A Novel Step Down Auxiliary Power Supply employed in a Micro Drive for a Three Phase Tesla Induction Motor

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Abstract: In this paper the authors proposed and analysed a novel solution for a low power, low cost auxiliary power supply based on step down topology with floating control circuit and indirect output voltage regulation. The proposed solution can be employed to feed a control unit and gate drive circuits in a micro PWM inverter for a three phase Tesla's induction motor in low cost variable speed applications. Experimental verification of 15 V at 150 mA auxiliary power supply has been done.

I. INTRODUCTION

In power converters such as *PWM* inverters, rectifiers and dc-dc converters, an auxiliary power supply is required to feed control circuit and gate drivers of power switches (usually *IGBT*s or *MOSFET*s). There are many possibilities to achieve this, and the applied topology depends on conditions, such as input voltage, output voltage, power rating, isolated or not isolated from the main dc bus. Typical topology of an auxiliary power supply used in motor drives is a dc-dc flyback isolated converter, supplied from main dc bus voltage of *300* to *900V* [1,2,9]. An auxiliary power supply used in boost power factor correction (*PFC*) converters is based on topology with auxiliary inductor coupled with the main boost inductor [7].

In standard design of a motor converter, the power supply takes approximately 25 to 35% of total PCB surface of the power converter [8].

In applications where small size and low cost are required, such as a converter integrated into the motor housing, a standard power supply is not an appropriate solution. A simple and cheep solution is required.

Fig 1 below shows a typical block diagram of a *230 V* mains supplied micro inverter. The inverter requires an auxiliary power supply fed from dc bus voltage, which can deliver *15 V* at load *100* to *150 mA*.

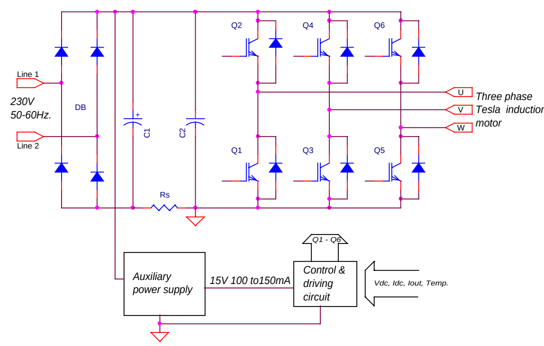


Fig.1: A micro drive topology

Yakow, Zelster, and Ivensky, analysed and proposed a snubber network employed as a power supply in power factor correction and similar applications [4,5].

In this paper a novel power supply solution is proposed. The topology of the proposed auxiliary power supply is based on a buck converter with floating control circuit. The power supply is applied to feed the control unit of a *230*V mains supplied three-phase inverter. The inverter feeds a three-phase Tesla induction motor in water pump and HVAC applications.

II. THE PROPOSED SOLUTION

The topology of the proposed solution is depicted in Fig 2 below. The power stage is a conventional buck converter with current mode control (*CMC*), which operates in discontinuous conduction mode (*DCM*). The control circuit is based on a commonly used integrated circuit *UC2842*, which directly drives the main switch *Q1*.

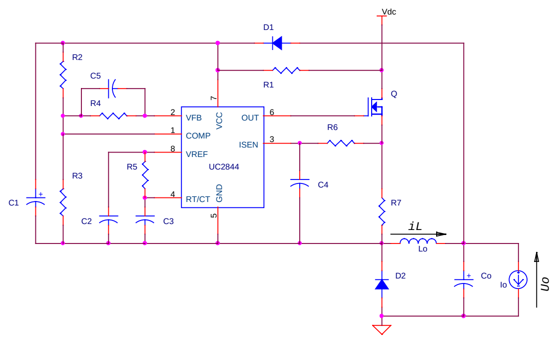


Fig.2: The proposed solution

The control circuit is floating and supplied through the charge pump diode *D1*. Voltage across the capacitor *C1* is approximately equivalent to output voltage U_0. At the moment switch *Q1* turns on, diodes *D1* and *D2* are off and the control circuit is supplied from capacitor *C1* while the switch *Q1* conducts (Fig. 3, stage *A*). At the moment when switch Q1 turns off, current in the inductor L_0 commutates to the diode *D2*. The reference voltage of the control circuit (0Vref), becomes approximately equivalent to the reference point of the output voltage (*GND)*. The charge pump diode *D1* starts to conduct and the capacitor *C1* charges until it reaches the level of the output voltage U_0 (Fig. 3, stage *B*). During stage B the current *iL* decreases. In the moment when the current reached zero, the diodes *D1* and *D2* turn off and the load is supplied from the capacitor C_0 (Fig.3, stage *C*). The control circuit is supplied from capacitor *C1* during the stage A and C.

