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PERFORMANCE EVALUATION OF FOUR SWITCH BUCK CONVERTER

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***Abstract*-To improve the transient response, high switching frequency method is employed. Due to the high switching frequency the efficiency is reduced because the switching loss is proportional to the switching frequency. Four switched buck converter is proposed to improve the transient response and efficiency. Simulation results show that the transient response is greatly improved.**

***Keywords*-buck converter; transient response; efficiency; switching los; switching frequency**

I. INTRODUCTION

In recent years, large growth in the usage of electronic equipment. All power electronic equipment generates losses and emit unwanted electric signals if the switching frequency is high. Due to the above concern, the efficiency of the equipment is affected.

A dc voltage is reduced by using a voltage divider circuit[1], but in the voltage divider waste of energy and bleeding off excess power as heat is occur and also the output voltage is not regulated. Compared to voltage divider circuit, buck converter is efficient and self regulating.

Soft-switching techniques have been introduced to reduce switching losses[2]-[5], but the drawback of these technique is, it can create more favorable switching trajectories for active power devices, they will generally increase the complexity of control .Due to this control complexity, the realibility of soft switched converter is reduced.

The interleaved operation improves the transient response but the circulating current problem exists [6,7]. High frequency switching converter is proposed to enhance the output voltage response but switching loss is more because of high frequency. This paper proposes a four switch buck converter to improve transient response and efficiency .

The novel topology consists of four switches: three controlled switch and one uncontrolled switch (Diode). It consists of inner cell and outer cell. Inner cell has one controlled switch which operates at low frequency and the outer cell consists consists of two controlled switches which operate at high frequency. The outer cell switches works complementarily. The proposed converter does not have circulating current problem

II. FOUR SWITCH CONVERTER

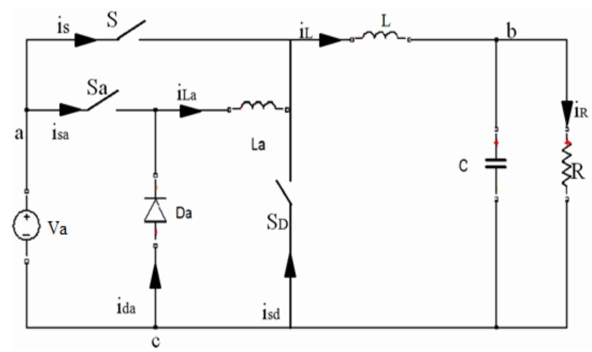

Figure 1. Proposed four switch buck converter

By increasing the switching frequency, the transient response of power converter is improved, but the efficiency is reduced.

A Four switch buck converter is proposed to improve the efficiency. This converter consists of an inner cell and an outer cell. The inner cell switches works at low frequency and the outer cell switches works at high frequency. The current in the outer cell switch is diverted through the inner cell switch. Thus the switching loss is reduced thereby increasing the efficiency and exhibits improved transient responses.

The inductor L and the switches S and S_D form an outer cell. The switches s and S_D operates at higher frequency. The inner cell consists of L_a, S_a, and D_a, the switch S_a operates at low frequency. The outer cell is to enhance the output performance and the inner cell is to improve the converter efficiency.

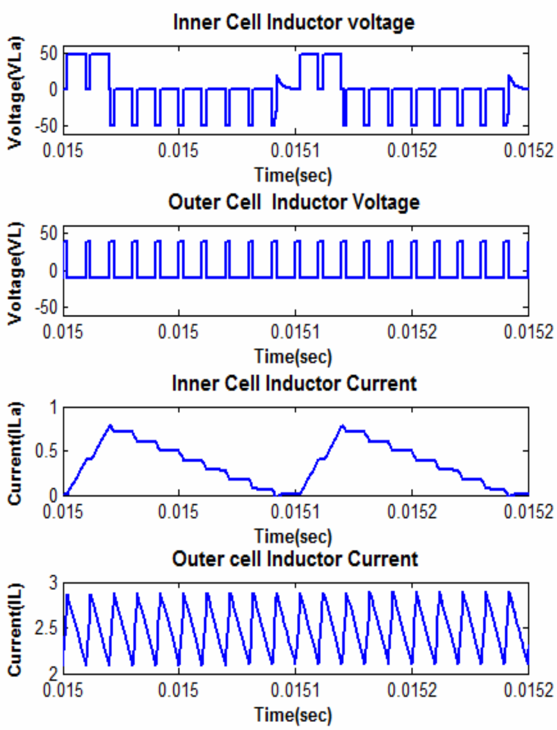

Figure 2. Voltage and current waveforms in switching period T_{sl}.

