Comparative Study of Modified Three-Level Buck Converter Topology

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Abstract-This paper deals with comparison of conventional and flying capacitor three level buck converters. A comparative study of the flying capacitor three level buck converters and a modified flying capacitor three level converter is done here. And analysis of the modified flying capacitor three level buck converter is done from the waveforms obtained. The main benefits of this topology is reduction in size of the converter and also higher efficiency. The conventional and the proposed circuits are simulated using PSIM.

***Index Terms*: Modified flying capacitor three level buck converter.**

I.INTRODUCTION

As the voltage stress on the switches is smaller by using a flying capacitor buck converter, it is mainly used in applications which requires high power. Advantages of using this topology are voltage stress on the switches are reduced by half ,size of the inductor is reduced and efficiency is increased as in [3][4], and as a result of this converter become more compact. And the switching losses are also reduced. This paper deals with the simulation of a Flying capacitor three level buck converter and modified flying capacitor three level buck converter. The simulation model is done using PSIM. One of the disadvantages of using this modified flying capacitor three level buck converter is switching loss will be more as there are three switches

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The section II deals with the comparison of conventional and flying capacitor three level buck converters. Detailed study of modified three level buck converters is performed in section III. Section IV contain simulation model of flying capacitor three level buck converter and modified flying capacitor three level buck converter. In section V, the simulation results of two converters are performed.

II. CONVENTIONAL BUCK CONVERTER VERSUS FLYING CAPACITOR THREE-LEVEL BUCK CONVERTER

A. *Conventional Buck Converter Topology*

Flying capacitor three-level buck converter is a topology preferred for high-power applications as voltage stress on the switches is smaller than a standard buck converter .Fig. 1 illustrates the topology of the conventional buck converter. Node *x* marks the left terminal of the inductor. Consequently, voltage *Vx* labels the voltage of node *x* with respect to the ground. In this paper, voltage *Vx* is referred to as the switching voltage since it can be switched to a different value by changing the status of the switches. In this topology, voltage *Vx* can operate at two voltage levels (0, *V*in). When switch *S* is conducting, voltage *Vx* equals *V*in and when diode *D* is conducting, voltage *Vx* equals 0.

Typical waveforms of the inductor current ripple and the status of switch *S* of the conventional buck converter operating in continuous conduction mode (CCM) are depicted in Fig. 2. *I*max and *I*min are the maximum and minimum values of the inductor current. Also, *T* denotes the time period of the inductor current, *f* denotes the inverse of *T*, and *D* denotes the duty ratio. Here, *f* is the frequency of the first harmonic that appears in the inductor current waveform and also the switching frequency of switch *S*. Considering Figs.1 and 2, one can write,

$$\Delta I = Imax - Imin \qquad (1)$$

$$Lmin = \left(1 - \frac{Vo}{Vin}\right)\frac{RT}{2} \qquad (2)$$

Where, *R* is the value of the load and *L*min is the minimum inductor value needed to guarantee CCM operation.

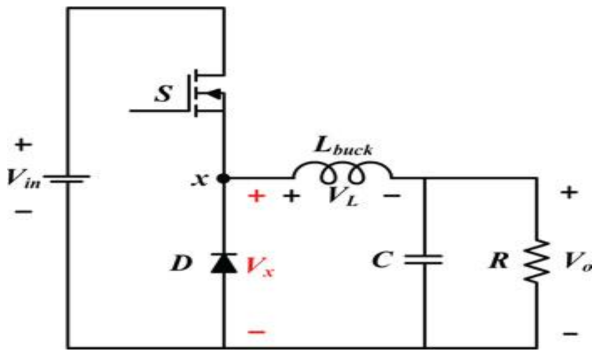

Fig.1.Conventional buck converter.

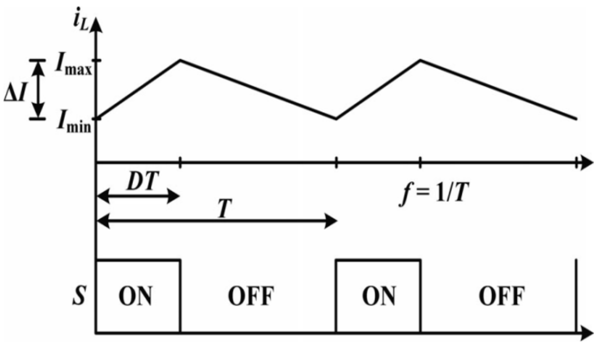

Fig.2.Inductor current ripple and status of switch S.

