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SOFTSWITCHING PWM REGULATOR

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ABSRTACT

This paper proposes soft switching capacitor pulse width modulation converter. The converter is acombination of switching capacitor converter and PWM regulator. The capacitor in the converter serves as the component of processing energy and meanwhile the output voltage is regulated by the duty cycle.The main switches achieve zero-voltage-switching and therectifier diode realizes zero-current-switching. A Simulink model is.developed forverifying in the proposed analytical derivations.

Keywords- switching capacitor converter; PWM regulator; soft switching.

I.INTRODUCTION

The classical switched-mode converter has been a popular topology for dc/dc power conversion because it is technologically mature and is easy to use. One of themaindisadvantages is that the size of their energy storage components, namely, capacitor and inductor, are very dependent on the switching frequency.Switched-capacitor converters [1] do not require any inductor. Therefore, much research has been carried out to develop such inverters during the last decade or so. Usually, these converters require a large number of transistors to change the topology of the circuit by connecting a switching capacitor between the source and load [2], [3]. The voltage regulation of such converter is also difficult because the magnitude of theoutput voltage must be a fraction or a multiple of the source voltage [4], [5]. In order to regulate the converter, the switching capacitor’s charge and discharge characteristics must also be taken into account and, thus, the switching device’s duty ratiois used to control the amount of power through the switchingcapacitor. The drawback of this converter is that the transistor’son-state resistance and the equivalent series resistance of thecapacitor must have the same order of magnitude as the capacitor’ impedance. Such constraint would decrease the efficiency of the converter.

Voltage regulators have recently been developed for getting a sub-1-V supply voltage needed in microprocessors[6]. These converter, purposely designed for high load current and fast dynamics, are still in the development phase for answering thetough requirements. The switched-capacitor converters, proposed in the 1990s,Can provide any steep conversion ratio (a tutorial on these circuits can be found in [7]).however they operate with a relatively low efficiency. and put di/dt challenges in the charging path of the capacitor.

For traditional converters (such as Buck, Boost, Buck-Boost), the output voltage can be regulated by the duty cycle and we call them PWM regulators. The inductor is in serieswith the main power delivery loop and acts as the component of transferring energy. As well known, the inductor current slew rate is constrained, which limits the energy delivery speed from input to output [8].To meet the requirement of high di/dt in some occasions, someone proposes the switching capacitor (SC) converter, which employs the capacitor as the main component of power delivery. The energy can be transferred from input to output fast. Therefore, it achieves good dynamic performance. And due to the absence of the inductor, the weight and volume decreases a lot. However, it has some drawbacks: 1) the output voltage is fixed and can't be regulated; 2) the switch turn-on inrush current is large [9-12].In order to combine the advantages of above two kinds of converter and overcome their shortcomings, a switching capacitor regulator is presented [13]. The capacitor in the converter serves as the component of processing energy and meanwhile the output voltage is regulated by the duty cycle.

II. ANALYSIS OF THE PROPOSED CONVERTER NEGLIGIBLE LEAKAGE INDUCTOR

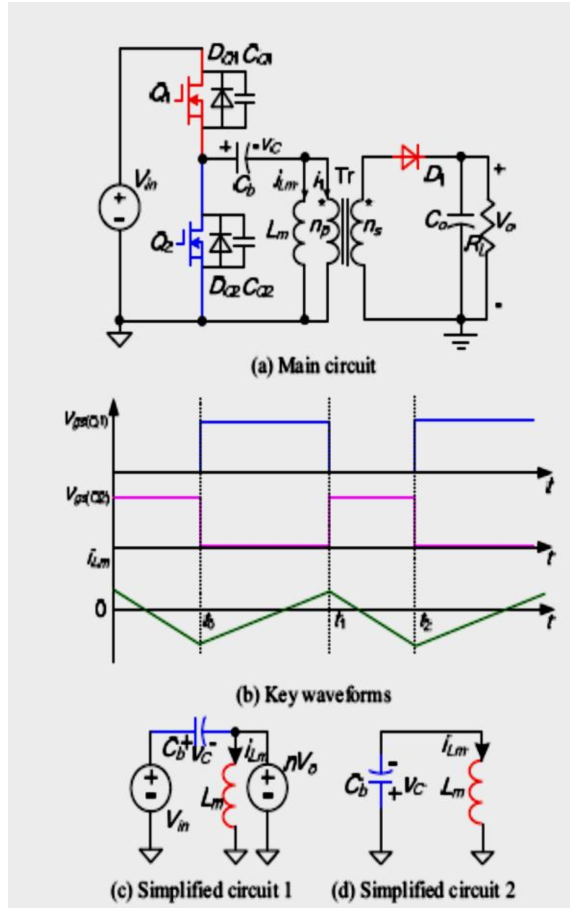

Fig.1.Isolated switching capacitor regulator.