At this analysis we can also assume infinity capacitance of the filter capacitor C_0, thus the voltage U_0 is constant during a switching period.

Equivalent circuit of the converter depends on the *Q1*, *D1* and *D2* states, and the three stages are shown in Fig 3.

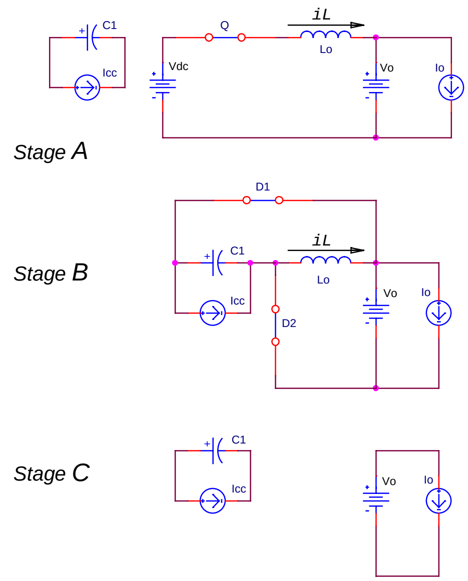


Fig.3: Equivalent circuit diagrams

The converter operates in discontinuous conduction mode (DCM), which can be achieved under conditions below.

$$L_0 \le \frac{U_0}{2I_{0\max}}\left(1 - D_{\max}\right)T_s \qquad (1)$$

The switching frequency is constant and defined by internal oscillator of a control circuit UC2842.

$$f_s = \frac{1}{T_S} = \frac{1.72}{R_5 C_3} \qquad (2)$$

Duty cycle in discontinuous conduction mode (DCM) depends on input voltage and load current.

$$D = \sqrt{\frac{U_0 I_0 2L_0}{E\left(E - U_0\right)T_s}} \le \frac{U_0}{E_{DC\min}} \qquad (3)$$

For design and choosing of a switch Q and a freewheeling diode, RMS, average and peak current have to be estimated. Peak current of the inductor L_0, switch *Q* and diode *D2* is defined in the following equation.

$$I_{\max} = \frac{\left(E - U_0\right)DT_s}{L_0}. \quad (4)$$

RMS and average current of the switch *Q* is

$$I_{pRMS} = I_{\max}\sqrt{\frac{D}{3}}$$

$$I_{pAV} = I_{\max}\frac{D}{2} \quad (5)$$

RMS and average current of the freewheeling diode D2 is,

$$I_{DRMS} = I_{\max}\sqrt{\frac{\frac{2I_{op}}{I_{\max}} - \sqrt{\frac{U_0 I_0 2L_0}{E\left(E-U_0\right)T_s}}}{3}}$$

$$I_{DAV} = I_{\max}\frac{\frac{2I_{op}}{I_{\max}} - \sqrt{\frac{U_0 I_0 2L_0}{E\left(E-U_0\right)T_s}}}{2} \quad (6)$$

RMS and average current of the inductor L_0 is,

$$I_{LRMS} = \frac{I_{\max}}{\sqrt{3}}\sqrt{D+D_1}$$

$$I_{LAV} = I_{op} \quad (7)$$

Where: D_1 is duty cycle of the freewheeling diode *D2*.

The output voltage ripple is caused by charge of the capacitor C_0 and it can be estimated as,

$$\Delta u_C \cong \frac{U_0 T_s^2\left(1-D\right)}{L_0 8C_0} \quad (8)$$

However, equivalent serial resistance (ESR) of the capacitor C_0 causes dominant component of the output voltage ripple, as it is expressed in the following equation.

$$\Delta u_{0r\max} \cong ESR \cdot \frac{U_0}{L_0}\left(1-D\right)T_s \quad (9)$$

The total voltage ripple is approximately,

$$\Delta u_0 = \Delta u_C + \Delta u_{0r\max}. \quad (10)$$

The second parameter of an electrolytic capacitor is RMS current. The RMS current of the filter capacitor C_0 reaches maximum at boundary between CCM and DCM, and it is defined in the following equation.

$$I_{C2RMS} \leq \frac{I_{0\max}}{\sqrt{3}} \quad (11)$$

The filter capacitor C_0 can now be chosen according to the ripple of the output voltage, equations 8, 9 and maximum of RMS current of the capacitor, equation 11.