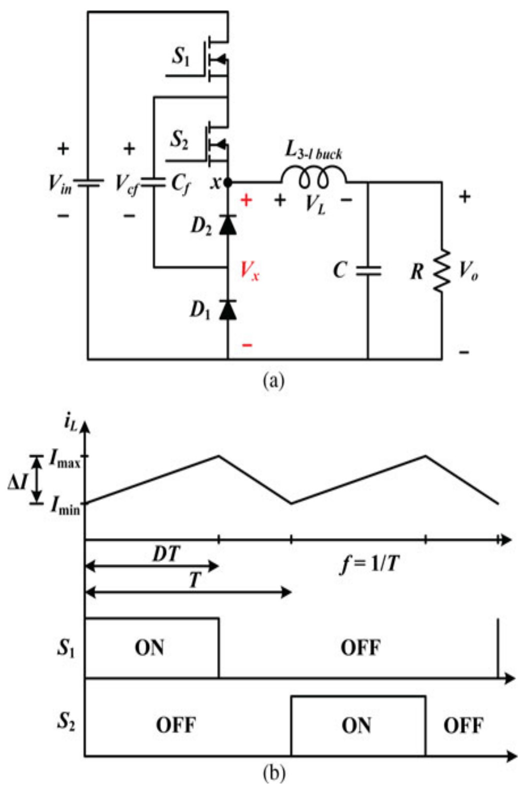

Fig.3.Flying capacitor three-level buck converter. (a) Topology of flying capacitor three-level buck. (b) Inductor current ripple and status of switches *S*1 and *S*2.

B. Flying Capacitor Three-Level Buck Converter Topology

The flying capacitor three-level buck converter topology is illustrated in Fig. 3(a). Again node *x* marks the left terminal of the inductor and *Vx* labels the voltage of node *x* with respect to the ground. In this topology, the converter can operate at three voltage levels (0, 0.5*V*in, *V*in). When switches *S*1and *S*2are conducting, voltage *Vx* equals *V*in. When switch *S*1and diode *D*2or switch *S*2and diode *D*1are conducting, voltage *Vx* equals 0.5*V*in. Finally, when diodes *D*1and *D*2are conducting, voltage *Vx* equals 0. Because of the additional voltage level, the size of the inductor used in design of the converter is small for the same output current ripple. Typical waveforms of the inductor current and the status of the switches *S*1and *S*2 of the flying capacitor three-level buck converter operating in CCM are depicted in Fig.3 (b). The flying capacitor voltage is maintained at half the input source voltage. One way of doing this is by driving switches *S*1and *S*2 180◦ out of phase to each other as it can be seen in Fig. 3(b). Hence, the frequency of inductor current ripple is twice as that of the switching frequency of switches *S*1and *S*2.

C. Comparison Summary

Three level buck converter works as a multilevel converter. The three level buck converters can offer high efficiency and high power density in voltage regulation and point of load applications. The gains are made possible by adding a flying capacitor that reduces the MOSFET voltage stress by half allowing for the use of low voltage devices, doubles the effective switching frequency, and decreases the inductor size by reducing the volt-second across the inductor. The three level buck converter topology gives a reduced inductor size so that the overall size of the converter is reduced. Thus comparing with conventional buck converter the inductor size is reduced which gives a higher power density. The ripple current frequency is doubled, so that the switches are subjected to low switching frequency than that of conventional buck converter.

A comparison of the conventional buck converter with the flying capacitor three-level buck converter is given in Table I. In this comparison, it is assumed that the flying capacitor of the three-level buck converter topology is maintained at a voltage that is equal to half the source voltage by driving switches *S*1and *S*2 180◦ out of phase to each other. Considering similar inductor current ripple, the three-level buck converter requires a smaller inductor. This is shown in the last row of Table I.

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	Conventional Buck	Flying capacitor three-level buck
Voltage Levels (V_x)	Switching States	
V_{in}	S : ON	S_1 : ON S_2 : ON
V_{in}-V_{cf}	-	S_1 : ON S_2 : OFF
V_{cf}	-	S_1 : OFF S_2 : ON
0	S : OFF	S_1 : OFF S_2 : OFF
Switching Frequency	S: f	S_1 : $f/2$ S_2 : $f/2$
Switch blocking voltage	V_{in}	$V_{in}/2$
V_o	$D^* V_{in}$	$D^*V_{in}/2$
L_{min} for CCM	$(1-\frac{V_o}{V_{in}})\frac{RT}{2}$	$(1-\frac{2V_o}{V_{in}})\frac{RT}{2}$

Table I. Comparison Of Conventional And Flying Capacitor Three-Level Buck Converters.

