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Comparison of Different Control Techniques for Interleaved DC-DC Converter

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ABSTRACT

Interleaved DC-DC converter with coupled inductor is used in standalone Photovoltaic, battery charger/discharger applications. The main issue of the Interleaved DC-DC converter is that, it does not provide constant output voltage for a change in input voltage. Therefore, the converter efficiency is reduced. Hence to overcome this drawback, proper controller has to be used. In this paper, different control techniques such as PI, PID and Fuzzy logic controller are used. The simulation was carried out using MATLAB/Simulink and the results were compared. Fuzzy logic controller provides better regulated output voltage with less settling time.

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1. INTRODUCTION

In renewable application such as Photovoltaic, ripple free output is required, therefore interleaving technique is used [1]. In intereleaved DC-DC converter, the current is shared and hence current stress of the switch is reduced [2]. By employing coupled inductor, the power handling capacity of the converter can be improved [3]-[4]. The DC-DC converter which is used in industrial application suffers input voltage variation. Thus different control techniques are used to provide proper output for variation in input voltage. PI and PID controllers can produce better output for linear systems [5]-[6]. But for non linear systems, FLC can be used [7]. Fuzzy Logic Controller (FLC) is used in many Engineering applications such as automobile, elevators, air conditioners, home appliances and in DC-DC converters [8]-[9]. Compared to other linear controllers, FLC presents better performance. Fuzzy logic is a heuristic approach method, therefore used for DC-DC converter which undergoes supply voltage disturbances and load disturbances. In [10], different control methods such as voltage control, current control, sliding mode control and Fuzzy logic control were compared. Different DC-DC converter control techniques were discussed in [11] and their advantage and disadvantages were also stated.

In most of the researches, the interleaved boost converter either uses PI or PID controller. In this paper different control techniques such as PI, PID and Fuzzy Logic Controller are used for Interleaved DC-DC converter with coupled inductor which undergoes input voltage variation. Section 2 describes the operation of the interleaved DC-DC converter. Section 3 describes the different control techniques. Simulation results and comparison of all three control techniques were discussed in Section 4 and in Section 5.

2. INTERLEAVED DC-DC CONVERTER WITH COUPLED INDUCTOR

The interleaved DC-DC converter with coupled inductor is shown in Figure 1. The purpose of coupled inductor is to reduce the input current ripples and reduces the size and weight of the converter as the two inductors are magnetically coupled in single core. There are four modes of operation. In mode 1, the switch S_1 and S_2 are ON. The two inductor currents linearly increase. In mode 2, the switch S_1 is ON and S_2 is OFF. The current through inductor L_1 increases and L_2 decreases. The voltage across output capacitor C_3 is $V_{c3}=V_{cb1}+V_{ca1}$. Mode 3 is same as mode 1. In mode 4, the switch S_2 is ON, therefore current through inductor L_2 increases. The voltage across output capacitor C_4 is $V_{c4}=V_{cb1}+V_{ca1}$.

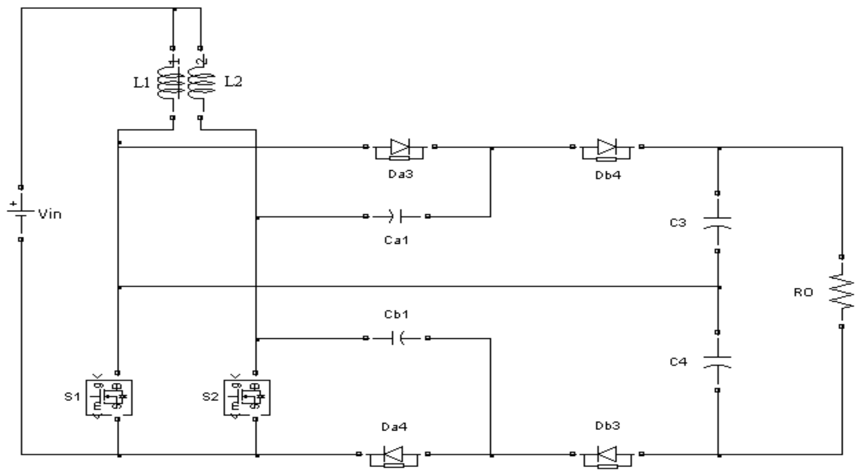

Figure 1. Interleaved DC-DC Converter with Coupled Inductor

3. CONTROL TECHNIQUES

The output voltage of the converter is maintained to a particular value by using different control techniques.

