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A Comparative Analysis of Integrated Boost Flyback Converter using PID and Fuzzy Controller

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ABSTRACT

This paper presents a comparative analysis of Integrated boost flyback converter for Renewable energy System. IBFC is the combination of boost converter and fly back converter. The proposed converter is simulated in open and closed loop using PID and FUZZY controller. The Fuzzy Logic Controller (FLC) is used reduce the rise time, settling time to almost negligible and try to remove the delay time and inverted response. The performance of IBFC with fuzzy logic controller is found better instead of PID controller. The simulation results are verified experimentally and the output of converter is free from ripples and has regulated output voltage.

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1. INTRODUCTION

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas such as electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services [1-3]. Modern renewables such as hydro, wind, solar and biofuels, as well as traditional biomass are contributed in about equal parts to the global energy supply. Rapid development of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation and economic benefits [4-7].

Fossil fuels such as coal, oil, and natural gas are non-renewable, they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve [8-12]. In contrast, renewable energy resources-such as wind and solar energyare constantly replenished and will never run out. For renewable energy systems, power electronics play a vital role. Sometimes they are the most expensive part of the system. Reducing cost, increasing efficiency and improving reliability of power electronics and electric machines are the technical challenges facing wider implementation of renewable energy power generation [13-17]. Renewable energy sources derive their energy from existing flow of energy, form on-going natural processes such as sun, wind, flowing water and geothermal heat flows. The most feasible alternative energy sources include solar, fuel cell and wind.

Fossil fuels are depleting day by day, therefore it is imperative to find out alternative methods in order to fulfill the energy demand of the world. Renewable energy is becoming more important nowadays. There exist applications of renewable energy which employ hundred of MW (high power) and there are also those which uses hundred of W (low power). Applications can also be classified depending if they are connected to the grid or not, as well known as cogeneration and stand alone systems [18-22]. This last one is a low power application, especially employed in remote places, where electricity is not available. Usually photovoltaic and wind systems are the source of energy in stand alone systems.

The conventional boost converters are not preferred, because at high voltage duty ratio it causes severe losses in power devices and high voltage stress across the switching devices. The diode reverse recovery problem increases the conduction losses, degrade the efficiency and limit the power level of conventional boost converter [23-25]. Owing to this scenario Integrated boost flyback converter is designed to reduce these problems and to interface with renewable energy system.

2. INTEGRATED BOOST FLYBACK CONVERTER (IBFC)

Integrated boost flyback converter is suitable for renewable energy system. Boost converter and flyback converter are connected serially to achieve high output voltage gain using coupled inductor technique shown in Figure 1. The input inductor is introduced in the proposed circuit to avoid the sudden damages in power devices and diode reverse recovery problem. The advantage of the switched capacitor reduces the voltage stress in power devices, but the diodes create a large current path which causes the conduction losses. To rectify this, active switch method is adopted to increase the voltage gain and efficiency [26-30].

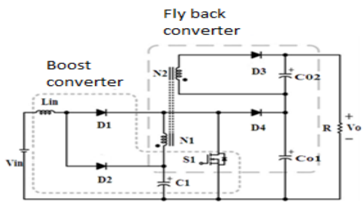


Figure 1. Circuit diagram of Integrated boost flyback converter

In active switch method the leakage energy is recycled via coupled inductor without wasting the energy. When switch is turned off, the leakage energy is recycled and it improves the efficiency of the converter. The proposed converter eliminates the switching losses and recycles the leakage energy. The transformer primary terminal and secondary terminal are connected in series for fast switching operation. In this proposed converter high step-up voltage is obtained by single power switching technique operating at low duty cycle with transformer inductors, switched capacitors and power diodes. In particular, the two stages are driven by a single switch S_1.

The features of the proposed converter are as follows:

a) The integrated boost flyback converter is effectively extended to a voltage conversion ratio and the first boost stage is benefited by input current ripple reduction.
b) In the second stage the leakage inductor energy of the coupled inductor can be recycled, which reduces the voltage stress on the active switch.

3. SIMULATION RESULTS

The Integrated Boost Flyback converter consists of boost converter and fly back converter driven by a single switch.IBFC is simulated in both open and closed loop ,with and without disturbance using MATLAB simulink and the results are presented. Scope is connected to display the output voltage.

The following values are found to be a near optimum for the design specifications:

Table 1. Simulation Parameters

Parameter	Rating
Input voltage	48 V
Input inductor L_{in}	29 µH
Magnetizing inductor L_m	94µH
Co1= Co2	220µF
C1	1000 µF
Lk1=Lk2	500 µH
Switching Frequency	50kHz
Diode	IN 4007
MOSFET	IRF840
Transformer turn ratio	1:4
R	200Ω
DC Motor	5HP,240,1750 RPM

3.1. Open Loop IBFC without Disturbance

Figure 2 shows the simulated diagram of open loop Integrated boost flyback converter with R-load and its output is measured.

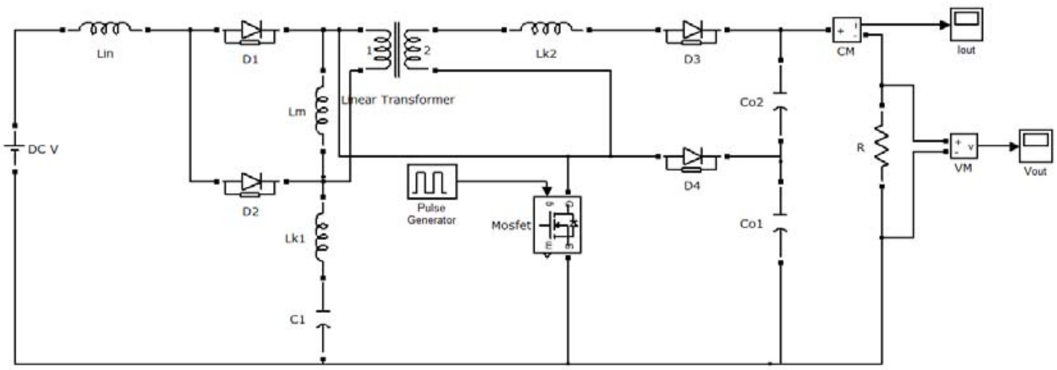
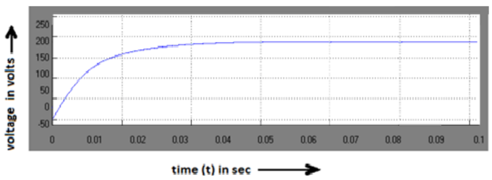


Figure 2. Simulated diagram of IBFC with R-load

Figure 3 shows the Output voltage of open loop Integrated boost flyback converter with R-load. Figure 4 shows the Output current of open loop Integrated boost flyback converter with R-load.



