Implementation of Hybrid Switching Scheme for series-Resonant DC-DC Converter

A.G.karthikeyan, K.Anand, P.Manikandan

Abstract— **This project presents a hybrid switching scheme for LLC series-resonant half-bridge (SRHB) dc-dc converter. The concept proposed hybrid switching scheme is changing the switching mode to improve power efficiency in a wide load range. The SRHB converter operates in three different switching modes depending on the output load condition. This three switching schemes provides efficient operation of system at different load condition. The simulation and Digital control of the system facilitates the implementation of the proposed hybrid switching. Hence high efficiency is achieved with a constant output voltage over wide load range.**

I. INTRODUCTION

Although in existence for many years, only recently has the LLC resonant converter, in particular in its half-bridge implementation, gained in the popularity it certainly deserves. In many applications, such as flat panel TVs, 85+ ATX PCs or small form factor PCs, where the requirements on efficiency and power density of their SMPS are getting tougher and tougher, the LLC resonant half-bridge with its many benefits and very few drawbacks is an excellent solution. Resonant conversion is a topic that is at least thirty years old and where much effort has been spent in research in universities and industry because of its attractive features: smooth waveforms, high efficiency and high power density. Yet the use of this technique in off-line powered equipment has been confined for a long time to niche applications: high-voltage power supplies or audio systems, to name a few. Quite recently, emerging applications such as flat panel TVs on one hand, and the introduction of new regulations, both voluntary and mandatory, concerning an efficient use of energy on the other hand, are pushing power designers to find more and more efficient AC-DC conversion systems. This has revamped and broadened the interest in resonant conversion. Generally speaking, resonant converters are switching converters that include a tank circuit actively participating in determining input-to-output power flow. The family of resonant converters is extremely vast and it is not an easy task to provide a comprehensive picture. To help find one's way, it is possible to refer to a property shared by most, if not all, of the members of the family. They are based on a "resonant inverter", i.e. a system that converts a DC voltage into a sinusoidal voltage (more generally, into a low harmonic content ac voltage), and provides ac power to a load. To do so, a switch network typically produces a square-wave voltage that is applied to a resonant tank tuned to the fundamental component of the square wave. In this way, the tank will respond primarily to this component and negligibly to the higher order harmonics, so that its voltage and/or current, as well as those of the load, will be essentially sinusoidal or piecewise sinusoidal

High efficiency dc-dc converter for wide load ranges is necessary for the applications which are battery-powered and have energy consumption constrains. For a high efficiency dc-dc converter, the LLC series-resonant half-bridge (SRHB) converter is gaining its popularity. Output voltage regulation is achieved by switching-frequency modulation .However, switching frequency increases as the output load decreases.

In order to achieve high power densities, there is a trend to operate power supplies at higher switching frequencies. As the switching frequencies increase, the switching losses associated with the turn on and turn off of the devices in the power supplies also increase. In switch-mode power supplies, these losses are so significant that the operation of the power supplies at very high frequencies are prohibitive because of low efficiencies. In resonant mode power supplies, however, the switching losses are low, which allows the operation of resonant Converters at very high frequencies. A number of full, quasi-, multi resonant dc/dc converter topologies have been reported in the literature. These converter topologies have reduced or near-zero switching losses; however, their output voltage is controlled and/or changed by varying the operating switching frequency. These converters are, therefore, unsuitable for the application where system synchronization is required.

The series-resonant asymmetrical-pulse width-modulated (SR-APWM) dc–dc converter is a half-bridge resonant converter that operates at constant frequency and uses duty cycle control to regulate its output. It is capable of high frequency operation and maintains efficiency greater than 80% for the entire load range. Further, the voltage stress of the switches is limited to the input voltage, which allows the use of low-voltage low ON-resistance switches. However, the SR-APWM suffers the main drawback of losing ZVS outside of a limited input-voltage range. To reap the benefits of the resonant converters while operating at a constant frequency, the asymmetrical pulse width modulation (APWM) is applied to the SRHB converter .The APWM SRHB converter features high efficiency by zero voltage switching (ZVS) operation. However, the disadvantage of the APWM SRHB converter is low efficiency at light loads. The switching losses constitute a major portion of the total power losses when lightly loaded. The key to achieve high efficiency under light load condition is reducing the load independent power losses. Variable-frequency APWM method reduces switching losses by lowering the switching frequency. However, it results in a higher peak current flowing through the power switches,

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which increases their respective current ratings and die size, eventually increases cost.

To deal with these problems, we propose a new switching scheme for the LLC SRHB converter. Hybrid switching mode is proposed for the LLC SRHB converter operating in a wide load range. The concept of the proposed switching mode is changing the switching mode according to the output load condition. The LLC SRHB converter operates in different switching modes depending on the output load condition.

