Dual Output Forward Converter with Feed Forward Control for Space Applications

Shweta S P[1], B.K Singh[2], Rudranna Nandihalli[3]

[1]PG Student, Department of Electrical and Electronics Engineering, RV College of Engineering, Bengaluru
[3]Department of Electrical and Electronics Engineering, RV College of Engineering, Bengaluru

---***---

Abstract – *The work is focused on the hardware implementation of Forward Converter with Feed Forward voltage control topology using coupled inductor for better load and cross regulation. The converter mainly operates at 500 kHz switching frequency. UC2825 DWTR IC is employed to work in both voltage mode and current mode control. PWM controller has better soft start, maximum control on duty, under voltage and high frequency operation. A dedicated winding is provided for feedback. This feedback power up the control circuitry. Feedback is employed from Feed Forward voltage mode control. For Feed Forward control isolation of the circuit is not required. It has the advantage of faster response with time consumption and simple construction. Converter consists of protections circuits such as UVP, OVP and Over Power.*

Key Words*: *Pulse Width Modulation (PWM), Integrated Chip (IC), Under Voltage Protection (UVP), Over Voltage Protection (OVP).

1. INTRODUCTION

Nowadays Switched mode power converters are widely used because of reduced size and highly efficient compared to liner power supplies. SMPS consists of some other advantages like reduced weight, low power dissipation, lower noise. Some of the applications of switched mode power supplies include battery charger, lighting, defence, aerospace and other electronic devices [1]. One of the widely used converter is DC-DC converter (Forward converter). In order to implement all the advantages Forward converter with Feed forward voltage control mode is used.

DC-DC converters are extensively utilized to get better regulated output, electrical isolation and multiple output. Forward converter uses transformer to increase or decrease the output voltage (depending on the transformer ratio) and it will provide a magnetic isolation to transfer energy from source to load. It has multiple output windings, so it is possible to provide both higher and lower voltage outputs simultaneously.

In this paper we will also be discussing about design of feed forward converter, coupled inductor and bias feedback technique. Usually in order to control output feedback need to be provided from secondary, but using bias/auxiliary winding as feedback.Notwithstanding these fundamental necessities, shared objectives of any force supply configuration are to diminish the size, weight and to expand the effectiveness. Customarily direct force supplies have been utilized for power change [2]. Nonetheless, the progressions in semiconductor innovation prompted exchanging power supplies that are more modest and considerably more proficient contrasted with direct force supplies.

Various applications like power supplies for computers, various consumer electronic goods, uninterrupted power supplies [UPS], telecommunication units and so on is served by the DC/DC converters Controlled DC power supplies are required for better and proficient activity of simple and computerized electronic frameworks [3]. The majority of the force supplies are intended to meet some essential necessities like managed yield, electrical disconnection and different yields.

1.1 Conventional Forward Converter

Forward converter is an isolated version of buck converter. One of the most widely used topology for obtaining regulated dc voltage from an unregulated input. Forward converter is highly efficient and is often chosen for output power under 200W [1]. It has many advantages over various isolated converter topologies. Forward converter transfers energy instantly from primary to secondary and does not rely on it for energy storage. Utilization of transformer is increased by having betting magnetizing inductance and no air gap. Transformer need to be provided with reset in order to avoid saturation. Secondary side LC filter is ensures in lower ripple voltage. The Generalized Forward Converter is shown in Fig-1.

At the time MOSFET M is turned on the primary winding is applied with input voltage. Based on number of turns Secondary voltage is reflected and rectified through diode and passed to low pass filter than to load.

At the time MOSFET M is turned OFF primary winding is open, current through both primary & secondary is zero. Freewheeling diode provides path for the load current, but high capacitor at output will maintain output voltage constant [4].

Energy is stored mainly in output inductor, and the capacitor is made small with a lower ripple current rating:

- The main purpose is to reduce the output voltage ripple.
- Low active device peak current.