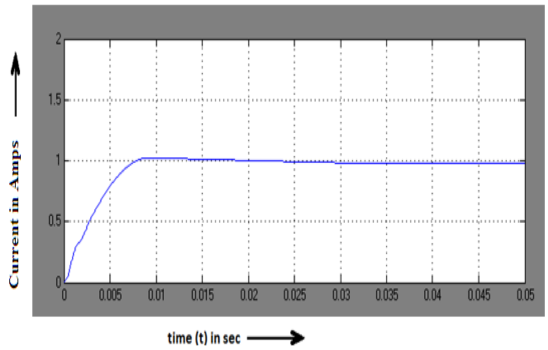


Figure 3. Output voltage

Figure 4 Output current

3.2. Open Loop IBFC with Disturbance

Open loop Integrated Boost Flyback converter with disturbance is simulated using R, RL, RLE load. In open loop system output can be varied by varying the input and the corresponding output voltage is measured.

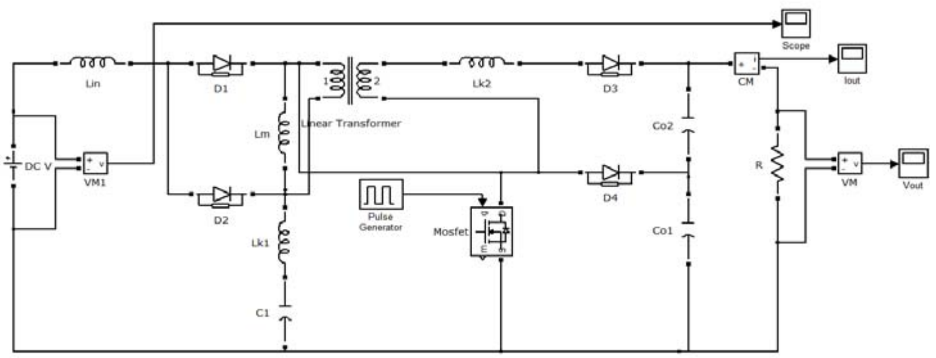


Figure 5. Simulated diagram of IBFC with R-load

Figure 5 shows the input disturbance is applied to the Integrated Boost Flyback converter with R-Load and its output is measured.

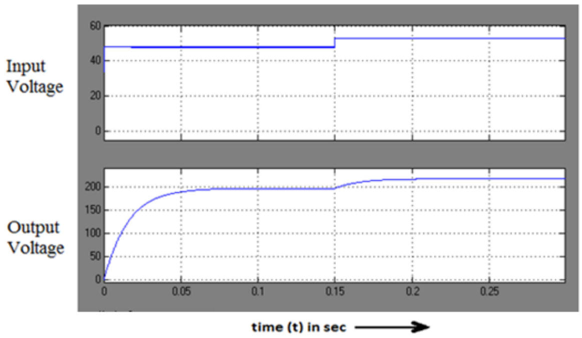


Figure 6. Input and output voltage of IBFC with R - load

Figure 6 shows the input disturbance in increasing the input voltage from 48V to 58V at 0.15sec. At 0.15sec the output voltage increases from 200 to 210V due to the additional voltage source applied at the input.

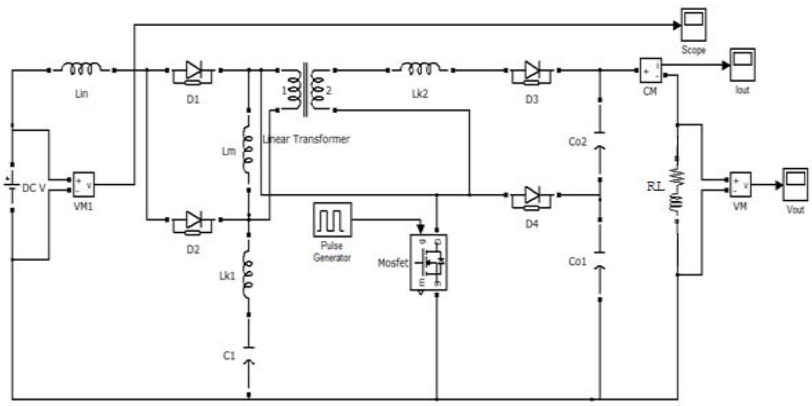


Figure 7. Simulated diagram of IBFC with RL-load

Figure 7 shows the input disturbance is applied to the Integrated boost flyback converter with RL-Load and its output is measured.

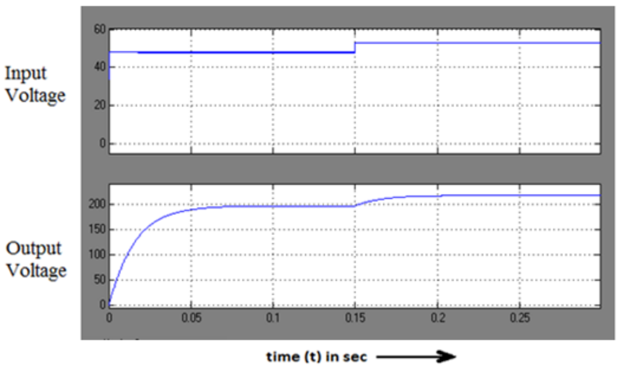


Figure 8. Input and output voltage of IBFC with RL-load

Figure 8 shows the input disturbance in increasing the input voltage from 48V to 58V at 0.15sec. At 0.15sec the output voltage increases from 200 to 210V due to the additional voltage source applied at the input.

