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Design and Implement Regulated DC-DC Interleaved Flyback Converter by Using Intelligent Controller in Airborne Application

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Abstract. This paper is designed, simulated and implemented DC-DC interleaved Flyback converter controlled by Arduino Uno which converts input voltage from battery 12 V to 180 V DC at 20 kHz for 120 W. Digital control design is done with the use of Arduino Uno microcontroller. Simulation carried out using MATLAB/Simulation. The objective of this paper is to design a DC converter that operates at low cost with high efficiency via improving Flyback converter topology. This occurs using interleaved Flyback converter. To obtain a regulated output voltage of the interleaved Flyback converter, closed-loop feedback with PI controller is employed (Proportional – Integral). The duty cycle is varied to control the output voltage and produced constant voltage under variation input voltage and load disturbance. The designed technique uses voltage mode control (VMC) to obtain a constant voltage under continuous conduction mode (CCM). To implement the interleaved Flyback converter with the PI controller, the microcontroller Arduino Uno is used. The Simulation and the practical results give a little output ripple voltage, current, and high efficiency 6% compared with conventional Flyback converter.

Keyword: Arduino Uno, aircraft (airborne) power supply, CCM, ferrite core, Interleaved Flyback, PI, VMC, MOSFET

1. Introduction

The Flyback converter is widely used in power electronics such as switch power supply, renewable energy application, aircraft (airborne) power supply and household electronic equipment where the output voltage of the load is required to be isolated from the input voltage source [1]. It is used in the low power range because it requires less components. The Flyback converter needs high frequency for operating which increases in switch losses and electromagnetic interference (EMI). Furthermore, the stress of the voltage and current of the MOSFET (switch) experienced from inductance leakage of the transformer. The result increases the peak voltage and current which causes low efficiency [2]. Furthermore, Flyback converter with a single transformer has high leakage inductance and flux. This causes a small efficiency of the transfer energy. For this reason, it is not used for high voltage and high-power systems and it is limited to the low power applications. Therefore, the objective of this paper is to develop a converter system by improving the Flyback converter topology at high power by using interleaved Flyback converter. The interleaved Flyback converter is used to reduce the output ripple voltage, the output ripple current, switches losses and size of the output capacitor. The DC-DC interleaved Flyback converter is used in a switch mode power supply (SMPS) with a closed-loop



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system to give a regulated output voltage. The converter with the closed-loop system is better sensitive to an environmental condition such as output voltage. Another most important advantage is that if there is any change in the specification, we do not need to change the component like the analogue controller, instead, we need to change the program so flexibility is greater than the analogue controller. It is also very compact and requires less area and mostly it is not very expensive.

The interleaved Flyback converter consists of two Flyback converters which connected in parallel and shares the same source [3]. This paper proposed a new digital PI controller used with interleaved Flyback controller which used microcontroller Arduino Uno. It is controlled by PI controller and implemented by microcontroller Arduino Uno to give constant output voltage under variation input voltage and load disturbance. PI controller employed to eliminate the steady-state errors and reduce overshoot of step response [4]. It gives stability to the system by sending the signal to the PI controller to change the duty cycle to obtain a constant output voltage under variable input voltage or load. The core of the controller is ATmega328 16MHz. It can be supplied from the USB of the computer. The driver IR2110 is employed to derive the MOSFET switch. The control technique is obtained by using PWM via VMC to improve the response of the control system. This paper proposed a design digital controller for interleaved Flyback converter. The digital controller has better flexible and rapid response for variation in the input voltage and load.

2. Configuration and Operation Interleaved Flyback Converter

Figure 2 shows the basic interleaved Flyback converter circuit diagram. It consists of two Flyback converters which have the same component. The two identical Flyback converter is connected in parallel and shared the same source to work in interleaved Flyback style [5]. The two Flyback converters consisted of one switch (MOSFET), one Diode, one capacitor, and one transformer. The gating signal of the two switches has the same magnitude and display from each other about 180 degrees. The introduced converter operates in two modes. When MOSFET 1 has ON state and MOSFET 2 is in OFF state, the primary current of the transformer (TF1) linearly increased and energy stored in transformer one. The diode 1 is being in reverse biased and the current will not pass through the load. But the load supplied from converter two during MOSFET 2, in turn, OFF (from the previous state). When MOSFET 2 turned ON and MOSFET 1 turned OFF the primary current of (TF2) linearly increased and the energy is stored in the primary winding of transformer two. The diode 2 is being in reverse biased and no current passes through load from converter two. The load supplied from converter one due to the diode 1 is forward biased (from mode one) [6-7]. Figure 3 shows the principle operation of the interleaved Flyback converter.

