PWM Control Technique of Opto-Isolated Synchronous Buck Converter for Low Power Applications

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Abstract- *This paper introduces an approach of PWM control technique of opto-isolated synchronous buck converter for low powered applications, for controlling the critical conduction mode of the inductor current in synchronous buck converter at different frequencies and different powers of synchronous buck converter, for switching of MOSFET's. Synchronous buck converters are better converters compared to buck converter in the controllability, as the diode is replaced by MOSFET which makes the switching faster, so the conduction losses are reduced. Here a control strategy is proposed which reduced switching losses, due to the internal capacitance available across the switches and LC circuits are used to get ripple free voltage and current at the output. A buck converter with 470Ω/50 watts featured by synchronous rectifier is designed.*

Keywords- ZVS, PWM controller, Opto-Isolated drivers, buffer, synchronous rectifier, PI controller.

I. INTRODUCTION

Buck converters are used for portable products, such as notebook PCs, displays, PDAs, GPSs, smart phones, microcontroller, ipods, all of which are powered by batteries. The appropriate voltage specification for each product is carried out by a buck converter for different portable products need different powers this can be achieved by PWM control technique of opto-isolated synchronous buck converter. The efficiency of a buck converter should be increased to prolong the operation of portable products and minimize battery drain. The efficiency of a buck converter is affected by the following factors. Conduction loss of a converter is one of the two factors as microprocessors and memories used in most portable products are driven by low voltage upto 5volts DC and opto-coupler drives with 1volt. Low-efficient standby mode is the other factor as portable products are in standby mode most of the time. Switching loss of a buck converter is decreased in low power condition. In order to reduce conduction losses and raise the entire efficiency, the PWM control technique of opto-isolated synchronous buck converter technique is used. Therefore, the diodes are replaced by MOSFET. Here switching frequency can be increased by using MOSFET instead of diodes, transistor.

The switching frequency of a PFM-controlled converter is higher in high power condition and reduced losses in connection with frequency increment. Based on the above, the PFM-controlled converter has better conversion efficiency than the conventional-controlled converter in low power condition, whereas the PWM-controlled converter has better conversion efficiency in high power condition. Therefore PFM is selected in light load, whereas PWM is used in high power condition. This method can achieve better efficiency. However, sub-harmonic noise occurs during operation because of the variable frequency. High frequency pulse width modulation converter the digital control technique perform better but require extra auxiliary switches and RLC passive components. The controller should be replaced by a digital system processor (DSP). As a result, the overall cost is going to high. The new control technique is proposed in this project. It enables a synchronous rectifier buck converter to have ZVS function and increase efficiency in low power condition without the need for extra auxiliary switches or RLC passive components.

This new control technique is low cost and easy to control. Furthermore, the synchronous rectifier control technique can be applied to a DC low voltage output (e.g., microprocessors and memory). Because the output rectifier diodes are replaced by MOSFET, conduction loss will be lower and the efficiency of the whole circuit will be higher. Finally, the output with 470 Ω resistive load, the buck converter is used to obtain varies voltages at different duty cycles with different loads.

II. ZERO VOLTAGE SWITCHING OVERVIEW

Zero voltage switching can best be defined as conventional square wave power conversion during the switches on- time with "resonant" switching transitions. For the most part, it can be considered as square wave power utilizing a constant off-time control which varies the conversion frequency, or on-time to maintain regulation of the output voltage. Regulation of the output voltage is accomplished by adjusting the effective duty cycle, performed by varying the conversion frequency, changing the effective on-time in a ZVS design. It is virtually identical to that of square wave power conversion. During the ZVS switch off-time, the L-C tank circuit resonates. This traverses the voltage across the switch from zero to its peak, and back down again to zero. At this point the switch can be reactivated, and lossless zero voltage switching facilitated. Since the output capacitance of the MOSFET switch (C_{oss}) has been discharged by the resonant tank, it does not contribute to power loss or dissipation in the switch. Therefore, the MOSFET transition losses go to zero -regardless of operating frequency and input voltage. This could represent a significant savings in power, and result in a substantial improvement in efficiency. Obviously, this attribute makes zero voltage switching a suitable candidate for high frequency, high voltage converter designs. Additionally, the gate drive requirements are somewhat reduced in a ZVS design due to the lack of the gate to drain (Miller) charge, which is deleted when V_{DS} equals zero.