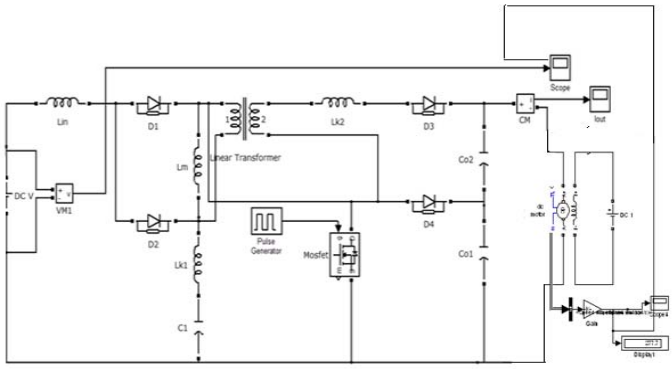


Figure 9. Simulated diagram of IBFC with RLE-load

Figure 9 shows the input disturbance is applied to the Integrated boost flyback converter with RLE-load and its output is measured.

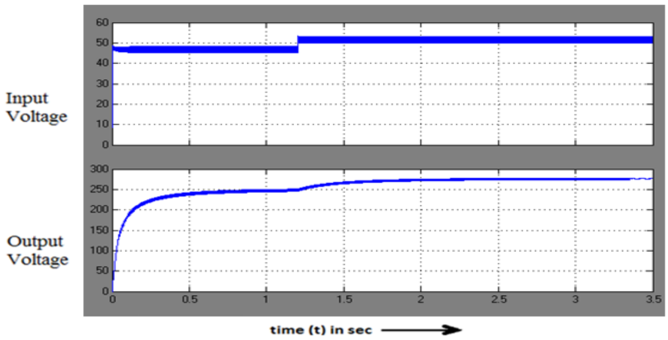


Figure 10. Input and output voltage of IBFC with RLE- load

Figure 10 shows the input disturbance in increasing the input voltage from 48V to 58V at 1.25sec. At 1.25 sec the output voltage increases from 250 to 280V due to the additional voltage source applied at the input.

In open loop IBFC there is a sudden rise in the output voltage. Gain cannot be easily controlled because there is no feedback in open loop system.Closed loop system is necessary for regulated output voltage.

3.3. Closed Loop Integrated Boost Flyback Converter

The closed loop Integrated boost flyback converter is simulated with R,RL,RLE load using PID and fuzzy controller and hence the results are presented. In closed loop system the output voltage is sensed and it is compared with a reference voltage . Then the error is given to the controller. The output of the controller generates pulses with reduced width. When these pulses are applied to the MOSFET in the output rectifier, the output reduces the set value. Thus the closed loop system is capable of reducing the steady state error.

3.3.1. Closed Loop IBFC using PID Controller without Disturbance

The Closed loop IBFC using PID controller without disturbance is simulated is shown in Figure 11. Figure 12 and 13 depicts the output voltage and current. The tuning of controller is done by Zeigler & Nichols method. Here K_p= 0.1 K_i= 0.2 K_d= 0.2.

$$\textbf{PID}= K_p\, e(t) + K_i \int_0^t e(x)dx + K_d \frac{d}{dt} e(t)$$

Where:
K_p-Proportional gain
K_i-Integral gain
K_d-Derivative gain
t-Instantaneous time
x-Variable of integration; takes on values from time 0 to present t

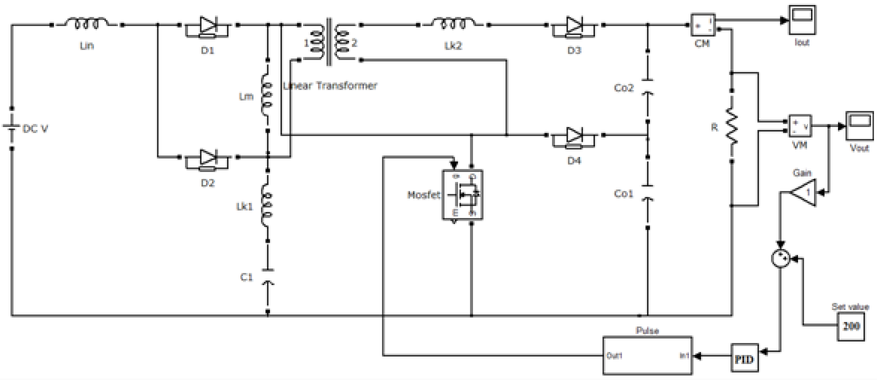


Figure 11. Simulated diagram of closed loop IBFC with R-load using PID-Controller

Figure 11 shows the simulated diagram of closed loop Integrated boost flyback converter with R-load using PID-Controller and its output is measured.

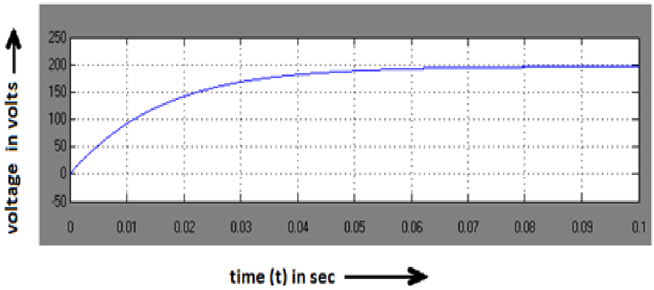


Figure 12. Output voltage

Figure 12 shows the Output voltage of closed loop Integrated boost flyback converter with R-load using PID-Controller.