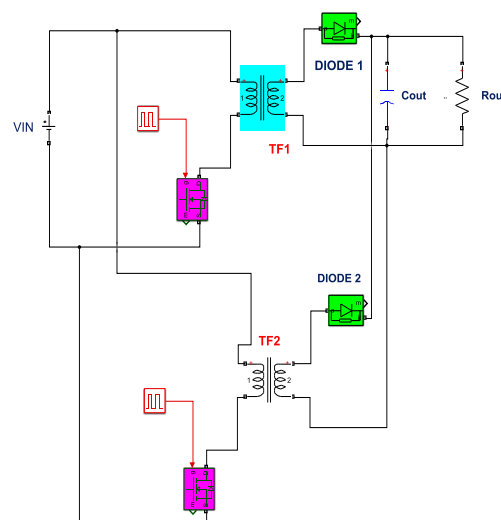


Figure 1. Schematic of an Interleaved Flyback Converter

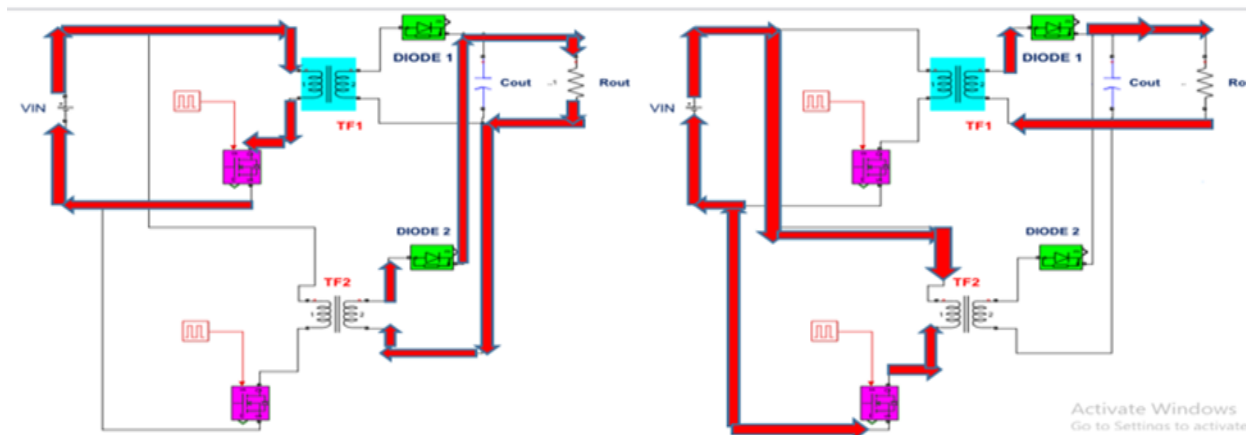


Figure 2. Principle operation of interleaved Flyback converter.

3. Flow Chart of the Proposed Converter with Intelligent Controller

To produce pulse width modulation signal, the Arduino controller is used. In this controller system, the output voltage from the converter is compared with references voltage and the differential value is sent to the microcontroller to produce the duty cycle. Figure 1 shows the flow chart for a converter with a controller. The duty cycle increased or decreased depending on the variation in the load or input voltage.

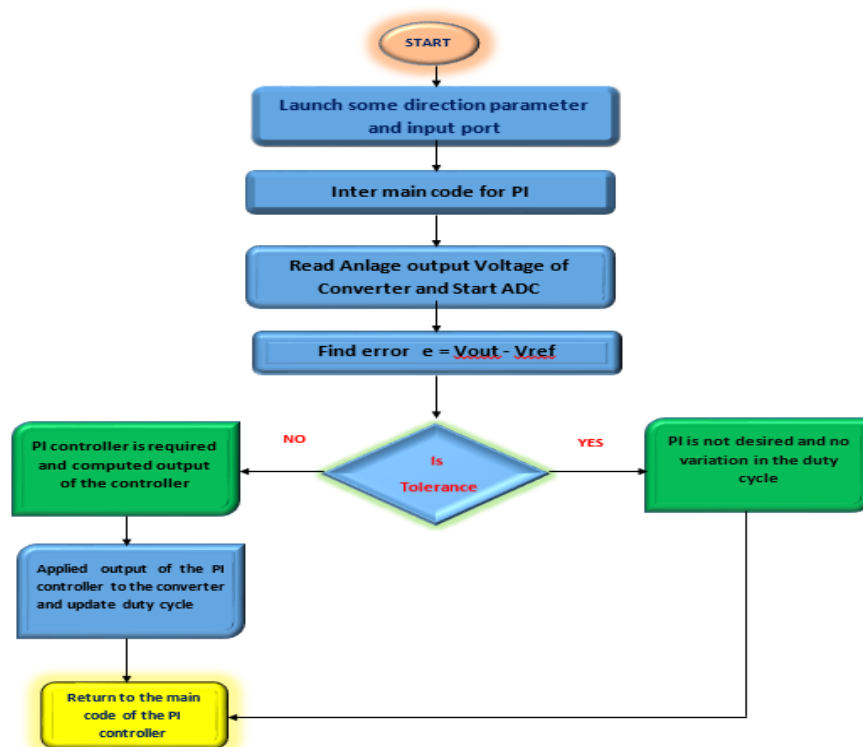


Figure 3. Flow Chart of proposed converter

4. Interleaved Flyback Converter with PI Controller

PI controller is widely used in control system because it has fewer parameters (proportional and integral) and simple in design. The interleaved Flyback converter has two switch MOSFET 1 and MOSFET 2. The two switches are controlled by a PI controller. The output voltage of the converter and the reference are compared to produce the error signal. The error signal is sent to the PI controller to reduce the overshoot and to make the steady-state error of the converter to zero. The output of the PI controller is supplied with PWM to switches. Figure 4 shows the block diagram of the PI controller with interleaved Flyback converter. To find the parameters of KP and KI, The Ziegler–Nichols tuning method is a heuristic method of tuning a PI controller [8-9].

