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Multi output Fly back Converter with Switching/Linear Post Regulators

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***Abstract*— In high power pulsed radar transmitter the gridded TWT is used as main power amplifier, the grid control includes the grid positive and grid negative power supplies, which control the beam ON and OFF of TWT. The negative voltage is used to maintain the TWT in an off state (bias), while positive voltage is used to turn on the TWT (drive). The grid supplies are referenced to cathode and thus float at high potentials making the design of these converters challenging, thermally as well as electrically. In this paper, an approach is presented that is easy to use, low cost & efficient. Preliminary work done to realize the prototype hardware & its results are also presented. The input of the converter is a regulated 28V DC. The prototype is realized using a free running multi output fly back converter operating at 100 KHz in CCM mode. The isolation requirement between the primary & secondary is achieved using a transformer realized with ETD core & moulding it using solid encapsulate. Multiple secondary outputs provide for grid supplies as well as low voltage supplies for drive & protection requirements.**

The switching/linear post regulators are proposed for maintaining necessary load regulation on all the outputs. The converter is over current protected, using pulse by pulse current limiting at the primary. The PWM technique based on the IC UC28025 is used for the fly back converter.

***Keywords*--Fly back converter, TWT (Travelling wave tube), linear post regulator, switching buck regulators, snubber).**

I. Introduction

The conduction loss of diode rectifier and switching loss significantly contributes overall power loss in a power supply. This paper analyses the application of two most popular isolated and non isolated topologies, Fly back & Buck converter. The limit of efficiency improvements that can be obtained using fly back multi output converter are determined. The conversion efficiency of different implementation are compared and verified with experimental results. Here, secondary side of multi output fly back converter will be floating at very high potentials. Therefore isolation between primary and secondary winding of fly back switching transformer winding is high.

As it is very difficult to take feedback signal for control circuit from secondary side of multi output fly back converter to primary side, because voltage level of primary side is 28V DC whereas voltage level of secondary side of fly back converter is 10kV with respect to ground, as shown in fig. 1.1 Hence there is a need of high efficiency post regulators for next stage. Here for secondary side Two outputs are high grid drive and grid bias and housekeeping supplies linear Post regulators are used for each good regulation purpose, but for high voltage grid drive 320 V output alternate switching buck regulator is used for good Tight Regulation Purpose

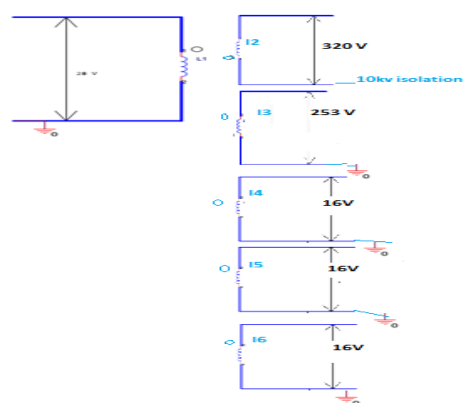

Fig1.1: Flyback muti winding transformer.

II. Multi Output Fly Back Converter

A Flyback multi output converter as shown in fig 2. When switch is turned on energy is stored from primary magnetizing inductance to secondary magnetizing inductance to output of load, similarly when switch is turned off, the energy stored from primary magnetizing inductance and does not flow to secondary magnetizing side. Hence leakage inductance is part of primary winding transformer, here leakage spikes will be more when switch turned off . In order to reduce spikes in primary side magnetizing inductance external RCD snubber used parallel to switch as shown in fig 2.

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And for secondary side high voltage grid drive and grid bias output, low housekeeping supplies as shown in fig2 After adding RCD snubber to primary side of fly back transformer spikes on the switch can be reduced. This also helps in reducing the EMI generation.

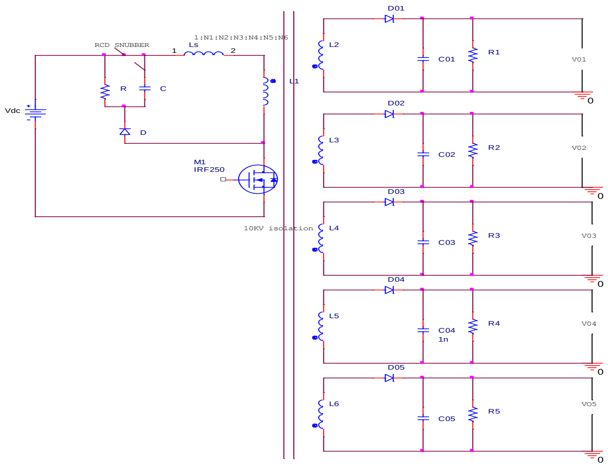

Fig 2. Schematic diagram of multi output fly back converter with Conventional RCD snubber.