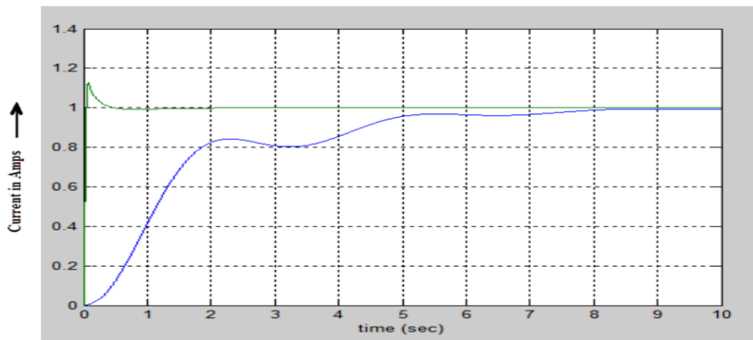


Figure 13. Output current

Figure 13 shows the Output current of closed loop Integrated boost flyback converter with R-load using PID-Controller.

3.3.2. Closed Loop IBFC using PID Controller with Disturbance

In closed loop IBFC using PID controller, a disturbance is injected at the input and its output voltage is measured.

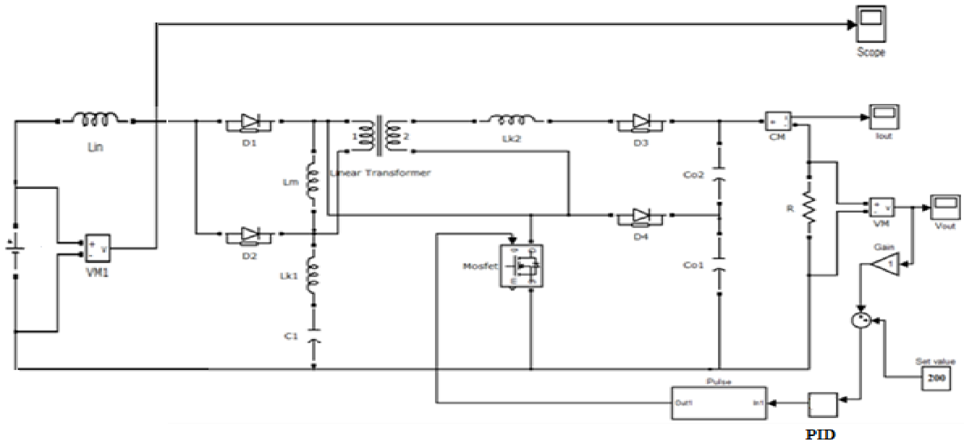


Figure 14. Simulated diagram of closed loop IBFC with R-load using PID-Controller

Figure 14 shows the input disturbance is applied to the closed loop Integrated boost flyback converter with R-load using PID controller and its output voltage is measured.

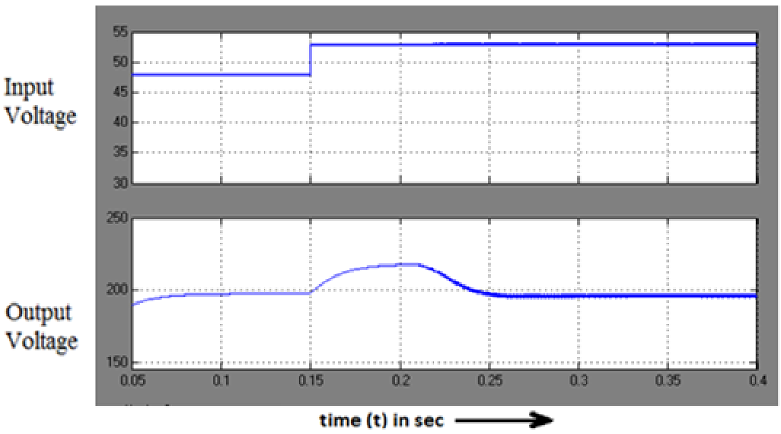


Figure 15. Input and output voltage of closed loop IBFC with R-load using PID-Controller

Figure 15 shows the input disturbance in increasing the input voltage from 48V to 53V resulting in increase of the output voltage.At 0.15sec the output voltage increases from 199 to 220V. At 0.2sec the output voltage reaches to the peak value and then it decreases to a steady state value of 199V at 0.25sec.

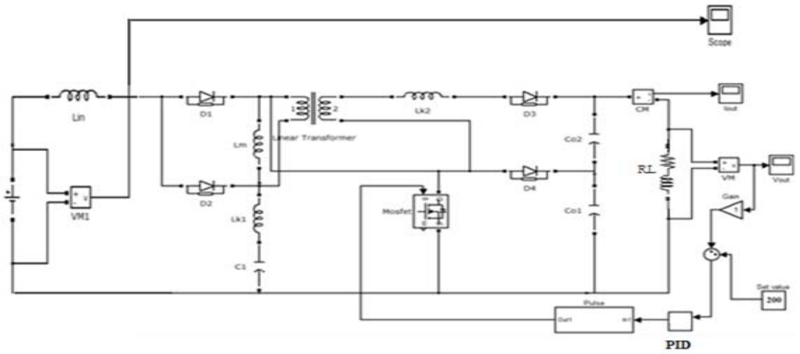


Figure 16. Simulated diagram of closed loop IBFC with RL-load using PID controller

Figure 16 shows the input disturbance is applied to the Integrated boost flyback converter with RL-load using PID-Controller and its output voltage is measured.

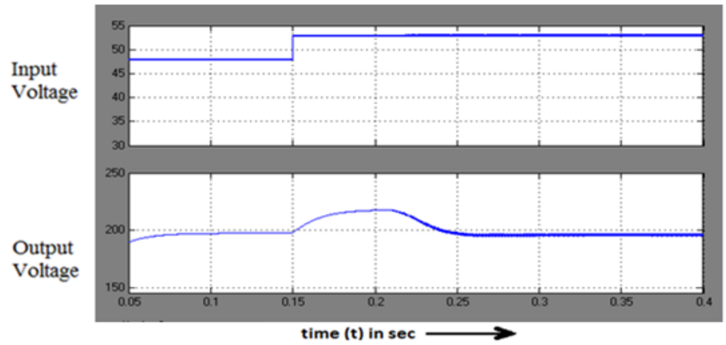


Figure 17. Input and output voltage of closed loop IBFC with RL load using PID-controller

Figure 17 shows the input disturbance in increasing the input voltage from 48V to 53V resulting in increase of the output voltage. At 0.15sec the output voltage increases from 199 to 220V. At 0.2sec the output voltage reaches to the peak value and then it decreases to a steady state value of 199V at 0.25sec.