3.1. PI Controller

The output of the system is regulated by Proportional-Integral controller. In this controller, the output of the system is compared with the reference value and the resulting error signal is given to PI controller. Using Ziegler-Nichols method, the value of proportional and integral gain constant were determined. Future error of the system cannot be predicted using PI controller, hence the rise time of the system cannot be decreased and oscillation cannot be neglected.

$$V_o(s) = (K_p + \frac{K_i}{s})E(s) \tag{1}$$

3.2. PID Controller

The derivative gain constant is included along with PI controller to eliminate or to reduce the overshoot. The derivative constant also reduces the oscillation of the output.

$$V_o(s) = (K_p + sK_d + \frac{K_i}{s})E(s) \tag{2}$$

3.3 Fuzzy Logic Controller

Fuzzy logic controller requires linguistic rules. Detailed knowledge of the process to be controlled is required for framing the rules. Figure 2 shows the Fuzzy control block.FLC has four major blocks.

Fuzzification

The crisp inputs are converted into fuzzy inputs. The crisp inputs are the real inputs such as voltage, current, temperature, pressure measured by sensors.

Knowledge base
It is a combination of rule base and database. Rule base uses set of IF..THEN rules. Database describes the membership functions that are used in fuzzy rules.
Interference Engine
This converts fuzzy input to fuzzy output by using set of IF.THEN rules.
Defuzzification
This block converts the fuzzy output to crisp output.

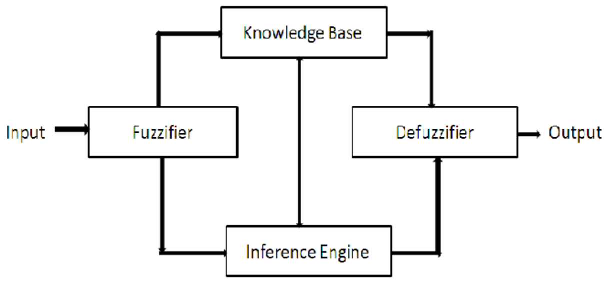

Figure 2. Fuzzy Control Block

4. SIMULATION RESULTS

The Interleaved DC-DC converter with coupled inductor is simulated using MATLAB software under open loop and closed loop. In closed loop, different control techniques such as PI, PID and FLC were used and the results are compared.

4.1. Open Loop

The Interleaved DC-DC converter coupled with inductor is subjected to input voltage variation under open loop condition. The component specification used in simulation is as follows: Blocking capacitor C_{a1}= C_{a2}= 10µF, output capacitor C_3= C_4= 250µF, Switching frequency f_s=40kHz. The input and the corresponding output voltage waveform is shown in Figure 3. Figure 4 shows the corresponding output power variation of the converter under open loop condition. Thus, when input voltage is 25V, the output of the converter is 400V and output power is 400W. At 0.3sec when the input voltage is incremented by 5V, the output voltage increases to 480V and the corresponding output power increases to 480W. Thus, under open loop condition, the output voltage of the converter is not regulated.

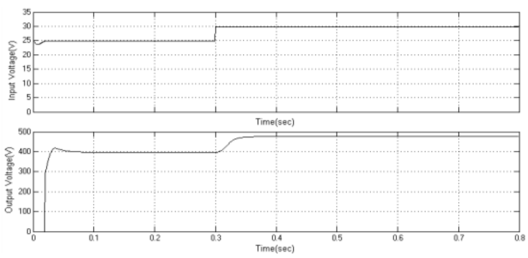

Figure 3. Input and Output Voltage Waveform of the Converter Under Open Loop

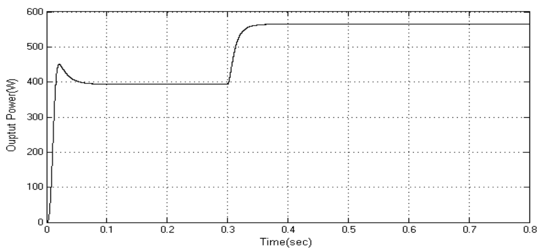

Figure 4. Waveform of Output Power of Converter under Open Loop

4.2. PI Controller

The output voltage of the converter is regulated by proportional integral controller. In this controller, the output voltage of the converter is compared with the set value and the resulting error signal is given to PI controller. Using Ziegler-Nichols method, the value of proportional gain constant and integral gain constant is obtained as 0.5 and 9 respectively. This controlled signal is given to produce pulse for the converter switch.Figure 5 shows the simulation circuit diagram of Interleaved Converter using PI controller. Figure 6 represents the input and output voltage waveform of the converter when PI controller is used. Figure 7 represents output power of the converter.It was found that using PI controller, the output voltage is regulated but with a overshoot of 32V and output power with a overshoot of 60W. Using PI controller the settling time was found to be t_s=0.62sec for which the output reaches steady state.

