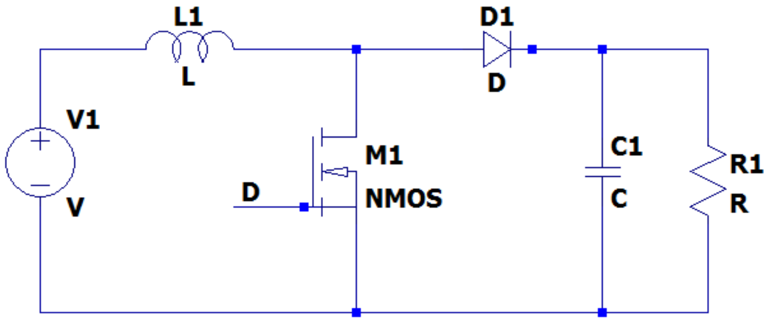


Fig. 4. The topology of the boost converter

As it can be seen from Fig. 4, the boost converter presented in this paper has one switch, which is MOSFET, a Schottky diode, an inductor, a capacitor, and a resistor that represents the load. The boost converter has two structure modes of operation. In the ON mode of operation, the inductor is charged with solar output voltage, and the solar energy will be stored in the inductor. Also, in the off mode of operation, the summation of solar energy and the stored energy in the inductor feed the DC bus [27]. In order to calculate the optimized inductor, capacitor, and duty ratio, the following equations are implementer.

$$\frac{V_o}{V_i} = \frac{1}{1 - Duty\ ratio} \tag{4}$$

$$L_1 = \frac{DV_i}{\Delta I_L . f_s} \tag{5}$$

$$C_1 = \frac{DV_o}{\Delta V_c . R . f_s} \tag{6}$$

Where V1 is the output voltage of the solar modules, $V2$ is the voltage of the DC bus, f is the switching frequency.

4. Fuzzy Tracking Technique

The schematic of the fuzzy tracking method is depicted in Fig. 5. The Fuzzy Logic Controller (FLC) design is shown in Fig. 6.

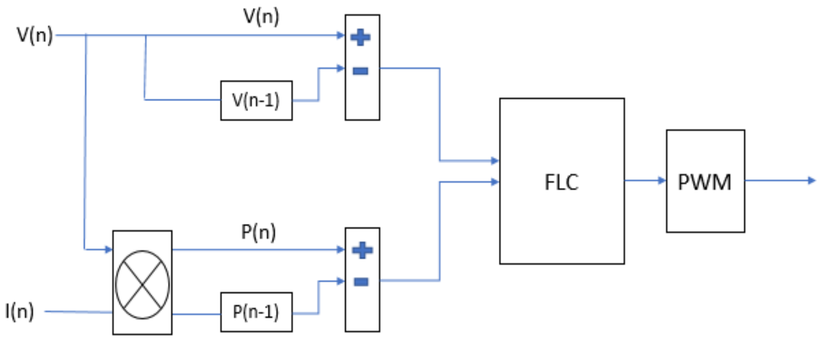


Fig. 5. Fuzzy logic controller schematic

In order to adjust the extracted power of the solar system with the duty ratio of the PWM signal, the fuzzy rule base should meet the following criteria [28], [29].

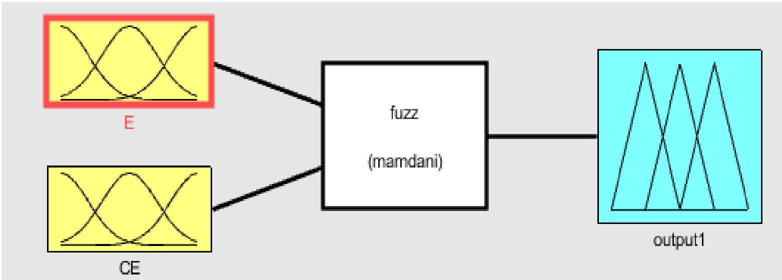
- If the output power is increased, the duty cycle should be increased; otherwise, the duty ratio should be decreased.
- When the maximum power point is far away from the latest maximum point, the big step size should be utilized to approximate the maximum power to increase tracking speed.
- Instead, to limit search loss, a smaller step size should be employed to approach the closed power point.

