POWER LOSS CALCULATION FOR IGBT and SiC MOSFET

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Abstract- : The efficiency of any system is mainly depended on power loss incurred in the devices used in it. In power converter circuits the main contribution for power loss is by the power switches used for converting signal. In this paper an attempt is made to describe the method available to find the power losses in converter circuit due to IGBT and SiC MOSFET. It is observed in the literature that the conduction losses for IGBT is lesser than MOSFET with same voltage and current rating whereas the switching losses are greater in IGBT compared to MOSFET. The calculations performed in the paper shows that SiC MOSFET supersedes the performance of IGBT and MOSFET and hence best suitable for high power and high switching frequency application.

Keywords – Power switch, Power loss, Conduction loss, Switching loss.

I. Introduction

Converters are the circuits used to convert one form of power into another form. The main converters used in power industries are DC-DC converter, DC-AC converters known as inverters, AC – DC Converters known as rectifiers and AC-AC converters. Fig 1. Shows a typical converter circuit. It contains mainly two parts. One switching converter and the other part is switching signal generator. Switching converters are generally made up of power switches connected in Half Bridge or Full Bridge form. These switches are controlled by a switching sequence generated in switching signal generator circuit. Hence, a power converter system has an input signal which can be either DC or AC depending on the application and switching signal used to control the power switches. The power switches that are popularly used in these power converter are IGBT and MOSFET. When we take simple bipolar junction transistor it is observed that the input impedance of BJT is not sufficient. The input impedance of the MOSFET is very high compared to BJT making it superior than BJT device. Whereas Insulated Gate Bipolar Transistor embeds the input characteristics of MOSFET as it is a gate driven device. But yet IGBT switching speed is less compared to MOSFET devices. But the main advantage of IGBT over MOSFET is its conduction loss. Hence both IGBT and MOSFET devices has created its own place in the power electronics domain. But in recent years SiC MOSFET has shown its performance that replaces IGBT and MOSFET. The SiC MOSFET drift resistance is 1/100th of its Si MOSFET equivalent [1]. In this paper calculation of conduction losses and switching losses for IGBT and SiC MOSFET is performed in a Full Bridge inverter application.

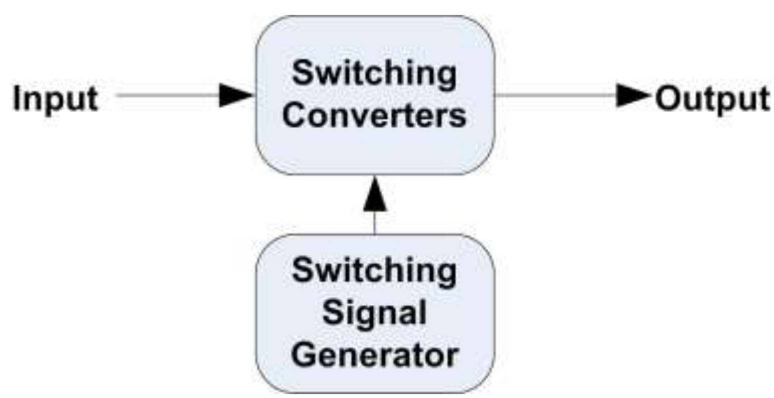

Fig.1: Power Converter

In the rest of the paper, Section II gives brief introduction of Full Bridge inverter. Section III Explores equations used to find the conduction mode losses of IGBT and SiC MOSFET. Section IV presents switching loss equations for IGBT and SiC MOSFET. Section V includes theoretical calculations of conduction losses and switching losses for an

IGBT and SiC MOSFET with same voltage and current rating. Section V presents a comparison of IGBT and SiC MOSFET along with concluding remarks.

II. Full bridge Inverter

Fig 2 shows a typical Full Bridge inverter circuit. It has two arms each includes two power switches [2]. The inverter circuit is controlled by pulse width modulated switching signal. This can be bipolar sine pulse width modulation, unipolar sine pulse width modulation or hybrid sine pulse width modulation. The efficiency of USPWM and HSPWM is greater than BSPWM. But the common mode characteristics of BSPWM is better compared to USPWM and HSPWM. The average power loss in the power switch usually includes conduction loss P_{cm}, blocking loss P_{bm} and switching loss components. Switching loss intern includes turn on loss P_{son} and turn off loss P_{soff}. Hence an expression for average total power loss in the switch is given by (1). Blocking mode losses of switches is less compared to conduction losses and switching losses, hence we neglect blocking losses in a switch.