2.1: Design And Simulation Result Of Multi Output Flyback Converter:

Specifications:

Input Voltage V_{in} (dc) = (28$\pm$0.5) V,

Switching Frequency = 100 KHz,

Outputs Specifications: (320V,15mA,) Grid drive

Grid bias : 253V,11mA

Low voltage side (16V, 100mA, 16V, 100mA, 16V, 100mA) $P0_{Total}$ =12.38 watts

Step 1: Establish primary & secondary turn Ratio:

$Np/Nsm = [V_{dc\ min} -1] D_{max} / [(1- D_{max})*(V_0+1)]$

$$\frac{Np}{NS1} = 0.06754 \quad \frac{Np}{NS2} = 0.08536 \quad \frac{Np}{NS3} = 1.2754$$

$$\frac{Np}{NS4} = 1.2754 \quad \frac{Np}{NS5} = 1.2754$$

Where D_{max} = 0.45 (assumed)

Step 2: Voltage stress of main switch (SW):

$$V_{ms\ max} = V_{dc\ max} + \frac{N_p}{N_{sm}}(V_o + 1)$$

= 50.18V

Where $V_{dc\ max}$ = Maximum dc input voltage, $V_{ms\ max}$ = Maximum stress on the device (2 times of $V_{dc\ max}$)

N_P = Primary no of turns

N_{sm}= Secondary no of turns (main output)

V_O = Output Voltage.

Step 3: Calculation of primary magnitude Inductance (Lp):

$$L_P = \frac{(V_{dc\ min}-1)*V_{dcmin}*(T_{onmax})^2}{2.5*P_{0min}*T_S} = 123\mu H$$

Where, given: f = 100 kHz, D= 0.45 $P_{0\ min}$ = 4.8watts; S0, T=1/f = 10 µs; $T_{on\ max}$ = D* T = 4.5 µs.

Let us take Pomin =3*16*100mA (Housekeeping supplies) =4.8w

Step 4: Calculation of primary peak current:

$$I_{cpr} = \frac{1.25*P_{0max}}{V_{dcmin}*D_{max}} \quad \text{(Assuming 80\% efficiency)}$$

= 1.25A

Ramp amplitude dI_p

$$dI_p = \frac{2.5*P_{0\ min}}{V_{dc\ min}*D_{max}} \quad (\text{Let } P_{0min} = 4.8W)$$

= 0.969A

Therefore peak current in the mosfet = Icpr + (dIp/2)

= 1.73 A

Step 5: Calculation of secondary peak current:

$$I_{csr} = \frac{P_{0max}}{V_0(1-D_{max})}$$

I_{CSR1}=0.0273A=27.3mA,I_{CSR2}=19.9~20mA, I_{CSR3}=I_{CSR4}=I_{CSR5}=0.181=185mA

Average of I_{csr} gives secondary load current

ie, Icsr (1-Dmax) = 0.332A

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Step 6: Calculation of output diode stress

$V_{do,max1}$ =742V, $V_{do,max1}$ =586.88~587V

$V_{do,max1}$ = $V_{do,max1}$ = $V_{do,max1}$ =38.34v ~ 39v

Step 7: Output filter capacitors C_{01} C_{02} C_{03} C_{04} C_{05}:

C01 = 0.675 uF C02 =0.495uF

$C_0 = \frac{D_{max} * P_0}{F_{sw} * V_0 * \Delta V_0}$ (Take ΔV_0 =0.1V)

