International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Comparative Analysis of Switching Characteristics of Non-Isolated converters using MOSFET and IGBT

Subhashree R[1], Lavanya M.C[2], Kanthalakshmi S[3], Boopathi k[4]

[1,3]*Department of Electrical Engineering, PSG College of technology, Coimbatore, Tamilnadu, India*
[2,4]*Research & Development (R&D), National Institute of Wind Energy, Chennai, Tamilnadu, India*

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Abstract - *This paper presents the design and implementation of DC-DC converter and compares their performance with their switching characteristics. The transistors such as Metal Oxide Semiconductor Field Effect Transistors (MOSFET) and Insulated Gate Bipolar Transistors (IGBT) acts as a switching devices and are used to switch the input signal to its output depending on the signal given to the gate. The switching speed depends on the duty-cycle, which determines efficient performance of converters. The DC-DC converter converts the source of direct current (DC) from one voltage level to other. The voltage, current and power at the output of those converters is measured and gives inference of which device favors low voltage, high voltage, low current, high current, low switching frequency and high switching frequency. The performance varies from application to application. The speed, size, cost also determines the performance of the circuitry. There are no universal standards to find out which device gives better performance in power supply applications like SMPS. This paper gives detailed analysis of switching characteristics of DC-DC converters and MATLAB/SIMULINK is used as a simulation platform for the analysis.*

Keywords: MOSFET, IGBT, Switching frequency, DC- DC converter, SMPS

1. INTRODUCTION

Nowadays, transistors play an important role in many switching operations. Mainly it is applicable in most of the applications such as controlling of DC motor, relay operations etc. Isolated converters such as Forward or fly-back transformer type converter does not have an electrical connection but it has a transformer providing barrier between input and output, whereas DC-DC converters are Non-isolated converters having an electrical connection between input and output. DC-DC converters are used to step up or step down the input voltage. The voltage can be adjusted based on the application which depends on the switching speed of the transistors. The switching speed is determined by the transistors ON and OFF state. The transistor in the converters is controlled by tuning the duty cycle of the device. It varies for different converters. This paper gives the detailed understanding of modeling of boost, buck and buck-boost converter, its operation, its switching speed and the efficiency it gives. Boost converter acts as a step-up converter. It helps in boosting the input voltage depending on the output load it is connected. The boosting of the voltage depends on the switching frequency of the transistor. When the switching speed increases, voltage gets fast delivered from input to the load. The switching speed is based on the duty cycle of the PWM generator which is given as a input to the gate which can be tuned manually or by tuning the duty cycle by implementing some algorithm such as P&O (Perturb & Observe), ABC (Artificial Bee Colony algorithm), CSA (Crow Search Optimization Algorithm)[1], etc. Buck converter is similar as step-down converter which lowers down the input voltage given depending on the load[2].

For example, if the input voltage given is 30V; if the duty cycle of the converter is 0.5 (50%), then the output voltage is 15V; Depending on the duty cycle the output gets varies. It is same for boost converter (i.e.) if the input given to the boost converter is 30V; it steps up the voltage and gives it as a 60V. Buck-boost converter is one which gives the output exactly same as an input. Because the first part of converter is a buck converter and the second part is the boost converter. If the input of the buck-boost converter is 30V, then it gives the output which is approximately equal to 30V. The comparison of the above converters, its modeling, its operation and the output while using switching devices such as MOSFET and IGBT is presented in this paper.

2. COMPARISON OF IGBT AND MOSFET

While considering most of the semiconductor devices, Power MOSFET is the one which is comparable with IGBT, because it is designed to handle power levels significantly. Even though the Power MOSFET and IGBT have the similarities in terms of its efficient power handling capacity, Power MOSFET has an advantage of high speed of computation and it has greater efficiency over IGBT when it is running at a lower voltage level. The blocking voltage and the current of Power MOSFET are high, but in case of IGBT it may be low due to the minimal inductive load.

At forward conduction current density, IGBT operates 5 times higher than power it has been shown that the IGBT operates at a forward conduction current density 20 times that of an equivalent MOSFET and 5 times higher than that of the power bipolar transistor. It has a vertical structure that both gate and the drain are at the opposite of the chip. It is the combination of MOSFET and bipolar technology that can be used for high power applications. The voltage rating depends on the doping and thickness of epitaxial layer and the current rating depends on the channel width (channel width increases its current increases). The efficiency of the power MOSFET is more; hence they are used in low voltage motor controllers, Power supplies and DC-DC converter.