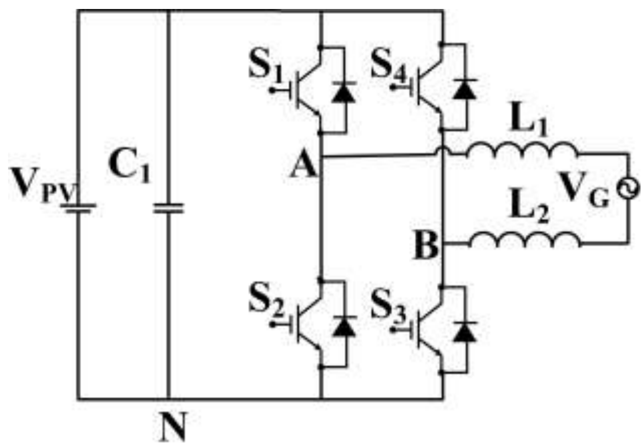

Fig. 2. Full Bridge Inverter

III. Conduction mode loss

The general expression for conduction loss in a switch is given by (2). Where V_o is zero current voltage drop of the switch and R_o is on state resistance of the switch. In the inverter, the power switch operates either at a low frequency or at a switching frequency of f_s. The duty cycle of the switch operating at a high frequency is expressed as in (3) and the low frequency as in (4). Average and rms value of current flowing through the switch is given by (5) (6) while the instantaneous current of the inverter is as in equation (7).

$$P_{avg} = P_{cm} + P_{bm} + P_{son} + P_{soff} \quad (1)$$

$$P_{cm} = (V_o I_{avg} + R_o I_{orms}^2) \quad (2)$$

$$dutycycle_{HF\_cm} = M \sin wt \quad (3)$$

$$dutycycle_{LF\_cm/bm} = (1 - M \sin wt) \quad (4)$$

$$I_{avg} = \frac{1}{2\pi} \int_0^{\pi} i(t)\, dutycycle\, dwt \quad (5)$$

$$I_{rms}^2 = \frac{1}{2\pi} \int_0^{\pi} i^2(t)\, dutycycle\, dwt \quad (6)$$

$$i(t) = I_m \sin wt \quad (7)$$

With all these basic equations the conduction losses for IGBT and MOSFET at low and high frequency can be found. For IGBT the on state resistance is denoted as R_{ce} and zero current voltage drop of the switch is mentioned as V_t. Hence for IGBT after simplifying the equation's the conduction loss at high frequency and low frequency is found to be as in equation (8) and (9) respectively. Where M is Modulation index of PWM signal.

$$P_{cmHFIGBT} = I_m V_t \frac{M}{4} + I_m^2 R_{ce} \frac{2M}{3\pi} \quad (8)$$

$$P_{cmLFIGBT} = I_m V_t \left(\frac{1}{\pi} - \frac{M}{4}\right) + I_m^2 R_{ce} \left(\frac{1}{4} - \frac{2M}{3\pi}\right) \quad (9)$$

Similarly for MOSFET the on state resistance is denoted as R_{ds}. While, zero current voltage drop is small. Hence, conduction mode loss equations for MOSFET at high and low frequency can be written as equation (10) and (11) respectively [3] [4].

$$P_{cmHFM} = I_m^2 R_{ds} \frac{2m}{3\pi} \quad (10)$$

$$P_{cmLFM} = I_m^2 R_{ds} \left\{\frac{1}{4} - \frac{2m}{3\pi}\right\} \quad (11)$$

IV. SWITCHING LOSSES

Switching losses of power switches depends on switching time and reverse recovery losses. There are few methods available to find the switching losses of power devices. While the simplest equation that can be used to find the power for comparing the switching losses of IGBT includes using energy loss during on state and off state directly from the device datasheet. The equations that can be used to find the switching losses during turn ON and turn Off of IGBT is given by equation (12) and (13) [5]. Where E_{on} is the total energy loss during switch on time, E_{off} is the total energy loss during switch off time and f_s is the switching frequency.

$$P_{Son} = E_{on} f_s \quad (12)$$

$$P_{Soff} = E_{off} f_s \quad (13)$$

In MOSFET also, the power loss can be found by using the equations, ie. (12) and (13). But in case of IGBT E_{on} and E_{off} is specified in the data sheet itself. Whereas for MOSFET it is required to find the energy loss by using other parameters given in datasheet. Hence, switch on and Switch off power loss for MOSFET is given by equation (14) and (18) respectively. The parameters in the equation are found by using equations (15), (16) and (17) for switch on and equation (19), (20) and (21) during switch off time. The detailed procedure for using these equations is given in [3]

$$P_{sonM} = V_{DD} f_s \left\{\frac{I_{don}(t_{don}+t_r)}{2} + q_{rr}\right\} \quad (14)$$

