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Zero Voltage Switching with Fuzzy Control Method For MHZ Boundary Conduction Mode Converters

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ABSTRACT

Boundary conduction mode (BCM) or critical conduction mode (CrM) is characterized by an inductor current that operates in the boundary between continuous (CCM) and discontinuous conduction modes (DCM), making the converter switching frequency dependent on the converter operating conditions. The advantage of this operation mode versus CCM is achieving zero current switching (ZCS) conditions for the converter rectifier, which makes it possible to use silicon (Si) diode rectifiers without having a penalty due to reverse recovery issues. Moreover, the main switch turn on loss is decreased due to ZCS conditions and valley switching operation. However, the penalty is an increased current stress in the circuit, and an increased main switch turn off energy loss. Implementation of synchronous rectifier in BCM converters makes it possible to achieve fuzzy controller zero voltage switching (ZVS) conditions by extending the synchronous rectifier conduction time after zero current condition in the inductor. High power density, high efficiency MHz implementations have already been demonstrated in the literature; however, none of the proposed solutions solves the controllability issues of the synchronous rectifier switch. This work proposes and validates a ZVS self-regulating control method for BCM converters operating in the MHz switching frequency range.

I. INTRODUCTION

SWITCHED-MODE mode power supplies (SMPS) technology has been an efficient solution for voltage and current conversion applications from the early 20th century. Compared to linear regulators, SMPS can ideally reach efficiencies up to $\eta = 100$ %. This technology, based on the combination of reactive elements with any type of switch, was initially developed employing mechanical switches, vacuum tubes, and finally semiconductor based switches such as thyristors, bipolar junction transistors (BJT), and Metal Oxide Semiconductor Field Effect Transistors.

The size and the cost of SMPS is heavily influenced by the size of reactive energy storage elements, which is inversely proportional to the converter operating frequency. Therefore, increasing the converter switching frequency allows for an increased converter power density and reduced cost. However, the switches, far from being ideal, present switching losses that put a practical limit on the maximum attainable converter switching frequency. Resonant SMPS topologies present an alternative solution for eliminating the converter switching losses and increasing the power density , at the penalty of an increased current stress due to the increased reactive energy circulation in the circuits. High frequency BCM based implementations have been demonstrated in the literature, where the increased conduction loss due to the increased current stress in BCM implementations is compensated by the reduction in switching loss. In, a 5 MHz ZVS boost BCM implementation with efficiency figures up to $\eta = 98\%$ is demonstrated. As presented in 7 and 8, MHz implementations allow for a large reduction of the converter input inductor and filter, which heavily affects the converter power density.

However, pushing the converter switching frequency in BCM implementations is only possible when the converter operates under ZVS conditions, which depend on the converter input to output voltage ratio and the non-linear switching node parasitic capacitance. In a ZVS extension method for BCM converters with synchronous rectification is presented. In this solution, the synchronous rectifier time is increased to create a negative inductor current to discharge the switching node capacitance, achieving ZVS independently of the converter input to output voltage ratio. A MHz BCM boost derived power factor correction circuit with ZVS extension is demonstrated.

However, both of the proposed prototypes, rely on measurements and characterization to map the necessary negative inductor current to achieve ZVS as a function of the converter input and output voltage conditions. This is a time consuming procedure, where components tolerance will create errors that will result in loss of ZVS conditions or increased components current stress. This paper presents a self-regulating control method for ZVS extension where the switching node voltage is regulated in close loop control by controlling the synchronous rectifier conduction time. The proposed method is demonstrated in a GaN based MHz boost Power Factor Correction (PFC) BCM implementation, however this solution can be applied to different topologies and applications.

II. LITERATURE SURVEY

Single-ended Dc-to-dc Converter With Two Individually Controlled Outputs

This project introduces a DC-to-DC converter which simultaneously regulates two output voltages individually by turning a transistor switch on and off to give good regulation and high conversion efficiency. The converter combines a buck and a buck-boost converter through one transistor switch; the buck circuit operates in the continuous inductor current mode, and the buck-boost circuit operates in the discontinuous inductor current mode. Together they can regulate two output voltages by controlling the duty ratio and operating frequency of the switching operation.

Characterization and evaluation of 600 V range devices for active power factor correction in boundary and continuous conduction modes.

