Analysis of Ripple Content in DC-DC Converters

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Abstract*— *The DC-DC converter has the major applications in LED, lamp flashers and computers, also in industrial applications like batteries, solar cells, drives, motors..etc. In this propose study the comparison of two switches in DC-DC Converters are taken, which are MOSFET,IGBT. DC-DC converters which are used in proposed method is buck and buck-boost converter. Outputs parameters are output voltage, output current, capacitor voltage, inductor current, ripple content in the output respectively.The simulation has done by using P-Spice software using Cadence tool, and then implemented using hardware components. Variation in the inductance and capacitance variation is done. By this analysis the dynamic response, steady state response, ripple and variation in the output can be found. By comparing hardware results and simulation results the better switch among them can be found. The proposed method consists of designing, simulation and stability analysis in transient state as well as in steady state. The best switch is used in dc-dc converter.

***Index Terms*— *Dynamic state, Steady state, Ripple content, Buck converter, Buck-boost converter*.**

I. INTRODUCTION

A. Objective of Study

- The proposed method gives the performance analysis of MOSFET, IGBT for buck and buck-boost converters
- This analysis gives the best switch among them can be found by simulation and hardware results

Main target in power electronics is to convert electrical energy from one form to another. To make electrical energy to reach the load with highest efficiency is the target to be achieved. Power electronics also targets to reduce the size of the device to convert these energy which aims to reduce cost, smaller in size and high availability. Dc-dc converter has a large number of industrial applications, such as batteries, solar cells and in low power applications, such as LED, light flashers and in computers..etc. It is required to convert a fixed dc voltage to a different dc voltage level, often with a regulated output.

A dc-dc converter directly converts a dc voltage of one level to another. It can be used to step-down (buck) the voltage, or step-up (boost) the voltage or both. The dc-dc converter for this proposed method is buck-boost converter and buck converter. Buck-boost and buck converters are use to convert unregulated dc input to a controlled dc output with a desired voltage level. The buck-boost converter will produces a dc output voltage which is either greater or smaller in magnitude than the dc input voltage 30Vdc to -12Vdc or - 45Vdc with a switching frequency 20kHz and buck will step down the input voltage 30Vdc to 12 Vdc with the switching frequency 20 kHz. The simulation is done by using P-Spice software using Cadence tool.

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This proposed method consists of simulation, stability analysis in transient as well as in steady state and comparison of switches. In the past, when only partial power was needed (such as for a sewing machine motor), a rheostat (located in the sewing machine's foot pedal) connected in series with the motor adjusted the amount of current flowing through the motor, but also wasted power as heat in the resistor element. It was an inefficient scheme, but tolerable because the total power was low.

Hence linear DC to DC conversion technique was introduced as an electronic device to supply required power to all the electronic components used in a device. But it is inefficient, big size, heavy and loss of power due to generation of heat is discussed in paper [1]. But, in mid 1970's, Switched Mode power supply was accepted and broadly used in every field. Basically, switching power supply offers more advantages upon linear power supply. Switching regulators are used as replacements for the linear regulators when higher efficiency, smaller size or lighter weight is required. The output of dc converters with resistive load is discontinuous and contains harmonics. The ripple content is normally reduced by an LC filter discussed in paper [2].

The inductor reduces the ripple in the current through the load resistor, while the capacitor directly reduces the ripple in the output voltage. Since the current through the load resistor is the same as that of the inductor, the voltage across the load resistor (output voltage) contains less ripple is presented in paper [3]. In buck converter for steady state waveforms it is discussed that the output voltage ripple is low ($\delta_v = \delta V_o/V_o << 1$). The charging and discharging current of the capacitor decides the voltage ripple. The switching period (T_s) must be very much less than the natural period ($T_0 = 2\pi\sqrt{LC}$) of the converter is discussed in paper [4]. Compare to SCR, GTO, BJT the MOSFET and IGBT are suitable for highly repetitive pulsed power modulator owing to their superior switching characteristics is described in paper [5,6]. The detailed study on the influences of parasitic elements on the MOSFET switching performance is presented in paper [7]. The design of the buck converter is referred by text book [8]. The proposed method mentioned the output voltage ripple for each switch, and the dynamic characteristics of each switch is referred by papers [9,10,11]. The dc-dc converters applications are mentioned in paper [12]. The proposed study uses the P-Spice software for simulation results. Hence this can be done by referring papers [13,14].