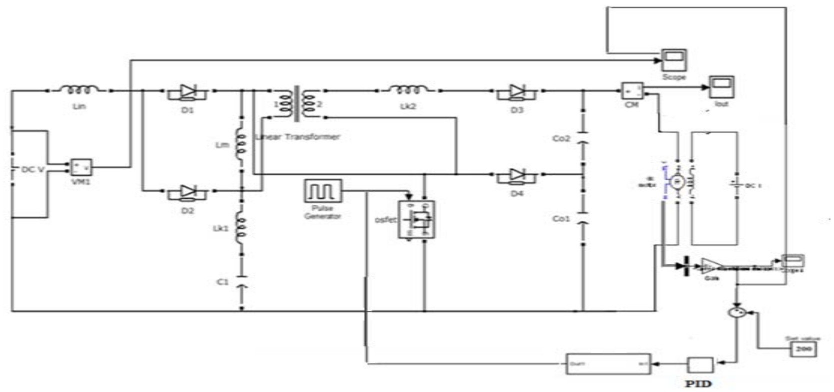


Figure 18. Simulated diagram of closed loop IBFC with RLE -load using PID-Controller

Figure 18 shows the input disturbance is applied to the closed loop Integrated boost flyback converter with RLE-load using PID controller and its output voltage is measured.

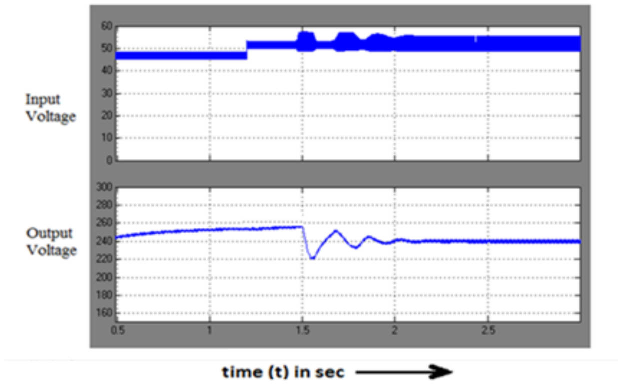


Figure 19. Input and output voltage of closed loop IBFC using PID-Controller

Figure 19 shows the input disturbance in increasing the input voltage from 48V to 58V resulting in increase of the output voltage. At 0.5sec the output voltage increases from 240V to 250V.At 1.5sec the output voltage decreases from 250 to 220V and then it reaches to a steady state value of 240V at 2 sec.

The performance of closed loop Integrated boost flyback converter using PID controller has low steady state error and low peak overshoot under change in load conditions. IBFC with PID controller perform slow switching operation, more voltage stress and high conduction losses.

3.3.3. Closed Loop IBFC using Fuzzy Controller without Disturbance

Fuzzy logic controller is a nonlinear control scheme with piecewise linear proportional and integral gain to control the duty cycle of the system. Control of the duty cycle, in turn controls the output voltage of the Integrated boost flyback converter.

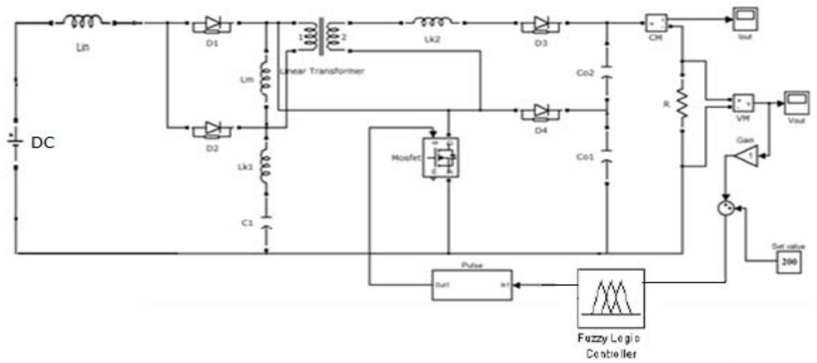


Figure 20. Simulated diagram of closed loop IBFC with R-load using Fuzzy controller

Figure 20 shows the simulated diagram of closed loop Integrated boost flyback converter with R-load using Fuzzy controller and its output voltage is measured.

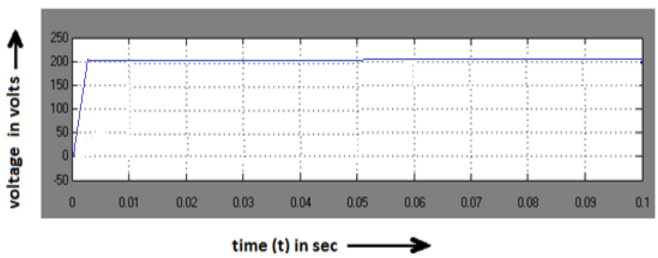


Figure 21. Output voltage

Figure 21 shows the Output voltage of closed loop Integrated boost flyback converter with R-load using Fuzzy controller.

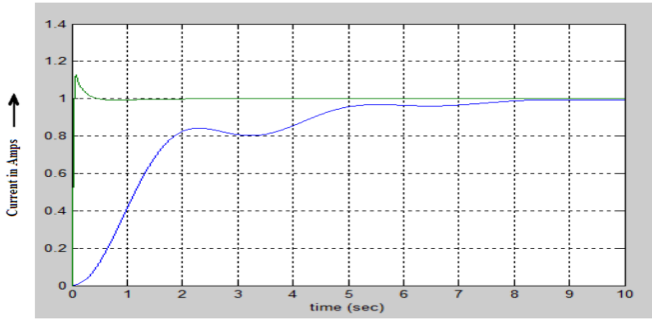


Figure 22. Output current

Figure 22 shows the Output current of closed loop Integrated boost flyback converter with R-load using Fuzzy controller.

3.3.4. Closed Loop IBFC using Fuzzy Controller with Disturbance

In closed loop IBFC with Fuzzy controller, a disturbance is injected at the input and its output voltage is measured.