III. MODIFIED FLYING CAPACITOR THREE LEVEL BUS CONVERTER TOPOLOGY

In the conventional buck converter, to supply energy to the load during a load step-up change, switch *S* will be turned ON for a longer period of time. Consequently, switching voltage *Vx* will be equal to input voltage *V*in. The inductor current slew rate can be expressed as

$$\frac{diL+}{dt} = \frac{Vx-Vo}{Lbuck} = \frac{Vin-Vo}{Lbuck} \qquad (3)$$

During the load step-down change, switch *S* will be open. Then, the inductor energy will be released through diode *D*. In this case, switching voltage *Vx* equals zero. The inductor current slew rate is

$$\frac{diL-}{dt} = \frac{Vx-Vo}{Lbuck} = \frac{-Vo}{Lbuck} \qquad (4)$$

In the above equations, *L*buck refers to the inductance of the conventional buck converter. It is known that the higher the inductor current slew rate, the faster the energy supply (load step up) or release (load step down) will be. In the buck converter, switching voltage *Vx* is limited to *V*in (load step up) or zero (load step down). Hence, the conventional buck converter has a slower dynamic response and a larger inductor ripple. The dynamic response can be improved by making the inductor smaller. The limitation would be *L*min.

For higher performance requirement, especially where stringent dynamic response is required, the flying capacitor three-level buck converter is an attractive topology.

The inductor current slew rates for load step-up and load step-down changes can be expressed as

$$\frac{diL+}{dt} = \frac{Vx-Vo}{L3-lbuck} = \frac{0.5Vin-Vo}{L3-lbuck} \qquad (4)$$

$$\frac{diL-}{dt} = \frac{Vx-Vo}{L3-lbuck} = \frac{-Vo}{L3-lbuck} \qquad (5)$$

In the above equations, $L3-l$buck refers to the inductance of the flying capacitor three-level buck converter (L in fig4). And the dynamic response of buck converter depends on the inductor current slew rate also. An additional switch called auxiliary switch Sa and auxiliary diode Da are connected. This gives the modified circuit,

When the auxiliary switch Sa is turned off, Da will not conduct. So the operation is similar to that of conventional flying capacitor three level converters. And when Sa conducts S1 and S2 will also be turned on. And when there is a decrease in load all the three switches are turned on.

