International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 12, December-2015

Two Transistor Forward Converter with Loop Compensation using TL431

Rajeshwari Mahadev Ukkalikar
M Tech Student ,
Power Electronics, BMSCE
Bangalore, India

V Champa
Associate Professor,
EEE, BMSCE
Bangalore, India

***Abstract*—This paper presents the design of two switch forward converter with a primary clamped diode and loop compensation using optocoupler and TL431. The converter is operating from DC Voltage (18V to 32V) providing regulated output voltage of 54V (2.2A). To realize the converter in a compact size and lower weight high switching frequency is used. MOSFET is switched ON and OFF using a UC28025 with switching frequency of 250 kHz. The converter also incorporates Zero current switching during turn on. The design procedure is presented in detail. For the tight regulation of the output, the compensation network is designed with optocoupler and TL431. Implementation of TL431 in the closed loop regulation is presented in the paper. The paper also presents simulation results using orcad and MATLAB. The ZCS is observed in the simulation result. Regulation is observed by performing closed loop simulation.**

***Keywords*—Two switch forward converter ,TL431 , Type 3 compensator.**

I. INTRODUCTION

The conventional two switch forward converter is shown in Fig 1.

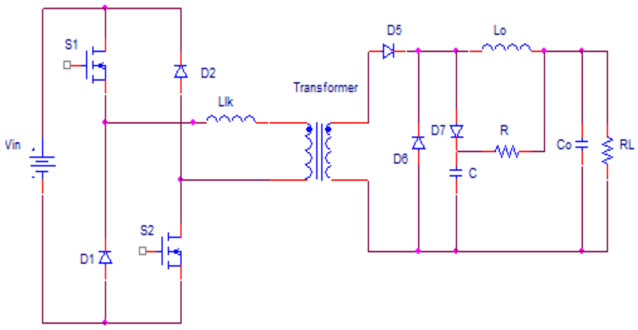

Fig 1 :Conventional two switch forward converter

Due to its simple operation and high reliability two switch forward converter is used more commonly. The switches used in two switch forward converter operate in hard switching and has high switching loss. During turn on and turn off, resonance occurs because of the reverse recovery parameter of the rectifier diode and the power transformer leakage inductance. Due to resonance, ringing and over shooting is seen. This results in overvoltage across the output freewheeling diode.

By using a RCD snubber on output diode, the over voltage may be limited to a safe level. The RCD snubber used at the diode is simple and less expensive. But due to the presence of high resistor value in the snubber there is high power dissipation at high power levels and hence efficiency is decreased. However, over voltage cannot be reduced completely because of the lead inductance of tracks. The damage due to over voltages may be overcome by using diode of higher voltage rating. However, this results in higher conduction and more recovery time .

In another method to minimize the over voltage and to recycle the energy active switched snubbers were used[1][2]. Active switched snubbers require additional active switches and control circuits for that switch. This will increase the cost and reduce the reliability of the circuit. A non-dissipative LCD snubber is used[3]. But problems still existed with the additional components L,C and diode.

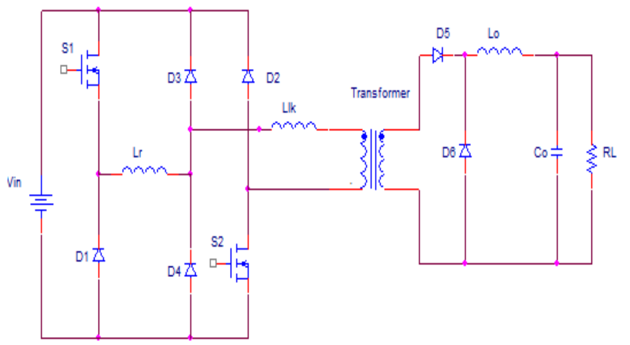

Fig2 :Two switch Forward converter with diodes clamped at the primary side of transformer

To overcome the problems mentioned above, a two switch converter topology with two diodes at the primary is proposed as shown in Fig2 [5]. Turn off di/dt of the rectifying diode is limited by adding an inductance in series with the power transformer primary. By introduction of series inductor the turn off di/dt of the rectifying diode is limited but heavy ringing is observed at the junction of L_r and power transformer. The heavy ringing is limited by introducing a clamping diodes namely D3 and D4, on the transformer primary.