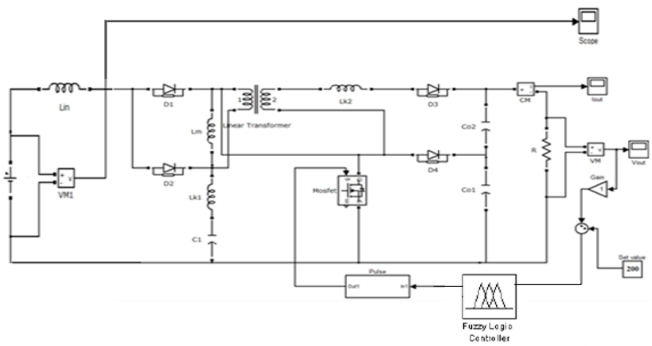


Figure 23. Simulated diagram of closed loop IBFC with R-Load using Fuzzy-Controller

Figure 23 shows the input disturbance is applied to the Integrated boost flyback converter with R-load using Fuzzy controller and its output voltage is measured.

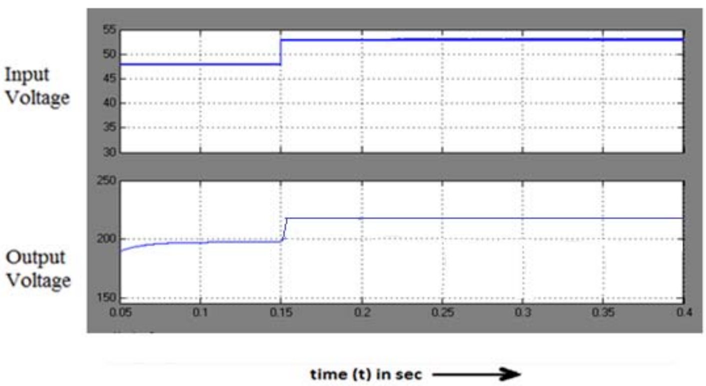


Figure 24. Input and output voltage IBFC with R-load using Fuzzy controller

Figure 24 shows the input disturbance in increasing the input voltage from 48V to 58V at 0.15sec. At 0.15sec the output voltage increases from 200 to 220V and it remains in that steady state value.

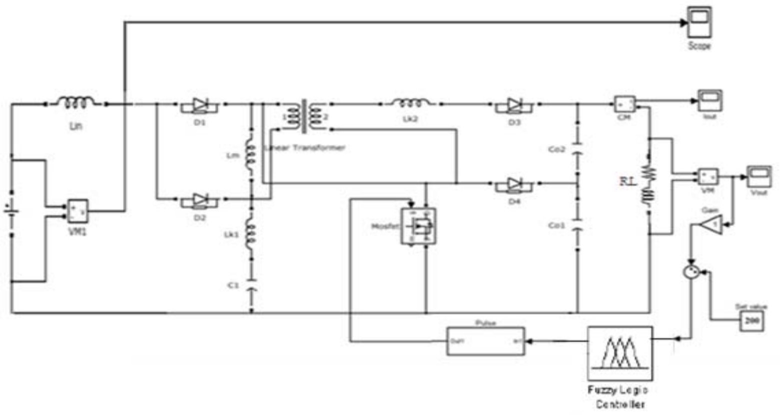


Figure 25. Simulated diagram of closed loop IBFC with RL-load using Fuzzy-Controller

Figure 25 shows the input disturbance is applied to the Integrated boost flyback converter with RL-load using Fuzzy controller and its output voltage is measured.

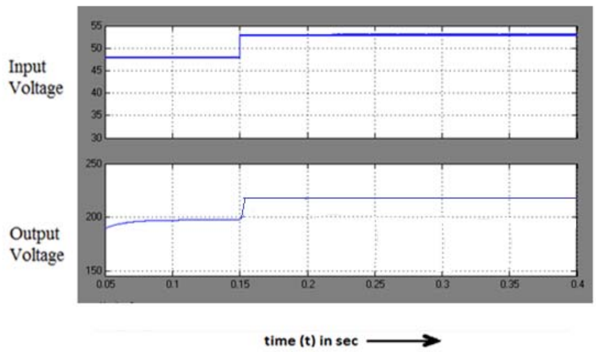


Figure 26. Input and output voltage of IBFC with RL-Load using Fuzzy-Controller

Figure 26 shows the input disturbance in increasing the input voltage from 48V to 58V at 0.15sec. At 0.15sec the output voltage increases from 200 to 220V and it remains in that steady state value.

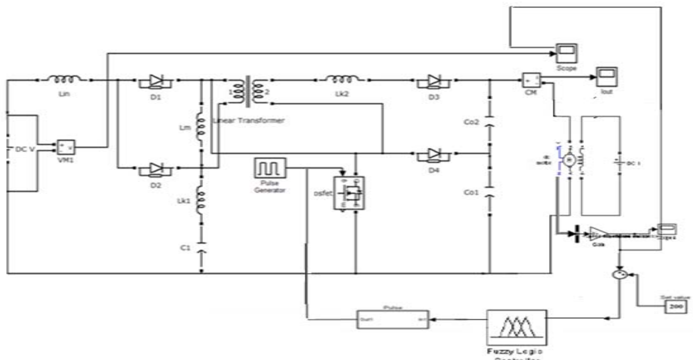


Figure 27. Simulated diagram of closed loop IBFC with RLE -load using Fuzzy-Controller

Figure 27 shows the input disturbance is applied to the Integrated boost flyback converter with RLE-load using Fuzzy controller and its output voltage is measured.