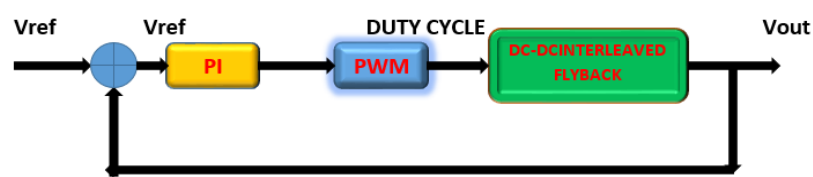


Figure 4. Block Diagram of PI Controller with Converter

5. Simulation Model and Results

The interleaved Flyback converter simulated by MATLAB/Simulink (shown in Figure 5) for output voltage 180 V with 120 W from input voltage 12 V. The normal duty cycle for the interleaved Flyback or Flyback converter limited from 0.1 to 0.5. The steady-state errors without using PI controller 22%. Therefore, the interleaved Flyback converter with PI controller eliminates the steady-state error and improves the performance of the system. The interleaved Flyback converter with PI controller is tested under two different input voltages (10 – 14) V and load (270-1000) Ω . It gives a regulated output voltage about 180 V under variable input voltage and loads with the help of PI controller. Figure 6 shows the simulation waveforms of interleaved Flyback converter.

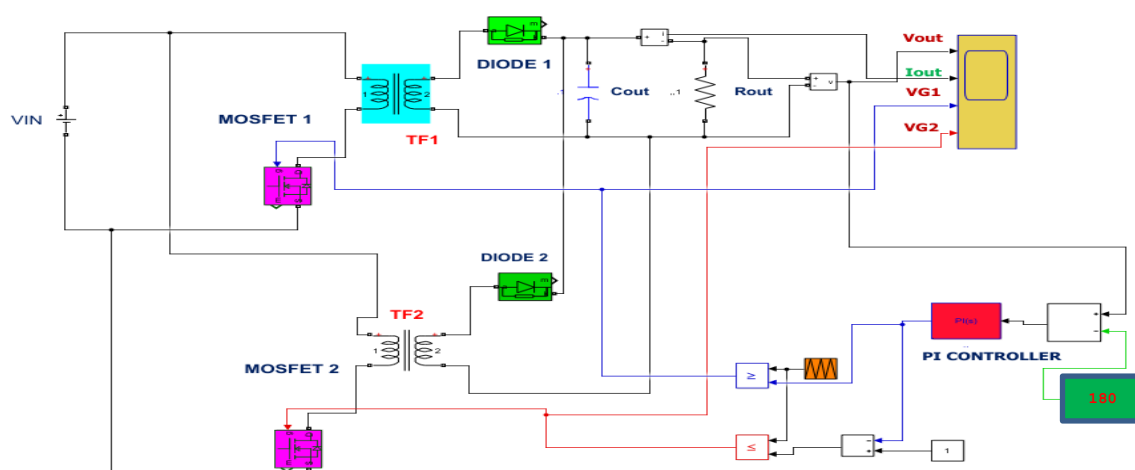


Figure 5. Interleaved Flyback Converter Controlled by PI Controller

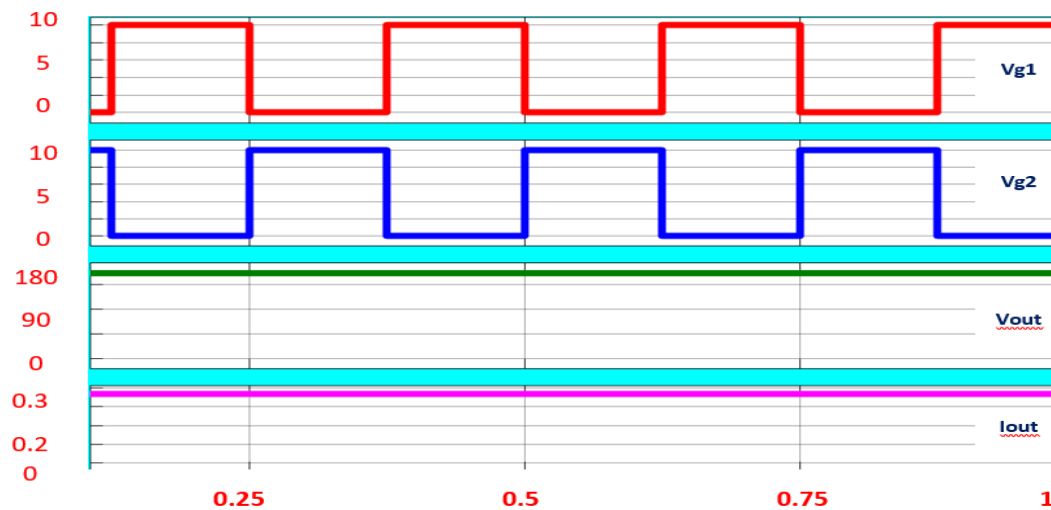


Figure 6. Waveforms of Interleaved Flyback Converter

From simulated results (shown in Table 1, Table 2 and Table 3), the interleaved Flyback converter with PI controller gives fast response and better flexibility in the control system under variation in the input voltage and load.