For this purpose, the following variables are generated:

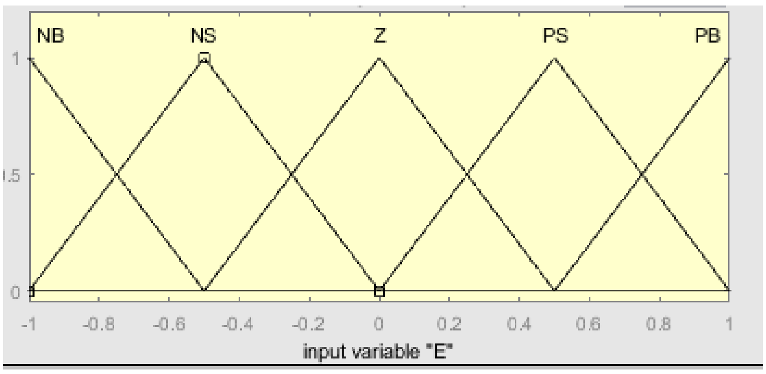
$$E(t) = \frac{P_{PV}(t) - P_{PV}(t-1)}{V_{PV}(t) - V_{PV}(t-1)} \tag{7}$$

$$CE(t) = E(t) - E(t-1) \tag{8}$$

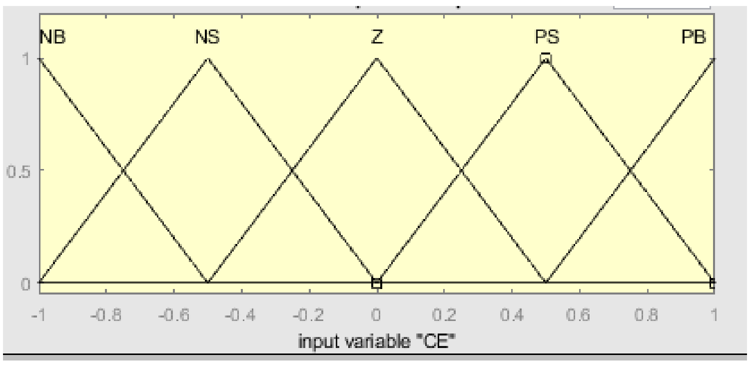
Where P (t) and V (t) are the values of power and voltage, the input of the fuzzy system is $E(t)$ and $CE(t)$ and the output is the pulse wide modulation (PWM).



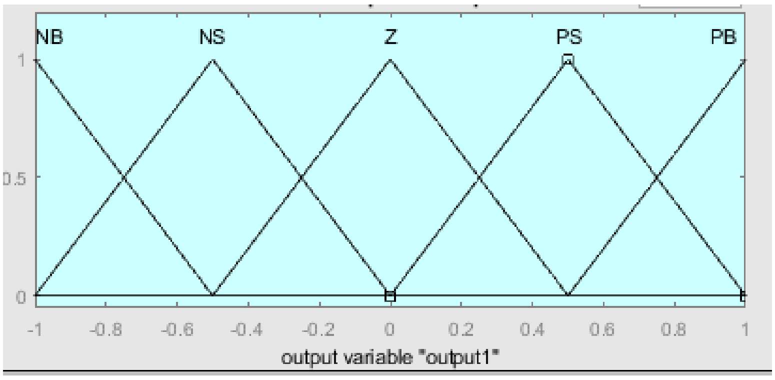
(a)



(b)



(c)



(d)

Fig. 6. (a) Fuzzy system (b) Input variable E (c) Input variable CE (d) The output of the fuzzy system

The 25-rule base is implemented to include all possible variables such as negative big (NB), negative small (NS), ZE (zero), PS (positive small), PB (positive big) [30]. In this system, the triangular membership function has been used for both the input and the output of the system. The Mamdani inference engine, the average center defuzzifier, and the singleton fuzzifier has been used. Table 1 shows the fuzzy rule base that meets the aforementioned three conditions.

Table 1. Fuzzy rule base

CE/E	NB	NS	Z	PS	PB
NB	NB	NB	NB	Z	Z
NS	NS	NS	NS	Z	Z
Z	NS	Z	Z	Z	PS
PS	Z	Z	PS	PS	PS
PB	Z	Z	PB	PB	PB

5. Simulation results

The MATLAB Simulink and LTSPICE are used to simulate the results. In this paper, two MPPT methods are used to extract the maximum energy from the sun. At first, P&O is utilized, which is fast and easy to track the maximum points. However, the losses around the operating point are high owing to the fact by using this method, there are some oscillations around the operating point, as can be seen in Fig. 7. According to Fig. 7, by utilizing the fuzzy tracking technique, the oscillation around the operating point is much less, and the new method is much faster without using light sensors.