II. METHODOLOGY

It covers working principle of buck and buck-boost converter, design, inductance and capacitance variation for buck converter.

A. Buck Converter

When switch is closed the diode becomes reverse biased. The input current rises and flow through filter inductor, filter capacitor and load resistor R. When the switch is opened the diode becomes forward biased. And it conducts due to energy stored in the inductor and the inductor current continues to flow through D, L,C and R. The inductor current falls until the switch will be closed again in next cycle. It covers working principle of buck and buck-boost converter, design, inductance and capacitance variation for buck converter When switch is closed the diode becomes reverse biased. The input current rises and flow through filter inductor, filter capacitor and load resistor R. When the switch is opened the diode becomes forward biased and it conducts due to energy stored in the inductor and the inductor current continues to flow through D, L,C and R. The inductor current falls until the switch will be closed again in next cycle.

$$L_{min} = \frac{(1-D)R}{2f} \quad ...(1) \quad \text{for continuous current}$$

where L_{min} is the minimum inductance required for continuous current. In practice, a value of inductance greater than L_{min} is desirable to ensure continuous current. In the design of a buck converter, the peak-to-peak variation in the inductor current is often used as a design criterion.

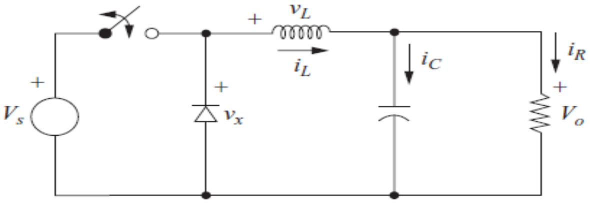

Fig. 1. Buck Converter

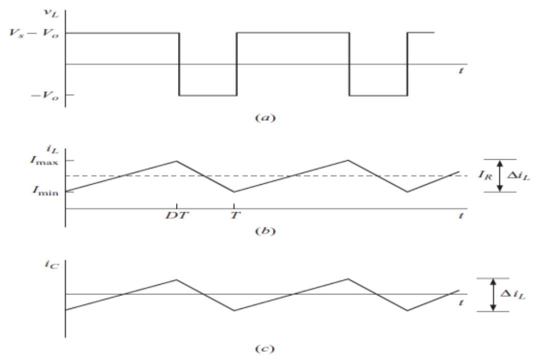

Fig. 2. Buck Converter Waveforms: (a) Inductor Voltage (b) Inductor Current, (c) Capacitor Current

Hence the continuous inductor is

$$L = \frac{V_s - V_o}{\Delta i_L f} D = \frac{V_o \ (1-D)}{\Delta i_L f} \quad ....(2)$$

The required capacitance in terms of specified voltage ripple:

$$C = \frac{(1-D)}{8\left(\frac{\Delta V_o}{V_o}\right) L f^2} \quad ....(3)$$

Input voltage(Vin) : 30V
Output voltage(Vout) :12V
Frequency(f) :20KHz
Load resistance(R) : 20Ω
Ripple voltage(ΔV_o) : should not exceed 5% i.e 0.05V
D=0.4
Inductor current is assumed to be continuous for entire time when switch is opened.
L_{min}= 0.26mH
L=1.25*L_{min}
L=0.337mH
C = 111µF. Hence the next standard value 120µF is taken.

B. Inductance Variations For Output Voltage When Mosfet As A Switch

The designed value of inductor is L=0.337mH, and it is taken as L_2

- $L_0 = L_2/4$ = 0.0842mH
- $L_1 = L_2/2$ =0.1685mH
- L_2=0.337mH
- $L_3 = 2L_2$ =0.674mH
- $L_4 = 3 L_2$ =1.011mH

As the inductance value increases, the overshoot(transient state) decreases, steady state ripple decreases, transient loss in the output voltage decreases and the total ripple in the output voltage decreases.