Co3, Co4, Co5 = 4.5μF

Take $C_{03,\ c04,\ c05}$ = 20μF

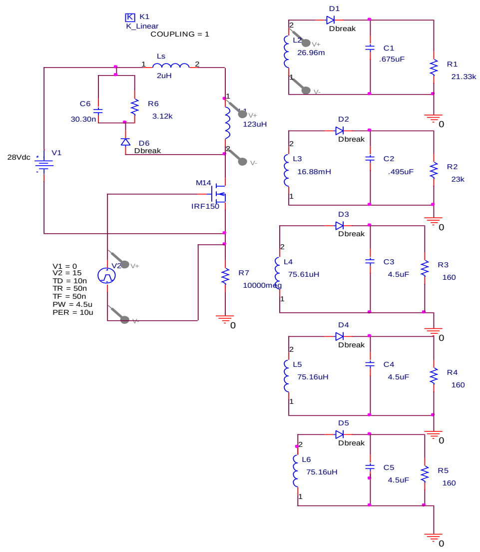

Fig 2.1 Simulation circuit of Multi output fly back converter

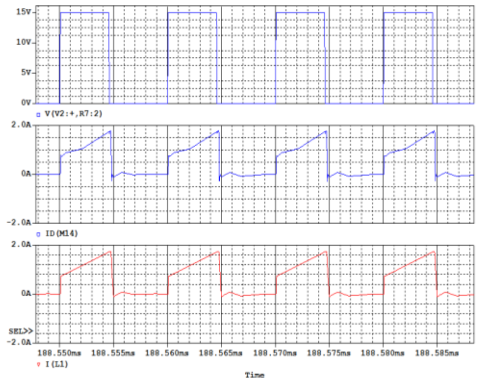

Fig 2.2 Gate pulse voltage, mosfet drain current

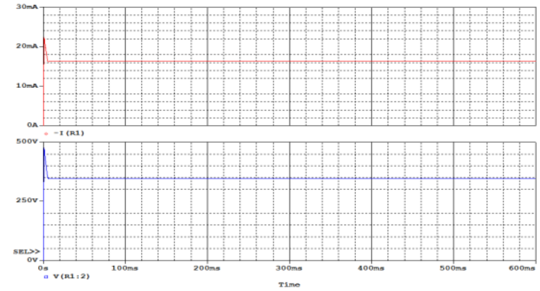

Fig 2.3: Output voltage across C1 (320V) & load current through R1 (15mA)

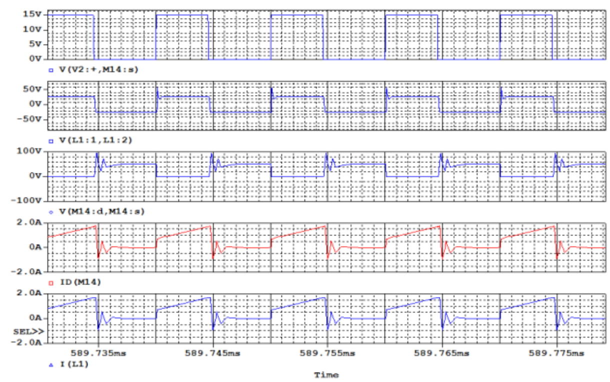

Fig2.4: Including leakage inductance Gate pulse voltage, primary voltage, and voltage stress across MOSFET, current through drain current & primary current

2.2: Transformer design:

Area product A_e = 173mm^2 for N87

Now select ETD 44 core and select material N87

Primary turns 6 turns
Secondary turns 89, 70 & 5 turns

Now wire selection is done accordingly and 10kV isolation requirements between primary/secondary multi output windings and secondary winding/core are met using polyimide sheet in fly back Transformer, as shown in Fig. 2.5.

Fig 2.5 ETD Core Transformer

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C: *PWM Controller For Flyback Multi Output Converter*

UC2805: For primary side fly back converter we are using UC 28025. UC28025 are fixed-frequency PWM controllers optimized for high-frequency switched-mode power supply applications. Targeted for cost effective solutions with minimal external components, UC28025 include an a oscillator, a temperature compensate reference, total band width error amplifier, high-speed current & low sense comparator and high-current active-high outputs to directly drive external MOSFETs.

III. POST REGULATORS

A buck converter is a simplest way to reduce the DC voltage of a power supply. It is also used for linear regulator. Thus linear regulators are at loss, as they can operate by dissipating excess of heat. Buck converter another side can be a remarkable efficient. Grid drive voltage requirement can have production variations of the order of about 100V between minimum and maximum values. This excess voltage has to dropped in the series pass element with 15mA of load current which leads to 1.5 to 2W dissipation .So, cooling will be the issue in linear regulator floating at higher voltages, especially when using solid encapsulate. Hence buck regulator is proposed for use in main output as alternate method, the Grid drive supply & for all outputs linear regulators are used as post regulator.