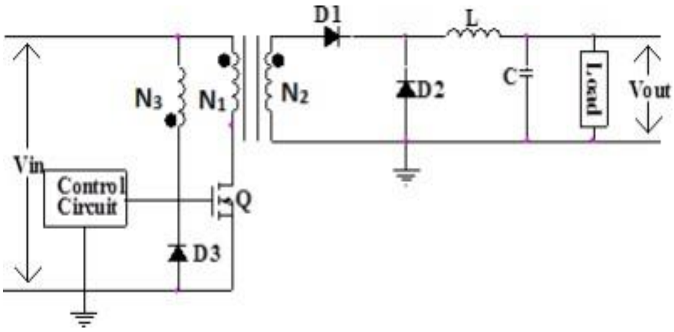

Fig -1: Generalized Forward Converter

Transformer is considered to be ideal with zero magnetizing current & zero losses. But to magnetizing current present in transformer a tertiary winding is required. It is because at the time MOSFET is OFF huge voltage developed across the primary winding need to be dissipated. This is performed by using one more winding reduces power loss. It is also called bifilar winding [5].

Closed Loop control of Forward converter is performed using voltage mode and current mode technique. Both has its own advantages & disadvantages.

1.2 Feed Forward Voltage Technique

Basically in a closed loop control system in order to control output we need to sense output voltage and compared with reference voltage [6]. Error voltage generated is compared with fixed ramp and it is fed back to PWM controller IC to change duty cycle accordingly. Sensing the output voltage with change in load and feeding the signal to primary controller will increases the response time of system or converter. Feed Forward Topology is shown in the Fig -2.

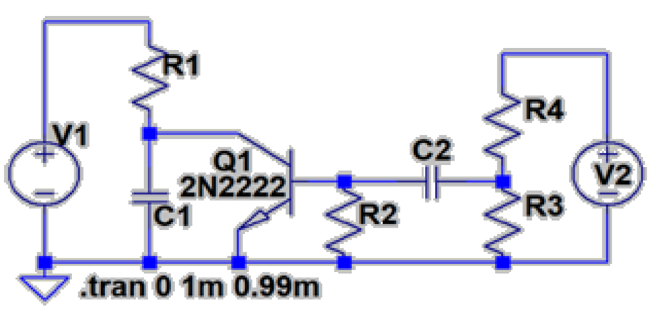

Fig -2: Feed Forward Topology

When the supply is ON the capacitor C1 is charged through supply and the clock pulse is high, transistor is turned on and the capacitor is discharged through transistor. This changes the slope of ramp with change in input voltage is compared with error voltage and in turn changes the duty cycle of PWM pulses [7]. Hence, it makes system faster to response with change in input.

1.3 Block Diagram of Forward Converter

The 32W dual output DC-DC Converter is designed and realized based on the specifications obtained by the Space Application Centre (SAC). Fig -3 shows the detailed Block Diagram of Forward Converter.

Block diagram shows the flow converter and operation of all circuitry.

EMI filters are designed and placed at the input section near to the input connector to meet the EMI/EMC requirements. 5kHz cut-off frequency (1st order) is the requirement for input filtering. 1 stage Common Mode filter (CM Filter) is considered in this design for a nominal input current of 3A to meet the EMI/EMC requirement. Differential Mode filter (DMI filter) is to meet the EMI/EMC requirement. At the time MOSFET is ON current flows from primary of transformer and energy is coupled to the secondary [8]. Secondary voltage passes through diode rectifier and a low pass filter results in output voltage.

A start up circuit will help PWM to turn on MOSFET initially, bias voltage will come in and provide power to PWM and other control Circuits. Bias voltage is kept more than the start-up voltage. Bias winding is used for feedback to maintain the output voltages.

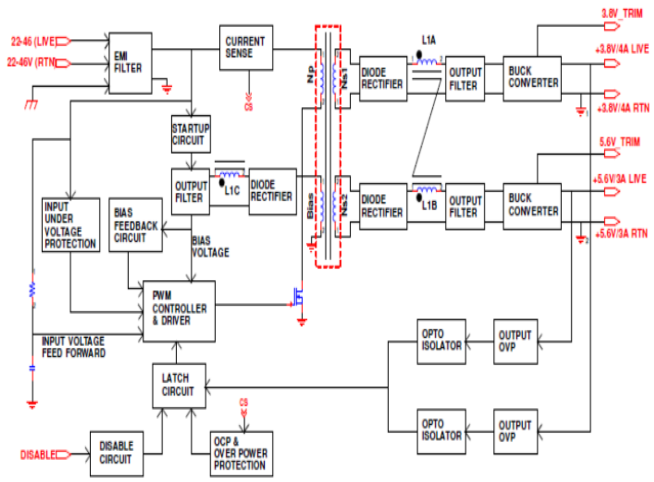

Fig -3: Block Diagram of Forward Converter

Input UVP (Under Voltage protection) circuit is designed with 28V with 2V hysteresis The circuit is ON, the turn OFF occur at 28V during under voltage condition whereas the turn ON threshold is around 30V. Input OPP (Over Power protection) circuit is designed for more than 150%.