Table 1. Output Voltage with Variation in the Input Voltage at Constant Load (270 Ω)

Input Voltage (V)	10	11	12	13	14
Output Current (A)	0.66	0.66	0.67	0.6	0.6
Output Voltage (V_o)	180.6	180.8	180.6	180.6	180.6

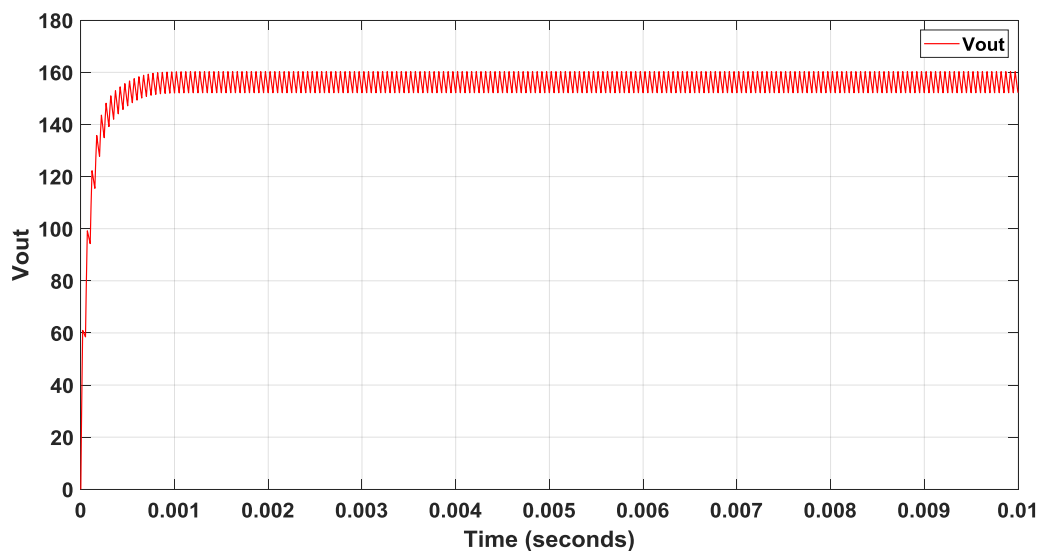
Table 2. Output Voltage with Variation in the Resistive Load at Constant Input Voltage (12 V)

Load Resistance (Ohm)	270	500	800	900	1000
Output Current(A)	0.67	0.36	0.22	0.19	0.17
Output Voltage (v)	179.6	179.7	179.8	179.8	179.8

Table 3. Output Voltage with Variation in the Input Voltage and Load

Input Voltage(V)	10	11	12	13	14
Load Resistance (Ohm)	270	500	800	900	1000
Output Current(A)	0.67	0.35	0.21	0.19	0.18
Output Voltage (V)	179.6	179.7	179.8	179.8	179.8

The second part of the simulated results based on the comparison between the interleaved Flyback converter and the conventional Flyback converter. According to the simulation results, the output voltage is higher than the conventional converter with less ripple in the output voltage and current, therefore, the efficiency increased by about 6%. Figure 7 and Figure 8 show the waveforms of the conventional Flyback converter.

**Figure 7.** Output voltage of Flyback converter

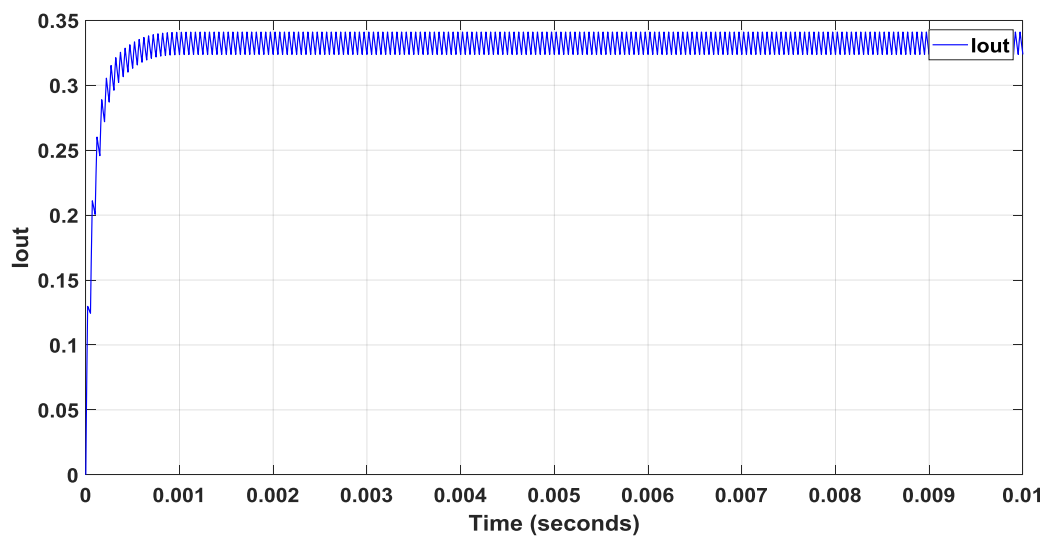


Figure 8. Output current of Flyback converter

Figure 9 and Figure 10 show the waveforms of the interleaved Flyback converter and then interleaved Flyback converter reduced the output ripple voltage and the output ripple current and increased the efficiency.