III BLOCK DIAGRAM OF PWM CONTROLLER

DC Supply is provided to the synchronous buck converter by stepping down 230v AC supply into 12v AC then it is rectified with the help of bridge rectifier to 12v DC.This DC supply is given to the synchronous buck converter. Here two step down transformers(230V/12V, 1Amp) are used for driver circuits(MCT2E) and one more transformer (230V/12V, 1Amp) is used separately to control circuit. Transformer is a electrostatic device which transfers electrical energy from one AC circuit to another AC circuit without change in frequency. The MCT2E, is optically coupled isolators consisting of a Gallium Arsenide infrared emitting diode and an NPN silicon phototransistor mounted in a standard 6-pin dual-in-line package.

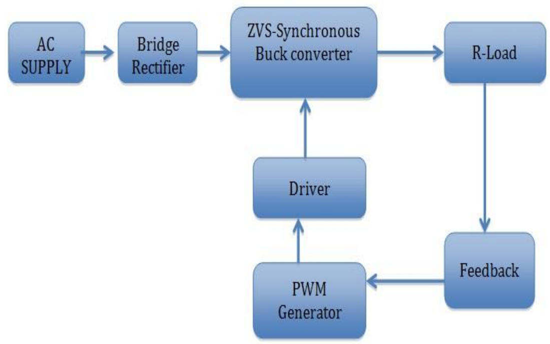


Fig: 1 Block Diagram Of PWM Control Technique Of Opt isolated Synchronous Buck Converter

LC Filter is an essential block in this paper, The performance of the filter is limited by the op-amp(frequency response, bandwidth, noise and offset). This filter is switched monolithic filter which offers the best performance in terms of cost. And it removes the ripple from the output of rectifier and smoothens the DC output received from this filter is constant until the mains voltage and load is maintained constant. The LC filter performance is very good compared to the fabricated filters. Here inductor value is chose such that 50µH, and capacitor value is 100µH and the output of filter is ripple free.In this paper resistor is used as load. Here 470Ω, 50watts resistor has implemented for the synchronous buck converter for low power applications. There is a option to change the resistance value for the further experiment. In this paper an opto-coupler MCT2E is used to isolate the gate drive circuit and the MOSFET's based on the power circuit. The opto coupler consists of an Infrared Light Emitting Diode (ILED) and a silicon phototransistor. The input signal is applied to the ILED and the output is taken from the photo-transistor. The use of opto-couplers ensures that power ground and control ground are separated. This means that development tools such as MPLAB can be satisfy connected to the system while it is connected to the AC supply.

IV. CIRCUIT OPERATION

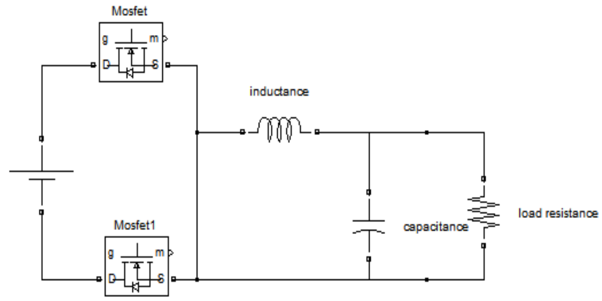


Fig:2 Conventional Synchronous Buck Convertor

The oscillogram of the inductor current and switches when the SR buck converter is operated in critical-conduction mode (CRM. In CRM, the average inductive current I_L of a SR buck converter. where T_S stands for switching frequency and D for duty cycle.

$$I_{LCRM} = \frac{DT_s}{2L}\left(V_{in} - V_0\right)$$

In the equation, the SR buck converter is operated in discontinuous conduction mode (DCM) if the mean value of the output current IO is lower than ILCRM. However, T_S, $V_{in,}$ V_O, L, and D remain unchanged. It is operated in a continuous conduction mode (CCM) if the mean value of the output current IO is higher than I_{LCRM}.