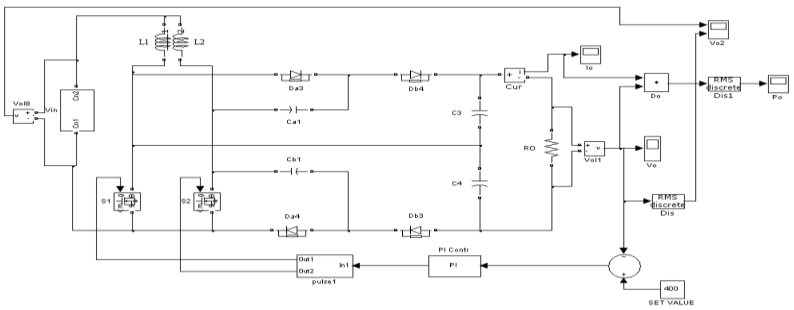

Figure 5. Simulation Circuit Diagram of Closed Loop Interleaved Converter using PI Controller.

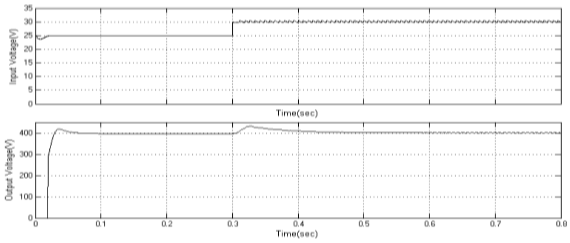

Figure 6. Input and Output Voltage Waveform of the Converter using PI Controller

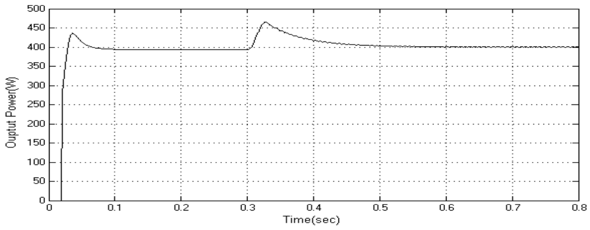

Figure 7. Output Power Waveform of the Converter using PI Controller

4.3. PID controller

The response signal of the converter is compared with set value and the error signal obtained is given to PID controller. The controller generates control signal which is used to produce the pulses to the switches. Using Ziegler-Nichols method, K_p, K_i and K_d value are obtained as 0.5, 9 and 0.02 respectively. Figure 8 shows the PID controller and PWM block. Figure 9 shows the input and output voltage waveform of the converter. Figure 10 shows the output power waveform of the converter.At 0.3sec, when the input voltage is varied from 25V to 30V , it was found that using PID controller, the output voltage is regulated but with a overshoot of 20V and the output power with a overshoot of 40W. The settling time to reach steady state was found to be 0.6sec.

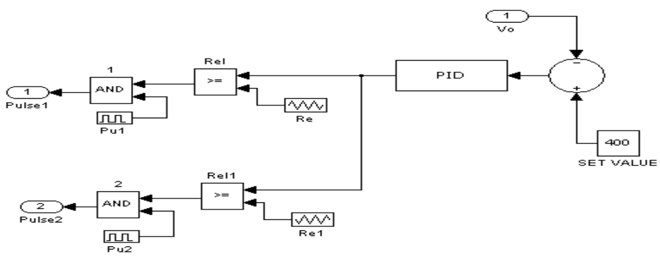

Figure 8. PID and PWM Block

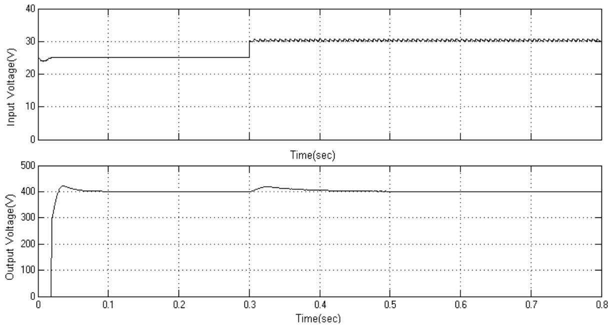

Figure 9. Input and Output Voltage Waveform of the Converter using PID Controller

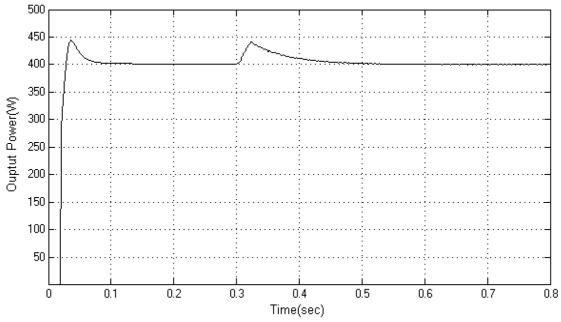

Figure 10. Output Power Waveform of the Converter using PID Controller

4.4. Fuzzy Logic Controller

For framing the linguistic rules, proper knowledge of the converter duty cycle is required. The following conditions have to be checked for fuzzy logic controller

1. If the response of the converter deviate more from the set value, then the duty cycle should be increased to bring the response to set value.
2. If the response is towards the set value, then duty cycle is slightly adjusted.
3. If the response is near to set value, then duty cycle is made constant
4. If the response is above the set value, then the duty cycle is made negative.