Traditional characterization of semiconductors switching dynamics is performed based on clamped inductive load measurements using the double pulse tester (DPT) configuration. This approach is valid for converters operating in continuous conduction mode (CCM), however in boundary conduction mode (BCM), if valley switching detection is used, the amount of energy recovered from the semiconductor output capacitance and the converter switching frequency need to be accurately calculated. This paper presents a characterization and evaluation procedure for conventional power factor correction circuits operating in CCM and BCM.

III. DC-DC CONVERTERS

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC-to-DC converter topologies.

BUCK CONVERTER STEP-DOWN CONVERTER

In this circuit the transistor turning ON will put voltage V_{in} on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode.

We initially assume that the current through the inductor does not reach zero, thus the voltage at V_x will now be only the voltage across the conducting diode during the full OFF time. The average voltage at V_x will depend on the average ON time of the transistor provided the inductor current is continuous.

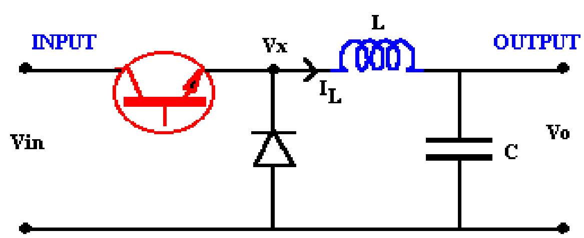

Fig 1.Buck Converter

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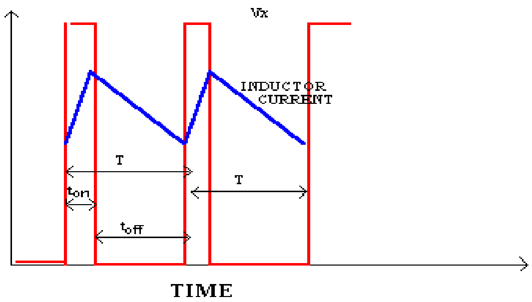

Fig .2 Voltage and current changes

BOOST CONVERTER STEP-UP CONVERTER

The schematic in Fig. 6 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

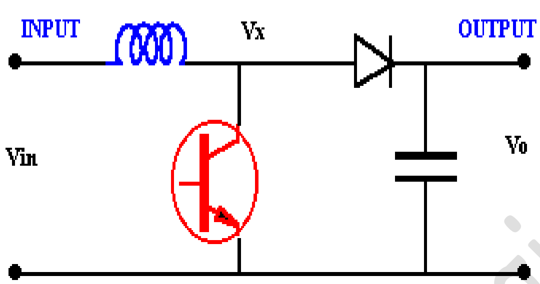

Fig .3.Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction).

IV. FUZZY

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic.

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with un sharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

In fuzzy Logic Toolbox software, fuzzy logic should be interpreted as FL, that is, fuzzy logic in its wide sense. The basic ideas underlying FL are explained very clearly and insightfully in Foundations of Fuzzy Logic. What might be added is that the basic concept underlying FL is that of a linguistic variable, that is, a variable whose values are words rather than numbers. In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution.

Fuzzy logic

Fuzzy logic is all about the relative importance of precision is how important is it to be exactly right when a rough answer will do You can use Fuzzy Logic Toolbox software with MATLAB technical computing software as a tool for solving problems with fuzzy logic. Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision something that humans have been managing for a very long time.

In this sense, fuzzy logic is both old and new because, although the modern and methodical science of fuzzy logic is still young, the concept of fuzzy logic relies on age old skills of human reasoning.

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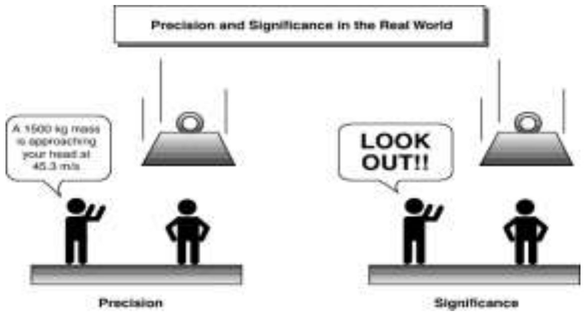

Fig.4. Fuzzy descriptions

Use fuzzy logic

Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything. Consider the following examples:

- With information about how good your service was at a restaurant, a fuzzy logic system can tell you what the tip should be.