The clamping diodes have smaller rating compared to converter overall rating . By using this method the voltage applied to transformer primary is clamped to input voltage. This results in clamped voltage at the power transformer secondary and also at the rectifying diodes namely D5 and D6.Low leakage inductance of the transformer can avoid overvoltage which is produced when the voltage is applied to rectifying diodes. Because of finite leakage inductance of the transformer, a small snubber is introduced across the output diode. The leakage inductance must be kept as low as possible. This technique of having clamping diodes at the transformer primary has one more advantage. Due to the introduced inductor Lr which takes finite time to set up the primary winding current, the switches can be turned-on at zero current switching (ZCS) . This also improves overall efficiency because, the excess energy stored in the inductor (Lr) will be supplied back to the source[5].

Power converter is controlled by a compensation network implementing an optocoupler and TL431. TL431 is selected because it lends itself very well into optocoupler control[7].

II. DESIGN FOR THE PROPOSED CONVERTER

Converter specifications:
V_{in} = 18V
V_o = 54V
Switching frequency = 250KHz
Output ripple, ΔV_O = 1% of V_O=0.54
Load resistor, R = 25Ω

Output current $I_O = V_o / R$ =2.2A
Therefore, output power $P_O = I_O^2 * R$=120W

Determination of output inductor and capacitor values:

Table 1: Capacitor and Inductor Values

Parameter	***Formulae***	***Value obtained***
Output Inductor	$L_0 = \frac{(V_0 - V_{in}) * V_0}{I_{Lripple} * V_{in} * F_S}$	***0.5mH***
Output Capacitor	$C_0 = \frac{L_0 * \Delta_I^2}{2 * V_0 * \Delta V_0}$	***470nF***

Output capacitor controls the ripples in output voltage as well as settling time. Higher the value of capacitor, lower the value of ripple but higher settling time and vice versa.

DESIGN OF TRANSFORMER FOR THE PROPOSED CONVERTER:

Area Product may be calculated by the equation
Area Product Ap = $(v_p * D_{on} * 2 * I_{rms}) / (f * \Delta Bm * J * kw)$

Based on the Area product the core selected is PC 36/22
Number of primary turns N1 = $\frac{Vccmax * Dmin}{Ac * Bm * fs}$ = 1

Number of secondary turns N2 = $\frac{N1 * Vout}{Deff * Vin}$ = 9

III. TL431 IN SWITCHING POWER SUPPLIES

A. TL431

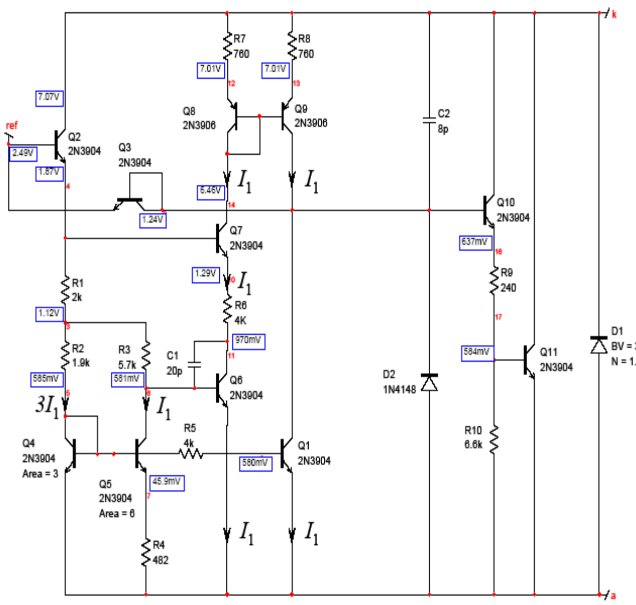

Fig 3: Internal schematic diagram of TL431

The TL431 is the popular choice in recent days design. Figure 3 shows the internal circuitry of a TL431.The device is shown with three terminals namely cathode k ,anode A and a reference. A TL431 configured with a reference point, cathode k and grounded anode behaves as an active 2.5V zener diode.