In fuzzification, two inputs namely error and change in error is fed. Error is the comparison of output voltage of the converter and set value.

$$e(t) = V_{ref} - V_o(t) \quad (3)$$

change in error,

$$ce(t) = e(t) - e(t-1) \quad (4)$$

Therefore, the change in error is the difference in present and past error. The error and change in error are represented as membership function in fuzzification. The membership functions used for input and output are NB, NS, ZE, PS, PB where NB=Negative Big, NS=Negative Small, ZE=Zero Equal, PS=Positive Small, PB=Positive Big.

Using membership function, certain rules are framed to get the output which decides the duty cycle of the switch and it is given in Table.1

Table 1. Fuzzy Control Rules

CE / E	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PB	PB
PS	NS	ZE	PB	PB	PB
PB	ZE	PS	PB	PB	PB

The Fuzzy logic control block is represented in Figure 11. Figure 12 shows the inputs and output of the controller which has proper membership function. The input and output voltage waveform of the converter is represented in Figure 13. The output power waveform of the converter is shown in Figure 14. It was found that using FLC, the output voltage and output power are regulated without any overshoot even when there is a input voltage disturbance. The settling time to reach the steady state is 0.04sec.

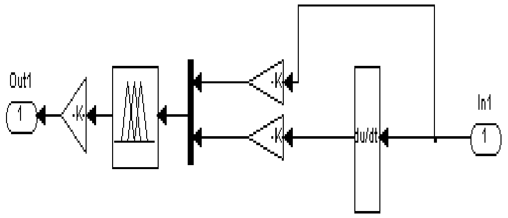

Figure 11. Fuzzy Logic Control Block

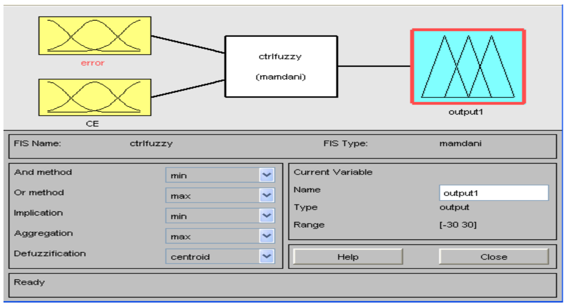

Figure 12. Inputs and Output of FLC

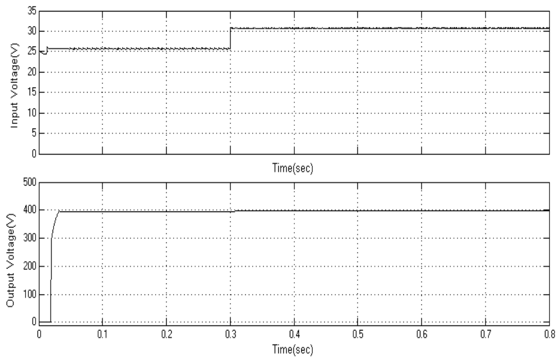

Figure 13. Input and Output Voltage Waveform of the Converter using FLC

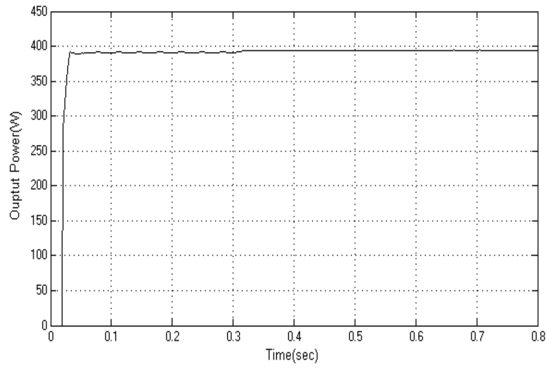

Figure 14. Output Power of the Converter using FLC

5. CONCLUSION

The interleaved DC-DC converter with coupled inductor is simulated under open and closed loop. In closed loop, the output voltage of the interleaved DC-DC converter with coupled inductor is regulated by different control techniques such as PI, PID and Fuzzy Logic when the input voltage is subjected to disturbances. With PI and PID controller, the output voltage is regulated but with a overshoot of 32V and 20V respectively. Using PI and PID controller the settling time of response is found to be 0.62 sec and 0.6sec respectively. Fuzzy logic controller gives better output without any overshoot and with less settling time of 0.04sec.

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