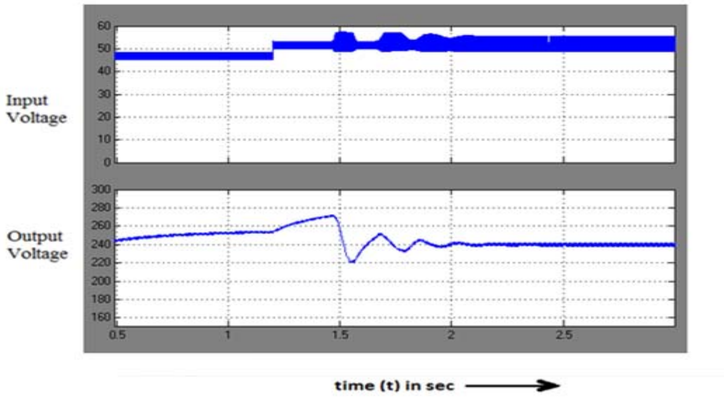


Figure 28. Input and output voltage of IBFC with RLE -load using Fuzzy controller

Figure 28 shows the input disturbance in increasing the input voltage from 48V to 58V resulting in increase of the output voltage. At 0.5sec the output voltage increases from 240V and reaches to 250V at 1.3sec. At 1.3sec the output voltage increases from 250 to 270V and then it decreases to 220V at 1.6sec. At 1.6sec the output voltage increases reaches to a steady state value of 240V at 2 sec.

The performance of closed loop Integrated boost flyback converter using Fuzzy controller has no steady state error and no peak overshoot under change in load conditions. IBFC is improved in terms of transient and steady state response, reduces the conduction losses and reduces the voltage stress on the active switch. IBFC with Fuzzy controller perform faster switching operation.

3.3.5. Performance Comparison PID and Fuzzy Controller in Integrated Boost Flyback Converter

Performance Comparision has been made between PID and Fuzzy controller based on Figure 12 and 21. The results are presented in Table 2.

Table 2. Comparison of PID and Fuzzy controller

SIMULATED RESULTS	PID-CONTROLLER	FUZZY CONTROLLER
Rise time	0.03 Sec	0.002 Sec
Peak time	0.062 Sec	0.003 Sec
Settling time	0.08 Sec	0.004 Sec
Non Linearity	0.2 Sec	0.01 Sec
Input Voltage	48 V	48 V
Output Voltage	200 V	200 V
Output current	1A	1A

Fuzzy logic controller (FLC) is much better in overall performance in terms of rise time, peak time, settling time and robustness as compared to PID controller. From the comparison results FLC shows less voltage deviation, Zero overshoot, fast response with higher accuracy and dynamic performance. With all of these advantages, FLC has a potential to improve the robustness of Integrated Boost Flyback Converter.

4. EXPERIMENTAL RESULTS

Integrated boost flyback converter is developed and tested in the laboratory. IBFC consists of two stages, first stage is the boost converter and the second stage is the flyback converter. The two stages are driven by a single Mosfet switch. The boost converter that includes an input inductor L_{in}, two diodes D_1 and D_2 and a switching capacitor C_1.The flyback converter that includes a dual-winding coupled inductor T_1 , two diodes D_3 and D_4 and two output capacitors C_{O1}andC_{O2}.

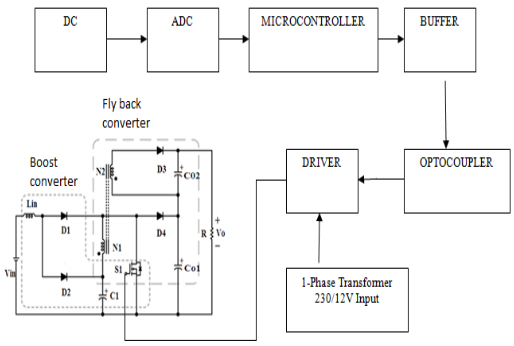


Figure 29. Schematic diagram of Integrated boost flyback converter

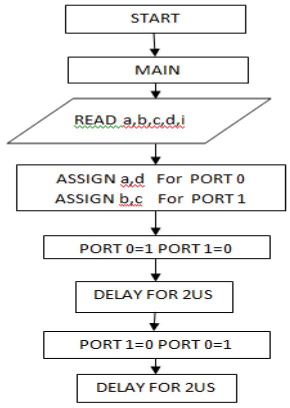


Figure 30. Flow chart for Embedded controller 8051

Figure 29 shows the schematic diagram of IBFCusing R-Load. IBFC is the combination of boost and flyback converter. Pulses required for the MOSFET are generated by using a ATMEL microcontroller 89C2051. These pulses are amplified by using a driver amplifier. The driver amplifier is connected between the optocoupler and MOSFET gate. The gate pulses are given to the MOSFET of the Integrated Boost Flyback converter. ADC0808 is used for interfacing analog circuit and comparator circuit. To isolate power circuit and control circuit optocoupler is used.8051 microcontroller has two 16-bit timer/counter registers namely timer 1 and timer 2. Both can be configured to operate either as timers or event counters in integrated boost flyback converter.

The following values are found to be a near optimum for the design specifications:

Table 3. Hardware parameters

Parameter	Value
Capacitor C_1	1000µF
Output capacitor $C_{O1}=C_{O2}$	220µF
Input Inductance	500µH
Input Voltage	48V
Resistance R	200Ω
MOSFET	IRFP450,10 A,10-500V
Regulator	LM7805,LM7812, 5-24V
Driver IC	IR2110,+500V or+600V
Diode	IN4007
Crystal Oscillator	230/15 V,500mA,50Hz
Microcontroller	AT89C2051,2.7V to 6V,0Hz to 24MHz

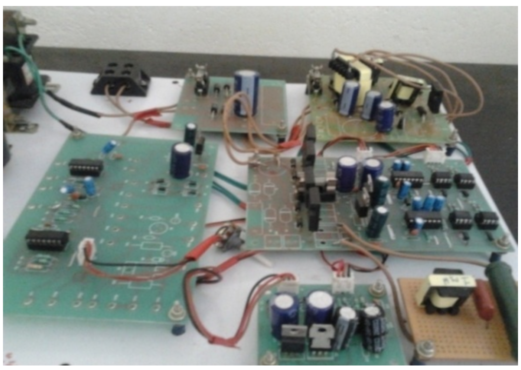


Figure 31. Experimental setup of Integrated boost flyback converter.