The control method proposed in this paper groups the operation of a SR buck converter into eight states according to the status of the switches based on the load conditions. The oscillogram of the inductive current and control signals in the eight operating states of a SR buck converter. According to the methods proposed herein, there are two kinds of operating state combinations based on different load conditions: heavy load and light load. The first combination is in the heavy load condition, i.e., State 1~State 2, whereas the second combination is in the light load condition, i.e., State 1~State 6. In the following paragraphs, the operating state of a SR buck converter will be described from the perspective of heavy load and light load respectively.

Low Power Condition

State 1(t0~t1):

In this state, the main switch Q_1 is conducted, whereas the synchronous rectifier switch Q_2 is off. The input current in flows through the inductor to the load. The inductor L is charged by $V_{in} - V_0$ at this time, whereas the inductor current $i_L(t)$ begins to increase linearly.

State 2(t1~t2)

In State 2, the main switch Q_1 is turned off, whereas the Q_2 is conducted. As the inductor current is continuous, it flows through Q_2 to avoid the breakage of inductor current. The inductor L is discharged by $-V_0$ at this time, and the inductor current i_L begins to decrease linearly.

State 3(t2~t3):

The inductor current has already dropped to 0 at t_2. The SR switch Q_2 is turned off to avoid energy losses of the buck converter. In this state, the inductor L start to resonant with the parasitic capacitor Coss of switch Q_1 and Q_2, this enables C_{oss1} to be discharged and C_{oss2} to be charged. The $i_L(t)$ and vCoss1 can be calculated as follows:

$$i_L(t) = -\frac{V_0}{Z}\sin\omega(t - t_2)$$

$$V_{Coss1}(t) = [V_{in} - V_0] + V_0\cos\omega(t - t_2)$$

Where

$$Z = \sqrt{\frac{L}{C}}, \quad \omega = \frac{1}{\sqrt{LC}}, \quad C = 2C_{Coss} = 2C_{Coss1} = 2C_{coss2}$$

State 4(t3~t4)

In State 4, the switch Q_1 keeps turning off, whereas the SR switch Q_2 is conducted. As a result, the inductor voltage is $v_L = -V_0$, this enables the inductor L to be charged and the inductor current to increase linearly in the opposite direction. The current $i_L(t)$ at this time is

$$i_L(t) = \frac{-V_0}{L}(t - t_3)$$

The parasitic capacitor voltage $v_{Coss1}(t)$ of switch Q_1 is

C_{oss1} in v (t) = V_{IN}

State 5(t4~t5)

State 5 is the duration for resonance. The switch Q_1 and the SR switch Q_2 are both turned off. The SR rectifying switch is turned off, whereas the inductor current must be continuous. This current will discharge to C_{oss1} and charges to C_{oss2} until the voltage of C_{oss1} is discharged to 0, and the voltage of C_{oss2} is charged from 0 to V_{in}. The $i_L(t)$ and $v_{Coss1}(t)$ of switch Q_1 are calculated as follows:

$$i_L(t) = -\frac{V_0}{Z}\sin\omega(t - t_4)$$

$$V_{Coss1}(t) = [V_{in} - V_0] + V_0\cos\omega(t - t_4)$$

State 6(t5~t6)

In State 6, the main switch Q_1 and the SR switch Q_2 are continuously turned off. However, C_{oss1} has been discharged, and C_{oss2} has been discharged by inductor current. The body diode D_1 is then conducted. In this state, the zero voltage condition of Q_1 has been completed.

V. EXPERIMENTAL RESULTS

The PWM control technique of opto-isolated synchronous buck converter for low power application with zero voltage switching technique is successfully.

