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Dual State DC-DC Converter with PI and Fuzzy PI Controller for LED Drivers

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Abstract *- The intent of this proposed work is to maintain a suitable DC voltage for high power Light Emitting Diodes (LED) from a variable low DC voltage obtained from the solar PV array. Normally, a high gain switched-capacitor DC-DC converter is employed to boost output voltage. Ironically, due to the varying nature of solar PV, the output obtained from the converter also changes. The Proportional Integral (PI) controller that is used to regulate output voltage takes a considerable amount of time to attain its steady-state voltage. To overcome this, fuzzy tuned PI controllers are proposed. The performance comparison of these controllers is analyzed with respect to the settling time of converter DC output voltage. The simulation of the converter with a proposed controller is done for a power rating of 200 W, and the output settling time with the fuzzy PI controller is less compared with that of the PI controller.*

Keywords — *Switched capacitor DC-DC converter, LED, PI controller, fuzzy PI controller*

I. INTRODUCTION

Energy and Eco-system are mutually dependent in many respects, and conventionally India's energy mix is governed by fossil fuel resources. These fossil fuels are curtailing as well as contributing to GHG emissions. Paving the way to green energy sources such as wind, solar, and fuel cells is a sustainable approach. However, the output obtained from these sources is highly variable and low. As a consequence, it is essential for the energy obtained from these sources to be converted into high power AC or DC based on the applications employed.

Several DC-DC converter topologies suitable for LED driver circuits were proposed in the literature [1-2]. Manuel Arias et al. explained the characteristics of LED lighting and the various rectifiers and converters employed for such applications [3]. Huang-Jen et al. suggested a LED driver which can be employed for low-power lighting applications. The LED current and light intensity were controlled with the help of enhanced PWM practice [4]. Solar PV is considered as one of the potential renewable energy resources as it provides the energy that is clean and emission-free. A LED-based street lighting system that uses sunlight as its first energy source and battery as its next energy source was developed and tested by Costa et al. During the daytime, the energy for LED lighting is provided by solar PV, and the battery is also getting charged. The energy from the battery is used to light the LED streetlight during the night [5]. John Lam et al. proposed a LED driver circuit that works on AC input with no DC link capacitor. The implemented driver circuit provides a high power factor with a low ripple current [6].

The DC-DC converter is employed in many applications that require constant DC voltage as its input. When the DC-DC converter is supplied from renewable energy sources like fuel cells, solar PV, the output voltage tends to vary due to the intermittent nature of the renewable energy sources. A PI controller is conventionally utilized to keep constant output voltage. However, under random load and line variations, the PI controller is not able to maintain the output voltage constant. Consequently, a fuzzy tuned PI controller is suggested in this work.

A step-up DC-DC converter that has low switching losses, better switching performance, and simple structure proposed in [7] is employed in this work to get high gain constant DC voltage from a low and variable DC voltage obtained from solar PV. The paper is structured as given. Section 1 explains the system description. Section 2 demonstrates the controller used in this work, and simulation findings are elaborated in section 3. Section 4 presents the conclusion of the work.

II. SYSTEM DESCRIPTION

Fig. 1 illustrates the block diagram of the suggested work. A low and fluctuating DC voltage of solar PV is converted into a fixed high value of DC with the help of high gain DC-DC converter. A high-power LED lamp is used as a load here. To maintain a constant DC voltage irrespective of line variations, a PI and fuzzy PI controller are employed.

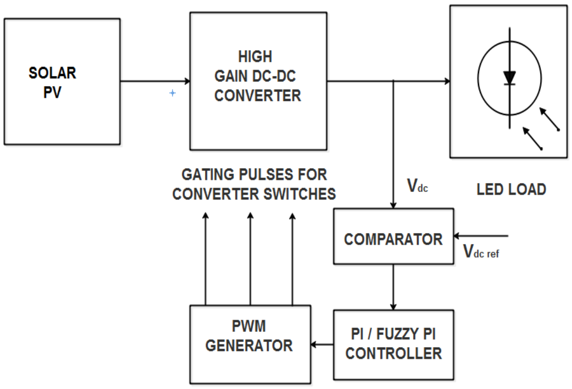

Fig. 1: Proposed work block diagram

Fig. 2 portrays the circuit of the high gain DC-DC converter employed in this work. It is comprised of two switches S_1 and S_2, one inductor L, four diodes D_0, D_1, D_2, and D_3, and LED load.