TABLE I
SWITCHING STATES

STATE	ACTIVE SWITCHES			
	S	S_a	S_D	D_a
A	ON	ON	OFF	RB
B	OFF	ON	ON	RB
C	ON	OFF	OFF	FB
D	OFF	OFF	ON	FB

State A:

The inductor Voltage V_L of the outer cell is positive and the inductor voltage V_{La} of the inner cell is zero. The current flowing through outer cell inductor L rises linearly and the current flowing through inner cell inductor L_a does not change.

The equations are,

$V_L=V_a-V_o$ (1)

$di_L/dt= V_L/L = V_a - V_o / L$ (2)

$V_{La} = 0$ (3)

$di_{La}/dt =V_{La}/L_a=0$ (4)

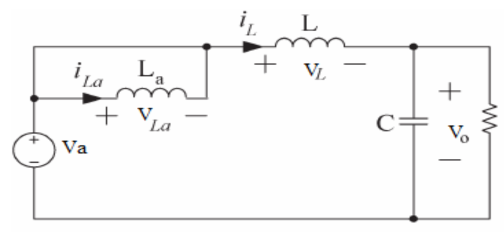

Figure 3. Equivalent circuit of four switch buck converter when S=ON, S_a =ON.

State B:

The inductor Voltage V_L of the outer cell is negative and the inductor voltage V_{La} of the inner cell is positive. The current flowing through outer cell inductor L decreases linearly and the current flowing through inner cell inductor L_a rises linearly.

The equations are,

$V_L =- V_o$ (5)

$di_L/dt= V_L/L = - V_o / L$ (6)

$V_{La} = 0$ (7)

$di_{La}/dt =V_{La}/L_a=0$ (8)

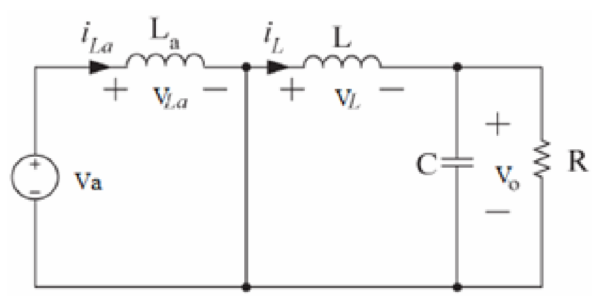

Figure 4. Equivalent circuit of four switch buck converter when S=OFF, S_a=ON.

State C:

The inductor Voltage V_L of the outer cell is positive and the inductor voltage V_{La} of the inner cell is negative. The current flowing through outer cell inductor L rises linearly and the current flowing through inner cell inductor La decreases linearly.

The equations are,

$V_L=V_a-V_o$ (9)

$di_L/dt= V_L/L = V_s - V_o / L$ (10)

$V_{La} = -V_o$ (11)

$di_{La}/dt = V_{La}/L_a = -V_o/L_a$ (12).

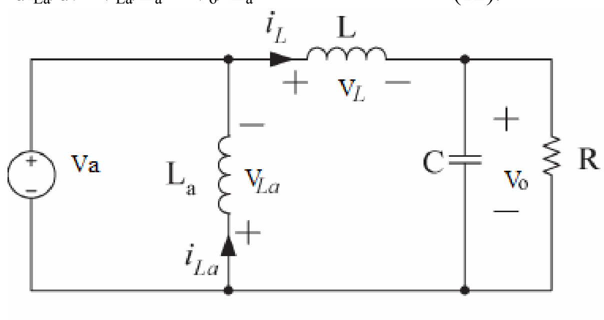

Figure 5. Equivalent circuit of four switch buck converter when S=ON, S_a=OFF.

State D:

The inductor Voltage V_L of the outer cell is negative and the inductor voltage V_{La} of the inner cell is zero. The current flowing through outer cell inductor L decreases linearly and the current flowing through inner cell inductor La remains the same.