On primary side of forward transformer, Bias winding is used to generate the bias voltage to power the controller circuits. The bias winding voltage is kept higher than the start-up circuit voltage so that a PWM controller circuit starts drawing the current from the bias winding instead of the start-up circuit [9]. The bias voltage is considered for feedback for the PWM controller. Hence bias winding act as the House Keeping Bus and continue to power the PWM IC and associated ICs [10]. The Secondary side voltage is rectified and filtered and connected to individual buck converters (POL) for generating +3.8V & -5.6V regulated outputs.

2. METHODOLOGY

Forward Converter is used mainly for its isolation for the protection purpose and to get the regulated output voltages (3.8 V and 5.6 V) with changes in the input voltage ranges of 26 V to 45 V. The Forward Converter is designed for the switching frequency of 500 KHz. PWM controller IC is selected for its high switching frequency. Feed Forward Voltage Mode Control is employed as feedback circuit. It has advantage of faster response. Output side Diode Rectifier is selected to regulate the output voltage. The converter includes protection circuits like Over Voltage, Under Voltage, Over Power.

The design of converter includes Filter Inductor, Filter Capacitor, Transformer winding, Coupled Inductors Snubber Resistor and Capacitor and protection circuit components. Some of the components are selected like UC2825 DWTR Controller IC, SOIC 16, Diode Rectifier ISL70003ASEHFE/PROTO IC. The MOSFET Switch STB33N60M2 600 V, 26A, Rds 0.125 is selected based on the low Drain to Source ON State resistance, low Conduction and Switching losses.

The selected components are placed on the Printed Circuit Board with help of Lead and Soldering Gun. The MOSFET switch is provided with Heat sink, in order to absorb the heat released by the switch. The Printed Circuit Board (PCB) is connected to the supply with help of wires. The converter is loaded with 10% to 100% loading conditions. According to the specification, the input voltage ranges from 26 V to 45 V, with varying input voltage the output voltage is regulated by feedback of Feed Forward Voltage Mode Control it will send the signal to the PWM Controller. The PWM Controller IC vary the duty cycle and the signal is sent to the MOSFET Switch to regulate the output voltage. The output voltage, current and Drain to Source Voltage waveforms are seen in the Digital Storage Oscilloscope (DSO). The readings for various inputs with varying loading conditions are noted down. According to these readings, the efficiency is calculated.

3. Design of Converter

Design of the converter includes Selection of transformer core, PWM controller IC, MOSFET Switch, windings, Filter Inductor, Filter Capacitor. Filter Inductor is used to reduce the Output Current Ripple, Filter Capacitor is used to reduce the Output Voltage Ripple.

The specifications of the converter is as follows

- Input Voltage Range : 26 V to 45 V
- Switching Frequency : 500 kHz
- Output Parameters : 3.8 V /4 A
  : 5.6 V /3 A
- Efficiency : ≥ 60%
- Line Regulation : < 1%
- Load Regulation : ≤ 3%
- Ripple & Noise : < 50 mV
- Load transient : < 100 mV
- Over Power Protection : > 150 %

And Consider,

- Dmax= 0.6
- Bm = 0.1 Tesla
- Kw = 0.3
- J = 6 A/mm^2
- Pout= 40W

3.1 Selection of Transformer

The two major selection criteria for transformer is power handling capacity and area product of transformer. Calculating the area product for the forward converter and select the core accordingly.

