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A new Technique for Soft-Switching Buck Converter for a Coupled Inductor

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ABSTRACT:

This letter presents a novel topology for a buck dc–dc converter with soft-switching capability, which operates under a zero-current-switching condition at turn on and a zero-voltage switching condition at turn off. In order to realize soft switching, based on a basic buck converter, the proposed converter added a small inductor, a diode, and an inductor coupled with the main inductor. Because of soft switching, the proposed converter can obtain a high efficiency under heavy load conditions. Moreover, a high efficiency is also achieved under light load conditions, which is significantly different from other soft-switching buck converters. The detailed theoretical analyses of steady-state operation modes are presented, and the detailed design methods and some simulation results are also given. Finally, a 600 W prototype is built to validate the theoretical principles. The switching waveforms and the efficiencies are also measured to validate the proposed topology.

Index Terms—***Buck converter, coupled inductor, soft switching, zero-current switching (ZCS), zero-voltage switching (ZVS).***

INTRODUCTION:

Buck converters, as the basic kind of dc–dc converters, have been used in many areas, such as consumer electronics, appliances, general industries, and aerospace. With technological developments, the demand for small size, lightweight, and high reliability for dc–dc converter increases sharply. High switching frequency can be used to reduce sizes and weights of converters. However, if converters work under hard-switching conditions, switching losses will increase as switching frequency increases, and the total efficiencies will drop. Soft switching technologies are the best methods to reduce switching losses, and improve efficiencies and reliabilities. Thus, the sizes of heat sinks can be reduced. The total sizes and weights of converters will also be reduced. There are many methods to realize soft switching, and the most common is using additional quasi-resonant circuits. By adding auxiliary switches, inductors, and capacitors, zero-current-switching (ZCS) conditions or zero-voltageswitching (ZVS) conditions can be easily achieved in quasiresonant converters. However, high voltage stresses and high current stresses for power switches are also generated It is not beneficial to select the proper rank of power switches, because there are more conduction losses when using higher voltage power switches. In addition, in some converters, auxiliary switcheswork under hard-switching conditions [8], orwork two times in a switching cycle.

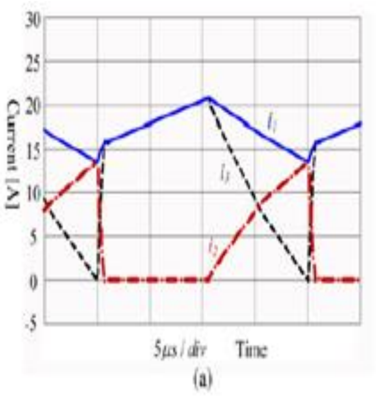
Existing System:

Description of the Proposed Converter

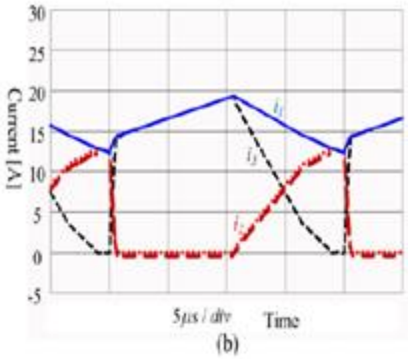
The proposed buck converter topology is shown in Fig. 1. In this topology, inductors *L*1 and *L*2 are tightly coupled on the same ferrite core, and *L*1 is the main inductor. *S*1 and *D*1 are the main power switches, like a conventional buck converter. *D*2 is an additional diode. The theoretical current waveforms of *L*1, *L*2 , and *L*3 of the proposed converter at steady state are shown in Fig. 2. When *S*1 is OFF, the converter comes into a free-wheeling stage. The branches of *L*2 and *L*3 will supply two flow channels for current free wheeling. Because $L3$ is very small, the current of $L3$ drops faster than that of $L1$, and also reduces to zero before $S1$ turns ON. It provides the ZCS condition for $S1$. Due to snubber capacitor$Cr1$, $S1$ can turn OFF under a ZVS condition. $Cp1$ is the parasitic capacitance of the MOSFET $S1$.