C. Capacitance Variations For Output Voltage When Mosfet As A Switch

The designed capacitance value is 111.11 µF, and it is taken as C_2

- $C_0 = C_2/4$=27.77 µF
- $C_1 = C_2/2$=55.55 µF
- C_2=111.11 µF
- $C_3 = 2 C_2$=222.22 µF
- $C_4 = 3C_2$=333.33 µF

As the capacitance value increases, the overshoot(transient state) increases, steady state ripple decreases, the transient loss in the output voltage increases and the total ripple in the output voltage decreases.

D. Buck-Boost Converter

A non isolated (transformer less) topology of the buck-boost converter is shown in Fig.3. The converter consists of dc input voltage source V_S, controlled switch S, inductor L, diode D, filter capacitor C, and load resistance R. when the switch is on, the inductor current increases while the diode acts as a reverse biased. When the switch is turned off, the diode provides a path for the inductor current. In the buck-boost converter the output voltage can be either higher or lower than the input voltage. The output voltage of the buck-boost converter is

$$V_s = -V_o \left(\frac{D}{1-D}\right) \quad ....(4)$$

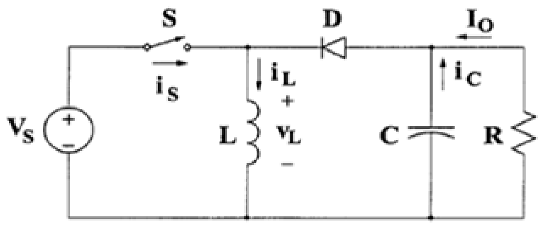

Fig. 3. Circuit Diagram

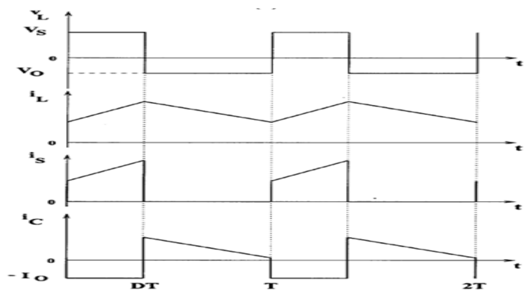

Fig. 4. Waveforms

Equation (4) shows that the output voltage has opposite polarity from the source voltage. Output voltage magnitude of the buck-boost converter can be less than that of the source or greater than the source, depending on the duty ratio of the switch. If D □ 0.5, the output voltage is larger than the input;

and if D □ 0.5, the output is smaller than the input. Therefore, this circuit combines the capabilities of the buck and boost converters.

The value of the inductor that determines the boundary between the CCM and DCM is

$$L = \frac{R\,(1-D)^2}{2f} \quad ……(5)$$

The capacitor must provide the output dc current to the load when the diode D is off. The minimum value of the capacitance that results in the voltage ripple Vr is given by

$$C = \frac{D\,V_o}{V_r\ \ Rf} \quad ………….(6)$$

Assume V_r / V_o = 1%
Input voltage(Vs) : 30V
Frequency(f) :20KHz
Load resistance(R) : 20Ω
Duty ratio D=0.13 for buck and 0.6 for boost
Then L = 0.08mH
C= 166µF. Hence the next standard value 220 µF is used.
By using above data's the simulation is done by using P-Spice software.