Building a fuzzy inference system

Fuzzy inference is a method that interprets the values in the input vector and, based on user defined rules, assigns values to the output vector. Using the GUI editors and viewers in the Fuzzy Logic Toolbox, you can build the rules set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS).

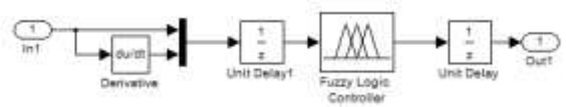

Fig.5.Fuzzy interference system

V. PROJECT DESCRIPTION AND CONTROL DESIGN

BOUNDARY CONDUCTION MODE OPERATION

Boundary conduction mode corresponds to an operation mode where the converter inductor current operates between the continuous and the discontinuous conduction modes. The ideal switching node voltage and the inductor current waveform are shown in Fig. 1. In this operation mode, the converter switching frequency varies according to (1), as presented in The parameter M is defined as the converter input to output voltage ratio for a conventional boost converter, as in (2)

However, during boundary conduction mode, valley switching or ZVS at the turn on of the main switch are preferred to reduce the semiconductor switching losses. As the converter switching frequency is increased, the valley switching or ZVS time and the switching node rise time need to be taking into account to accurately predict the converter switching frequency.

A. Valley Switching Operation

A conventional boost converter with the typical valley switching waveforms under boundary conduction mode operation is depicted in Fig. 1. When the inductor current decreases to zero at t3, the rectifier becomes reverse biased, and the parasitic capacitances attached to the switching node resonate with the input inductor. The equivalent circuit during the resonant period, can be simplified to an ideal LC circuit, where the MOSFET output parasitic capacitance (COSS) appears in parallel with the diode junction capacitance (Cj), and resonate with the converter input inductance with angular frequency ω0 , as in ω0 =·+ 1 L ( ) C C OSS j .

In conventional BCM boost implementations, if the switching node capacitance is assumed to be ideal, the boost switch will lose its ability to soft switch when the converter input voltage Vin is higher than Vout /2 or M

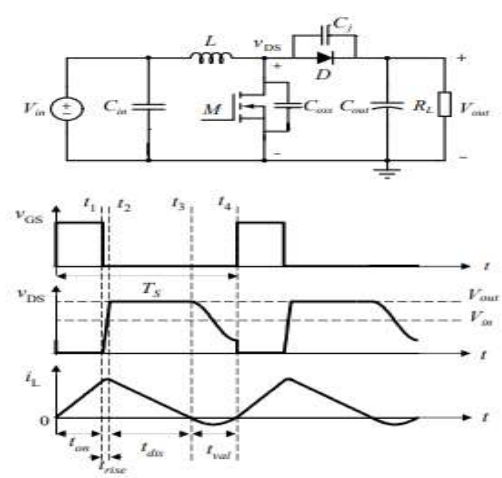

Fig. 6.. Conventional boost with BCM valley switching operating waveforms (M < 2).

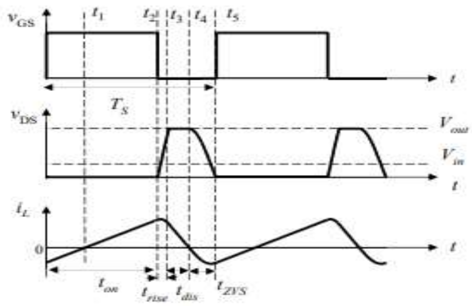

Fig. 7. Key operating waveforms under natural ZVS conditions (M > 2).

Natural Zero Voltage Switching Operation

When the converter input voltage Vin is smaller than Vout /2 or M >2, the boost switch will operate under ZVS conditions as shown in Fig.4.2. During this operation mode, all the energy stored in the switching node parasitic capacitance is recovered before the boost switch turn on event.

Natural Zero Voltage Switching Operation

If the rectifier diode is replaced with a synchronous rectifier, it is possible to extend the zero voltage switching range of the converter. This can be achieved, as previously presented in by extending the conduction time of the rectifier beyond zero current condition in the inductor. The schematic and the converter operating waveforms under extended ZVS conditions are depicted in Fig4.3.