The proposed hybrid switching mode includes three switching modes: switching frequency modulation is used at heavy load condition, pulse frequency modulation at medium-to-light load condition, and pulse duty-cycle modulation at very light load condition. Digital control of the system facilitates the implementation of the proposed switching scheme. High efficiency is achieved in a wide output load range. The overall system configuration is briefly described. The proposed hybrid switching scheme is presented. The scheme is presented to evaluate the feasibility of the proposed switching scheme for the LLC SRHB converter.

II. SYSTEM CONFIGURATION

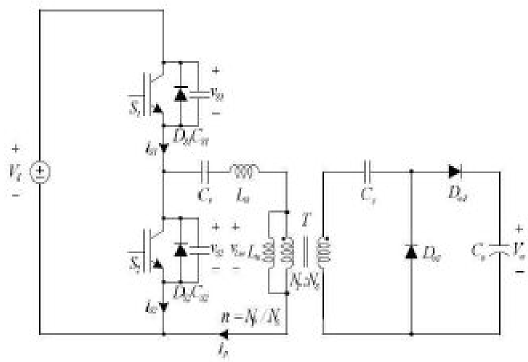


Fig.1 Circuit diagram of LLC SRHB converter

The proposed a new switching scheme for the LLC SRHB converter. Hybrid switching mode is proposed for the LLC SRHB converter operating in a wide load range. The concept of the proposed switching mode is changing the switching mode according to the output load condition. The LLC SRHB converter operates in different switching modes depending on the output load condition. The proposed hybrid switching mode includes three switching modes: switching frequency modulation is used at heavy load condition, pulse frequency modulation at medium-to-light load condition, and pulse duty-cycle modulation at very light load condition. Digital control of the system facilitates the implementation of the proposed switching scheme. High efficiency is achieved in a wide output load range. The overall system configuration is briefly described. The proposed hybrid switching scheme is presented.

Fig. 1 shows the LLC-SRHB dc-dc converter with a voltage doubler rectifier stage. Vd and Vo are the input and output voltages, respectively. The power switches S1 and S2 include their body diodes DS1 and DS2, respectively. CS1 and CS2 are the output capacitors of S1 and S2, respectively. The transformer T is an ideal transformer which has the magnetizing inductor Lm and leakage inductor Llk with the turns ratio n (= Np /Ns). The capacitor Cs and the output diodes Do1 and Do2 form the voltage doubler rectifier stage. In the primary-side, the series-resonant circuit consists of the leakage inductor Llk and the equivalent capacitor Ceq where

Ceq=n^2*Cs*Cr/Cr+n^2*Cs……eq.1

The resonant frequency fr is determined as

fr = 1/2*3.14*(Llk* eq)^0.5……eq.2

In the series-resonant circuit, the switching frequency fs is faster than the resonant frequency fr; the primary current ip is lagging with respect to the voltage VLm across Lm. Turn-on switching losses of the power switches are reduced under zero voltage switching condition as the conventional LLC-SRHB dc-dc converter . When S2 is turned off, the primary current ip starts to charge CS2 and discharge CS1. The voltage vS1 across S1 decreases and the voltage vS2 across S2 increases owing to the negative primary current ip. After ip discharges CS1 completely, the body diode DS1 is turned on. ip flows through DS1. Then, zero-voltage turn-on of S1 is achieved because ip has already flown through the body diode DS1. S1 is turned off by the similar operation.

III. HYBRID SWITCHING SCHEME

The LLC SRHB converter in Fig. 1 operates in three different switching modes depending on the output load condition. Fig. 2 shows the flowchart of the hybrid switching control scheme. which Contains various modulation schemes which posses the efficient operation of the SRHB converter .In this scheme stress to the switches at light load is reduced hence results in the increase in the life of the switches in the converter also reduces the cost of the system. In the closed loop operation of the system a PI controller is used which possess the feedback path to provide efficient change in the pulses by comparing it with the reference value. This results in the switching pulses to the switches will change according to load used in the converter. Hence the hybrid switching scheme overcome the asymmetrical pulse width modulation and drawbacks in the soft switching methods. The flowchart given below divided in to two stages A and B respectively. In these two stages the operation of the PI controller and the comparison with that with the reference value according to the load is given briefly as follows

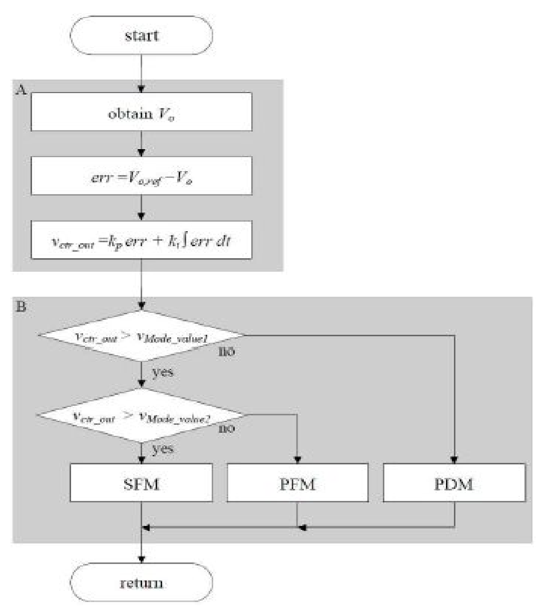


Fig.2 Flowchart of the proposed hybrid switching scheme.