Table 1. Comparision of MOSFET and IGBT

Device characteristics	MOSFET	IGBT
Input impedance	High	High
Output impedance	Medium	Low
Switching speed	Fast (ns)	Medium
Rating (Voltage)	High (<1KW)	Very high (>1KW)
Rating (current)	High (>500)	High (>500)
Cost	Medium	Low

3. BOOST CONVERTER

Boost converter is a DC-DC converter with constant output voltage. If there occurs any fluctuation or variations in the input, boost converter has the ability to step up the voltage which is given as an input using feedback technique. The output voltage (V) of the converter is measured and it is compared with the reference voltage (V_{ref}). The pulse width modulation (PWM) signal is produced in order to control the switch in the converter by finding the difference in the compared value. It is used to "step-up" an input voltage to higher level which is needed for the load[6].

The principle of boost converter is to resist the current changes, by creating and to destroy the magnetic field depending on the tendency of an inductor. The output voltage is always higher than the input voltage depending on the gain of the converter. Depending on the switch condition the operation of the boost converter is determined.

3.1 Operation of boost converter:

The boost converter contains both active and passive components such as inductor, capacitor, and transistors etc. The converters are used for reliability purpose[7]. The operation of the boost converter is mainly determined by the switch condition. The boost converter produces the output based on the switch opening and closing. The circuit of boost converter with switch open and close is shown in the Fig.3.

a) When the switch gets closed, current (I) flows through the inductor in clockwise direction and by generating magnetic field; the inductor stores some amount of energy. Since the polarity of left side of inductor is positive.

b) When the switch gets opened, current (I) will reduce because of the high impedance value. The previously created magnetic field gets destroyed in order to maintain the current towards load. Thus, the polarity of the inductor will be negative (i.e. the polarity gets reversed). As a result, two sources will be in series thus causing the higher voltage. This higher voltage is to charge the capacitor by using diode (D). The parameters used to calculate power stage in boost converter are Input voltage, Nominal output voltage, Max output current, Integrated circuit used to build the converter[8].

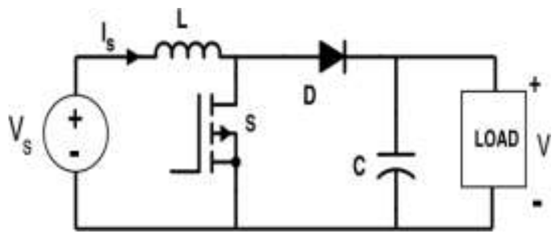


Figure 3 - Equivalent circuit of boost converter

The efficient output is obtained by switching off and on of the switch in the circuit. The operations can be achieved by using transistors such as MOSFET, IGBT etc as a switch. The cycling of switch determines the efficient output. If the cycling speed of the switch gets increased, the inductor will not completely discharge between the charging stages. The load connected to output side will always have the voltage greater than the input voltage when the switch gets opened. At that time, when the switch opens the capacitor which is connected in parallel with the load is charged to this combined voltage. When the switch gets closed and the input side is shorted out from the output side, the capacitor can provide the voltage and energy to the load. During this time, the diode prevents the capacitor from discharging through switch. Hence, to prevent too much of discharge from the capacitor the switch must be opened fast again and again.

Fig.3. gives the operation of the boost converter and the current flows through the circuit when the switch is open. I_S Is the current moving into the inductor (L). I_L, I_D are the current flows through load, diode respectively. V , are the input, output voltage respectively.