In a configuration such as classical loop-control, TL431 sees a fraction of the output voltage at its ref pin and converts the observed fraction of output voltage into an output current which is sank between the cathode and the anode. As such, TL431 can be considered as a trans-conductance amplifier[7]

To understand its operation , let us assume that negligible base current flows through all the transistors which implies transistors with a high current gain in the circuit. The secret of operating the device lies in the equilibrium imposed by transistors Q_9 and Q_1. when output voltage reaches its targeted value that is when conditions are properly met, the voltage at the reference pin V_{ref} will be equal to 2.5 V, and same current will be shared by transistors Q_9 and Q_1. V_{ka} remains constant. Any changes in this condition due to change in output power demand on the regulated converter changes the currents flowing through Q_9 or Q_1 thereby changing the bias of the output darlington configuration made around transistors Q_{10} and Q_{11}. Because of this action the voltage across anode and cathode V_{ka} goes down or up respectively and results in current variation in the LED diode which is attached to the cathode of TL431 in a power supply loop application.

B. Implementing Type 3 Compensator with TL431

A type 3 compensator circuit using TL431 and optocoupler is as shown in fig4. To create a fixed dc level a zener diode is used.

The transfer function of the circuit presentated in fig 4, provided R3<<R1 obeys the following equation [7].

$$\frac{VFB(s)}{Vout(s)} \approx Rpullup \frac{CTR}{Rled} \frac{(sR2C1+1)(sR1C3+1)}{sR1C1(1+sRpullupC2)(sR3C3+1)}$$

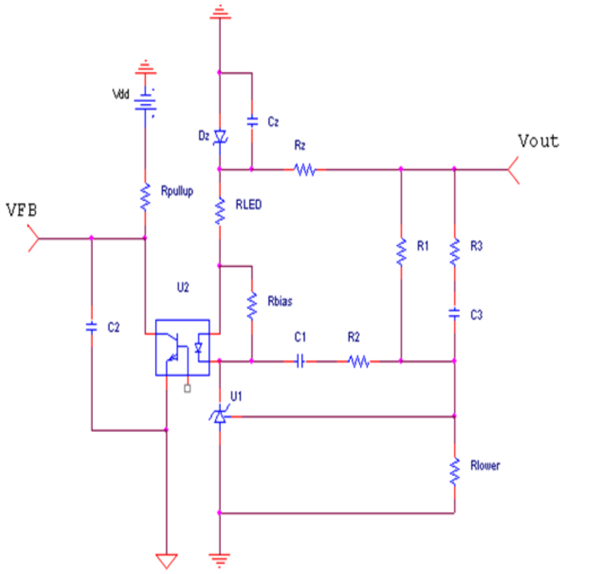

Figure 4: Type 3 compensator with TL431

C. Design of Type 3 Compensator with TL341

Calculation steps:

$ESR(C_o) = 8m\Omega$

$F_s = 250kHz$

$I_o(max) = 2.2A$

$F_{LC} = 1/(2*\pi*\sqrt{Lo*Co}) = 42.32MHz$

Crossover frequency $F_0 = 1/6 * F_s = 41.66kHz$

Since $F_{LC} < F_O < F_S/2 < F_{ESR}$,Type III(B) compensator is used.

The compensator has 3 poles and two zeroes and are as shown in table2

Table 2: Poles and Zeroes

Parameter	Formula	Values obtained
F_{P1}	0	0
F_{P2}	$F_o*\sqrt{(1+\sin\theta)/(1-\sin\theta)}$	236.26kHz
F_{P3}	$F_S/2$	125 kHz
F_{Z2}	$F_o*\sqrt{(1-\sin\theta)/(1+\sin\theta)}$	7.34kHz
F_{Z1}	$0.5 * F_{Z2}$	3.67kHz

1) Calculatation of R_{LED}

The maximum value of LED series resistor can be calculted by the equation

$$RLED = \frac{Vz - Vf - VTL431min}{Vdd - VCEsat + Ibias\, CTRmin\, Rpullup} Rpullup\, CTRmin$$

Where:

V_Z represents the Zener diode breakdown voltage(6.2V)

I_{bias} , is the biasing current flowing through1kΩ resistor connected in parrallel with LED (usually 1kΩ for a 1-mA bias)

$V_{TL431,min}$ is equal to 2.5v and represents the minimum voltage attainable by TL431.

