Components selection for frequency inverter to control high speed electrical machines

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Abstract

This paper presents an overview for many topics about high-speed electrical machines, new ways and many uses for these machines machines and theoretical study of their limits are presented.
The main goal from this paper was to determine what are the best components to build a frequency inverter that can be used to control the high-speed electrical machines(mainly from 0 up to 100v) in the best way with the lowest losses, The results of some experiments for testing the best components to build the frequency inverter are reported, the static losses for different kinds of transistors that can be used to design this inverter (SiC, IGBT) are also reported(Vin=5->100 V, I=0 ->20 A), the dynamic losses are also reported for these transistors (Vin=20->60 V, f=3->20 KHZ, I=0->6 A), and finally a new kind of these components is proposed to test and use for this inverter in the future work.

Keyword: high-speed electrical machines, frequency inverter, SiC, IGBT, power losses, static losses, dynamic losses.

1. Introduction

High-speed electrical machines have been developed and used for a long time, and now considered a mature and reliable technology for a number of engineering applications, Such applications include turbochargers, mechanical turbo-compounding systems, helicopter engines, racing engines. The research and development in high-speed electrical machinery has seen a rapid growth in the last few decades, with a considerable application uptake in the last decade. The development of the high-speed electrical machines showed significant impact in many application areas. This is also reflected by the large number of national and international funded research programs in this area [1].
To understand the meaning of High-Speed electrical machines, and to know which application they can be used for, what are their advantages and disadvantages and what are the speed for these machines (here it is focused mainly on the machines with the speed 20000->50000 r.p.m), many papers has to be presented:
"High speed PM machines: applications, trends and limits" [2], This paper gives an introduction to high-speed permanent magnet machines, it analyzes many applications of these machines, defines the attribute “high-speed” and presents a general theoretical study of speed limits of PM machines. This paper also clarifies speed, power and size of PM machines, an example of a high-speed machine can be seen in (figure1), with speed 40 000 RPM, torque 7 Nm.
"An SiC inverter for high-speed permanent magnet synchronous machine"[4], when dealing with high speed machines, current with higher frequency should be provided when comparing it to the normal electrical machines, It was needed to use frequency inverter, but IGBT based on the experiment showed much switching losses (especially turn-off loss) and less efficiency when compared to the SIC MOSFET in the field of the higher frequencies.
SIC inverter showed great results even up to 500KHZ switching frequency, and the target was only 100KHZ.
So it can be seen that in the high frequencies SiC transistors can be the best option because it has lower switching losses when compared to the other transistors technologies.
"Combined heat and power generator with high-speed permanent magnet synchronous machine"[5], This paper presents the description and the results during the development of a small combined heat and power unit, wich consists of a turbine and a high-speed permanent magnet synchronous machine, it also shows the main problems and issues that is needed to solve in this unit (The main problem of the unit is its mechanics).
In this work the main goal was to create an affordable power supply for combined electrical energy and heat production, it was possible to reduce the speed using some transmission but this decreases the efficiency and makes mechanical problems so the turbine was connected directly to the generator and use PMSM controlled with an inverter.

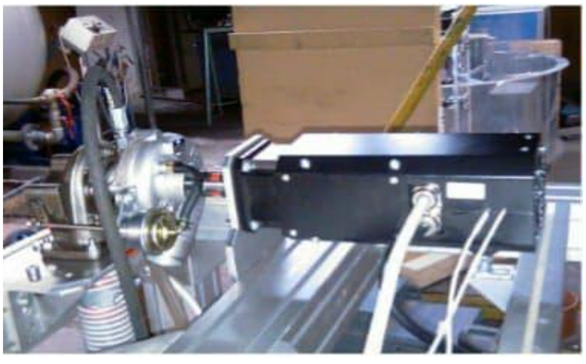

Figure 1. *high speed electrical machine [3]*

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2. Testing the power losses for SiC and IGBT transistors

creating a frequency inverter is a good method to control the high-speed electrical machines in the best way.
The goal was to make this inverter to control a high-speed machine (48V) mainly, and to do it with the lowest possible power losses in this inverter.
When planning to design a frequency inverter, for sure good components should be used, which gives the best results with the lowest power losses.
After searching and investigating about the most common transistors which are suitable to use for building frequency inverters, 3 different transistors were found, those transistors are separated into 3 different groups:

-IGBT transistors (insulated-gate bipolar transistor).
-SiC transistors (silicon carbide transistors).
-Gan transistors (Gallium nitride transistors).