Table 2. Specifications to be considered for designing boost converter

S.NO.	PARAMETER	NOTATION	VALUE
1	Input Voltage	Vin	15V
2	Output Voltage	Vo	30V
3	Output Capacitance	C	70µF
4	Inductance	L	360µH
5	Load Resistance	R_L	25Ω
6	Nominal duty ratio	D	0.5

The values of proposed Boost converter is given by calculating the values of capacitor, inductor and duty ratio

The capacitor value can be given by,

$$C = \frac{I_{out} * D}{f * \Delta V_{out}} \quad \text{............. (1)}$$

The value of an inductor can be given by,

$$L = \frac{V_{source} * (V_{out} - V_{source})}{\Delta I_{load} * f * V_{out}} \quad \text{............. (2)}$$

The duty ratio is defined by.

$$D = 1 - \frac{V_{source}}{V_{out}} \quad \text{............. (3)}$$

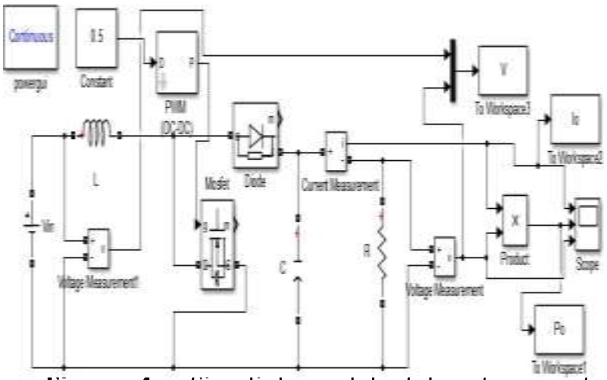
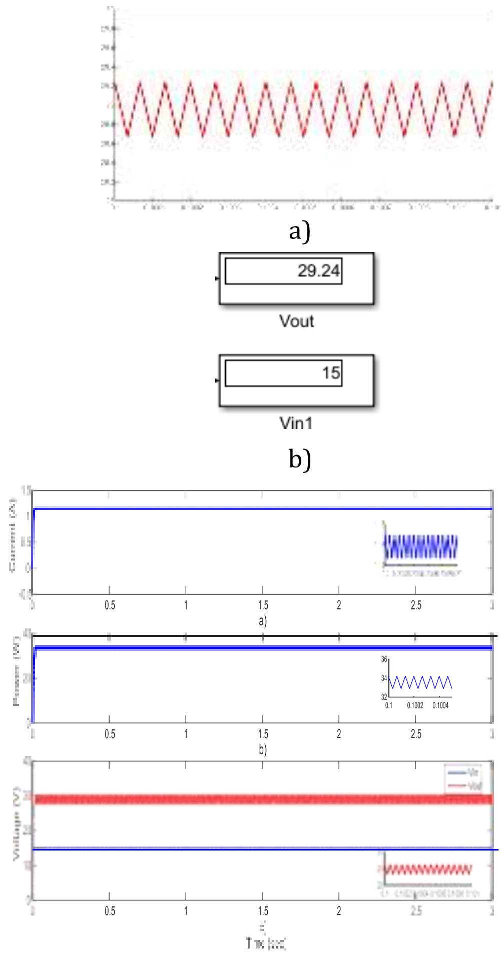


Figure 4 - Simulink model of boost converter

Fig.4 shows the simulink model of boost converter using MOSFET. Voltage measurement block is connected in the input and the output side of the converter in order to measure the input and output voltage. PWM generator is connected to the gate of the MOSFET to operate the transistor.



c)

Figure 5 - a) Variations in V_ob) Output of boost converter using MOSFET c) Display of boost converter

The output such as Voltage, Current and the Power of the boost converter using MOSFET is shown in the Fig.5 a). The deviation in the output voltage is shown in b) which is around 0.9 while using MOSFET.

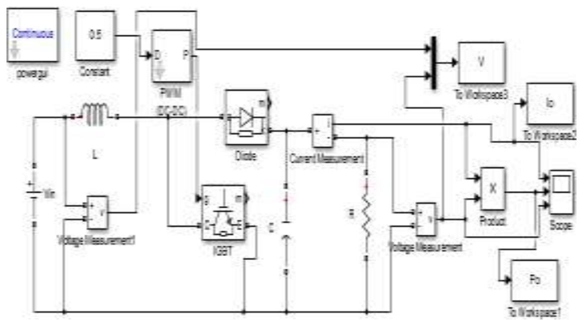
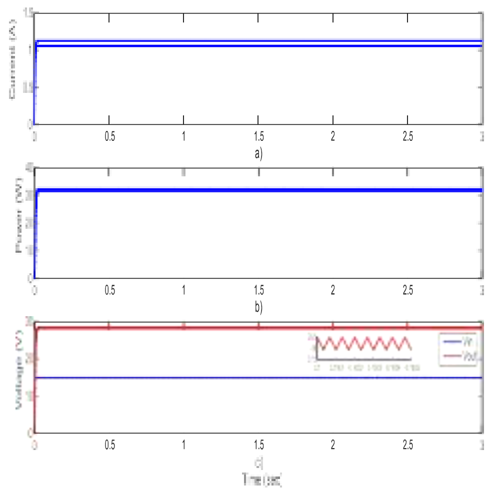
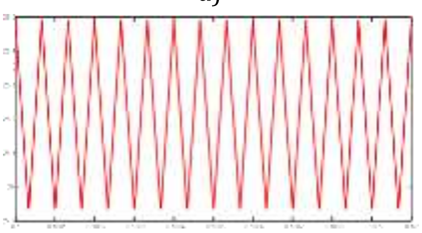