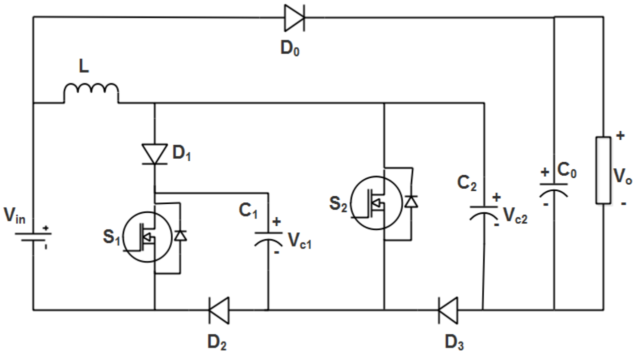

Fig. 2: High Gain DC-DC Converter

Fig. 3 illustrates the mode of operation when MOSFETs S_1 and S_2 are turned ON. The diodes D_1, D_2, and D_3 are forward biased, and inductor L gets charged while D_0 is reverse biased. The corresponding equations obtained by applying KVL are given in (1) and (2).

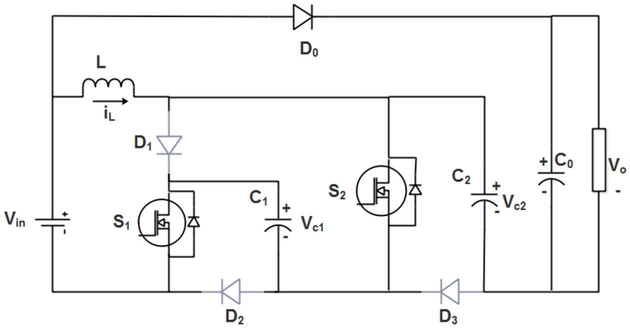

Fig. 3: Mode of 0peration when S_1 and S_2 are ON

$$L\frac{di_L}{dt} = V_{in} + V_{c1} \tag{1}$$

$$V_o = V_{in} + V_{c1} + V_{c2} \tag{2}$$

Fig. 4 exemplifies the mode of operation while both the switches are in the OFF state. The inductor starts discharging while C_1 and C_2 get charged. The diodes D_1, D_2, and D_3 conduct while D_0 is in an OFF state. The voltage equations obtained in this mode are given in (3) and (4). The gain of the converter is mentioned in (5) and is obtained from equations (1) to (4).

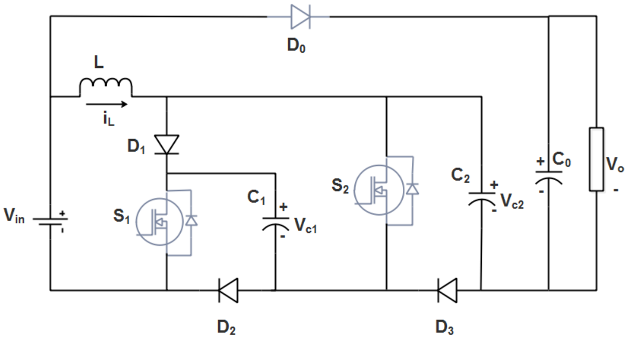

Fig. 4: Mode of Operation when S_1 and S_2 are OFF

$$L\frac{di_L}{dt} = V_{in} - V_{c1} \tag{3}$$

$$V_{c1} = V_{c2} \tag{4}$$

$$\frac{V_O}{V_{in}} = \frac{3-2D}{1-2D} \tag{5}$$

A. PI Controller

In this work, the output of solar PV is provided as input to the DC-DC converter, which is not constant due to variations in solar irradiation. Hence a PI controller is employed here to control the output voltage. Fig. 5 reveals the configuration of a PI controller.

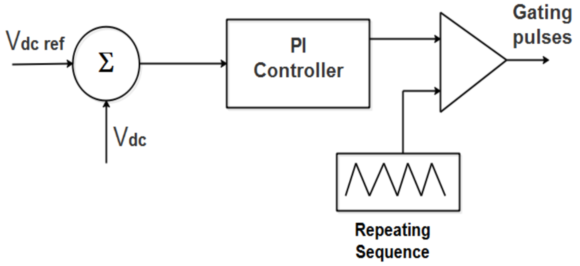

Fig. 5: Configuration of PI controller

The reference voltage $V_{dc\ ref}$ and the obtained voltage V_{dc} from the DC-DC converter are given to the comparator block, which outputs the error voltage. The PI controller processes the error and produces a control signal which is then compared with a repeating sequence to generate gating signals for DC-DC converter switches. Due to the nonlinear nature of solar PV, the PI controller is not able to retain the output voltage steady under random variations of solar PV output.