$$\mathrm{Ap} = \frac{\sqrt{\mathrm{Dmax}} \times (\mathrm{Pout} + \mathrm{Pbias}) \times (1 + \frac{1}{\mathrm{Eff}})}{\mathrm{K_w} \times \mathrm{J} \times 10^{-6} \mathrm{B_m} \times \mathrm{F_{sw}}} \qquad (1)$$

$$\mathrm{Ap} = 797.83 \text{ mm}^4$$

Selected Toroid Core: ZP-41605TC, Material: P, Ur:2500, AL: 1375nH/1000T

Once area product is calculated and core is selected and number of turns required, Turns ratio need to be calculated.

$$Tratio_{bias} = \frac{(|Vbias|) + VLDb) + VDb * Dmax}{Dmax * Vin\_min} \qquad (2)$$

$$Tratio_{bias} = 0.3$$

Calculation of Winding Inductance is calculated as follows

$$Lp = Np^2 \times AL = 3.09 \times 10^{-4} H$$

$$Ls1 = Ns1^2 \times AL = 1.38 \times 10^{-4} H$$

$$Ls1 = Ns1^2 \times AL = 1.38 \times 10^{-4} H$$
$$LNbias = Nbias^2 \times AL = 3.09 \times 10^{-4} H$$

Number of Turns is calculated as follows

$$Np = \frac{Vin\_min * Dmax}{Bm * Ac * 10\text{^}\{-6\} * Fsw} = 15.4\ turns$$
$$Np \cong 15\ turns$$
$$Bm = \frac{Vin\_min * Dmax}{Np * Ac * 10\text{^}\{-6\} * Fsw} = 0.1026\ T$$
$$Nbias = Tratio_{bias} \times Np = 15.45\ turns \cong 15\ turns$$
$$Ns1 = \frac{(Vout1 + VLD1) * Nbias}{Vbias} = 10\ turns$$
$$Ns2 = \frac{(Vout2 + VLD2) * Nbias}{Vbias} = 10\ turns$$
$$Nmag = Np \frac{(1 - Dmax)}{Dmax} = 8\ turns$$

3.2 Inductance and Capacitance Filter Design

Filter Inductance and Capacitance values are designed to reduce the Output Voltage and Current Ripple.

$$L1 = \frac{V\_out1(1 - D_{min1}) \times Ts}{K1 \times I_{out1}} \quad (3)$$

$$L = 9.4609\ \mu H$$

$$C1 = \frac{K1 \times I_{out1}}{8 \times Fsw \times Delta_{v1}} \quad (4)$$

$$C1 = 6.25\ \mu F$$

4. Hardware Implementation and Results

Experimental results that depict line regulation, load regulation, cross regulation, efficiency and ripple voltage measured at different outputs are tabulated. Various waveforms like Output voltage, Output current, Drain voltage, Gate pulse, Output ripple waveforms of Forward converter are presented.

- The hardware implementation of the converter includes various parts

A. PWM IC (UC2825DWTR)
B. MOSFET
C. Transformer
D. Differential-mode filter inductor
E. Common-mode filter inductor
F. Output Diodes
G. Diode Rectifier.

4.1 Electrical Test Results

Waveform of the output voltage 1 is shown by using the DSO. For changes in the input voltages ranging from 26 V to 45 V, the output voltage is regulated. Waveform of output voltage 1 is shown in Fig -5.

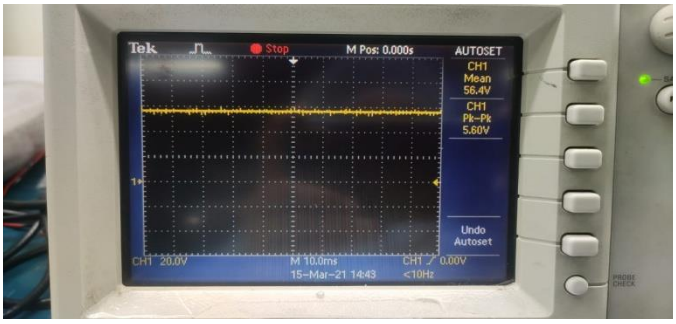

Fig -5: Output Voltage Waveform for Output 1

Waveform of the output current 1 is shown by using the DSO. For changes in the input voltages ranging from 26 V to 45 V, the output voltage is regulated. Waveform of output current 1 is shown in Fig -6.