Figure 6 - Simulation of boost converter using IGBT

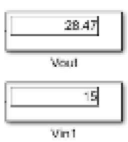
Fig.6 depicts the simulation of boost converter using IGBT and current and voltage measurements gives the voltage and current and the switching device used here is IGBT which operates by triggering the gate using PWM generator which depends on the duty cycle[9].



a)



b)



c)

Figure 7 - a) Output of boost converter using IGBT b) Deviations in output voltage (*V*) c) Display of boost converter using IGBT

Fig.7 is the output of boost converter using IGBT. From Fig.5 & Fig.7 it is observed that MOSFET used boost converter gives an efficient output of increasing the input voltage (i.e. boosting the input voltage depending on the duty cycle of the converter) than IGBT used converter.

5. BUCK CONVERTER

A buck converter is a kind of DC-DC converter which is also known as a step down converter. This converter step downs the voltage from input supply to the output load while the current is stepped up. Earlier this converter contains at least two conductors such as diodes and transistors [6]. It is a class of SMPS (Switched Mode Power Supply) switch. The modernized version replaces the diodes with another transistor for synchronous rectification. There is a need for energy storage element in every circuitry such as diode and inductors. In this converter both the storage elements are used in combination. In buck converter, discontinuous mode operation results in a higher than expected output voltage for a given duty cycle. Filters made of capacitors are added to the output and to the input of the converter; sometimes it may be used along with inductor in order to reduce the voltage ripple.

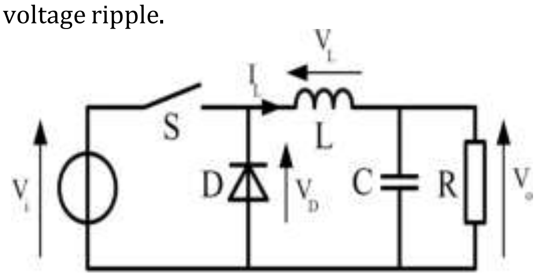


Figure 8 - Equivalent ciruit & Operation of buck converter

It gives a more efficient output power than the linear regulators, which are simpler circuits that lower the voltage by dissipating power as heat, but do not step up output current. The inductor connected to the circuit of the buck converter has the current flow which is controlled by using two switches (Transistor, Diode)[10]. In the ideal buck converter, when both the switch and the diode is ON it has zero voltage drop and when it is OFF no current flows through the circuit and inductor has zero resistance. The simulink model of a buck converter is shown in the fig.9. the buck converter gives the ouput which is reduced with respect to input depending on the duty cycle[9]. To design the buck converter the following specification are to be considered[11].

The value of the capacitors is given by[12],

$$C = \frac{\Delta I_{load}}{8 * f_s * \Delta V_{output}} \qquad \text{.................(1)}$$

The inductor value is given by,

$$L = \frac{V_{output} * (V_{input} - V_{output})}{\Delta I_l * f_s * V_{in}} \qquad \text{.................(2)}$$

The duty cycle is defined by,

$$D = \frac{V_{output}}{V_{input}} * \eta \qquad \text{.................(3)}$$

Table 3. Specifications to be considered for designing buck converter

S.NO.	PARAMETER	NOTATION	VALUE
1	Input Voltage	Vin	30V
2	Output Voltage	Vo	15V
3	Output Capacitance	C	130µF
4	Inductance	L	50Mh
5	Load Resistance	R_L	0.5Ω
6	Nominal duty ratio	D	0.5

The simulink model of the Buck converter using MOSFET is shown in the Fig.9. The purpose of this converter is to reduce the input voltage given to it.