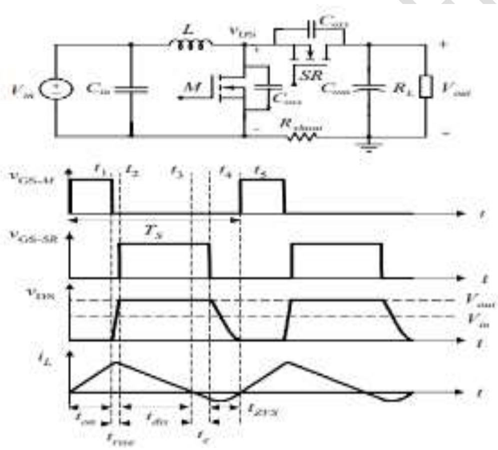

Fig.8 Conventional boost converter with synchronous rectifier under extended ZVS conditions

Where the initial current condition and the extra conduction time te after zero current condition to achieve ZVS conditions, can be calculated by solving for the inductor initial current condition iL (0) or by evaluating the energy transfer in the ideal resonant circuit.

SELF-REGULATING CONTROL FOR ZVS EXTENSION

This work proposes the implementation of a closed loop control to ensure ZVS conditions under any circumstances. The implemented control loop is based on sampled information from the converter switching node voltage. Conventional BCM controllers operating under valley switching conditions, use information of the instantaneous switching node voltage in order to determine the turn on instant of the main switch, and minimize the energy stored in the parasitic capacitance. In high voltage, and more specifically in PFC applications, this voltage is sensed through an auxiliary winding in the input inductor (Waux), as shown in Fig. 6. The use of this auxiliary winding makes it possible to scale down the switching node voltage, without using resistor divider networks, which are lossy and have bandwidth limitation problems. The proposed control method in this work is similar to a conventional valley switching control scheme, where the derivative of the switching node (vDS_der) is used in order to determine the turn on instant of the main switch. The ZVS control block diagram is presented in Fig. 7. Fig. 8 shows the key operating waveforms of the ZVS boost converter with extended synchronous rectifier conduction time. As can be observed in Fig. 8, at t4 the synchronous rectifier is turned off. After t4 the resonant interval tZVS begins, and after the switching node derivative has reached zero volts at t5, two events take place. First, the scaled down switching node voltage vDS_div, obtained from the auxiliary winding voltage (vaux=(vDS–Vin)/n), is retained in the sampling capacitor CS&H-1. Second, the main switch M is turned on. Turning on the main switch at zero switching node voltage derivative, means that the switching node voltage has reached

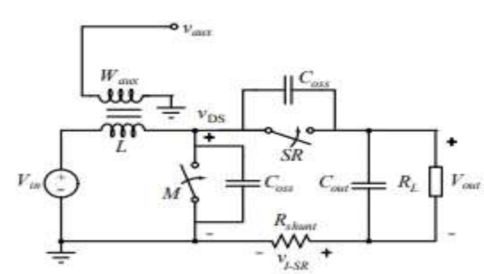

Fig.8.. Boost converter with synchronous rectifier and inductor with auxiliary winding.

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its minimum value, and therefore, the main switch can be turned on under minimum switching loss condition. When the main switch M is turned on, the sampled value, which is stored in the sampling capacitor CS&H-1, is transferred to the second sampling capacitor CS&H-2. Therefore, the voltage vsample in this sampling capacitor is a continuous voltage waveform representing the switching node voltage under valley switching conditions (or at zero switching node voltage derivative). This sampled voltage is used as the control variable for controlling the extra conduction time te of the synchronous rectifier by means of a PI regulator. The implemented control scheme also includes a low speed loop, which ensures constant on time of the converter main switch M across the line cycle, and regulates the converter output voltage. Fig. 9 shows a Spice based simulation of the implemented control scheme in a conventional boost PFC converter. This simulation demonstrates the ability of the control loop to regulate the extra conduction time of the synchronous rectifier under a fast changing converter input voltage. In this simulation, the parasitic switching node capacitance is assumed to be ideal. The output capacitance (Cout) and load (RL) are replaced with an ideal voltage source with voltage value Vout and the main switch on time (ton) is inserted as