B. Fuzzy PI Controller

To get better control performance, a fuzzy PI controller [8] is suggested here. The gains of the PI controller are suitably tuned by using the Fuzzy Logic Controller (FLC) to get more appropriate results. Fig. 6 shows the fuzzy PI controller structure employed in this work. The error and change in error are given as input to FLC, and it generates gains K_p and K_i for the PI controller.

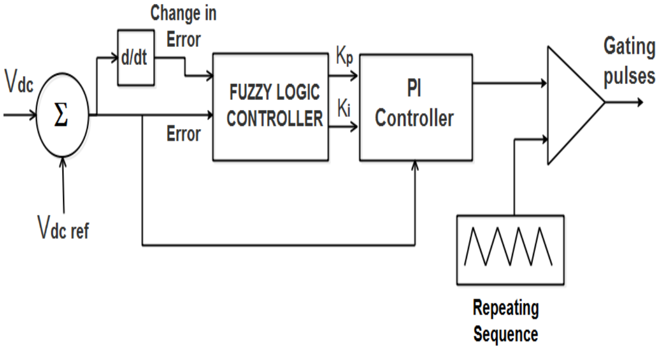

Fig. 6: Fuzzy PI controller configuration

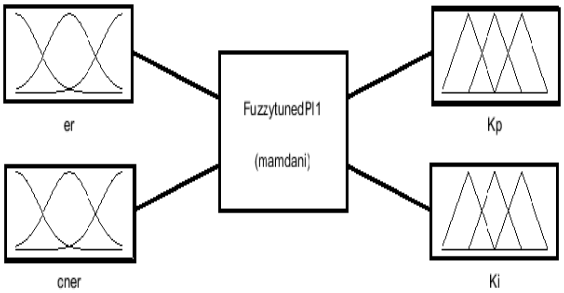

Fig. 7: Fuzzy PI controller structure in MATLAB

Fig. 7 shows the fuzzy PI controller arrangement employed in MATLAB. The seven Membership Functions (MF) of FLC used are N_{Big}, N_{Medium}, N_{Small}, ZE, P_{Small}, P_{Medium}, and P_{Big}. The FLC employs a 7×7 rule base and is displayed in Table I.

TABLE I. FLC rule base for K_p and K_i

E / CE	N_{Big}	N_{Medium}	N_{Small}	ZE	P_{Small}	P_{Medium}	P_{Big}
N_{Big}	N_{Big}	N_{Big}	N_{Big}	N_{Big}	N_{Medium}	N_{Small}	ZE
N_{Medium}	N_{Big}	N_{Big}	N_{Big}	N_{Medium}	N_{Small}	ZE	P_{Small}
N_{Small}	N_{Big}	N_{Big}	N_{Medium}	N_{Small}	ZE	P_{Small}	P_{Medium}
ZE	N_{Big}	N_{Medium}	N_{Small}	ZE	P_{Small}	P_{Medium}	P_{Big}
P_{Small}	N_{Medium}	N_{Small}	ZE	P_{Small}	P_{Medium}	P_{Big}	P_{Big}
P_{Medium}	N_{Small}	ZE	P_{Small}	P_{Medium}	P_{Big}	P_{Big}	P_{Big}
P_{Big}	ZE	P_{Small}	P_{Medium}	P_{Big}	P_{Big}	P_{Big}	P_{Big}

Fig. 8a, 8b, 8c, and 8d indicate the MF plot of inputs error, change in error, and outputs K_p and K_i.