The equations are,

$V_L = -V_o$ (13)

$di_L/dt = V_L/L = -V_o/L$ (14)

$V_{La} = 0$ (15)

$di_{La}/dt = V_{La}/L_a = 0$ (16)

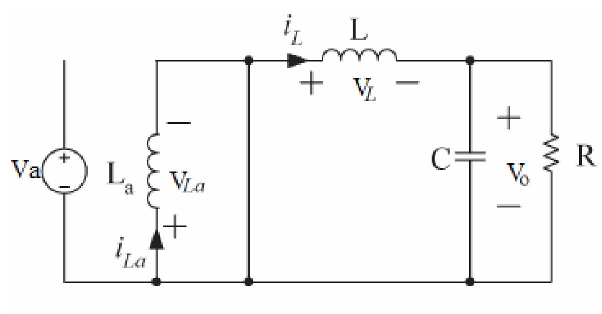

Figure 6. Equivalent circuit of four switch buck converter when S=OFF, S_a=OFF.

The voltage across the outer cell inductor is $V_a - V_o$ when the switch is on, and is $-V_o$ when the switch is off. The voltage and current waveforms of four switch buck converter in one low frequency Cycle T_{sl} are shown in Fig.2

A. Performance Evaluation:

Transient Performance Analysis:

The transient performance of four switched buck converter is analysed by changing the load from 2R to R, the current across the load is increased from $I_R/2$ to I_R. The current through the inductor cannot change abruptly. Due to the increased load current the output voltage decreases. The inner cell inductance is larger than the outer cell to reduce the current ripple i_{La}.

If the load resistance is changed from R to 2R, the current across the load is decreased from I_R to $I_R/2$. At this transient event, current through inner cell i_{La} can freewheel through S_D if the switch S is OFF. The energy stored in inner cell inductor can be fed back to source through the switch S.

If the load is changed from 8 to 4 Ω at the 0.03s time instant. A major portion of the increased load current is diverted to the inner buck cell, while the current through the outer cell switch remains the same. The diversion of current enables the reduction of switching loss in outer buck cell and the efficiency is improved.

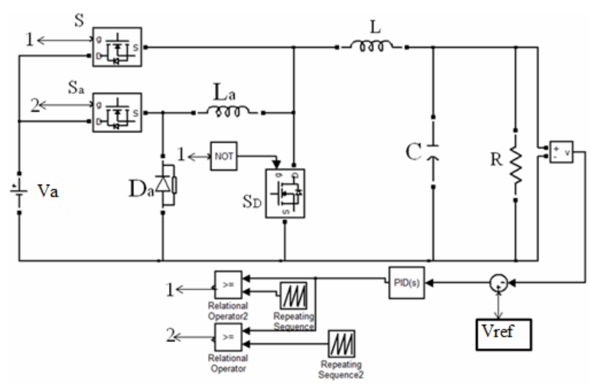

Figure 7. Four switch buck converter with PID controller

Efficiency Analysis:

The efficiency is analysed using the formula[5,6]

Efficiency= Pout/(Pout + losses) (17)

In the efficiency analysis ,only switching loss is considered because major loss of the circuit is caused by switching loss. Losses of the output capacitor and output inductor are not considered here.

In a single-frequency buck converter, when the input voltage is V_a, duty ratio is D, the inductor average current is I_L, and the switching frequency is f_s, then the total loss comes from, the conduction loss P_{scon} and switching loss P_{ss} of the active switch *S*, and the conduction loss P_{dcon} and switching loss P_{sd} of the diode, the losses can be estimated from the equations [8,9]:

$P_{scon} = D.V_{on} I_L$ (18)

$P_{dcon} = (1-D).V_f I_L$ (19)

$P_{ss} = 1/2\ f_s .V_a\ I_L\ (t_{on}+t_{off})$ (20)

$$P_{sd} = 1/2\ f_s.V_a\ I_L\ (t_{on}+t_{off}) \qquad (21)$$

For four switch buck, the losses consist of two portions: outer cell losses and inner cell losses.

The switching loss is calculated according to the following equations:

The losses in the outer cell which has high frequency are

$$P_{sconO} = D.V_{on}\ I_L \qquad (22)$$

$$P_{ssO} = 1/2\ f_h\ .V_a\ I_L(t_{on}+t_{off}) \qquad (23)$$

The losses in the inner cell which has low frequency are

$$P_{sconI} = D.V_{on}\ I_{La} \qquad (24)$$

$$P_{ssI} = 1/2\ f_l\ .V_a\ I_{La}\ (t_{on}+t_{off}) \qquad (25)$$

B.Simulation Results for Switching Loss:

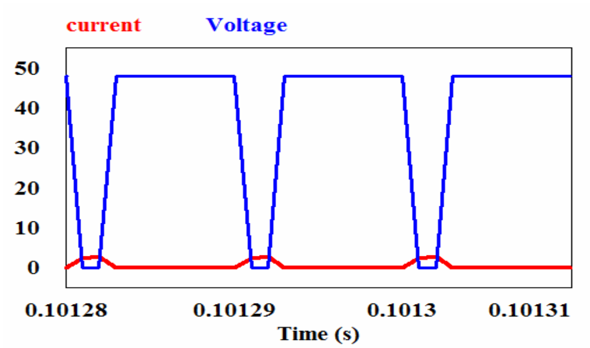

Figure 8. Switching loss across outer cell switch

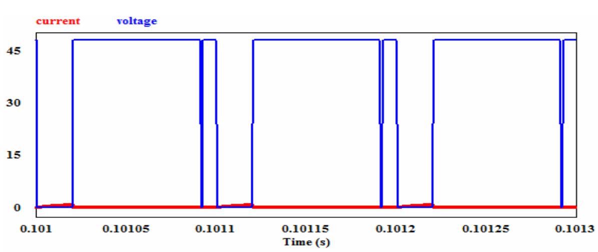

Figure 9. Switching loss across inner cell switch

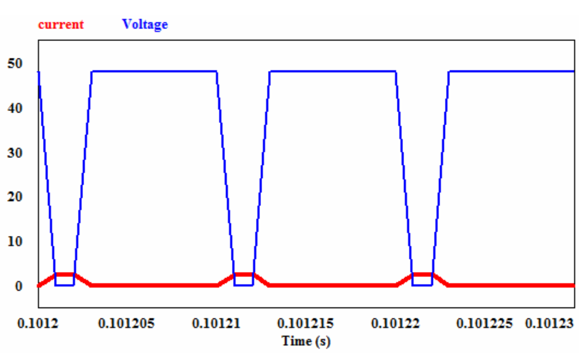

Figure 10. Switching loss of Single High frequency converter

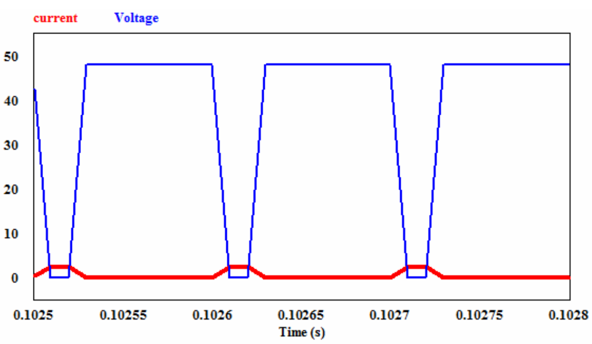

Figure 11. Switching loss of Single Low frequency converter

From the above graph the total currents flowing through the four switch buck converter switches are the same as that through a single-frequency buck. The total switching loss is nearly the same as the single low-frequency buck, and is much smaller than that of the single high-frequency buck. The switching loss is reduced by 16watt when compared to single high frequency buck. Hence, the four switch buck converter improves the efficiency by current diversion to the inner cell.

TABLE II

Converter	Switching Loss(watt)	Efficiency(%)
Single Low Frequency Buck Converter	11.3074	67.07
Single High Frequency Buck Converter	28.42	44.77
Four Switch Buck Converter	12.07	66.80