The voltage on the control circuit *Vcc* is well regulated with the error amplifier of the control circuit. The voltage *Vcc* depends on resistors *R1* and *R2* and internal reference voltage of 2.5V.

$$V_{CC} = 2.5\left(1+\frac{R_2}{R_3}\right) \cong U_0 \quad (12)$$

It can also be assumed that the output voltage U_0 is approximately equivalent to the well-regulated voltage *Vcc*. The error amplifier is *P* type regulator with a high frequency pole. The resistors in voltage divider and regulator can be chosen according to the following equation.

$$\frac{R_4\left(R_3+R_2\right)}{R_2 R_3} \geq \frac{3}{e_{\max}}\left(1+\frac{R_2}{R_3}\right) \quad (13)$$

Where e_{max} is total output voltage error, approximately several %.

III. EXPERIMENTAL RESULTS

To verify the previous theoretical analysis, several tests have been done on a micro drive ***TRISTALAN750*** that was designed in the Laboratory for Digital Control of Power Converters at Department of Electrical Engineering, University of Belgrade. The drive ***TRISTALAN750*** is used to feed a three phase Tesla induction motor *750W 3x200V* employed in industrial water pump. The auxiliary step down power supply is used to feed the microprocessor in motor control unit and gate drive circuit of the IGBTs in output inverter stage.

The required performances:

Input voltage: - $E=150$ to $350V_{DC}$,

Output voltage: - $U_0=+15V$ +/-5%,

Load current: - $I_0=150mA$, and

Voltage ripple at nominal load: -$\Delta U_0=200mV_{pp}$

Figure 4 below shows input V_{DC} and output voltage U_0 at start up of the power supply. The start up test has been done at 90% of load current and nominal input voltage of 300V. Power up time is approximately 480ms.

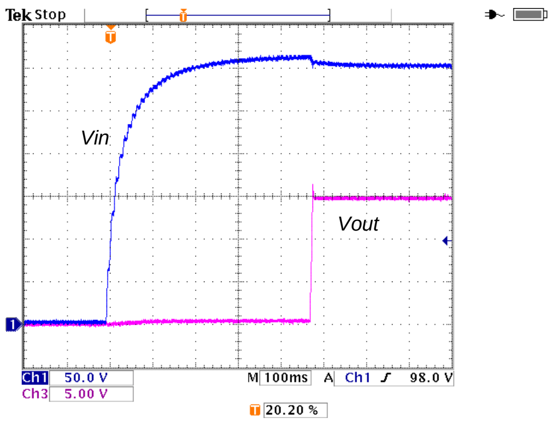


Fig.4: Start up of the supply at 300V input voltage and 90% of load.

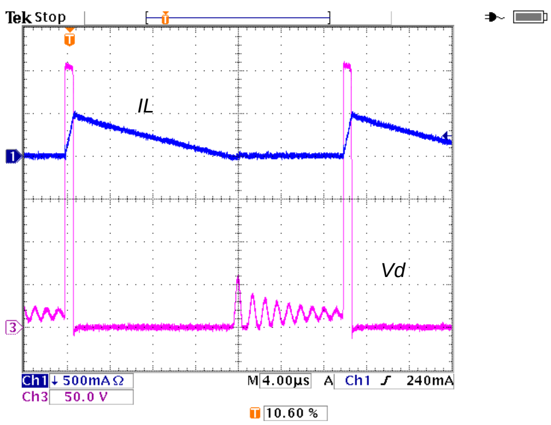


Fig.5: Waveforms of the inductor current and diode D1 voltage at input voltage of V_{dc}*=300 V* and load of *50%.*

Figure 6 shows the inductor current and output voltage ripple at 300 V input voltage and different load current. The ripple in output voltage is approximately 30 mV. High frequency oscillations in the voltage are measurement noise.

Figure 7 shows response of output voltage to the transient load current from 10% to 90% of nominal load. The voltage error of the output voltage is approximately 800 mV, and it is mostly the static error caused by floating control circuit.