It was intended to build a 48V inverter that can be used to control a high-speed electrical machine, and for this reason some experiments was done using the SiC and also IGBT transistors in the voltage range from 0 up to 100V.

2.1 The static losses for SiC and IGBT

The experiment for testing the static losses was done according to the schematic that shown in (figure 2), The applied voltages were (5->100)V .

Used Instruments:
-Transistor (SiC CCS050M12CM2, IGBT SKM75GD124D).
-Power supply (120V, 20A).
-Resistors-load (100 ohm).
-Voltmeter.
-Ammeter

The transistor Q1 is always off, so the current flows through Q2 only (figure 2).
The Static Losses for all the applied voltages were almost exactly the same for SiC, the same situation for IGBT also, and here are the results for the (40 and 60)V(figures 3-4) (since we are mainly interested in 48v):

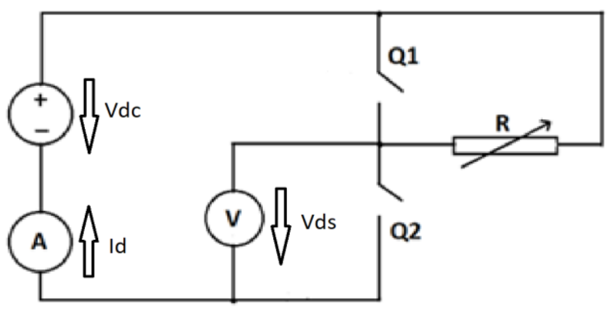

Figure 2. *static losses schematic*

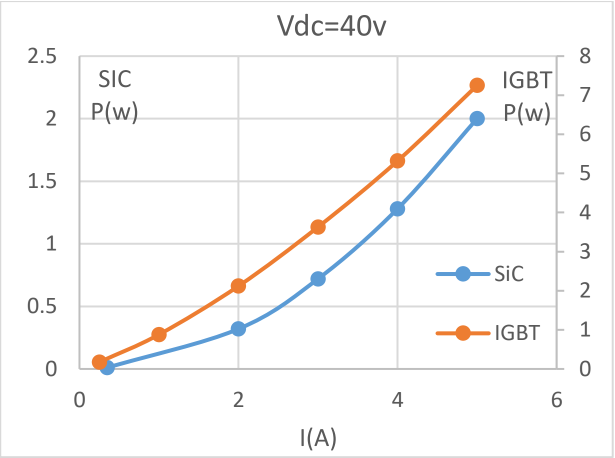

Figure 3. *static losses comparison between SiC and IGBT(Vin= 40V)*

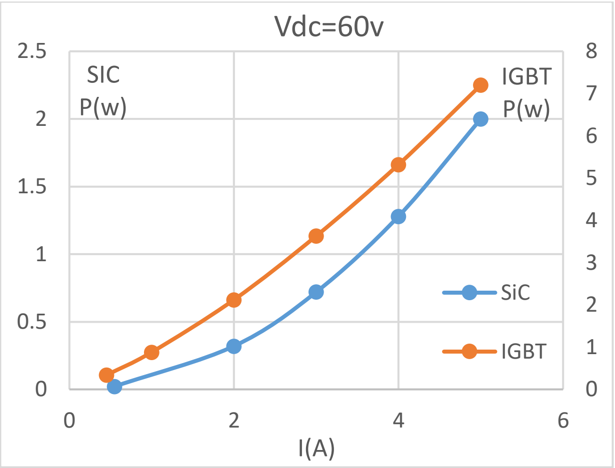

Figure 4. *static losses comparison between SiC and IGBT(Vin= 60V)*

The results for the static losses for all the applied voltage in both SiC and IGBT are shown in (figures 5-6), The applied voltages can be seen on the right of each chart.