V_f is the forward drop across optocoupler LED (≈1V)

CTR_{min} is the minimum current tranfer ratio of selected optocoupler (30%)

$V_{CE,sat}$ is the saturation voltage of optocoupler (≈300mV at a 1-mA collector current)

V_{dd} is the internal bias of the pull-up resistor

Assume $R_{pullup} = 20k\Omega$

$R_{LED,max} = 1.5k\Omega$

Allowing 50% margin $R_{LED,max} = 750\Omega$

2) Considering $I_{bias} = 250\mu A$ current through divider bridge which is a good trade-off between noise immunity and standby power performance[7] and Calculating the upper and lower resistors:

RLower = 2.5/250μ = 10kΩ

Considering 12v input to compensator through voltage divider from the converter output we have,

$$R1 = \frac{12 - 2.5}{250\mu}$$

The compensator component values are calculated as given in the table 3.

Table 3: Values of compensator component

Parameter	Formula	Values obtained
C_3	$\frac{1}{2\pi\, Fz2\, R1}$	0.57nF
R_3	$\frac{1}{2\pi\, Fp2\, C3}$	1.18kΩ
R_2	$\frac{1}{2\pi\, Fz2\, R1}$	0.57nF
C_1	$\frac{1}{2\pi\, Fz1\, R2}$	4.5nF
C_2	$\frac{1}{2\pi\, Fp3\; Rpullup}$	133pF

After the calculation of all the components ,zener bias resistor R_z can be chosen. The total current flowing through R_z is made up of current flowing through 1kΩ bias resistor plus LED current which depends on CTR of optocoupler plus the current flowing through the zener diode which also depends on CTR.

$$Rz < \frac{Vout - Vz}{IRz} < 1k\Omega$$

To improve the ac rejection of V_{out} ,a capacitor of value 0.1μF has been added across the diode [7].

IV. SIMULATION RESULTS

A. Open Loop Simulation

Soft switched two switch forward converter is verified using the software ORCAD and MATLAB. This gives the expected waveforms when simulation is done with the following specifications:

Specifications:
Input voltage = 18V
Output voltage = 54V
Output current = 2.2A
Output power = 120W
Switching frequency = 250kHz
Designed values of the components are: Lr = 0.2u, Lo = 0.5m, Co = 470n

The open loop and closed loop response of the converter for duty cycle D=0.5 is presented.

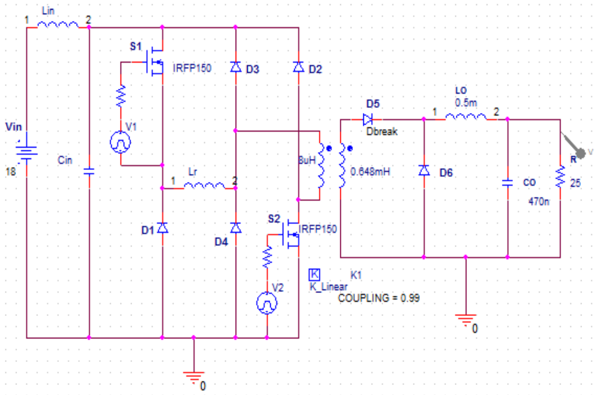

Fig: 5 open loop ORCAD model of the proposed topology

The different waveforms such as switch voltage ,switch current, output voltage Vo and output current Io are shown below