III. SIMULATION RESULTS

A. Buck Converter

a) When MOSFET As A Switch

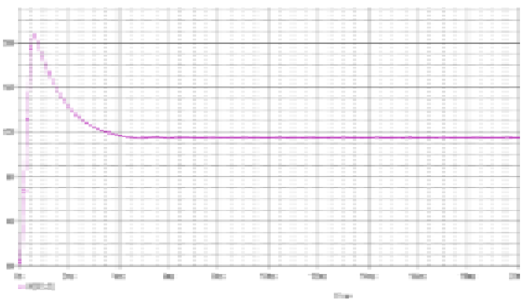

Fig.5. Output Voltage

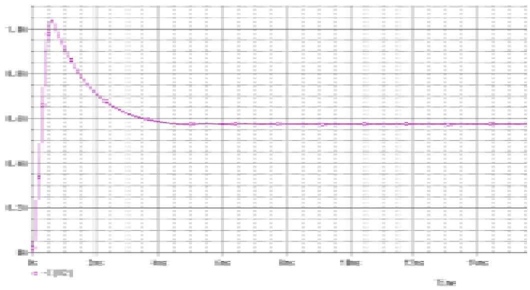

Fig.6. Output Current

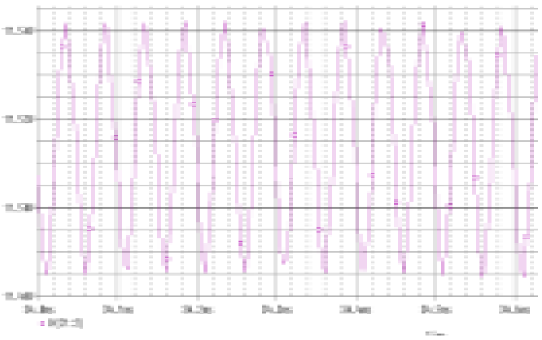

Fig. 7. Capacitor Voltage

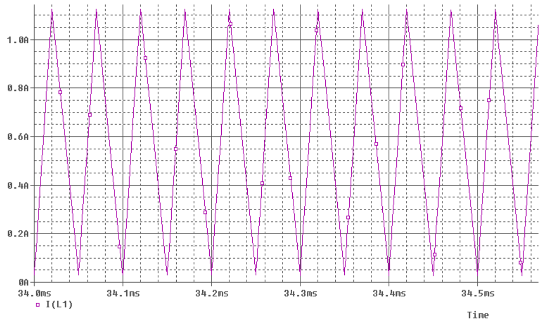

Fig. 8. Inductor Current

b) When IGBT As A Switch

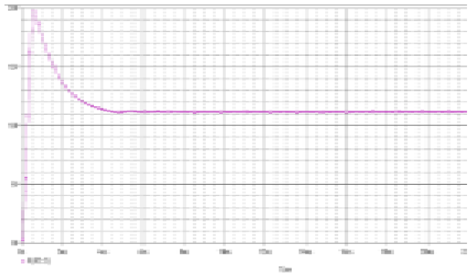

Fig. 9. Output Voltage

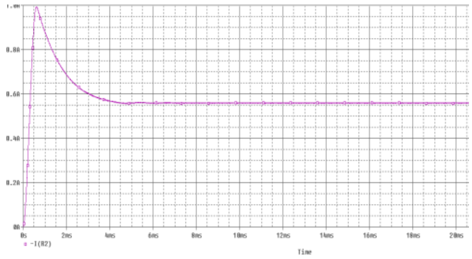

Fig. 10. Output Current

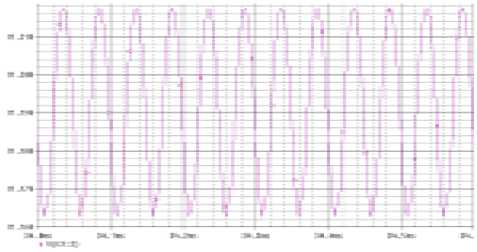

Fig. 11. Capacitor Voltage

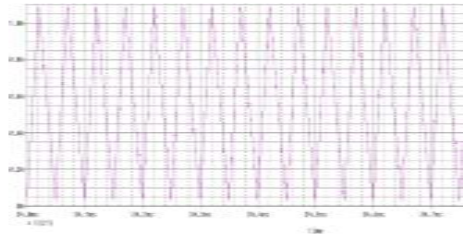

Fig. 12. Inductor Current

B)Buck-Boost Converter

a) When MOSFET AS A Switch

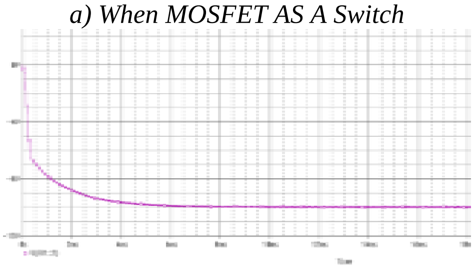

Fig. 13. Output Voltage

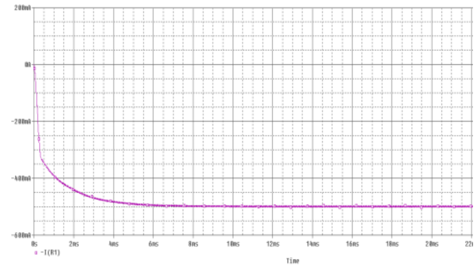

Fig. 14. Output Current

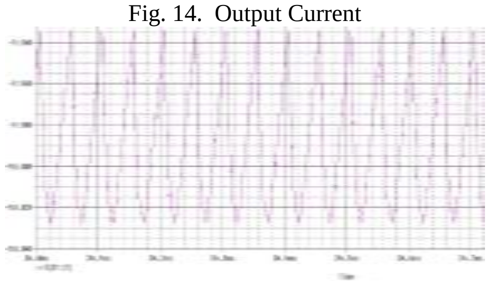

Fig. 15. Capacitor Voltage

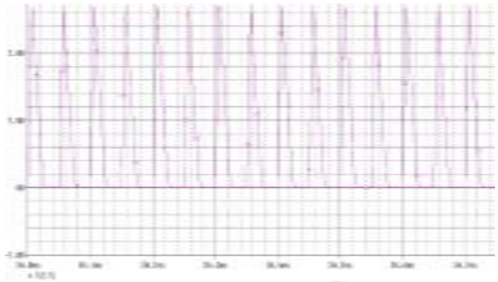

Fig. 16. Inductor Current