Fig.3: Optocoupler input voltage

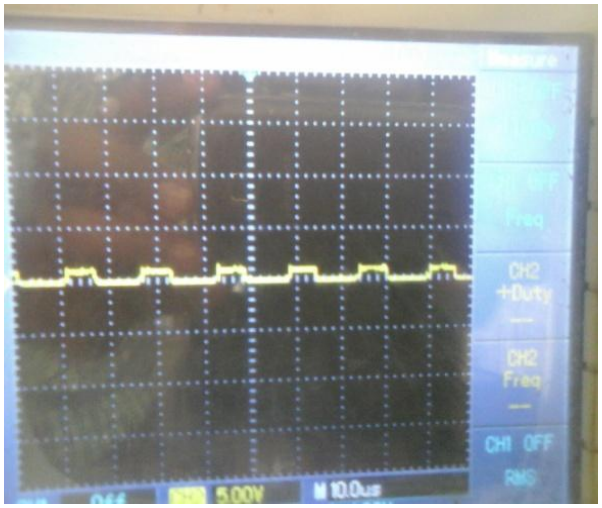


Fig.4: Switching Time Period

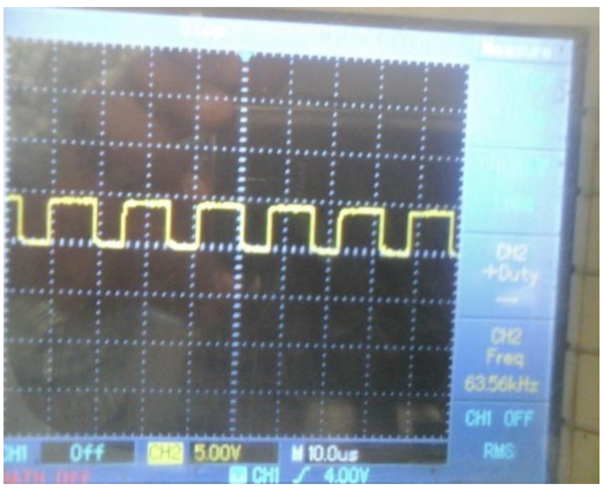
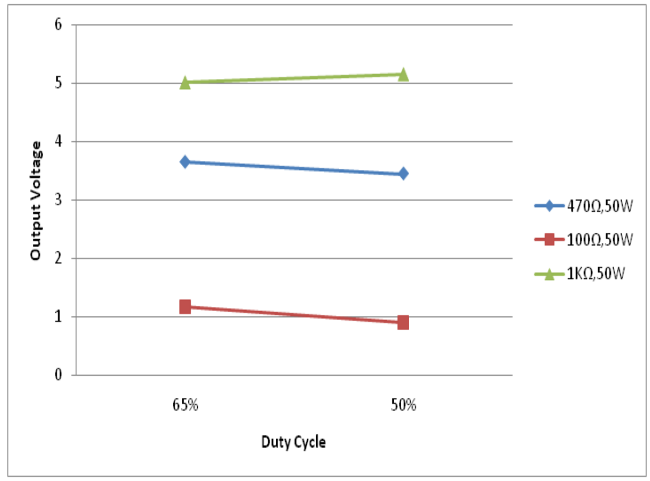


Fig.5: output voltage

Table1
Comparative Results Of Synchronous Buck Converter With Respective Duty Cycle And Load

S.No	Duty Cycle (%)	Load(Ω,w)	Output voltage(v)
1	65%	470Ω,50W	3.65
2	50%	470Ω,50W	3.45
3	65%	100Ω,50W	1.18
4	50%	100Ω,50W	0.90
5	65%	1KΩ,50W	5.01
6	50%	1KΩ,50W	5.15

Output Waveform Of Synchronous Buck Converter With Respective Load And Duty Cycle



Graph-1

VI. CONCLUSION

PWM control technique of opto-isolated synchronous buck converter for low powered applicationsindeed reduces the temperature of the MOSFET due to internal diodes, reducing the switching losses. The synchronous buck converter is implemented in the simulation and the results are shown in the graph. The simulation is done using MATLAB software. The results are compared with the hardware results are as per the expectation. The results gives zero voltage switching and the results are compared with the hardware opto-coupler synchronous buck converter model.

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