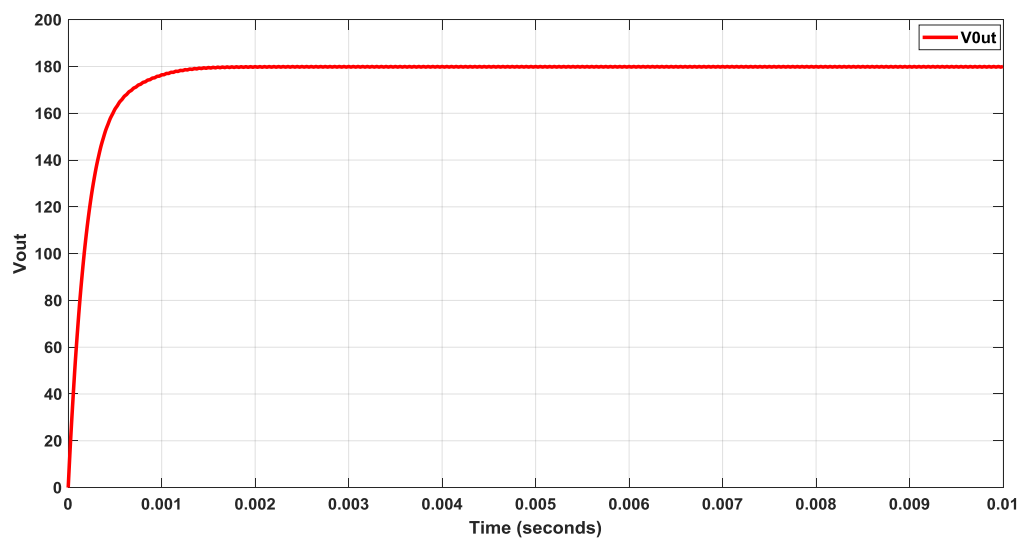


Figure 9. Output voltage of interleaved Flyback

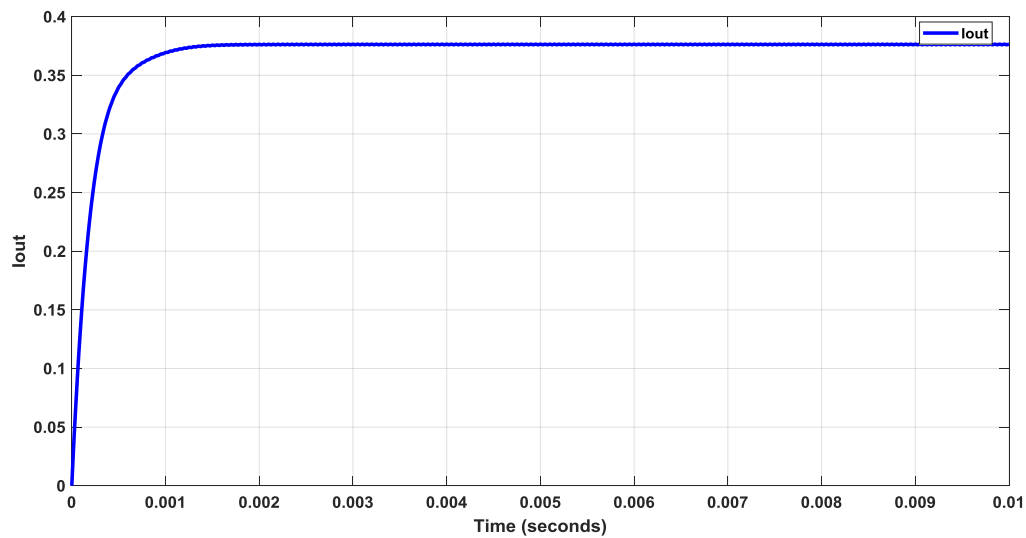


Figure 10. Output current of interleaved Flyback

The table below shows the parameter design of the interleaved Flyback and Flyback converters [10].

Table 4. Parameter of Interleaved Flyback Converter Compared with the Conventional Flyback Converter

Parameter	Flyback converter	Interleaved Flyback converter
Input voltage	12	12
Output voltage	150	180
Efficiency	78%	84%
Magnetizing inductance	13 mH	13 mH
Output capacitance	220 uF	220 uf
Output power	50 W	120 W

6. Hardware Implementation

The interleaved Flyback converter circuit is shown in Figure 11. To implement the interleaved Flyback with PI controller the Arduino Uno microcontroller is used. The interleaved Flyback converter with closed-loop feedback is presented to obtain a regulated output voltage. Depending on the variation in the input voltage or load, the duty cycle of the switch is increased or decreased. Arduino Uno is used to produce a pulse width modulation to control the duty cycle of two switches (MOSFET 1 and MOSFET 2). The gate driver with IC IR2110 is used with each MOSFET.

The duty cycle of gate 1 is displaced from gate 2 by 180 degrees (as shown in Figure 12). From the results, the output ripple voltage and output ripple current of interleaved Flyback converter is reduced compared to the conventional Flyback converter.