Fig.1 shows the proposed isolated switching capacitor regulator's main circuit, key waveforms and simplified circuits.

Stage 1([*t*0, *t*1]) (Fig.1(c)): *Q*1 is turned on. The output voltage *Vo* reflects to the primary side and is in series with the capacitor *Cb*, and then in parallel with the input voltage *Vin*. It acts as a switching capacitor converter and has good transient response.

Stage 2([*t*1, *t*2]) (Fig.1(d)): *Q*1 is turned off and *Q*2 isturned on. The transformer is reset, and the output voltage is regulated by the duty cycle of *Q*2. The converter acts as aPWM regulator.

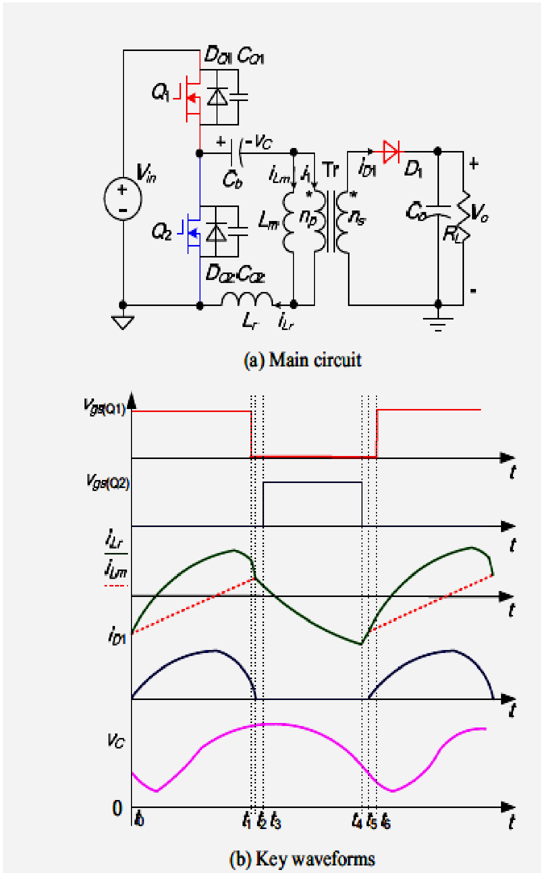

Fig.2. The isolated switching capacitor regulator with the leakage inductor

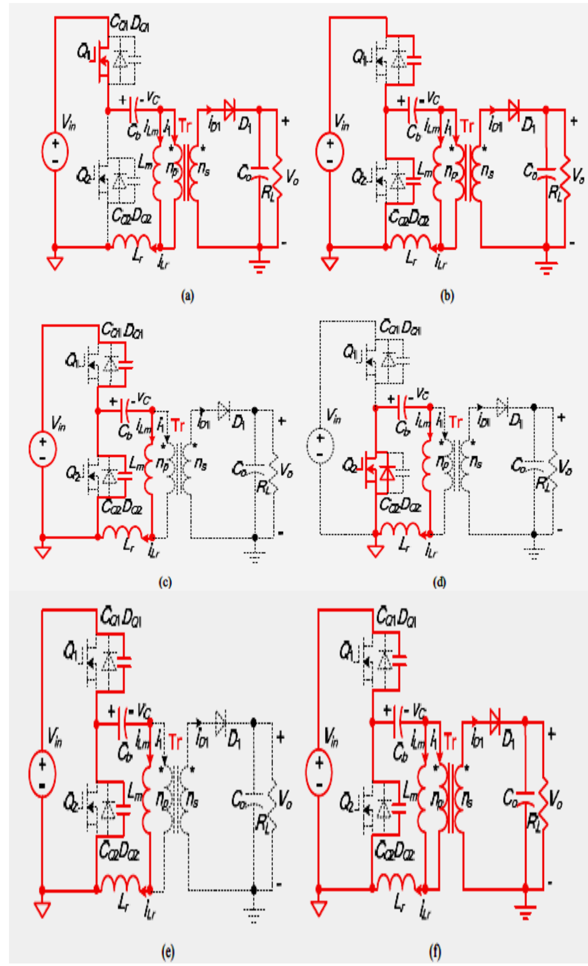

Fig.3 The equivalent circuits

According to the analysis, it is seen that the converter is the combination of a switching capacitor converter and a PWM regulator. It has good dynamic characteristics and capability of regulating the output voltage. From the above analysis, the conversion ratio from input tooutput can be derived:

$$V_o = \frac{DV_{in}}{n} \quad (1)$$

Where D is the duty cycle of $Q2$, n is the turn ratio from primary to secondary side.