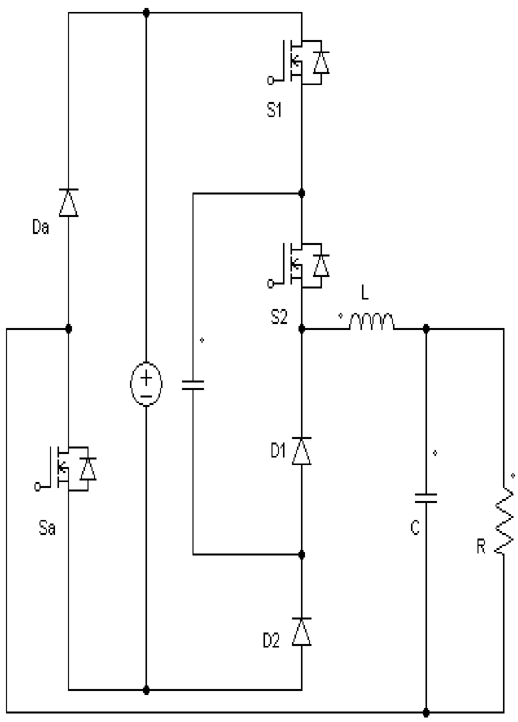

Fig.4 Modified Flying Capacitor converter topology

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IV. SIMULATION MODEL

A. Flying Capacitor Three Level Buck Converter

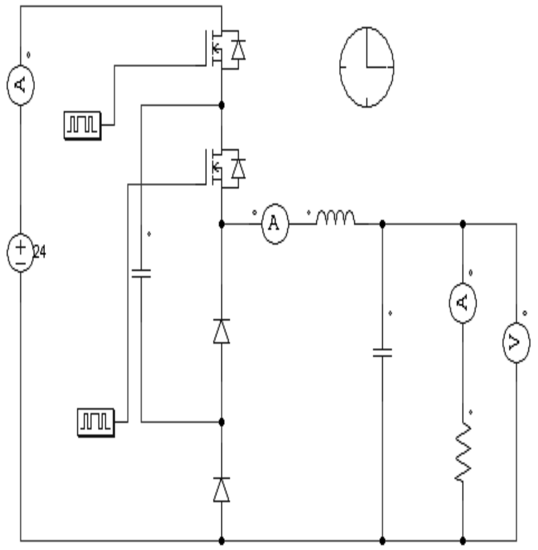

Fig.5. Circuit layout of Flying Capacitor three level buck converter in PSIM

In this input voltage is given as 24 V. and the flying capacitor is having 27 F. Inductance value is taken as 300 H. This circuit shows the conventional flying capacitor three level buck converters.

B. Modified Flying Capacitor Three Level Buck Converter

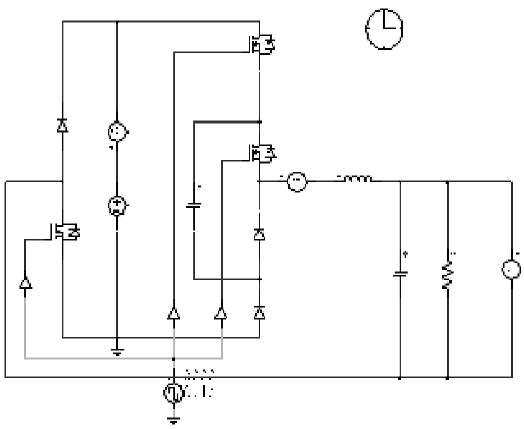

Fig 6.Circuit layout of Modified Flying Capacitor Three Level Buck Converter in PSIM

The simulation parameters are same for both the circuits. The above Fig.6 gives the simulation model of modified flying capacitor three level buck converter.

V. SIMULATION RESULTS

A. Flying Capacitor Three Level Buck Converter

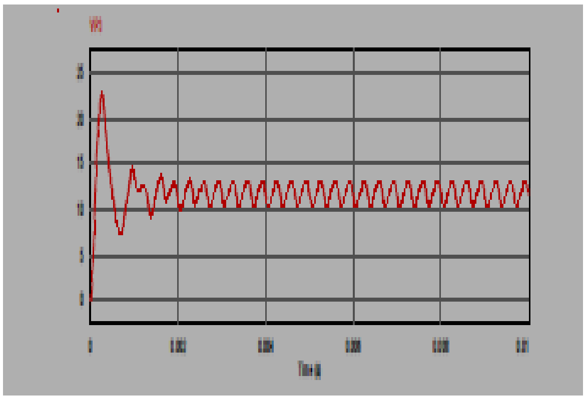

Fig7.Output of three level buck converter

B. Modified Flying Capacitor Three Level Buck Converter

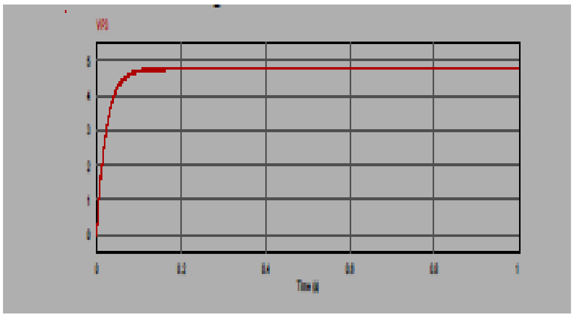

Fig8.Output Voltage of modified three level buck converter

TABLE II
COMPARISON OF SIMULATION RESULTS

Parameters	Flying Capacitor Three Level Buck Converter	Modified Flying Capacitor Three-Level Buck Converter
Input Voltage	24V	24V
Flying Capacitor	27µF	27µF
Inductor	300 µF	300 µF
Output Voltage	12V	6V

Table II. Comparison of Simulation Results

VI. CONCLUSION

A comparative study of flying capacitor three level buck converter and a modified flying capacitor three level buck converter is done. By comparing the conventional and modified topology it is clear the output voltage obtained using the conventional topology is 12V but by using modified topology it has been reduced to about 6 V. The ripple in output voltages is reduced by using the modified topology. Here, the simulation model is set up using PSIM.

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