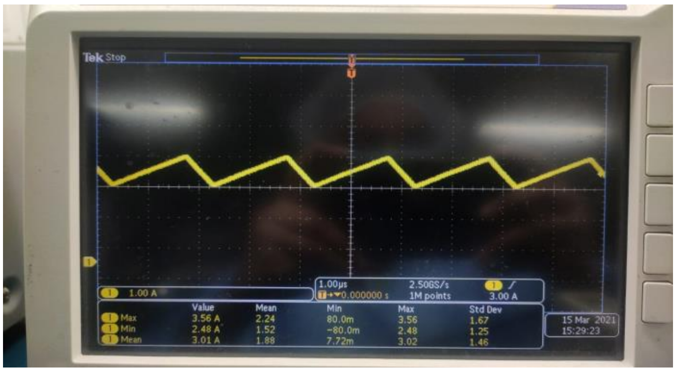

Fig -6: Output Current Waveform for Output 1

Waveform of the output voltage 2 is shown by using the DSO. For changes in the input voltages ranging from 26 V to 45 V, the output voltage is regulated. Waveform of output voltage 2 is shown in Fig -7.

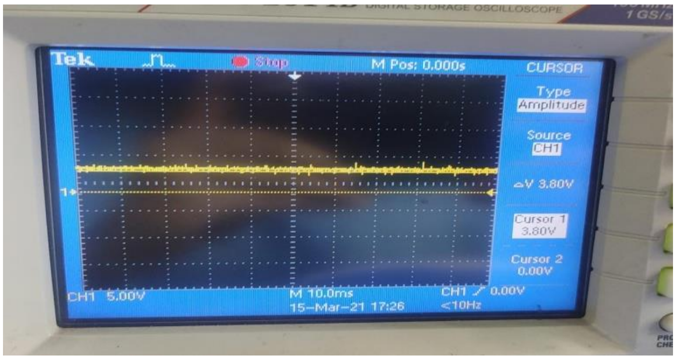

Fig -7: Output Voltage Waveform for Output 2

Waveform of the output current 2 is shown by using the DSO. For changes in the input voltages ranging from 26 V to 45 V, the output voltage is regulated. Waveform of output current 2 is shown in Fig -8.

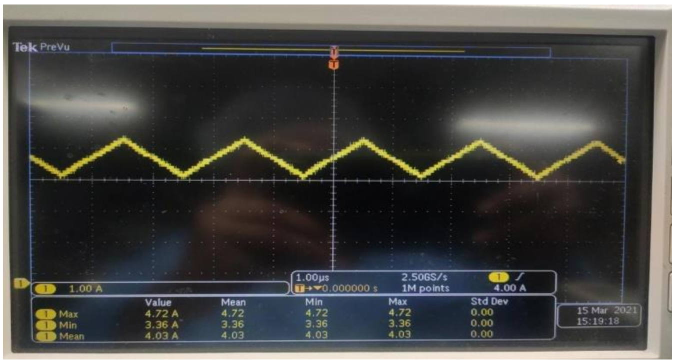

Fig -8: Output Current Waveform for Output 2

The output voltage ripple waveform is shown in the Fig -9. The specification is to be less than 50mVpp. From practical calculation the, the obtained ripple voltage is less than 50mVpp. If the voltage ripple is less, the losses are to be reduced. The voltage ripple is reduced by considering the large value of capacitor across the output side.

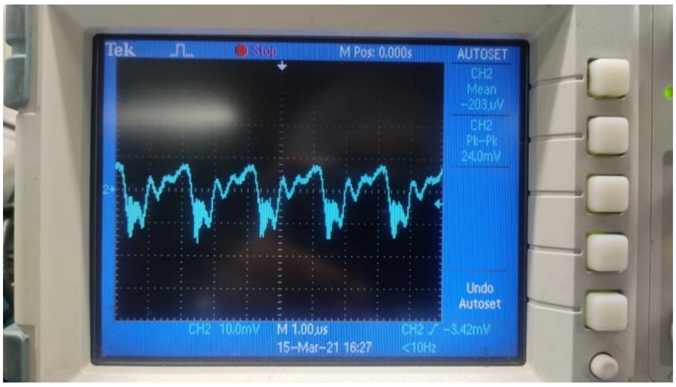

Fig -9: **Output Voltage Ripple Waveform**

The output voltages are regulated for changing input voltage ranges. The practical values for Output Voltage, Output Current, Output Voltage ripple are shown in Table -1.