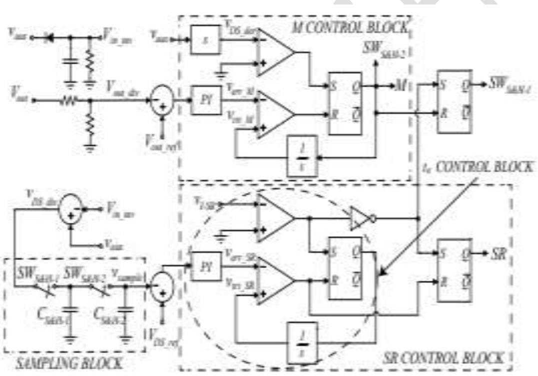


Fig. 7. Proposed ZVS control block diagram.

fixed value. Table I shows the values used in this simulation. The simulated converter input voltage vin (top waveform), inductor current iL (middle waveform), and the synchronous rectifier error voltage verror_SR (dotted line waveform at the bottom), are plotted across half period of the input line. The simulated error signal is compared to the calculated extra conduction time te. The calculated extra conduction time te (continuous line waveform at the bottom) is scaled by the gain of the comparator that controls the on time of the synchronous rectifier as in (9). In this simulation, the time base for control of the synchronous rectifier is modeled by an ideal current source and a capacitor with a dv/dt slope of k = 10 V/μs. As it can be observed, the control scheme accurately predicts the necessary extra conduction time to operate under ZVS conditions across the input line cycle.

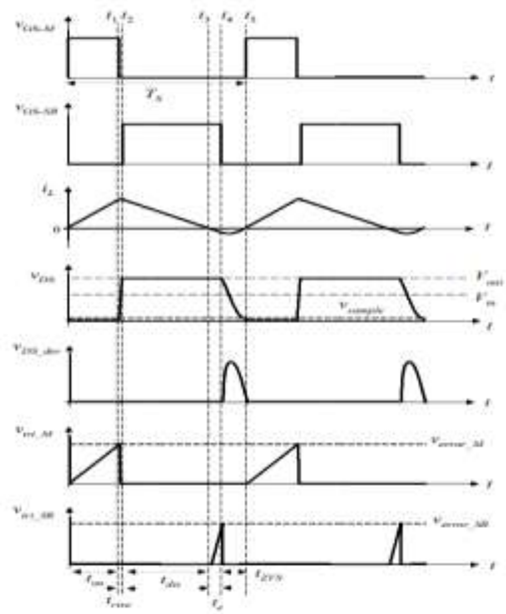


Fig. 9. Key operating waveforms of the ZVS boost converter with extended synchronous rectifier conduction time.