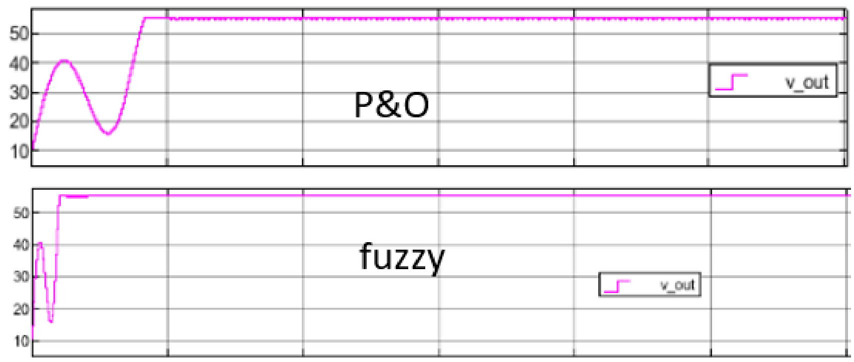


Fig. 7. The output voltage of the system by fuzzy and P&O method

Comparing the two methods in Fig. 7, the fuzzy method has reached the operating point faster and has less oscillation, which leads to fewer losses. The input and output voltages and also the current through the inductor are shown in Fig. 8.

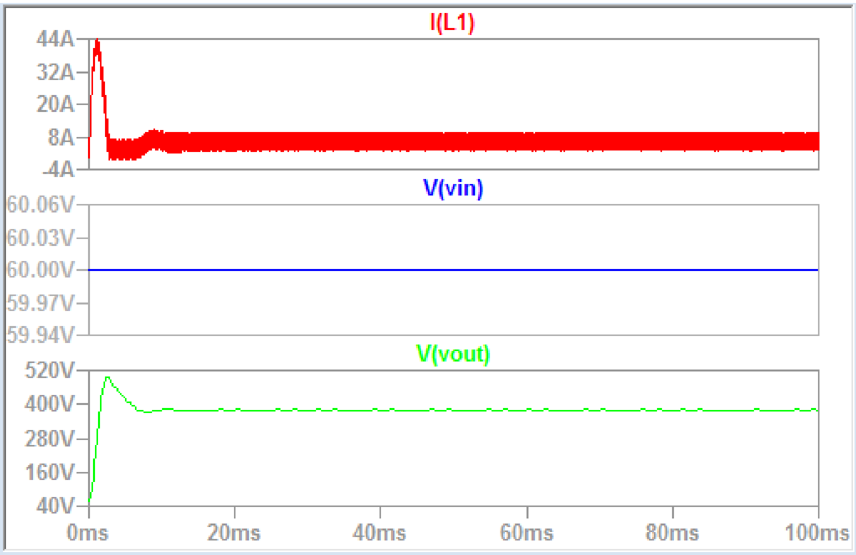


Fig. 8. Input and output voltage and the current through the inductor of the boost converter

According to the above figure, the output voltage of the boost converter is 400 V which is the same as the voltage across the DC bus. Table 2 indicates the comparison table of both methods to charge an EV.

Based on Table 2, the output power of the P&O method is 1762 watts, and the output power of the fuzzy method is 1781 watts, which indicates that by using the fuzzy MPPT method, the losses will be lower. In addition, the efficiency of the system when using a fuzzy method is higher.

Table 2. Comparison of two different methods to charge an EV

	Generated power	**Efficiency %**
P&O	1762 W	93.23 %
Fuzzy	1781 W	96.88 %

6. Conclusion

The main purpose of this paper is to reach the highest extracted energy from the sun in order to feed the batteries of an electric vehicle. Among MPPT techniques, the fuzzy method is easy to use and fast. Simulation results showed that by using the fuzzy method, there is much less oscillation around the operating point, which leads to having a lower amount of losses. In addition, the voltage of the charging station for charging the EVs is 400 V, and by using a boost converter, the output DC voltages of solar panels are converted to a suitable level that is usable for batteries in the EV. Future research will focus on optimizing the fuzzy MPPT method with an intelligent algorithm such as a genetic algorithm to extract more power from the same solar system.

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