Cross Regulation of a Leakage-Compensated Multi Output Auxiliary Power Supply

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Abstract

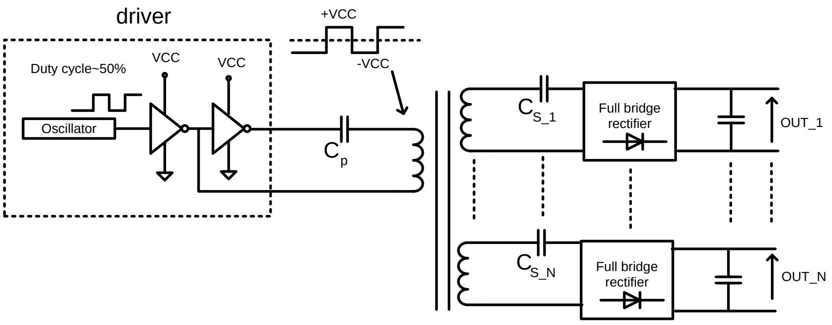
Transformer isolated, multi-output power supplies (MOPS) are useful as gate drivers auxiliary supply in multi switch conversion systems such as motor drive inverters. This work investigated the use of series resonant capacitors at the secondaries of the transformer to compensate the leakage inductance and explored the issues of cross regulation and parasitic oscillation at light load. Analytical, simulation and experimental studies, conducted in this work, showed that good overall performance can be obtained by the proposed choice of the components of the MOPS.

Synopsis

Transformer isolated, multi-output auxiliary power supplies (MOPS) are useful as gate drivers supply in multi switch conversion systems such as motor drive inverters. Systems based on WBG devices require low interwinding capacitance of the MOPS isolation transformers. This gives rise to large leakage inductance of the transformer which in turn results in poor load stability and cross regulation. This work investigated the use of series resonant capacitors at the secondaries of the transformer to compensate the leakage inductance and explored the issues of cross regulation and parasitic oscillation at light load. The effects of the non-idealities were investigated analytically, by simulation and experimentally. The results of these studies were used to develop recommendations for considerably improving the performance of the MOPS by proper choice of the resonant capacitors, the rectifying diodes and an LDO which dissipate rather low power.

1. Introduction

Typical multi-switch conversion systems apply high side and low side gate drivers. In high power, high frequency systems, as implemented by SiC and GaN MOSFETs, the power supplies to the gate drivers, and especially for the high side driver, need to be isolated. Another requirement is that the capacitance between the input and output of the driver's power supply will be extremely small. This to avoid the injection of high peak current from the output back to the input [1, 2]. A cost-effective solution for a large number of auxiliary power supplies requirement is to use a transformer based multi-output auxiliary power supplies (MOPS) as depicted in Fig. 1. However, the requirement of low interwinding capacitance means that the primary and secondary windings of the transformers be a part. This, in turn, increases the leakage inductance, causing a voltage drop when the output current is increased and resulting in poor cross regulation[3-5]. The objective of this study was to investigate the behavior of the native MOPS and to propose ways to improve the performance of the MOPS given the relatively high leakage inductance.



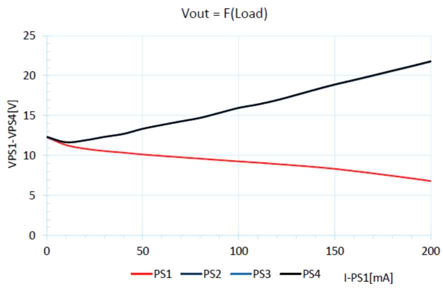


Fig. 1: Generic representation of a transformer based multi-output auxiliary power supplies (MOPS).
Fig. 2: Typical output voltage unequally loaded MOPS channels. Red: voltage of the loaded output. Black: voltage of all others unloaded channels.

2. The transformer based multi-output auxiliary power supply

Considering the large leakage inductance, the output impedance of the MOPS increases and humpers the load and cross regulation. This behavior is clearly observed in simulation and experimentally (Fig. 2). The red trace in Fig. 2 shows the output voltage drop of a loaded output as a function of load current when all other channels are unloaded. The black trace of Figure 2 shows the voltage change of an unloaded channel as a function of the current in the loaded channel. The parameters of the investigated MOPS were: driver is made of two units of UCC27518DBVR, full bridge rectifier is made of 4 units of SB130-T, $C_s = 15[nF], C_p = 10[\mu F],\ L_{primary} = L_{secondary} = 1.37[mH]$, and $k = 0.956$.

3. Leakage compensation by resonant capacitors

Following the solution described in [2] resonant capacitors were added at the outputs. The large signal operation of the output section can be described by the circuit Fig. 3a which represents the functionality at each half of MOPS switching cycle. Figure 3b depicts the leakage inductance current [3].