Table -1: 100% Loading Conditions for 26 V Input Voltage.

PARAMETER	26 V INPUT	
	OUTPUT 1	OUTPUT 2
Input voltage	25.877	
Input current	1.642	
Load current	4	3
Output voltage	3.805	5.591
Output power	15.22	16.77
Total output power	31.99	
Input power	42.49	
Total loss	10.50	
Efficiency(%) Spec>60%	75.3	
Output ripple(mVpp) spec<50mVpp	24	

5. CONCLUSION

Dual Output Forward Converter with Feed-Forward Control for Space Application has been designed. The selected topology was Forward Converter. The main components include PWM Controller IC, Driver Circuit, MOSFET Switch and Transformer. The hardware implementation results shown that the two Output Voltages obtained were 3.8 V & 5.6 V and the Output Currents obtained were 4 A & 3 A. The obtained efficiency was more than 60%, and obtained Output Voltage Ripple was less than 50 mVpp. The obtained efficiency and Output Voltage Ripple were within the specified limits.

REFERENCES

[1]N. L, L. Venkatesha and N. J, "Design and Implementation of a Separate Control Driven High Current Synchronous Rectified Forward Converter with Non-Dissipative Snubber Reset", Global Conference for Advancement in Technology (GCAT), February 2019, pp. 1-6, doi: 10.1109/GCAT47503.2019.8978437.
[2]M. Krishnaja, S. Samanta, K. Shukla and R. Singh, "Peak Current Mode Controlled Active Clamp Forward Converter with Magnetic Feedback", IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), December 2018, pp. 1-5, doi: 10.1109/PEDES.2018.8707671.
[3]M. Gagan, B. k. Singh and V. S. Chippalkatti, "Two Switching Pulse Based Hysteresis Control Circuit for Active Clamp Reset Forward Converter", 4th International Conference on Electrical Energy Systems (ICEES), August 2018, pp. 494-499, doi: 10.1109/ICEES.2018.8443221.
[4]N. M. Mukhtar and D. D. Lu, "An Isolated Bidirectional Forward Converter with Integrated Output Inductor-Transformer Structure", IEEE 4th Southern Power Electronics Conference (SPEC), December 2018, pp. 1-7, doi: 10.1109/SPEC.2018.8635880.
[5]M. Krishnaja and S. Samanta, "Effect of Optocoupler Feedback Dynamics on Peak Current Mode Controlled Active Clamp Forward Converter", IEEMA Engineer Infinite Conference (eTechNxT), June 2018, pp. 1-6, doi: 10.1109/ETECHNXT.2018.8385375.
[6]J. Kim, J. Choe and J. Lai, "Forward-Flyback Converter for LED Driving with Reduced Number of Components", IEEE Energy Conversion Congress and Exposition (ECCE), February 2017, pp. 3684-3687, doi: 10.1109/ECCE.2017.8096652.
[7]J. Sreedhar and B. Basavaraju, "Design and Analysis of Synchronous Buck Converter for UPS Application", 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), December 2016, pp. 573-579, doi: 10.1109/AEEICB.2016.7538356.
[8]A. Bhat, K. U. Rao, Praveen P K, B. K. Singh and V. Chippalkatti, "Multiple Output Forward DC-DC Converter with Mag-amp Post Regulators and Voltage Feed Forward

Control for Space Application", Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE), July 2016, pp. 1-6, doi: 10.1109/PESTSE.2016.7516488.

[9]A. Bhat, K. U. Rao, Praveen P K, B. K. Singh and V. Chippalkatti, "Multiple Output Forward DC-DC Converter with Regenerative Snubber for Space Application", Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE), January 2016, pp. 1-5, doi: 10.1109/PESTSE.2016.7516487.

[10]Y. Lo, T. Song and S. Yen, "Analysis and Design of a Two-Output Forward Converter with an Output Voltage Objective Function", IEEE International Conference on Industrial Technology, June 2006, pp. 540-545, doi: 10.1109/ICIT.2006.372196.