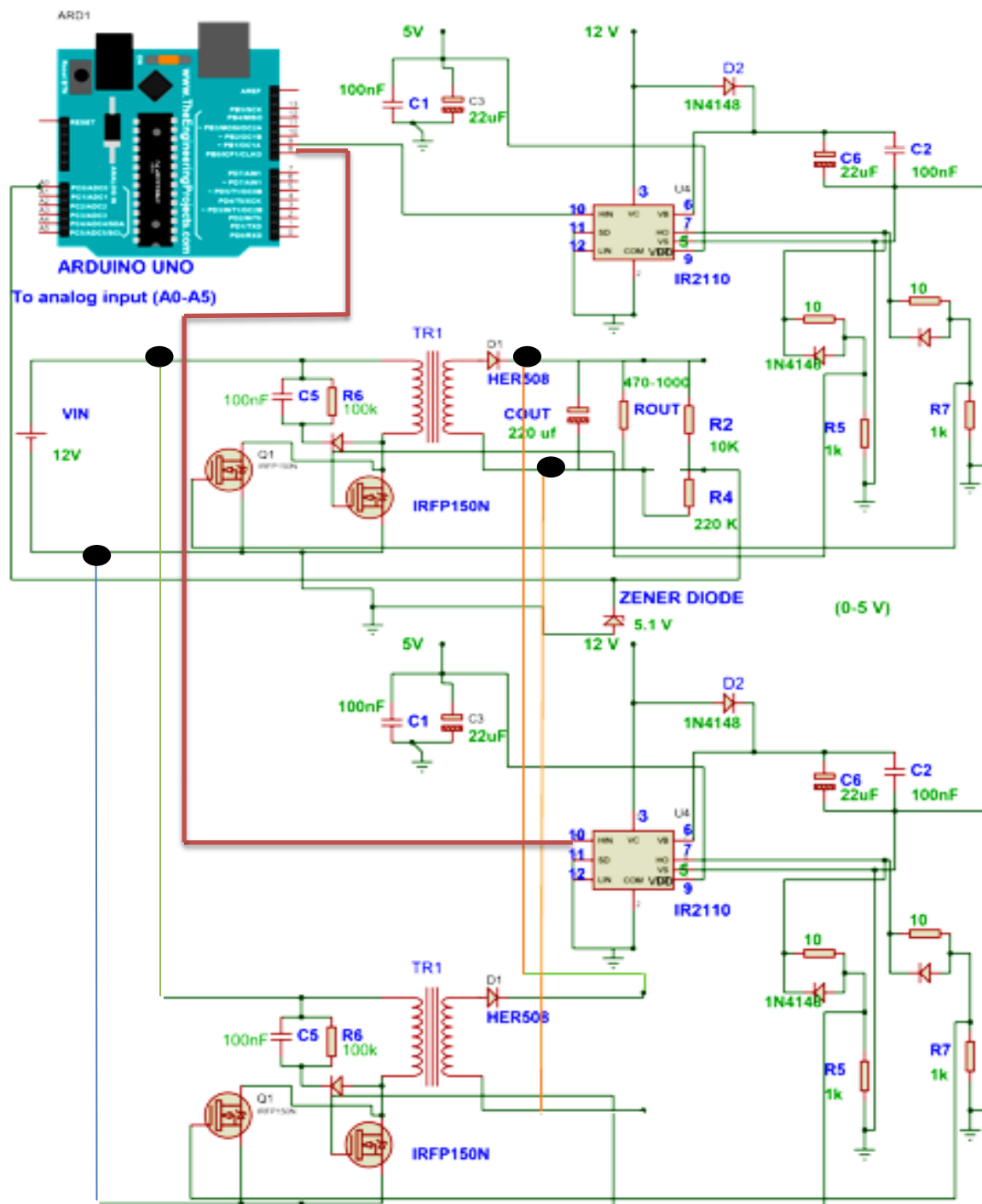


Figure 11. Complete Circuit Design of Interleaved Flyback Converter

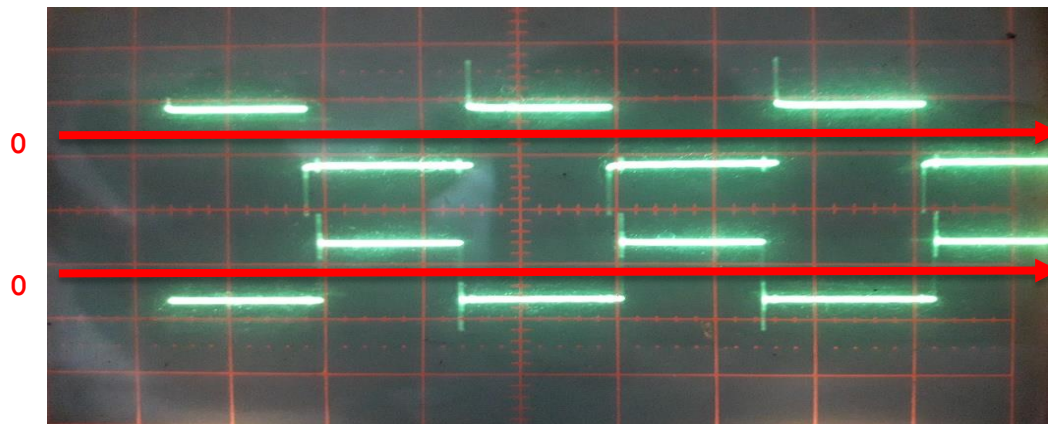


Figure 12. Gate Pulses Switches (ch1, ch2, 5 V/div, 20us)

Figure 13 and Figure 14 show the output voltage of the conventional Flyback converter and interleaved Flyback converter respectively.