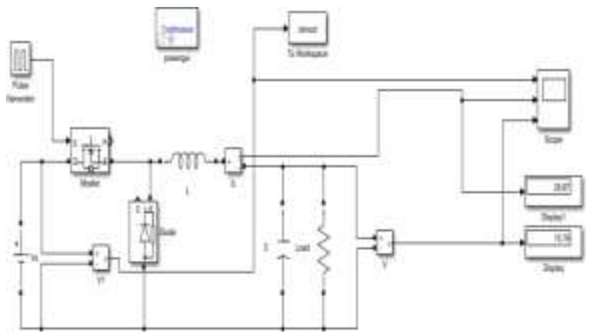
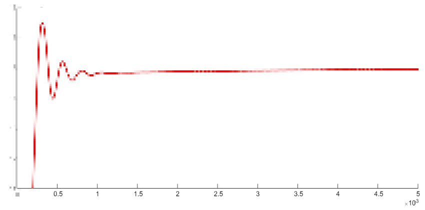


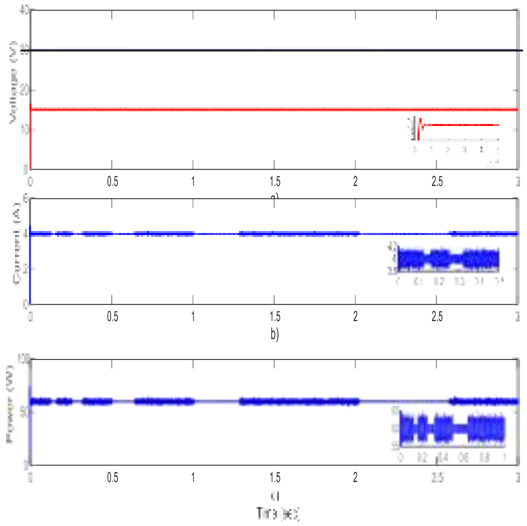
Figure 9 - Simulink model of buck converter using MOSFET

The output of the buck converter gives an efficient output i.e the input to the buck converter is 30V which gives the output voltage half as its input.

While using MOSFET there occurs some deviations that can be represented in Fig.10.



a)



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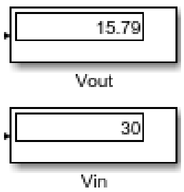
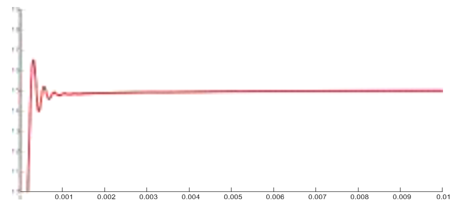


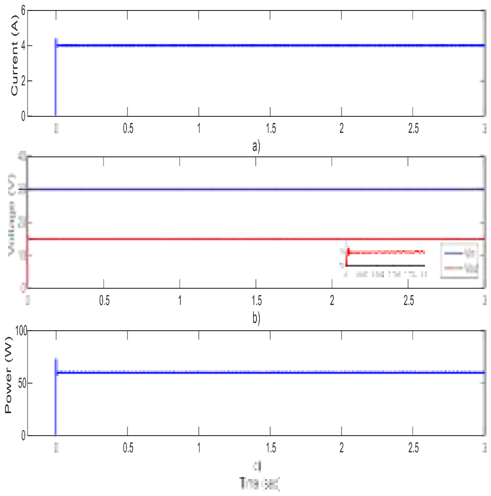
c)

Figure 10 - a) Output of buck converter using MOSFET b) Variation in output voltage c) display of buck converter output



a)

Buck converter gives the output as 17.67V when 30V input is given. The output is shown in the Fig.11.