C. Simulation Results of Transient Analysis :

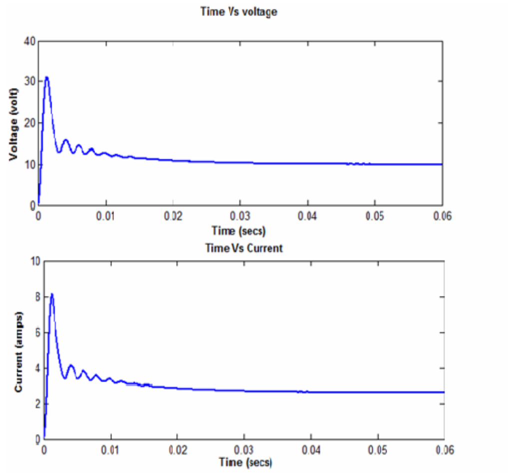

Figure 12. Simulation result of low frequency buck converter

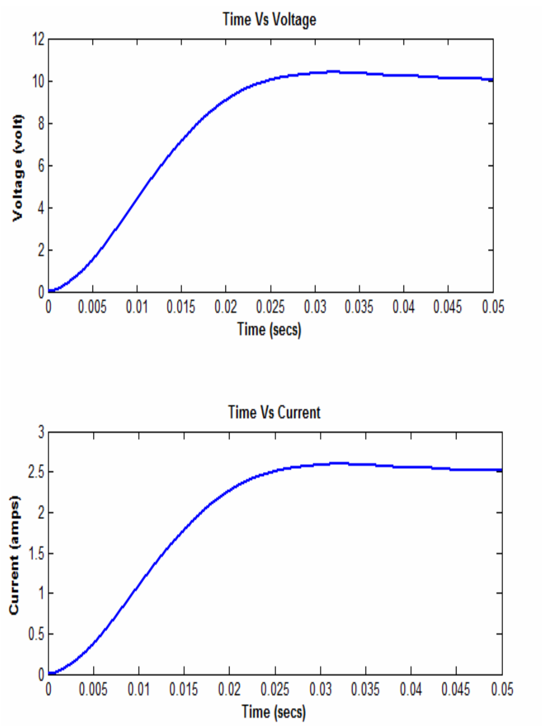

Figure 13. Simulation result of high frequency buck converter

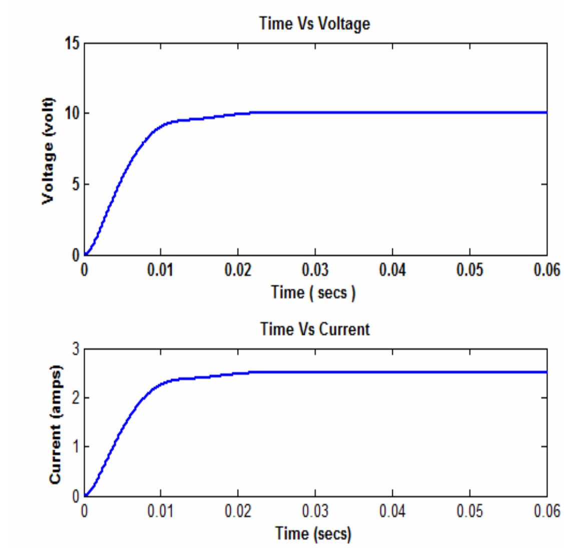

Figure 14. Simulation result of four switch buck converter

From the above graph, it is revealed that the Four switch buck converter improves the dynamic response when compared to the low frequency buck converter and high frequency buck converter.

TABLE III
DYNAMIC RESPONSE

Parameters	Low Frequency Buck converter	High frequency buck converter	Four switch buck converter
Maximum Overshoot	**22**	**0.4**	**0**
Rise Time (secs)	**0.005**	**0.025**	**0.02**
Settling Time (secs)	**0.037**	**0.055**	**0.031**

From the above simulation results, the Table II is tabulated. The simulation results shows that the Four switch buck converter improves the dynamic response and more or less equal to that of single high frequency buck converter and better than the single low frequency buck converter.

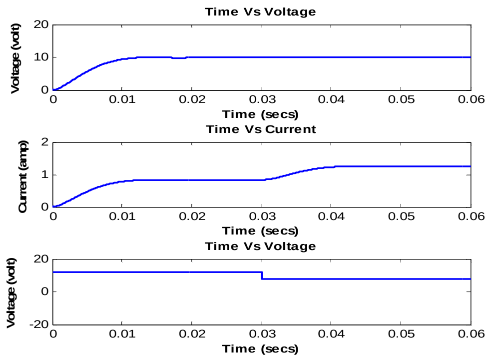

Figure 15. Simulation result of four switch buck converter with load side disturbance

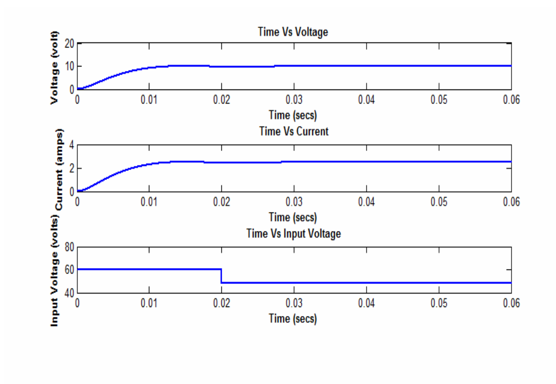

Figure 16. Simulation result of four switch buck converter with source side disturbance

III CONCLUSION

The proposed four switch buck converter greatly improves the efficiency and exhibits nearly the same transient response as the conventional high-frequency buck converter and efficiency of the four switch buck converter is nearer to the low frequency buck converter. Future work will investigate whether the proposed four switch buck converter is applicable for high dynamics specifications.

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