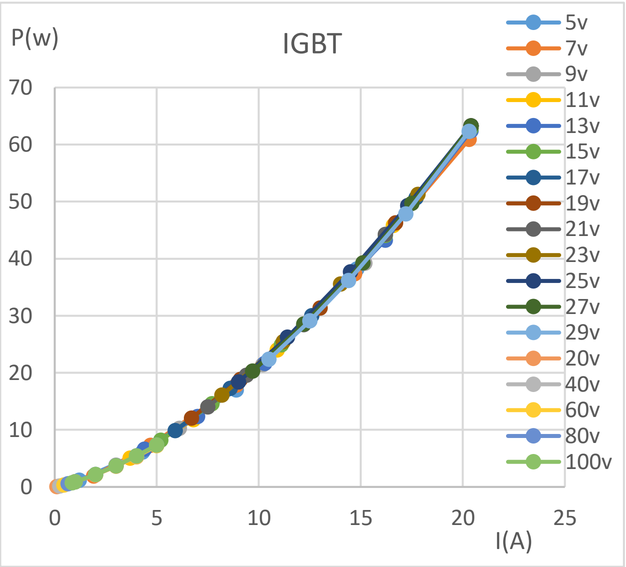

Figure 5. *static losses for all the voltages(0->100)V for IGBT*

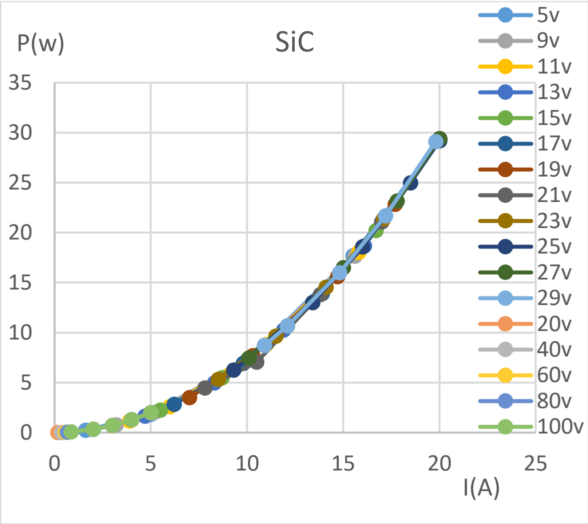

Figure 6. *static losses for all the voltages (0->100)V for SiC*

2.2. The dynamic losses for SiC and IGBT

The experiment was done according to the schematic that shown in (figure 7), the applied voltages were (20-40-60) V, and the applied frequencies from the pulse generator were (3-9-15-20) KHZ.

Used Instruments:
-Transistor (SiC CCS050M12CM2, IGBT SKM75GD124D).
-Power supply (120V, 6A).
-Resistors-load (100 ohm).
-Voltmeter.
-Ammeter.
-Oscilloscope.
-Pulse generator.

the transistor Q1 is always off, so the current flows through Q2 only (figure 7).

Here are some of the results for the dynamic losses when we apply 60v for different frequencies(figure 8).