b) When IGBT AS A Switch

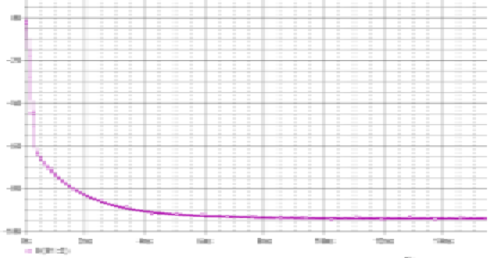

Fig. 17. Output Voltage

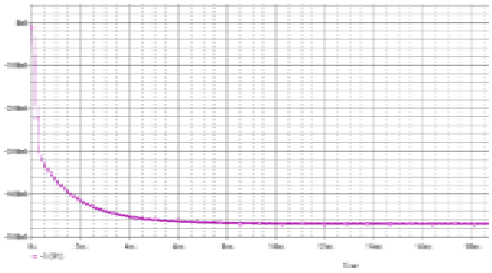

Fig. 18. Output Current

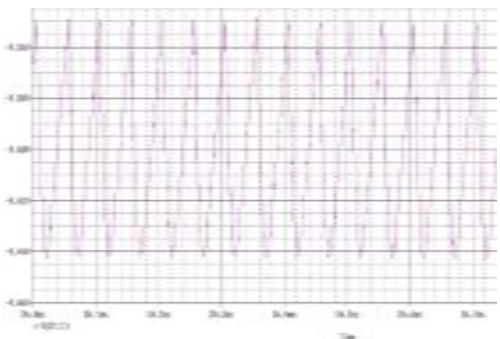

Fig. 19. Capacitor Voltage

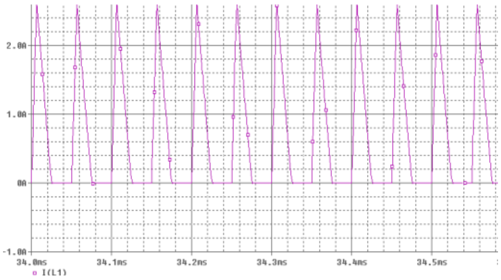

Fig. 20. Inductor Current

IV. HARDWARE RESULTS

A) Buck Converter

a) MOSFET AS A Switch

Fig. 21. MOSFET as a Switch

b) IGBT AS A Switch

Fig. 22. IGBT as a Switch

B) Buck-Boost Converter

a) MOSFET AS A Switch

Fig. 23. Acts as a Buck

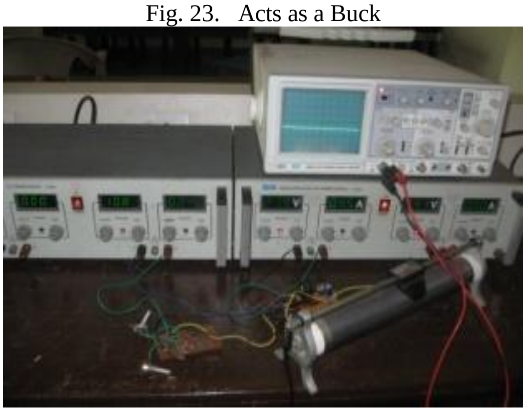

Fig. 24. Acts as a Boost

V RESULTS AND DISCUSSIONS

A) Buck Converter

a) Inductance Variation

Table 1. Inductance Variation when MOSFET as a Switch

Inductance value in mH	Output voltage in volts	Steady state ripple in volts	Overshoot in volts
L_0= 0.0842	18.15	0.168	20.94
L_1=0.168	14.57	0.156	20.85
L_2=0.337	11.53	0.103	20.83
L_3=0.674	11.50	0.055	20.80
L_4=1.011	11.47	0.018	20.21