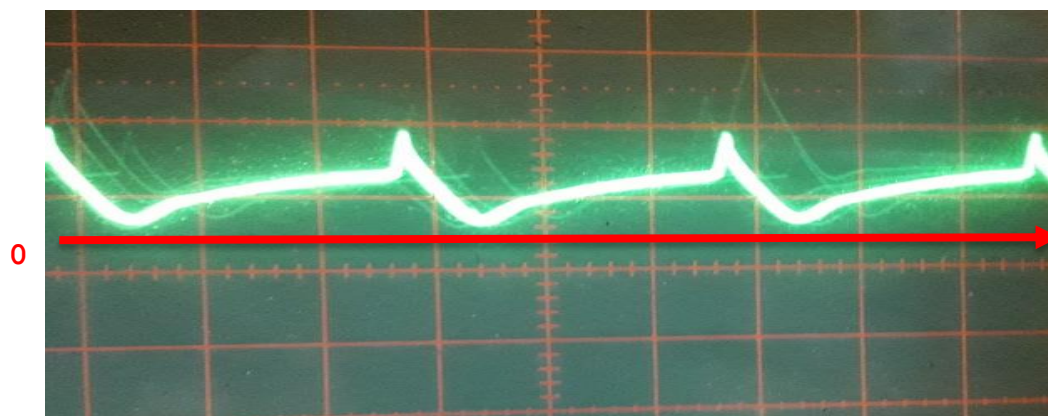


Figure. 13. DC Output Voltage Waveform of Flyback Converter (ch1, 20 V/div, 20us)

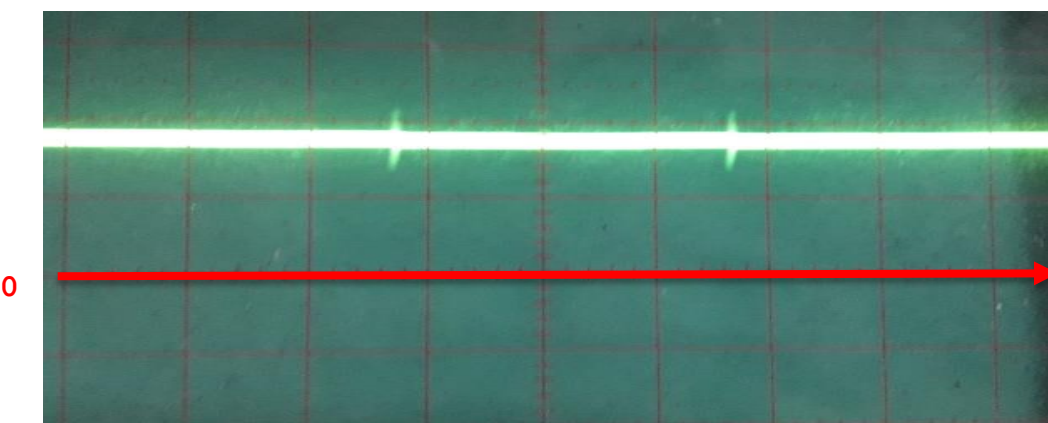


Figure 14. DC Output Voltage Waveform of Interleaved (ch1, 20V/div, 20us)

Figure 15 and Figure 16 shows the output secondary voltage for conventional Flyback converter and interleaved Flyback converter, respectively. The interleaved Flyback converter consists of two conventional Flyback converter which are connected in parallel. This proposed assures that the output power does not cut off on the load during ON and OFF switching while the load supplied only during

OFF state in the conventional Flyback converter. Therefore, the efficiency and the output voltage are increased. The proposed converter gives output voltage of 180 V, 120 W at variation in the input voltage and load disturbance.

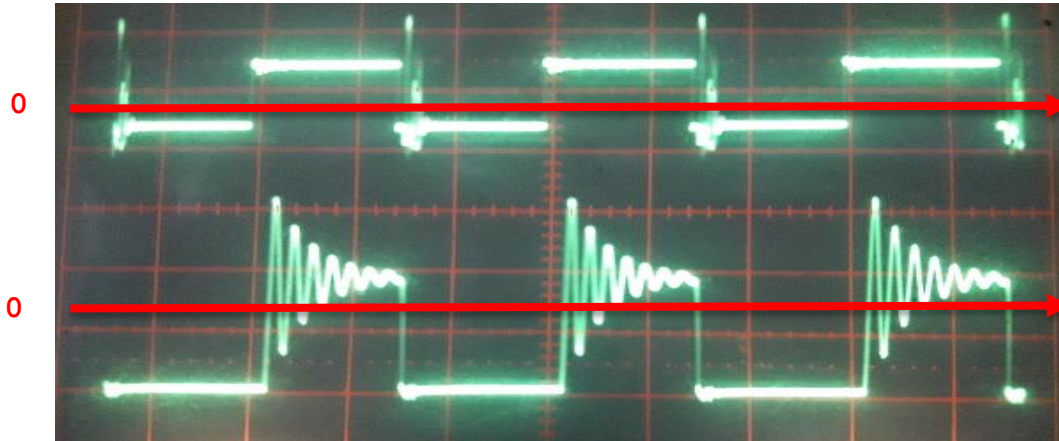


Figure 15. Secondary Voltage of Conventional Flyback (ch2, 20 V/div, 20us) with gate pulse (ch1, 5 V/div, 20us)