In stage A of the flowchart, the output voltage Vo is first measured. Then, the error voltage e is calculated as

e= Vo*- Vo…….eq.3

where Vo* and Vo are the reference and measured output voltages. A proportional-integral (PI) voltage controller generates the output value vctr_out as

$$v_{ctr\_out} = k_p e + k_i \int e dt$$

where kp and ki are the proportional and integral gains. The output value of the PI voltage controller is proportional to the amount of output load. It is compared with output load reference values in the next stage.

In stage B of the flowchart, the switching mode of the SRHB converter is determined by comparing vctr_out with the reference values. vMode_value1 and vMode_value2 are the output load reference values, and vMode_value1 > vMode_value2. Fig. 3 shows the gating signals of the switches for each switching mode. ξk is the time at which the kth cycle starts, Tk is the duration of the kth switching period, .k is the on-time of each switch, and dk=Qk/Tk is the duty cycle. It is assumed that each switch is turned on subsequently with a fixed dead-time.

1) Switching Frequency Modulation (SFM) Mode:

When vctr_out is higher than vMode_value1, switching frequency modulation is used. Fig. 3(a) shows the gating signals of the switches in switching frequency modulation mode. The LLC SRHB converter operates at heavy load condition. The on-time of each switch is identical as Qk= Tk / 2. The switching period Tk is modulated by adding a modulated switching period Δ Tk,sfm to the minimum switching period Tk,min as

Tk=Tk,min +ΔTk,sfm........eq.4

The modulated switching period Δ Tk,sfm is represented as

ΔTk,sfm=(k,max – k,min)α……eq.5

Where Tk,max is the maximum switching period. The modulation index is expressed as

$$\alpha = \frac{v_{ctr\_out} - v_{Mode\_value1}}{v^{*}_{ctr\_out} - v_{Mode\_value1}}, \qquad 0 \le \alpha \le 1$$

Where vctr_out is the maximum output value of the PI voltage controller. As the output load decreases, vctr_out approaches vMode_value1, and α is close to zero. The switching period scales down with the decreasing output load. The switching frequency fs can be faster than the resonant frequency fr. ZVS operation is ensured at heavy load condition.

2) Pulse Frequency Modulation (PFM) Mode:

When vctr_out is between vMode_value1 and vMode_value2, fixed-on-time pulse frequency modulation [15] is used. Fig. 3(b) shows the gatingsignals of the switches in fixed-on-time pulse frequency modulation mode. The LLC SRHB converter operates at medium-to-light load condition. The on-time .k of each switchis fixed to Tk,min / 2. The switching period Tk is modulated by adding a modulated switching period. Tk,PFM to the minimum switching period Tk,min as

Tk=Tk,min +ΔTk,pfm........eq.6

The modulated switching period Δ Tk,sfm is represented as

ΔTk,pfm=(k,max – k,min)β. eq.7

Here, The modulation index β is expressed as

$$\beta = \frac{v_{Mode\_value1} - v_{ctr\_out}}{v_{Mode\_value1} - v_{Mode\_value2}}, \qquad 0 \le \beta \le 1.$$

3) Pulse Duty-Cycle Modulation (PDM) Mode:

When vctr_outis lower than vMode_value2, pulse duty-cycle modulation is used. Fig. 3(c) shows the gating signals of the switches in pulse duty-cycle modulation mode. The LLC SRHB converter operates at very light load condition. The switching period Tk is fixed to Tk,max. The on-time Qk of each switch is modulated as

Qk=Tk,min γ........eq.8

Where the modulation index γ is expressed as

$$\gamma = \frac{v_{ctr\_out}}{v_{Mode\_value2}}, \qquad 0 \le \gamma \le 1.$$

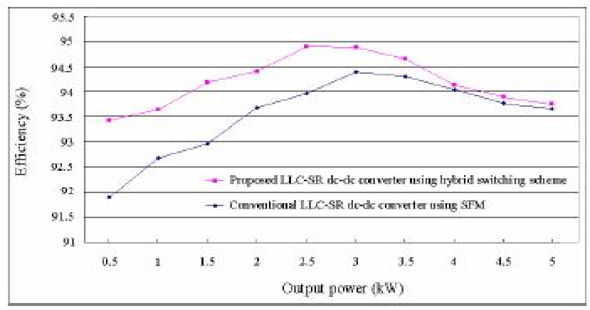


Fig.4 Measured efficiency.