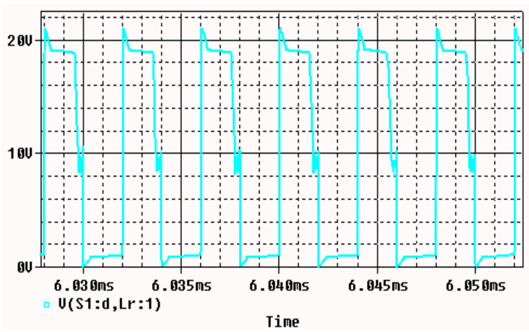

Fig6:Voltage across the switch

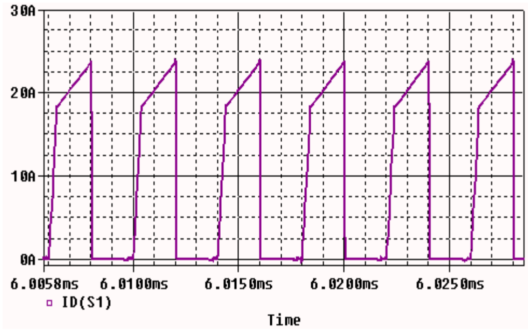

Fig7:Current througth the switch

The obtained waveforms from the simulation of open loop converter shown in Fig 7 and fig 8 reveals that ZCS has been achieved during turn on.

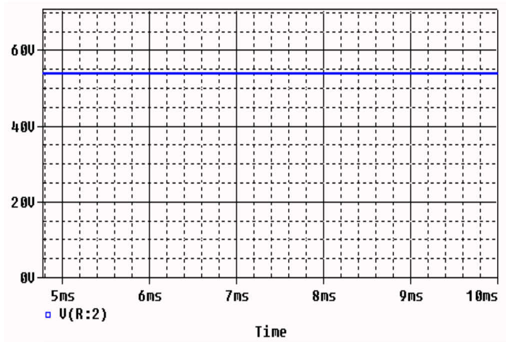

Fig 8:Output voltage Waveform

The output voltage is found to be 54 volts with very low ripple as indicated by the waveform shown in fig8 .

B. Closed Loop Simulation in MATLAB

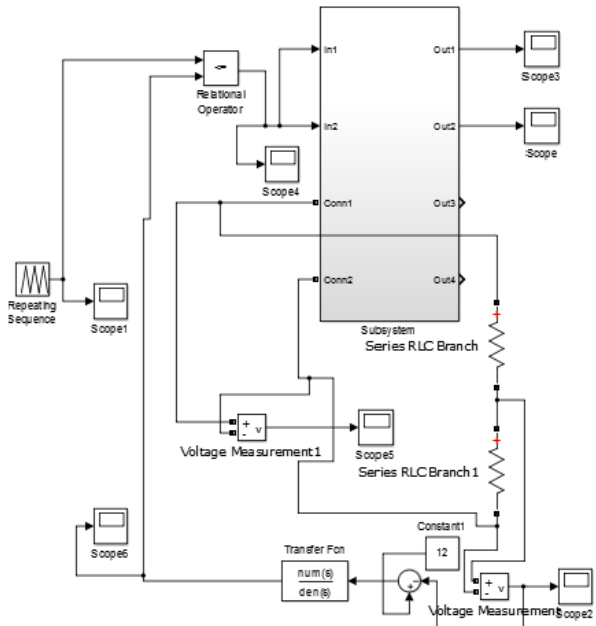

Fig 9:Closed loop simulation model in MAT LAB

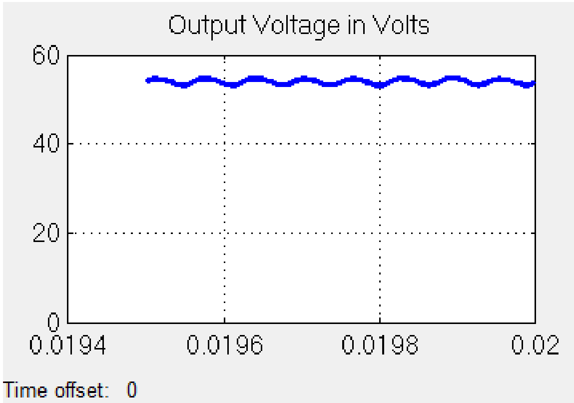

Fig 10 output voltage waveform

The output voltage is also obtained from simulation of closed loop converter circuit using MATLAB software and is shown in fig 10.The result obtained shows the regulation using the designed compensator network for the input voltage of 18v.