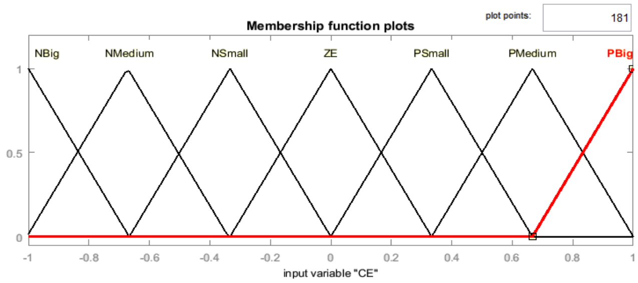

Fig. 8a: MF plot for error E

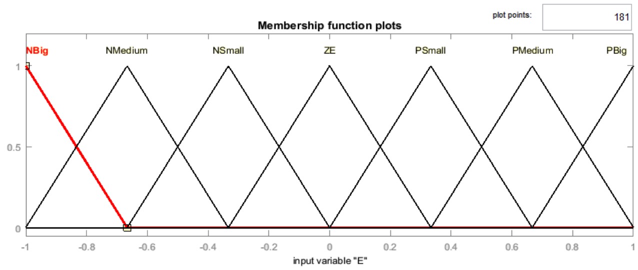

Fig. 8b: MF plot for change in error CE

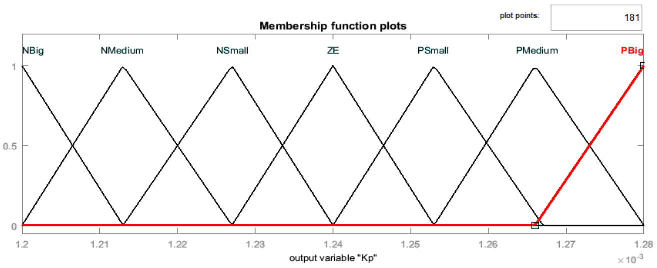

Fig. 8c: MF plot for gain K_p

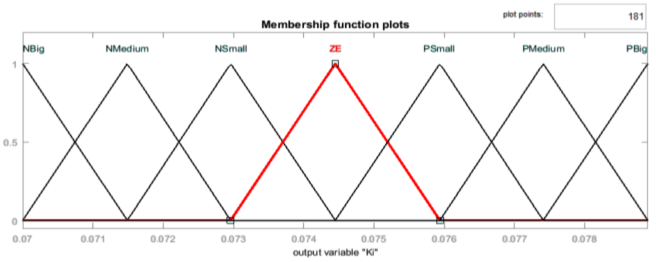

Fig. 8d: MF plot for gain K_i

Fig. 9a and 9b portrays the fuzzy surface viewer illustration of gains K_p and K_i obtained from MATLAB.

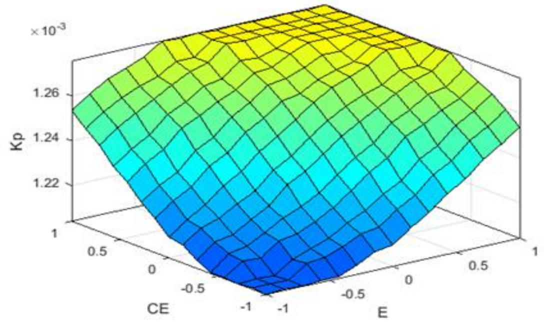

Fig. 9a: Fuzzy surface viewer illustration for gain K_p

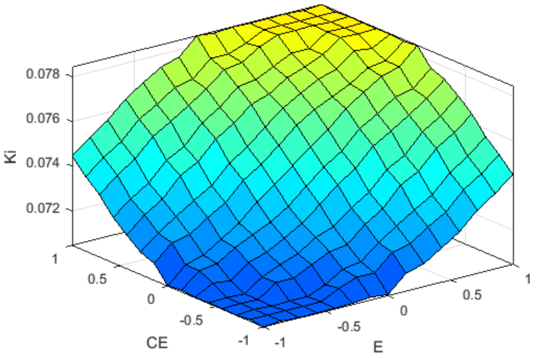

Fig. 9b: Fuzzy Surface viewer illustration for gains K_i

III. SIMULATION RESULTA AND DISCUSSIONS

The proposed system is simulated in MATLAB, and the findings are presented in this section. Table II shows the various parameters of the DC-DC converter used in the simulation.

TABLE II. Simulation Parameters of the DC-DC converter

Parameter	Values
Capacitor C_0	110 µF
Capacitor C_1	22 µF
Capacitor C_2	22 µF
Inductor L	0.5 mH
Switching Frequency	50 kHz
V_0	200 V
P_{out}	200 W

A solar PV module of 300 W_p is utilized here. The output from solar PV is given as input to the switched capacitor-based DC-DC converter. It boosts fluctuating DC voltage from solar PV into a fixed high value of DC voltage suitable for LED lighting applications. Fig. 10 portrays the simulation diagram of the system employed.