The on-time of each switch is adjusted with the output load at a constant frequency. Power efficiency is improved with low output voltage ripple and improved dynamic response at extremely light load condition.

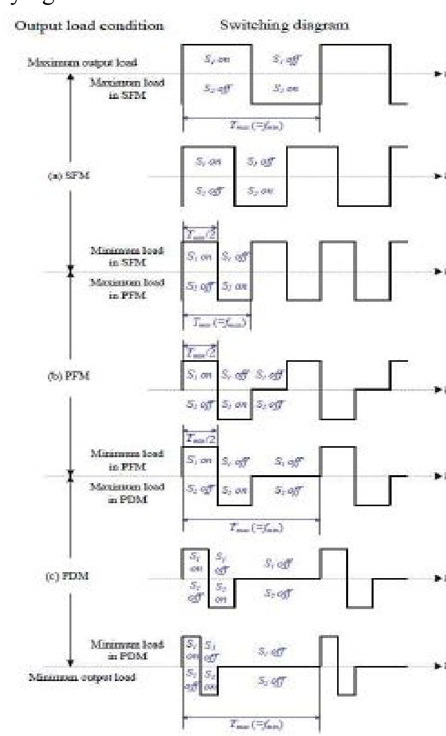
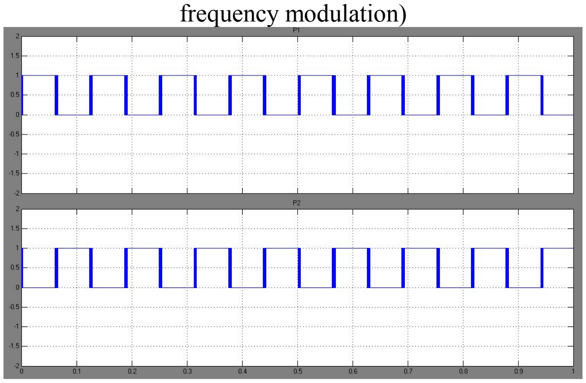


Fig.4 Switching diagram with output load condition.

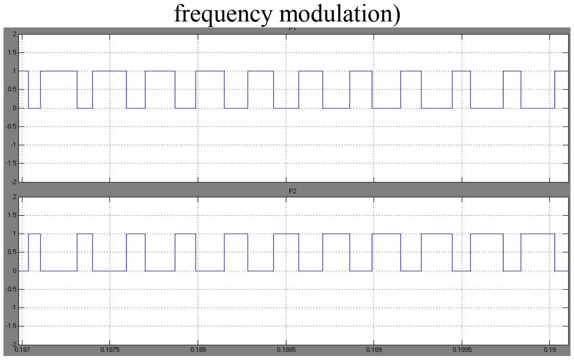
IV. SIMULATION RESULTS

This SRHB converter is simulated using MATLAB. Here the input voltage is given as Vd=200V and output is Vo=100V for this load is varied and the switching pulses is obtained for three different load conditions. The changes in the time interval of the switching pulses is shown in the following waveforms

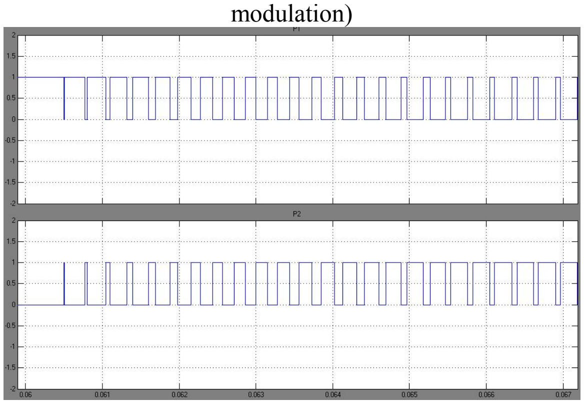
4.1 Switching pulses at heavy load condition (Switching frequency modulation)



4.2 Switching pulses at medium load condition (Pulse frequency modulation)



4.3 Switching pulses at light load condition (Pulse duty modulation)



CONCLUSION

In this project new hybrid switching scheme for the LLC SRHB dc-dc converter has been proposed for different load ranges. The concept of the proposed hybrid switching scheme is changing the switching modes depending on the output load condition. The LLC-SRHB converter operates in three different switching modes, achieving a high-efficiency over different load ranges .The simulation results for this is obtained using MATLAB/SIMULINK which comprises the switching modulation.

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