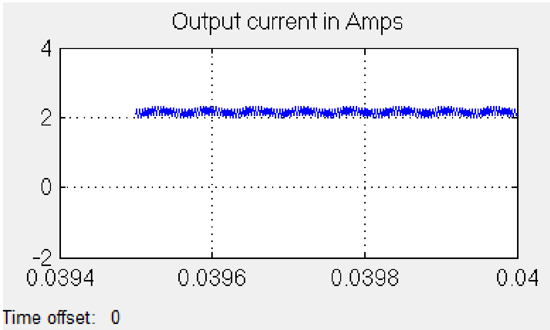

Fig 11 :output current waveform

The full load output current as obtained by closed loop simulation in MATLAB is shown in fig 11 and is found to be 2.2amps tallying with the theoretical value.

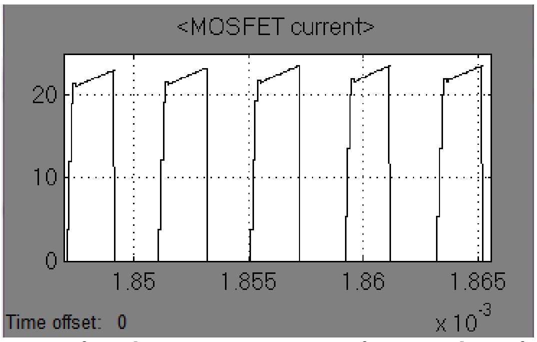

Fig 12 waveform showing MOSFET current for input voltage of 18v

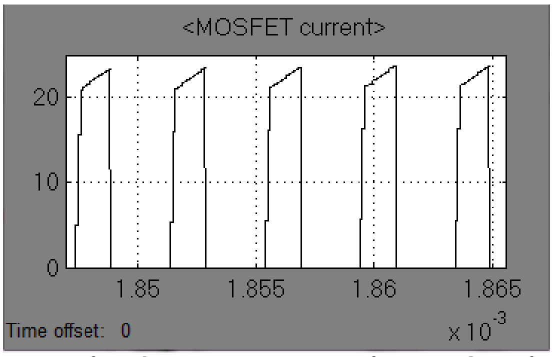

Fig 13 waveform showing MOSFET current for input voltage of 23v

The waveform shown in Fig 12 & Fig 13 are the current through the switch for the input voltage equal to 18v and 23 volts respectively.They reveal that the pulse width is varying to provide regulation of output voltage. The on period varied from 2µs to 1.5 µs for a change of input voltage from 18v to 23v .

ACKNOWLEDGMENT

Our thank to Venkatesh prabhu ,scientist E ,LRDE for the kind support and guidance for completion of this work. And also we extend our thankfulness to the BMS college of Engineering for the support and encouragement for completion of this work.

REFERENCES

[1] Harada and H. Sakamoto " Switched snubber for high frequency switching ", In IEEE PESC Conference record 1990,pp.181-188.

[2] D. B. Dalal and Fu-Sheng Tsai " A 48V, 1.5kW front-end-zero voltage-switched, PWM converter with lossless active snubbers for output rectifiers". In IEEE APEC Conference record 1993, pp. 722-728.

[3] C. H. G. Treviso. A. A. Pereira, V. J. Farias, J. B. Vieira Jr. and L. C. de Freitas " A 1.5 kW Operation with 90% Efficiency of a Two Transistors Forward Converter With Non-Dissipative Snubber" In IEEE PESC Conference record 1998, pp 696-700.

[4] M. L. Heldwein, A. F. de S o u and Ivo Barbi " A Primary Side Clamping Circuit Applied to the ZVS-PWM Asymmetrical Half-Bridge Converter " In IEEE PESCConference record 2000, pp.199-204.

[5] Dharmraj V Ghodke and K. Muralikrishnan"1.5KW Two switch forward zczvs converter using primary side clamping" In IEEE PESC Conference record 2002,pp.893-898

[6] Amir M Rahimi, Parviz parto , and Peyman Asadi "Compensator Design procedure for Buck converter wiith voltage mode error amplifier",Application Note AN-1162

[7] Christophe Basso, Petr Kadanka - ON Semiconductor " The TL431 in Switch-Mode Power Supplies loops"