III.ANALYSIS OF THE PROPOSED CONVERTER WITH NON-NEGLIGIBLE LEAKAGE INDUCTORS

In practical applications, the transformer is not ideal and will introduce a leakage inductor. If the leakage inductor is large and can't be ignored, the leakage inductor will beresonant with the blocking capacitor. The main circuit and keywaveforms are shown by Fig.4 And Fig.5 shows theequivalent circuits of all the modes.

Stage 1([$t0$, $t1$]) (Fig.3(a)): $Q1$ is turned on. The block capacitor Cb is resonant with the leakage inductor Lr.

Themagnetizing current *iLm* rises linearly.

Stage 2([*t*1, *t*2]) (Fig.3(b)): The switch *Q*1 is turned off. The leakage inductor current *iLr* charges *Q*1's parasiticcapacitor *CQ*1 and discharges *Q*2's parasitic capacitor *CQ*2.

Stage 3([*t*2, *t*3]) (Fig.3(c)): At *t*2, *iLr* is equal to themagnetizing current *iLm*. The diode *D*1 achieves zero-currentswitching. The primary side is separate from the secondary side. The transformer works as an inductor.

4) Stage 4([*t*3, *t*4]) (Fig.3(d)): At *t*3, the voltage of *CQ*2 isdischarged to zero and *DQ*2 starts to conduct. After this moment *Q*2 can achieve zero-voltage-switching. In this stage, the block capacitor is resonant with the magnetic inductor and leakage inductor.

TABLE I COMPARISON BETWEEN THE PROPOSED CONVERTER AND OTHER SIMILAR TOPOLOGIES

Topology	Isolated switching capacitor regulator (proposed)	Flyback converter	Asymmetrical half-bridge flyback converter[8]	LLC resonant converter (half-bridge)[9]
DC gain	$V_o = \frac{D}{n} V_{in}$	$V_o = \frac{D}{(1-D)n} V_{in}$	$V_o = \frac{D}{n} V_{in}$	Related to D and frequency
Voltage stress	V_{in}	$V_{in} + nV_o$	V_{in}	V_{in}
Soft switching	ZVS	no	ZVS	ZVS
Switches	2 active switches 1 diode	1 active switch 1 diode	2 active switches 1 diode	2 active switches 2 diodes
Magnetic components	transformer	transformer	transformer	transfomer resonant inductor

5) Stage 5([*t*4, *t*5]) (Fig.3(e)): At *t*4, *Q*2 is switched off, and*iLr* charges *CQ*2 and discharges*CQ*1.

6) Stage 6([*t*5, *t*6]) (Fig.3(f)): At *t*5, the voltage of thesecondary side is equal to the output voltage and *D*1 starts toconduct.

7) Stage 7([*t*6, …]) (Fig.3(g)): At *t*6, the voltage of *CQ*1 isdischarged to zero and *DQ*1 starts to conduct. After thismoment *Q*1 can achieve zero-voltage-switching.

Table.1 shows the comparison between the proposed isolated switching capacitor regulator and other similarconverters. The proposed converter has the following

advantages: low voltage stress, few magnetic components andswitches , and achievement of zero-voltage-switching.

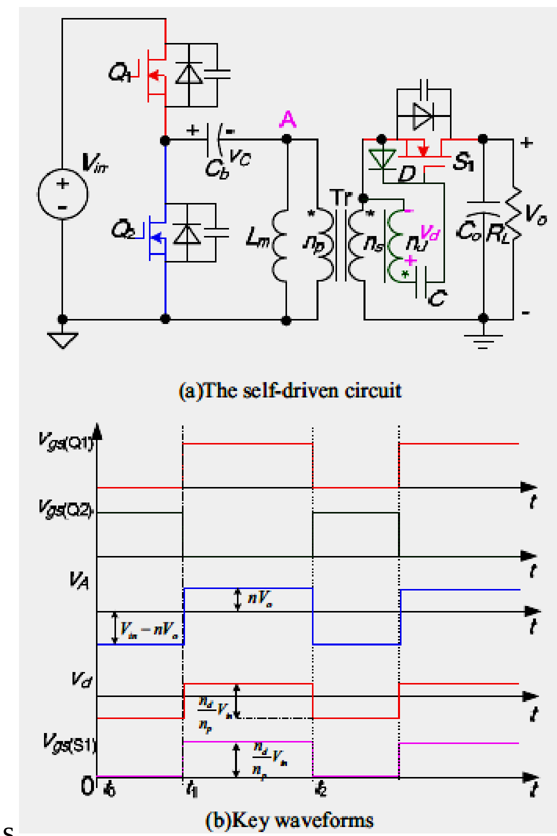

Fig.4 The self-drivenmethod

IV. SELF-DRIVEN SYNCHRONOUS RECTIFIER

In order to improve efficiency in the large output current application, synchronous rectifier (SR) should be used. Compared to external-driven method, the SR self-driven method can reduce SR drive loss and body diode conduction loss. Therefore, self-driven method is employed in the proposed circuit to further improve efficiency and increase power density. By adding an additional winding and blocking capacitor [10], we can obtain the appropriate drivingsignal for the synchronous rectifier. The main circuit and keywaveforms are shown in Fig.4.