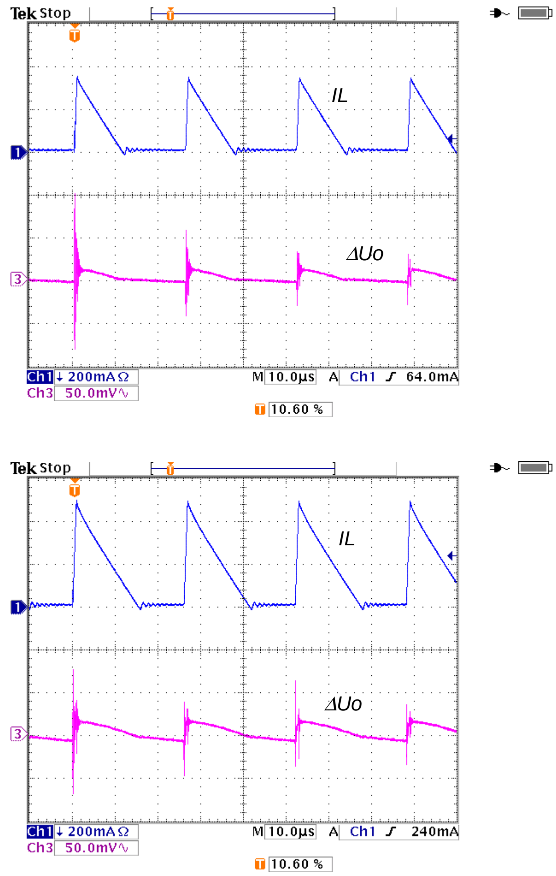
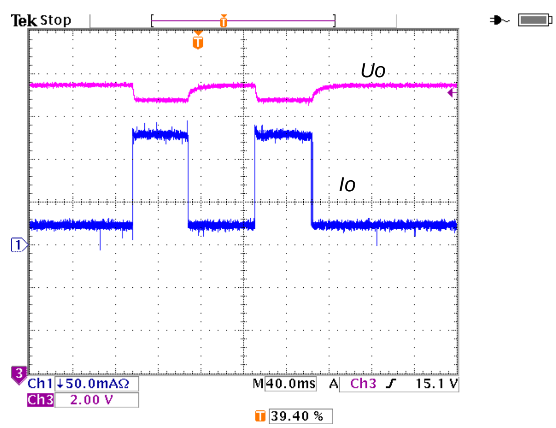


Fig.6: Waveforms of the inductor current and ac component of the output voltage at input voltage of V_{dc}*=300 V* and load of *50%* (upper) *and 90%* (lower).



7: The output voltage and step load of *10%* to *90%.*

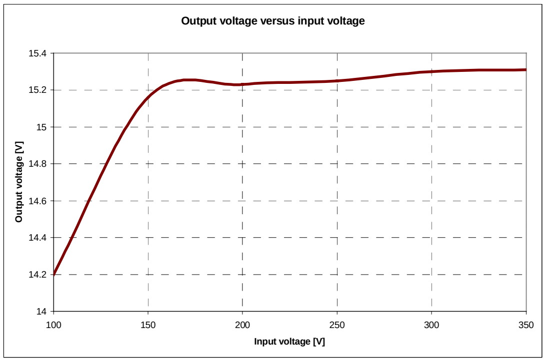


Fig.7: The output voltage versus input voltage at nominal current of *150 mA*.

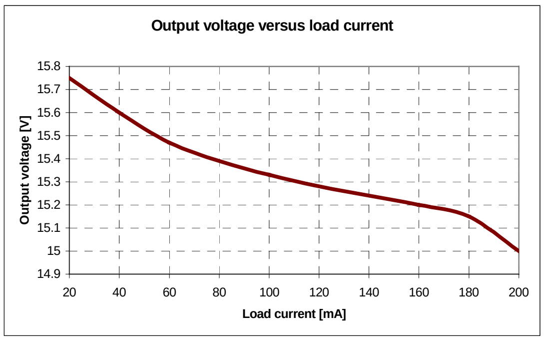


Fig.8: The output voltage versus load current at nominal input voltage of ***300 V***.

IV. CONCLUSION

This paper describes a step down converter with floating control and gate drive circuit. The proposed solution for auxiliary power supply is cheap, robust and simple. Thus it can be used in application with low load; small volume and low cost required.

Typical application where the proposed solution can be used is a micro inverter integrated in the housing of a three phase Tesla induction motor employed as a mechanical actuator in fans, pump and other similar industrial applications. The auxiliary power supply feeds the control unit and gate drive circuit of the converter.

The proposed solution has been tested on a micro inverter ***TRISTALAN750*** that was developed in Laboratory for Digital Control of Power Converters and Drives at Department of Electrical Engineering in Belgrade.

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