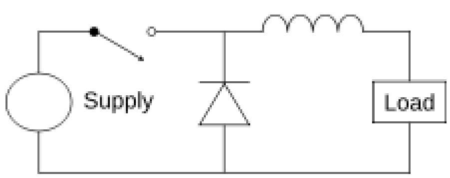

Fig 3.1: Buck converter circuit diagram.

The conceptual model of the buck converter is used in terms of the relation between current and voltage of the inductor. Beginning with the switch open (in the "off" position), the MOSFET switch current is zero. When switch is closed the MOSFET current will slightly begin to increase and other side the inductor will produce an opposing voltage across its terminals in response to the changing current. When the voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Thus the rate of change of current decreases and the voltage across the inductor also decreases. It also increases the output voltage at the load. During this time, the inductor is storing energy in the form of a magnetic field.

B: Design And Simulation Results Of Switching Regulator

Specifications:

Input Voltage V_{in} (dc) = Output of fly back multi output converter = 320 V,

Switching Frequency = 100 KHz,

Outputs Specifications: (225V, 15mA).

Step1: Calculation of Inductance (L)

$T_s = 1/f_s$ =10 µs, $D = V_0/V_{in}$ = 70%, P_{out} = 3.375W Inductor will be chosen so that the current remains continuous if the DC output current stays above a specified minimum value. (Typically this is chosen to be around 30% of the rated load current, or 0.3 Io, where "Io" is defined as the nominal output current.)

Therefore, $I_{0\ (min)} = 0.3\ I_0 = (I_2 - I_1) / 2$ i.e. $\Delta I = I_o$ = 9mA,

$L = [5(V_{IN} - V_0)^* V_0^* T_S] / [V_{IN} * I_0]$ = 37mH.

Step2: Calculation of Output capacitor (C_0):

$C_0 = [(1 - D)^* T_S^2 * V_0] / [8 * L^* \Delta V_0]$ = 20 µF

Where ΔV_0 = Consider 1% of V_0.

Step3: Calculation of R_{load}:

$$Rl = \frac{vout}{vin} = 15k\Omega$$

Simulation circuit:

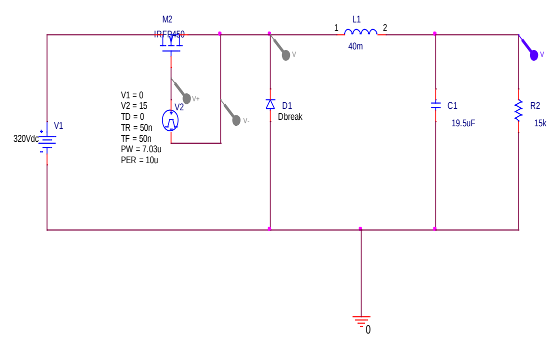

Fig 3.10: simulation circuit for buck converter

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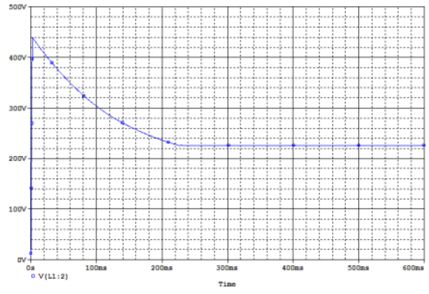


Fig 3.2: output voltage of buck converter

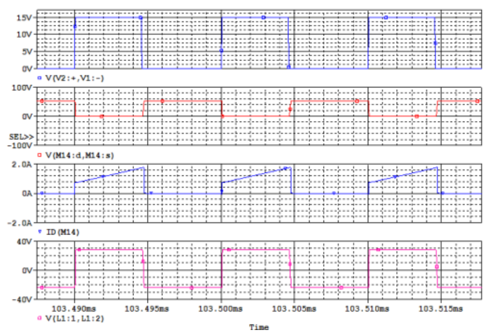


Fig 3.4 : Gate pulse voltage, voltage stress across mosfet, drain current, primary voltage

C. *PWM Controllr For Buck Regulator*

UC1823A: This IC is used for either voltage or current mode control. The UC1823 family of PWM control ICs is optimized for high frequency switched mode power supply applications. Particular care was given to minimizing propagation delays through the comparators and logic circuitry while maximizing bandwidth and slew rate of the error amplifier. This controller is designed for use in either current-mode or voltage-mode systems with the capability for input voltage feed-forward.