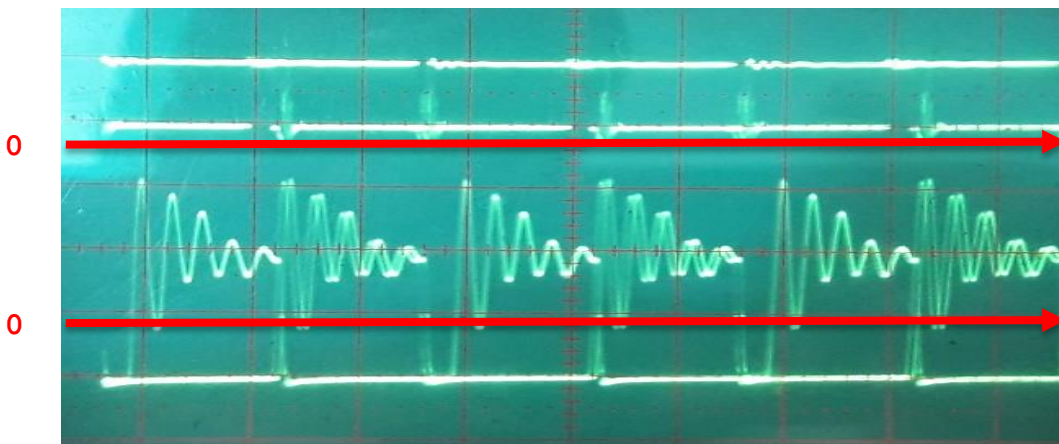


Figure 16. Secondary Voltage of Interleaved Flyback (ch3, ch4, 20 V/div, 20us) with gate pulse (ch1, ch2 5 V/div, 20us)

The voltage applied on the analog input pin (A0) less than 5 V. Therefore, a voltage divider employed on the terminal of the converter to step-down voltage to the range of Arduino Uno pin. It consists of two resistances which has high value in order to minimize the losses ($p = I^2.R$). Figure 17 shows the practical hardware circuit of interleaved Flyback converter. To increase the converter redundancy, two MOSFET are connected in parallel [11].

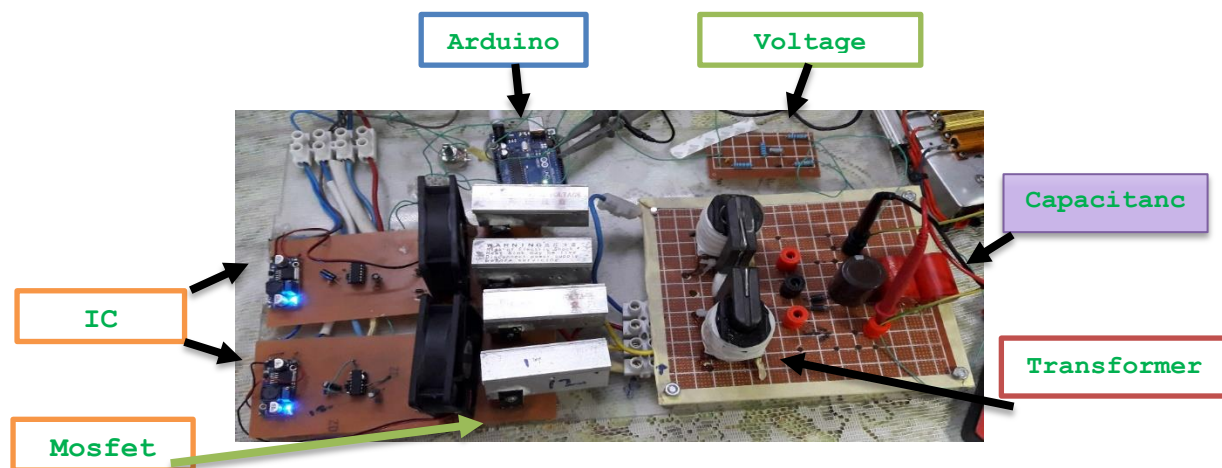


Figure 17. Hardware Prototype of Interleaved Flyback Converter

7. Conclusion

This paper proposed a design and implementation of the DC-DC interleaved Flyback converter with PI controller. PI controller is simulated by MATLAB/Simulink. The hardware of the converter is implemented by Arduino Uno. It employs and represents a digital PI controller to regulate the output voltage. Since Arduino Uno is presented, it gives fast response and better flexibility at any change in the input voltage and load disturbance. This converter gives a constant voltage of 180 V with very low output ripple voltage, then low output ripple current and improved the efficiency by 6% compared to the conventional Flyback converter.

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