Stage 1([*t*0, *t*1]): *Q*2 is switched on, and *vd* is negative.The diode *D* conducts and the capacitor *C*is charged. So inthis stage *S*1 is switched off.

Stage 2([*t*1, *t*2]): *Q*2 is switched off and *Q*1 is switched on*vd* is positive and *S*1 is switched on.
By adjusting the turns number of the additional winding,the SR loss is further reduced.

V.SIMULATION RESULTS

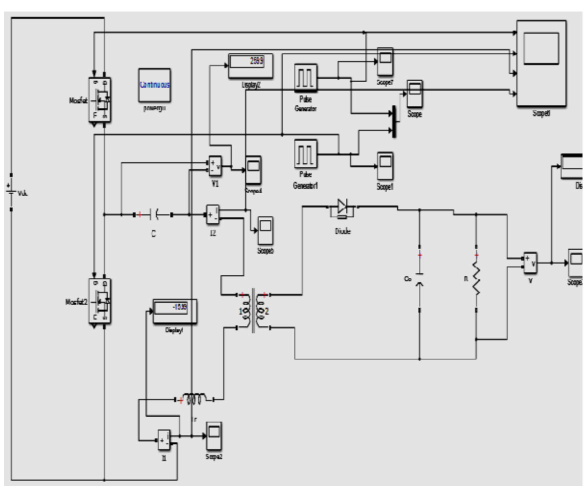

Fig.5.simulation circuit

Fig.5.shows simulation circuit for the proposed converter. here zero voltage switching is used for main switches and zero current switching refered for rectifier diode.

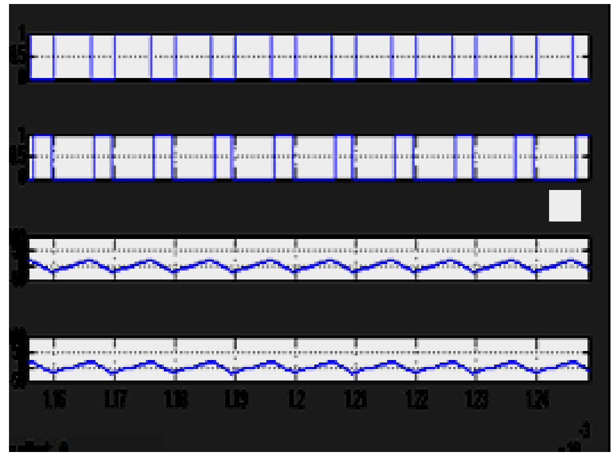

Fig.6. output wave forms

In Fig.6.one and two wave shapes represent the pulses generated for the main switches.
Waves 4and 5 represant *Lr and Lm*.

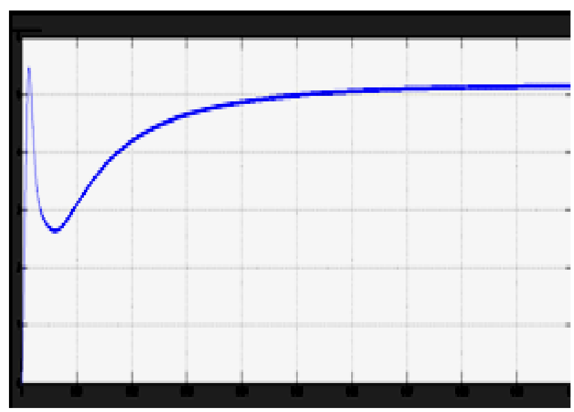

Fig.7. output voltage wave form

Fig.7. shows the output voltage converted from the converter for an input voltage of 400v the converter regulated to the 5vdc.

VI. CONCLUSION

An isolated switching capacitor regulator is proposed in this paper. The proposed converter has the following advantages: 1) Fast transient response and the output voltage can beregulated as well. 2) The main switches achieve zero voltage-switching and the rectifier diode realizeszero-current-switching. 3) Self driven synchronous rectifier can be employed to improve efficiency.

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