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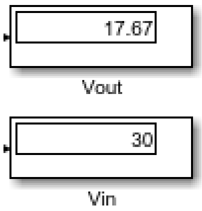


c)

Figure 11 - a) Variation in the output voltage b) Output c) display of buck converter using IGBT

MOSFET gives better efficient output than output produced by converter while using IGBT

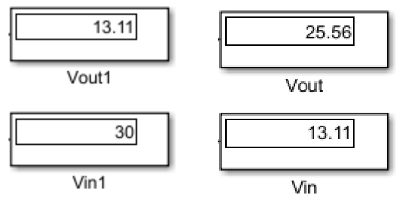
6. BUCK-BOOST CONVERTER

Buck-boost converter is developed with two topologies. One that produces a output voltage with a range much higher than the input voltage, goes almost to zero. The output voltage can be adjustable with the help of duty cycle of the transistor. It also used in sepic converter with different topologies depends on the usage of multiple inductors[13]

This converter does not have terminal at its ground which makes the circuit more complicate. If the polarity of the power supply and diode are reversed, the power supply gets isolated from the load. Hence, the circuit does not produce any output. When it is in reverse biased condition, the switch such as MOSFET or IGBT can be either in supply side or in ground side[14]. These occur when the input and the output are of different polarity which acts in an inverting mode. When both are in same polarity it is in non-inverting mode of operation. In such a condition, switches are used instead of diode, the single inductor itself acts in both buck mode or in boost mode[15].

Fig.12 depicts the simulink model of Buck-Boost converter using MOSFET. The MOSFET itself acts as a switching device for both buck and boost stages. Both devices having the duty ratio of 50%.

The input buck converter is 30V and the output taken from buck converter is 25.56V. The output of buck converter is given to the boost converter which is connected in series with the buck converter. Hence, the Buck-boost circuit gives the output same as that of input. The output of the circuit is 28.61 which are approximately equals to the desired input while using MOSFET as a switching device.



a) b)

Figure 13 - Display of a) buck b) boost stage while using MOSFET

The display of buck stage and Boost stage of Buck-Boost converter can be shown in the Fig.13. The output voltage, Power and the current can be displayed is shown in the Fig.14.

The buck converter and the boost converter individually show the output which is efficient while using MOSFET than IGBT. But when both the buck converter and boost converter connected in series, which is said to be Buck-Boost converter which gives an efficient output[16] while using MOSFET and also it gives the maximum power which is necessary for many renewable applications such as solar power calculation, solar forecasting [17][18]etc. The topology for buck-boost converter is same, but the only change to it is instead of MOSFET, IGBT is replaced. Fig.15 depicts the buck-boost converter's output using IGBT which gives voltage output efficiently but the power becomes low which is not applicable for applications such as solar etc.