Table II. Inductance Variation when IGBT as a Switch

Inductance value in mH	Output voltage in volts	Steady state ripple in volts	Overshoot in volts
L_0= 0.0842	17.80	0.168	19.84
L_1=0.168	14.22	0.103	19.80
L_2=0.337	11.24	0.052	19.66
L_3=0.674	11.22	0.027	19.56
L_4=1.011	11.18	0.018	19.42

b) Capacitance Variation

Table III. Capacitance Variation when MOSFET as a Switch

Capacitance value in µF	Output voltage in volts	Steady state ripple in volts	Overshoot in volts
C_0=27.77	11.58	0.241	20.07
C_1=55.55	11.56	0.108	20.50
C_2=111.11	11.54	0.058	20.82
C_3=222.22	11.54	0.029	20.87
C_4=333.33	11.54	0.019	20.90

Table IV. Capacitance Variation when IGBT as a Switch

Capacitance value in µF	Output voltage in volts	Steady state ripple in volts	Overshoot in volts
C_0=27.77	11.26	0.238	19.31
C_1=55.55	11.20	0.117	19.65
C_2=111.11	11.18	0.054	19.77
C_3=222.22	11.18	0.03	19.83
C_4=333.33	11.18	0.019	19.88

Table V. Comparison of Switches in Buck Converter

Switches	Output voltage in volts	Output current in Amps	Capacitor voltage in volts
MOSFET	11.54	0.057	V_{max}=11.53 V_{min}=11.48
IGBT	11.18	0.034	V_{max}=11.21 V_{min}=11.16

Table VI. Comparison of Switches in Buck-Boost Converter

Switches	Output voltage in volts	Output current in Amps	Capacitor voltage in volts
MOSFET	-10	-0.48	V_{max}=11.53 V_{min}=11.48
IGBT	-9.44	-0.47	V_{max}=-9.44 V_{min}=-9.35

As the inductance value increases the overshoot of the output voltage becomes decreases and the transient state ripple will be decreased. Similarly when the capacitor value increases the overshoot becomes increases and hence the transient loss will be increased. As the input voltage increases the transient loss as well as steady state ripple will be increased. Here for the same duty ratio, for same load and same design the overshoot for MOSFET is 20.78V and for IGBT 19.86V, hence in transient state the IGBT is the best switch. Similarly for buck-boost converter.

VI. CONCLUSION

In this proposed method the comparison of two switches in dc-dc Converters are taken, which are MOSFET,IGBT and is simulated in P-Spice software using Cadence tool, and then implemented using hardware components. Outputs parameters are output voltage, output current, capacitor voltage, inductor current respectively.

Analysis of open loop circuit is done using P-Spice software using Cadence tool. Simulation output is presented. Open loop circuit is rigged up and variation of output voltages with respect to variation in the inductance value, capacitance value and input voltage is observed. As the inductance value increases the overshoot of the output voltage becomes decreases and the transient state ripple will be decreased. Similarly when the capacitor value increases the overshoot becomes increases and hence the transient loss will be increased. As the input voltage increases the transient loss as well as steady state ripple will be increased. Here for the same duty ratio, for same load and same design the overshoot for MOSFET is 20.78V and for IGBT 19.86V hence in transient state the IGBT is the best switch. Similarly for buck-boost converter also.

Proposed method has greater efficiency, Smaller size , Lighter weight, Lower heat generation due to higher efficiency and it has ideal storage elements like like inductors, capacitors. As a further improvement for this circuit, closed loop implementation can be done. This can be done by using DSP interfacing. It can also be done by using PIC microcontroller. PWM chip can be used for this purpose. DC-DC Buck converter is used in real time AC-DC drives.

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