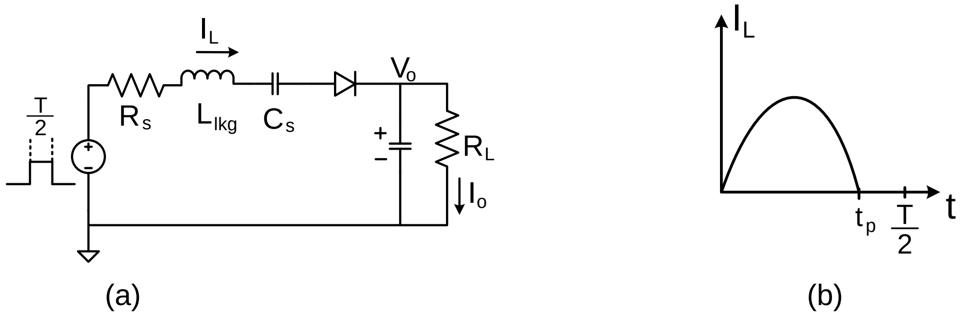


Fig. 3: (a) Equivalent circuit of output section for half a period, (b) Current waveform for half a period.

Referring to Fig. 3a,b, the relationship between the leakage inductance current and the output current can be expressed as

$$I_o = \frac{2}{T}\int_0^{t_p} I_L(t)\cdot dt \quad (1)$$

where

$$t_p = \frac{\pi}{\frac{1}{\sqrt{L_{lkg}\cdot C_s}}\cdot\sqrt{1-\left(\frac{1}{2\cdot Q}\right)^2}} \quad (2)\,; \qquad Q = \frac{1}{R_L}\cdot\sqrt{\frac{L_{lkg}}{C_s}} \quad (3)$$

Based on the above, a behavioral average model of the output section was developed (Fig. 4).

The parameters of the average model were extracted as follows:

$I^2_{L\_RMS} \cdot R_s = I_o^2 \cdot R_e \quad (4)\ ;\ R_e = R_s \cdot \frac{I^2_{L\_RMS}}{I_o^2} \quad (5)\ ; V_{DM} = 2 \cdot V_f \quad (6)\ ; R_{SW} = \frac{P_{sw}}{I_o^2} \quad (7)$

Where P_{sw} is the diodes' switching losses.

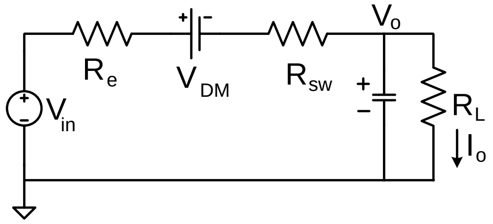
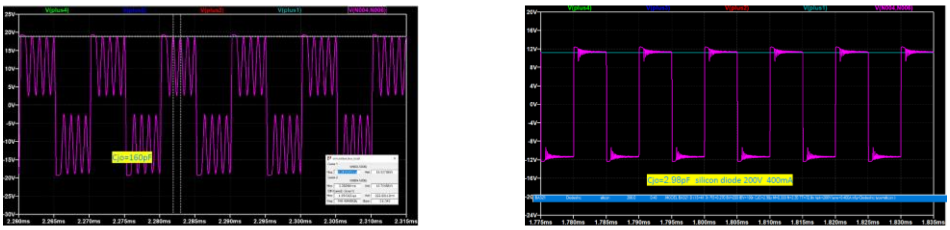


Fig. 4: Average behavioural model of the output section.

Considering the complex and highly nonlinear nature of the MOPS behavior, a simulation and experimental study was carried out to locate an optimum resonant capacitor (details in full paper).

4. Parasitic oscillation at light load

The leakage inductance and the diodes' capacitance form a resonant network which, at low load, initiates parasitic oscillations that are a substantial EMI source, as illustrated by the simulation plots of Fig. 5. Analytical consideration, simulations and experimental results confirm that the magnitude of the oscillation are suppresses to a large degree when high voltage low current Si diodes are used (details in full paper).



(a) (b)

Fig. 5: Output oscillations for different rectifying diodes. (a) 30V/1A Schottky (b) 200V/0.4A Si diode.

5. Conclusions

A comprehensive study conducted on the MOPS resulted in the development of a behavioral average model of the system and a set of design guidelines that optimize the performance of this family of auxiliary power supplies. The guidelines include: (1) Consideration for the selection of resonant capacitors to compensate the leakage inductances while minimizing load and cross regulations. (2) Selection of series capacitors to alleviate the problems due to an asymmetrical drive. (3) Selection of rectifying diodes to minimize the parasitic oscillations at light load. (4) Optimizing the turns ratio of the transformer to minimize losses when LDOs are used at the outputs.

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