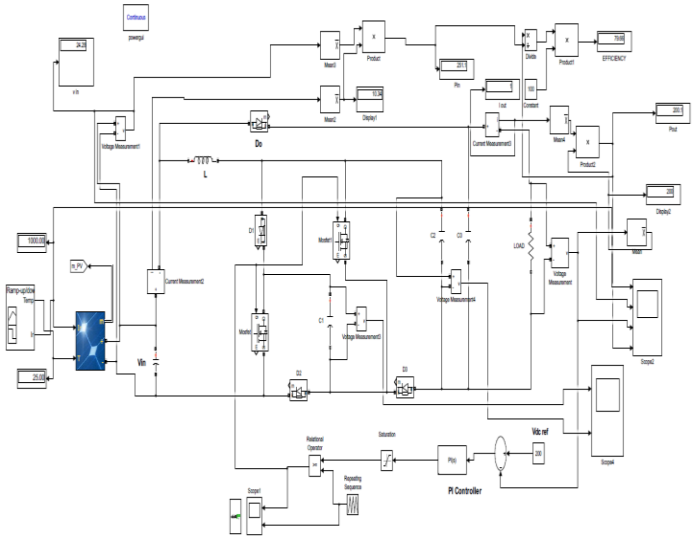

Fig. 10: Simulink diagram of the proposed system

Fig. 11 shows the simulated waveforms with PI controller when solar irradiation is switched from 1000 W/m^2 to 800 W/m^2 at t =0.5 s. The settling time of DC output voltage is 120 ms.

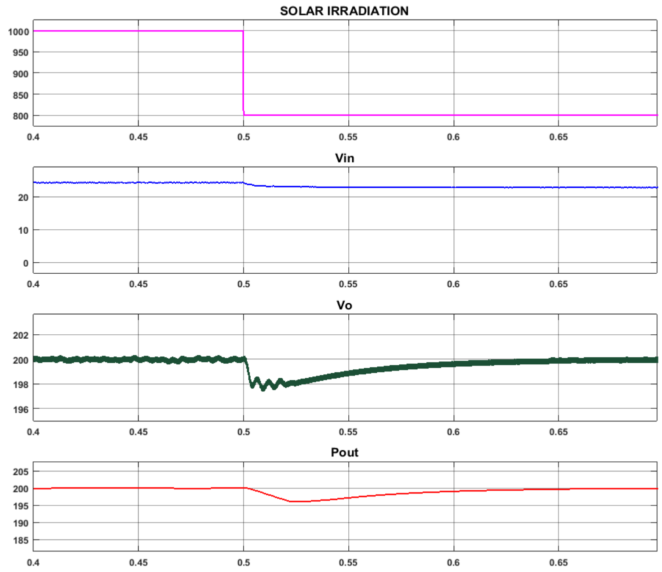

Fig. 11: Simulated waveforms with PI controller with change in solar irradiation

Fig. 12 shows the simulated waveforms with a fuzzy tuned PI controller. The solar irradiation is switched from 1000 W/m^2 to 800 W/m^2 at t = 0.5 s. A settling time of 80 ms is obtained with the fuzzy PI controller.

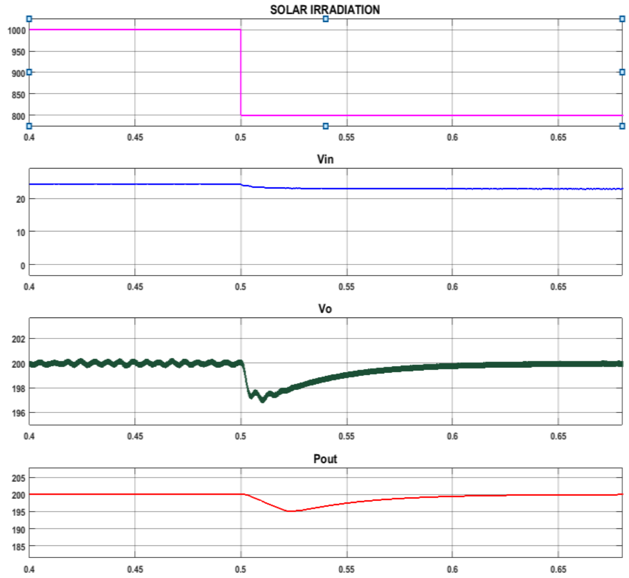

Fig. 12: Simulated waveforms with the fuzzy tuned PI controller with the change in solar irradiation

IV. CONCLUSION

In this work, the low and variable DC voltage obtained from solar PV is boosted with the help of switched capacitor-based DC-DC converter suitable for high power LED applications. The converter output is kept at a constant value irrespective of the output obtained from solar PV with the help of PI and fuzzy PI controller. Simulation results obtained demonstrate that the fuzzy tuned PI controller functions appropriately compared to the PI controller in terms of settling time of DC output voltage.

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