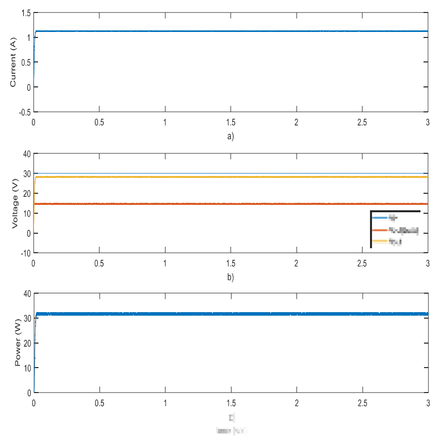


Figure 14 - Output of Buck-boost converter using MOSFET

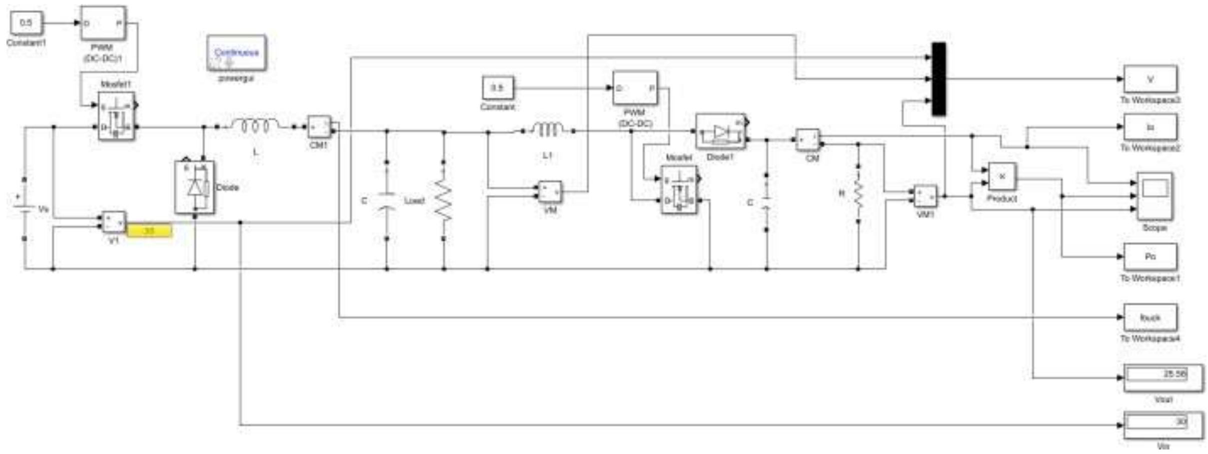


Figure 12 - Simulink model of buck-boost converter using MOSFET

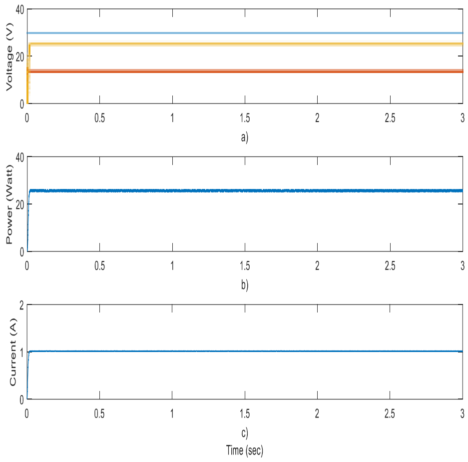
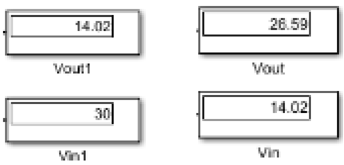


Figure 15 - Output of Buck-boost converter using IGBT



a) b)

Figure 16 - Display of a) buck b) boost converter using IGBT

Hence, the output gives the clear understanding of converters using both MOSFET &IGBT. This gives an understanding of usage of switching devices in converters that are used in commercial as well as industrial purpose[5]. They can be used in various applications in renewable energy source such as Solar PV system[20], MPPT optimization by different algorithms[21][22], in the automotive fields such as hybrid vehicles. The optimization is achieved by tuning the duty cycle of the converter. The optimization algorithms such as Perturb & Observe[9], Artificial Bee Colony[13], incremental conductance[23] etc.

7. INFERENCES

It is inferred that the output of such converters not only depends on switching devices but also on the passive components such as resistors, inductors, capacitors etc. MOSFET favors low voltage, low current and high switching frequency while IGBT favors high voltage, high current and low switching frequency.

8. TECHNOLOGY IMPROVEMENT

In the race to get more efficient electric devices, designing of Power electronic converters play an important role. At present Silicon Carbide (Si-C) becomes an emerging technology while manufacturing the power electronic components. Silicon power/switching devices such as Si-MOSFET and Si-IGBT are widely used in converters, but it has limitations of low switching frequency, minimum band-gap energy and minimal thermal conductivity. The devices such as Silicon Carbide (SiC) and Gallium Nitride (GaN) enables large thermal conductivity and high breakdown voltage thereby providing larger band-gap. This Silicon Carbide device replaces Silicon devices in high switching frequency, high voltage and high temperature.

9. CONCLUSIONS

The mathematical modeling, analysis, comparison of boost converter, buck converter and buck-boost converter using both MOSFET and IGBT has been presented. From the results taken from the converter it is shown that MOSFET gives an efficient output than IGBT with the same specification defined. IGBT is more resistive to electrostatic Discharge (ESD) [19], hence it is preferred in industries. The alternative is Silicon Carbide Power MOSFET handles the Power at High levels; switching speed is more when compared to MOSFET. Hence, for industrial applications instead of using Silicon

MOSFET and IGBT; Silicon Carbide Power MOSFET's are recommended to use because of its efficient output, switching speed and it is susceptible to handle high Power applications.

ACKNOWLEDGEMENT

The authors would like to acknowledge Dr. K. Balaraman, Director General and Mr. K. Boopathi, Director & Division Head, NIWE, PSG College of technology, Coimbatore for giving great support for doing this survey work.

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