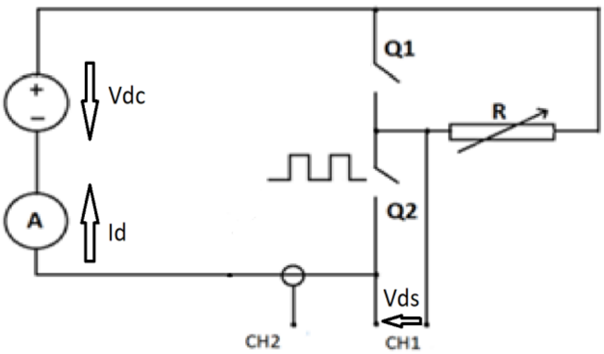

Figure 7. *dynamic losses schematic*

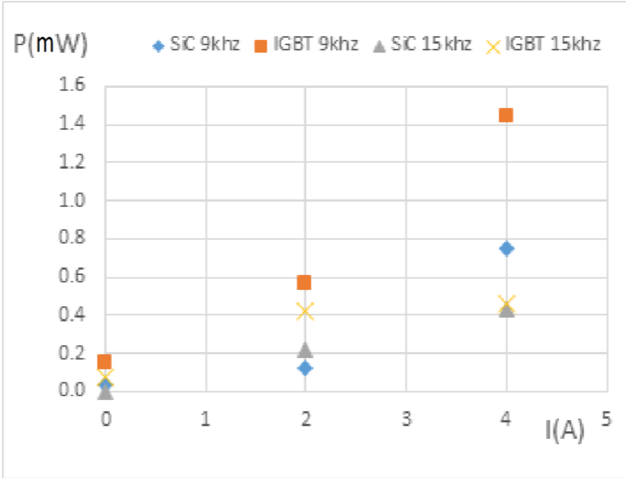

Figure 8. *dynamic losses comparison between SiC and IGBT when switching off(Vin=60V, f=9KHZ, 15KHZ)*

3. Conclusion

From the previous results it can be state that:

1.The static losses are the same in SiC for all the voltages, and the same situation for IGBT.
2.The static Losses for IGBT are twice higher than SiC for the same currents and same applied voltage.
3.SiC has almost similar turn-on losses as IGBT.
4.IGBT has almost double turn-off losses if we compare it with SiC.

SiC showed lower power losses than IGBT transistors for the voltages (20 up to 60)V and for frequencies (3 up to 20) KHZ.
So for sure SIC is better than IGBT to use for creating frequency inverter to work with the 48v.

4. Future work

The third kind of transistors that has been propossed to test for our inverter is the Gallium nitride (GaN), it seems a very good option to use in high frequency inverter, and when compared with the SiC transistors it can be state that it has lower switching losses (figure 9).
The purpose from this experiment was to get the experimental data for SiC, because in the future when we have the Gan transistor we can compare losses for the same voltages and currents, and since our application is for 48v, we are focusing on low voltages because maybe the SiC is very good choice for large voltages but not as good as Gan to use with the low voltages, and it is not preferable to use the SiC transistors with low voltage applications (below 300 V), it is achievable but it will lose part of its merits (high efficiency, high switching speed), But it is good to use with voltages between 300-600V, where it is very recommended to use with high voltages(>600V) [6].
And since the goal is building a frequency inverter to work with 48V, it is important to make sure that it is possible to achieve the lowest losses for this inverter while controlling a high speed machine, that is why some experiments will be done in the near future to test Gallium

nitride (GaN) transistors, and test the losses to make sure that it is the best option for working in the low voltage range, it is expected that it will be the best choice and the best components that can be used for building this inverter.

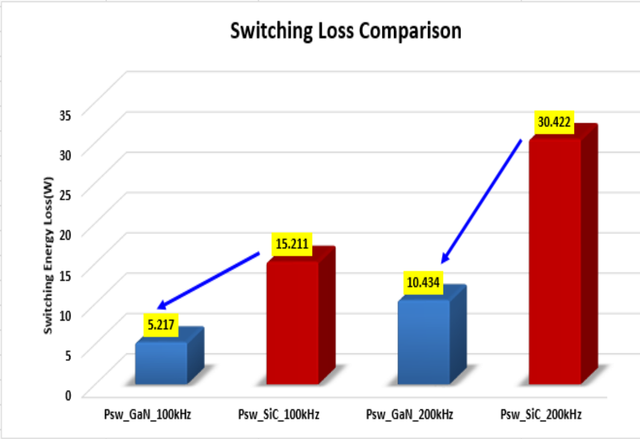

Figure 9. *a comparison between GaN GS66508T (650 V/ 30 A, 50 mΩ) and SiC Mosfet C3M0065090J (900 V/ 35 A, 65 mΩ), that shows the switching losses for these two types [7]*

Literature

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