Proposed System:

To ensure that the proposed converter operates under the softswitching condition, component parameters must be designed properly, especially the selections of the inductors ($L1$, $L2$, and $L3$). From the analyses in Section II, the current of $L3$ must be discontinuous to achieve soft-switching conditions. As the load increases, the duration that the current of $L3$ remains zero will reduce to zero, and then $L3$ willwork at a continuous conduction mode (CCM), i.e., soft switching cannot be obtained. Therefore, the boundary conduction mode (BCM) between CCM and discontinuous conduction mode (DCM) can be used to calculate the parameters of main circuits. It can be assumed that the proposed converter would operate under BCM at a theoretic maximum load, which is more than the real maximum load. The theoretical waveforms of inductor currents at BCM are shown in Fig. 4. In this design, the theoretic maximum load is set to be 1.1 times the real maximum load. In Fig. 4, it can be seen that mode 5 does not occur in BCM. Because the duration time of mode 3 is very short, it is not considered for calculating inductor parameters. One switching cycle can be divided into three intervals. Based on the slopes and variations of $L1$, $L2$, and $L3$, some equations can be obtained .



(a)



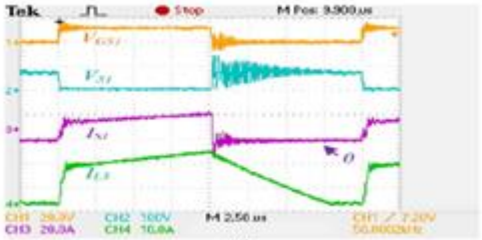
(b)

Fig. 5. Simulation waveforms of inductor currents. (a) Theoretical maximum load. (b) Real maximum load.

EXPERIMENT RESULTS

According to the designed parameters in Section III, a prototype converter has been built to verify the aforementioned analyses. The photograph of the proposed converter prototype is shown in Fig. 6. For the power semiconductors, IRFP4232PBF by the International Rectifier is used for $S1$, and 60EPU02PBF.

The switching waveforms of $S1$ and current waveforms of $L3$ are shown in Fig. 7, which is measured at the maximum output power 600 W. Fig. 7(a) shows the waveforms in a switching cycle, where the current of $L3$ has been zero for a short time before $S1$ is triggered ON. The turn-on process of $S1$ is shown in Fig. 7(b). After the gate trigger signal $VGS1$ is applied, current $is1$ increases slowly. Therefore, ZCS turn on is achieved. In Fig. 7(c), the turn off of $S1$ is presented. It can be seen that when the turn-off trigger signal is applied, $is1$ decreases sharply to zero, and then $Vs1$ increases to Vin . Hence, ZVS is also achieved in the turn-off process.



(a)

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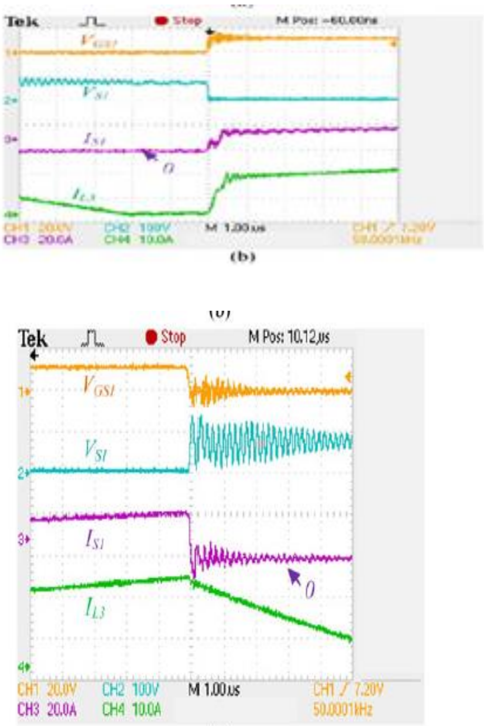

(c)

Fig. 7. Switching waveforms of S_1, and current waveform of L_3. (a) One switching cycle. (b) Turn-on process. (c) Turn-off process.

in a wide range of load conditions. At the maximum load, the efficiency is 94.57%.When the load goes down, high efficiency can also be obtained. It is because *L*3 usuallyworks under DCM, and the conduction losses of the auxiliary circuits will decrease as the load reduces. The operating mode of auxiliary circuits is different from that of the converter .

CONCLUSION

In this letter, a soft-switching buck converter with coupled inductor has been proposed. By making inductor *L*3 to work under DCM, ZCS turn on and ZVS turn off for *S*1 are achieved. The detailed theoretical analyses of the operating principle at steady state have also been given. The design methods of the main circuits are discussed. The prototype of the proposed buck converterwas built, and the experiment results validated that soft switching of *S*1 is achieved, and the related theoretical analyses are also verified. High efficiency can be obtained under both heavy load and light load conditions. Moreover, no auxiliary MOSFET is added in this topology, so the control method is as simple as that of a conventional buck converter.

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