VI. SIMULATION RESULTS

Simulation Results

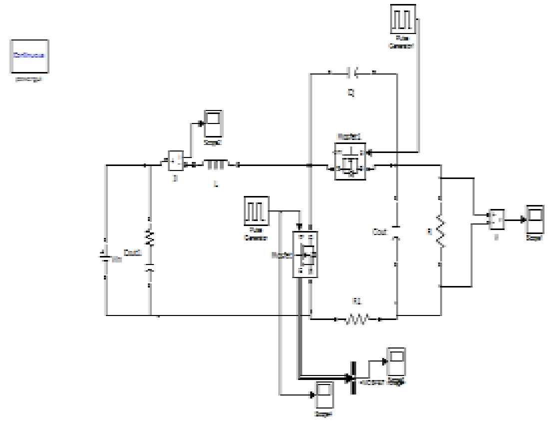


Fig .10. Simulink model of conventional boost converter

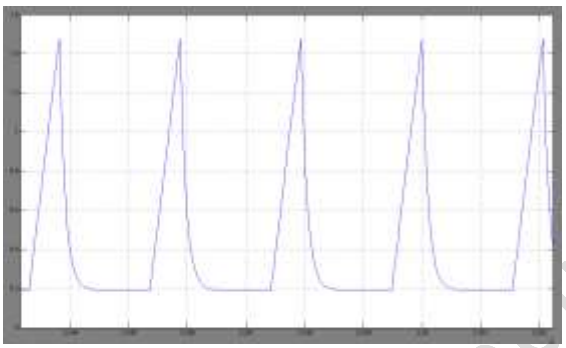
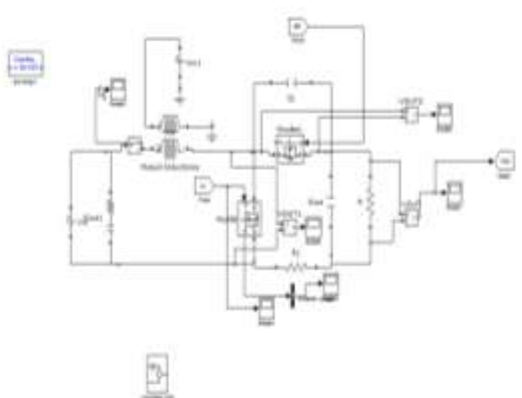
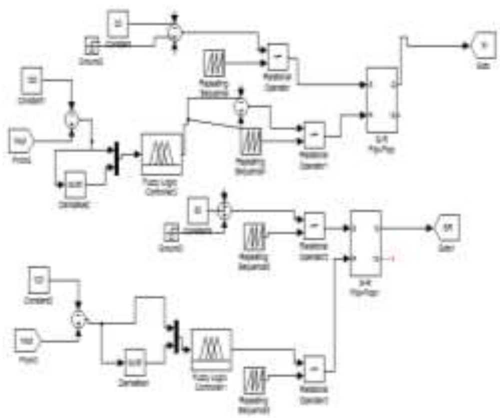


Fig .11. Inductor Current (Il)





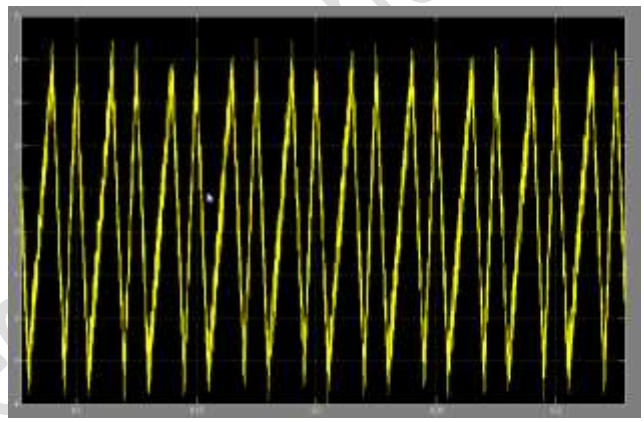


Fig.12. Inductor current

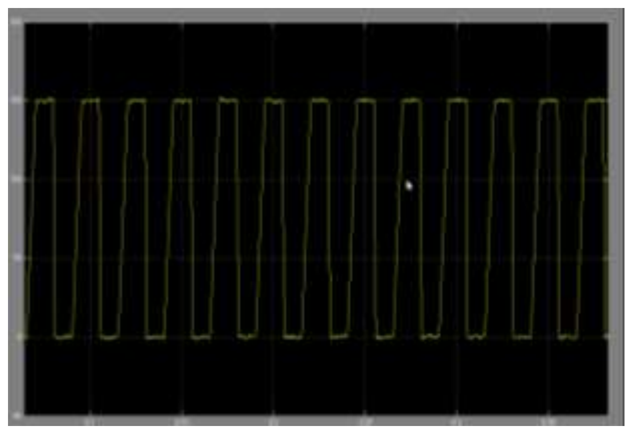


Fig .13. Switch voltage (Vsw)

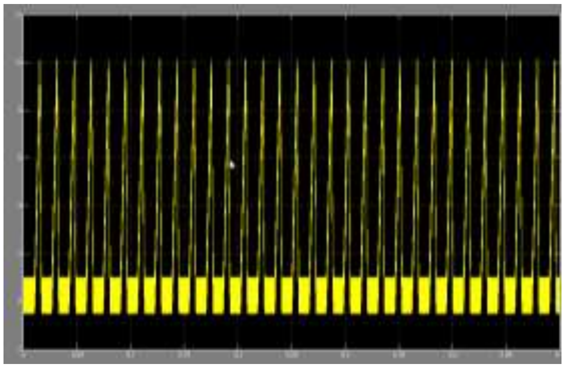


Fig .14. synchronous Rectifier voltage

VII. Conclusions

In this project proposes a ZVS with fuzzy controller based Various BCM converters have been reported in the literature operating in the MHz switching frequency range. It is proven that the increased current stress in BCM implementations compensated by the reduction in switching losses at the main switch turn on event due to ZCS and ZVS or valley switching conditions. However, the ability of the converter to operate under ZVS conditions, or the amount of energy recovered under valley switching conditions, is determined by the switching node capacitance and the converter input to output voltage ratio M. On the other hand, extension of the ZVS range is possible in implementations using synchronous rectification, which is achieved by extending the synchronous rectifier conduction time after zero current condition at the inductor.