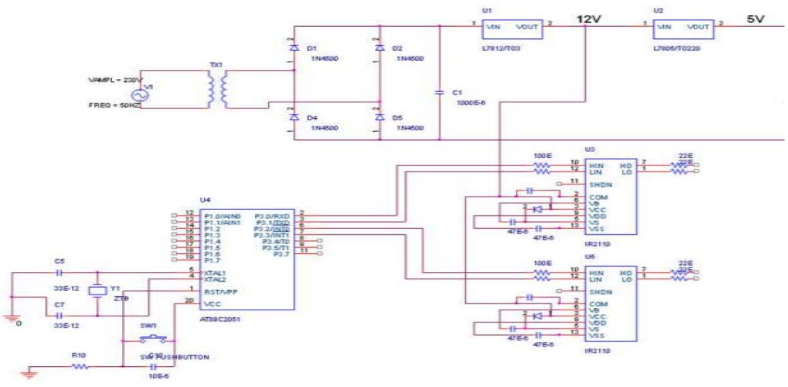


Figure 32. Control circuit of Integrated boost flyback converter.

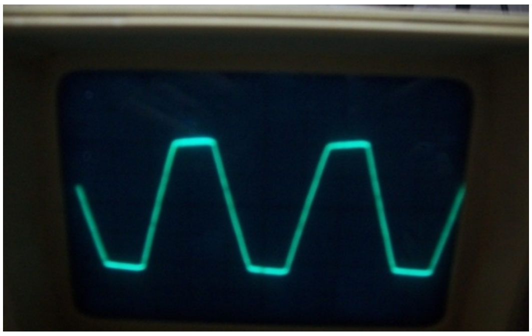


Figure 33. AC input voltage

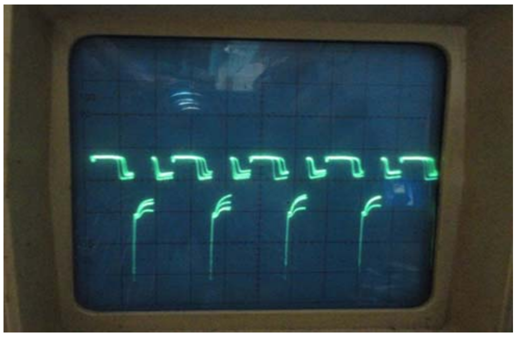


Figure 34. Transformer Primary Voltage (Vp)

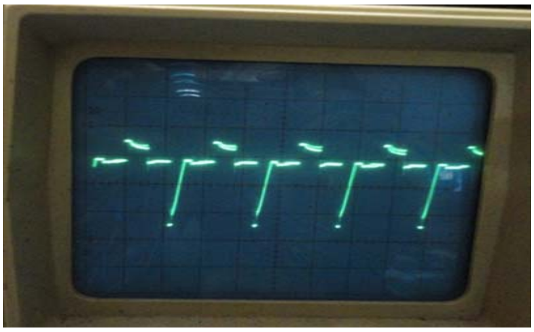


Figure 35. Transformer Secondary Voltage (Vs)

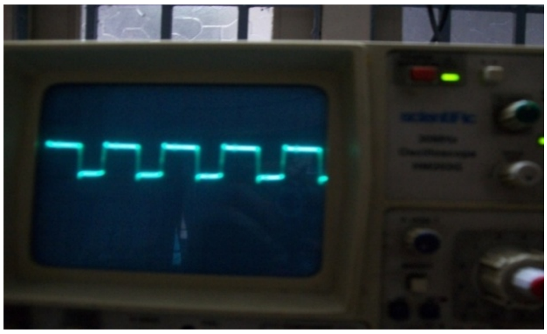


Figure 36. Gate pulses for MOSFET

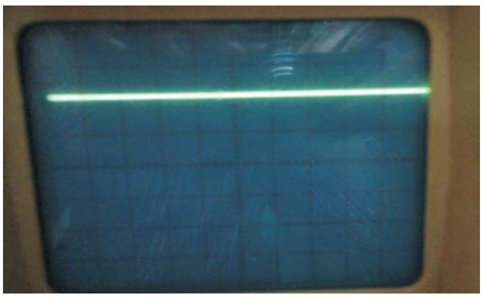


Figure 37. DC Output voltage

Figure 37 shows the ripple free and regulated DC output voltage of Integrated boost flyback converter.

Table 4. Comparison of Matlab Simulation, Theoretical and Experimental results obtained for 50 KHz open loop Integrated boost flyback converter using R-Load

Load Resistance (Ω)	Simulation Results (Volts)	Theoretical Results (Volts)	ExperimentalResults (Volts)
1	196.9	180.0	195.0
20	197.5	180.0	195.5
30	198.0	180.0	196.0
50	198.7	180.0	196.7
75	199.0	180.0	197.9
100	199.5	180.0	198.2
200-1K	200.0	180.0	199.2

From Table 4, it is known that the simulation results and hardware results for open loop Integrated boost flyback converter with R Load nearly coincides. But the theoretical result was not beyond 180V.

6. CONCLUSION

In comparative analysis Integrated boost fly back converter using FUZZY controller is found to be suitable for Renewable energy system. IBFC produces high step-up voltage gain by single power switching technique operating at low duty cycle with transformer inductors, switched capacitors and power diodes.

The proposed converter eliminates the switching losses, conduction losses and recycles the leakage energy. However IBFC achieves high step-up voltage gain with low duty cycle and low voltage stress on the power switch. Additionally the energy stored in the leakage inductor can be recycled to the output capacitor. The use of fuzzy controller provides the zero steady state error, increases the stability, very less oscillations, zero overshoot, fast switching operation and dynamic performance. With all these advantages fuzzy controller has a potential to improve robustness of integrated boost fly back converter. Fuzzy controller scheme helps to remove the delay time and inverted response shown in graphs. Rise time and settling time are also reduced. Closed loop IBFC using fuzzy controller provides regulated output voltage, high voltage gain and improves the overall efficiency. Thus Fuzzy controller is found better instead of PID controller. The simulation and experimental results indicate that the output of the converter is free from ripples and has regulated output voltage.

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