IV. Proposed Topology Of Multi Output Flyback Converter With Switching/Linear Post Regulator

In whole circuit the Secondary side of fly back converter will floating on very high voltage line which puts a high voltage isolation barrier between primary and secondary winding of fly back transformer. So it is very difficult to take feedback signal for control circuit from secondary side of fly back converter to primary side.

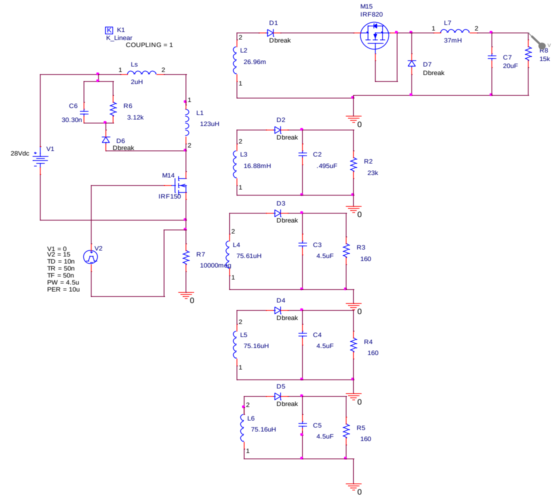
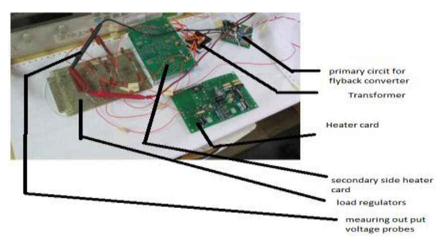


Fig 4.0: Schematic diagram of proposed circuit

V. Hardware Implimentatin Of Proposed Topology And Testing Result

To implement the hardware topology and design mentioned in sections 2.1, 2.2 flyback multi output circuit as shown. Applied input is 28 ± 0.5V DC with 100 kHz switching frequency by using IC UC28025 in primary side of flyback converter, and secondary side high voltage grid and grid bias so using linear post regulator for tight regulation obtained.



1) Primary circuit for fly back converter 2) Transformer 3) secondary side heater card 4) heater card 5) load regulators

Fig 5.0: Hardware circuit for multi out fly back converter with switching/linear post regulators

Fig 5.1: Hardware testing circuit.

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5.1 Wave form of hardware circuit

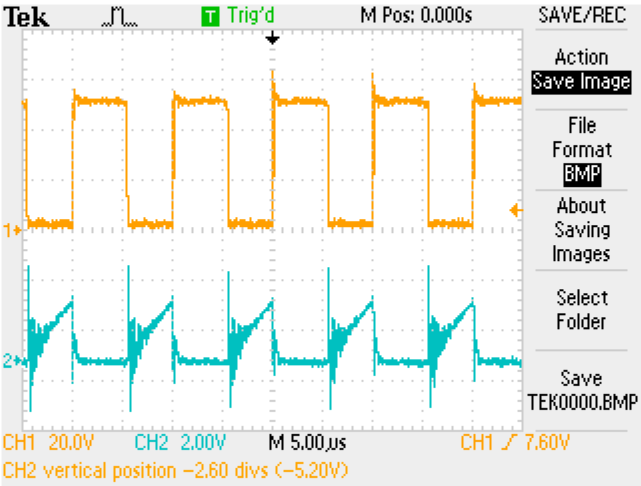

Fig5.3: Wave form of ch1 VDS and ch2 MOSFET current of flyback multioutput converter in proposed topology

5.2 Testing Results of Hardware circuit

Table -1
Fly back multi output converter

Vin (V)	I in (A)	Pin (W)	Pout (W) (Vout1*I out1)+ (Vout2*I out2)+ (Vout3*Iout3)+ (Vout4*Iout4)+ (Vout5*Iout5)	Efficiency (%) = pout/pin
27.5	0.612	16.83	14.01	83.25
28.0	0.629	17.61	14.68	83.36
28.5	0.642	18.29	15.21	83.16

At the R load1 =23.2k, Rload2=23k, (Rload3=4=5) =160Ω

VI. CONCLUSION

The design of flyback multi output with switching/linear post regulators is proposed in this paper. The fly back converter topology is best suited for application less than 100W.This proposed topology as outstanding characteristics. We archived less power loss and high efficiency. It is suitable to used for power supplies. Since secondary side of this scheme is less dissipative, it is best suitable for heater converter stage of TWT grid Power supply floating on high voltage. Preliminary work done to realize the prototype hardware & its results are also presented.

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