References

[1] O. Kiltie, "New Type of D-C to A-C Vibrator Inverter," Am. Inst. Electr. Eng. Trans., 1940.

[2] W. H. Morman, M. H. Ramsey and R. G. Hoft, "50-kW Thyristor DCto-DC Converter," Ind. Appl. IEEE Trans., Vols. IA-8, no. 5, p. 617– 635, 1972..

[3] M. Kohno and K. Kuwabara, "Single-ended Dc-to-dc Converter With Two Individually Controlled Outputs," in International Telephone Energy conference, 1978. INTELEC 78., Washington, DC, USA, 1978.

[4] A. Knott, T. M. Andersen, P. Kamby, J. A. Pedersen, M. P. Madsen, M. Kovacevic and M. A. E. Andersen, "Evolution of Very High Frequency Power Supplies," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 2, no. 3, pp. 386-394, 2014.

[5] X. Huang, Z. Liu, Q. Li and F. C. Lee, "Evaluation and Application of 600 V GaN HEMT in Cascode Structure," IEEE Transactions on Power Electronics, vol. 29, no. 5, pp. 2453-2461, 2014.

[6] X. Huang, Z. Liu, F. C. Lee and Q. Li, "Characterization and Enhancement of High-Voltage Cascode GaN Devices," IEEE Transactions on Electron Devices, vol. 62, no. 2, pp. 270-277, 2015.

[7] J. C. Hernandez, L. P. Petersen and M. A. E. Andersen, "Characterization and evaluation of 600 V range devices for active power factor correction in boundary and continuous conduction modes," in IEEE Applied Power Electronics Conference and Exposition (APEC), Charlotte, NC, USA, 2015.

[8] J. C. Hernandez, L. P. Petersen and M. A. E. Andersen, "A comparison between boundary and continuous conduction modes in single phase PFC using 600V range devices," in IEEE 11th International Conference on Power Electronics and Drive Systems, Sydney, NSW, Australia, 2015

[9] B. Su, J. Zhang and Z. Lu, "Totem-Pole Boost Bridgeless PFC Rectifier With Simple Zero-Current Detection and Full-Range ZVS Operating at the Boundary of DCM/CCM," IEEE Transactions on Power Electronics, vol. 26, no. 2, pp. 427-435, 2011.

[10] Z. Liu, X. Huang, M. Mu, Y. Yang, F. C. Lee and Q. Li, "Design and evaluation of GaN-based dual-phase interleaved MHz critical mode PFC converter," in IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, PA, USA, 2014.

[11] Z. Wang, S. Wang, P. Kong and F. C. Lee, "DM EMI Noise Prediction for Constant On-Time, Critical Mode Power Factor Correction Converters," IEEE Transactions on Power Electronics, vol. 27, no. 7, pp. 3150-3157, 2012.

[12] Y. Yang, Z. Liu, F. C. Lee and Q. Li, "Analysis and filter design of differential mode EMI noise for GaN-based interleaved MHz critical mode PFC converter," in IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, PA, USA, 2014.

[13] C. Marxgut, J. Biela and J. W. Kolar, "Interleaved triangular current mode (TCM) resonant transition, single phase PFC rectifier with high efficiency and high power density," in International Power Electronics Conference (IPEC), Sapporo, 2010.

[14] C. Marxgut, F. Krismer, D. Bortis and J. W. Kolar, "Ultraflat interleaved triangular current mode (TCM) single-phase PFC rectifier," IEEE Transactions on Power Electronics, vol. 29, no. 2, pp. 873-882, Feb. 2014.

[15] Q. Huang, R. Yu, Q. Huang and W. Yu, "Adaptive zero-voltageswitching control and hybrid current control for high efficiency GaN MHz Totem-pole PFC rectifier," in IEEE Applied Power Electronics Conference and Exposition (APEC), Tampa, FL, 2017.

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