$$t_r = \frac{t_{fv1}+t_{fv2}}{2} \quad (15)$$

$$t_{fv1} = (V_{DD} - R_{DSon} I_{Don})\, R_G \,\frac{C_{GD1}}{V_{dr} - V_{platuae}} \quad (16)$$

$$t_{fv2} = (V_{DD} - R_{DSon} I_{Don})\, R_G \,\frac{C_{GD2}}{V_{dr} - V_{platuae}} \quad (17)$$

$$P_{soffM} = V_{DD} f_s \left\{ \frac{I_{doff}(t_{doff}+t_f)}{2} \right\} \quad (18)$$

$$t_f = \frac{t_{rv1}+t_{rv2}}{2} \quad (19)$$

$$t_{rv1} = (V_{PV} - R_{DSon} I_{Don})\, R_G \,\frac{C_{GD1}}{V_{platuae}} \quad (20)$$

$$t_{rv2} = (V_{PV} - R_{DSon} I_{Don})\, R_G \,\frac{C_{GD2}}{V_{platuae}} \quad (21)$$

V. CALCULATIONS OF CONDUCTION AND SWITCHING LOSSES FOR AN IGBT AND SIC MOSFET FROM DATASHEET

To calculate the total average power loss in IGBT and SiC MOSFET devices from the data sheet a typical power switches from Infineon [6] are used. Two range of switches are selected. In the first case the IGBT and SiC MOSFET with high rated voltage of 1200V with rated current of 26-30A is used. In the second case IGBT and SiC MOSFET of voltage rating 600V-650V with rated current 20A is selected. For an inverter assuming maximum current flow is equal to rated current of power switches all the calculations are performed. The conduction mode loss at high frequency and low frequency and switching loss in the IGBT and SiC MOSFET is calculated by using the above equations and listed in Table 1. For finding conduction mode loss of IGBT R_{ce} resistance has to be calculated from the output characteristics of IGBT. In this paper a typical characteristics with V_G = 17V is used to find R_{ce} value and the same is been mentioned in the table. For SiC MOSFET switching loss calculation, to get accurate results one can use all the equations mentioned and the procedure given in [4]. Now to find out typical power loss at rated voltage and current the values of various switching time parameters are directly taken from the device datasheet and equation (14) and (18) are used to find out the losses. Also, for SiC MOSFET the reverse recovery loss is negligible. So one can approximate qrr equal to zero while calculating turn ON loss.

Table 1. Typical Power loss in IGBT and SiC MOSFET [6]

Power Switch	**IGBT**		**SiC MOSFET**	
PART Number	IGW15N120H3	IKD10N60RF	IMZ120R090M1H	IMZA65R107M1H
Rated Maximum Voltage (V)	1200V	600V	1200V	650V
Rated Maximum Current (A)	7A	20A	26	20
Zero current voltage drop (V)	2.3	2.2	NA	NA
On state resistance (Ω)	1/18	1/11.5	0.09	0.107
T_{don} (ns)	-	-	5.4	6.6
Typical t_r (ns)	-	-	3	7.4
Typical t_{doff} (ns)	-	-	11.5	12.2
Typical t_f (ns)	-	-	11	6.4
I_{doff} (µA)	-	-	0.5	1
E_{on} (mJ)	1.1	0.19	-	-
E_{off} (mJ)	0.45	0.16	-	-
Conduction Loss (W) at high frequency	21.12	15	10	7.3
Conduction Loss (W) at low frequency	11	7.7	4	3.3
Switching Loss (W)	31	27	2.62	1.82

VI. CONCLUSION

This paper presented a simple method of calculating power losses in most popularly used power switches such as IGBT and SiC MOSFET. It is found in literature that the on state resistance of the IGBT is very less compared to MOSFET hence the IGBT conduction mode losses are comparatively less. At the same time energy loss during turn ON and turn OFF period of IGBT is more than MOSFET. These difference yields high switching loss in IGBT compared to MOSFET. Thus, one can conclude that, as conduction mode losses are less in IGBT, it can be used at low switching frequency and if the switch has to be operated at high frequency then it is beneficial to use MOSFET. In full bridge inverter, in the hybrid sine pulse width modulated switching technique two switches works at low frequency while the other two at switching frequency. Hence, one can use IGBT for the two switches operating at low frequency and to use MOSFET for the switches that are operating at high frequency. This will optimize the power losses in the Full Bridge inverter. But in SiC MOSFET as on state resistance is considerably reduced, it can be seen from Table 1 that the conduction loss of the SiC MOSFET is much lesser than IGBT of same ratings. And also the reverse recovery losses in the SiC MOSFET is negligible hence the overall Switching loss of SiC MOSFET is lesser than Si MOSFET. Thus SiC MOSFET is replacing IGBT and Si MOSFET in most of the power converter applications.

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