Performance Comparison of Single-Phase Cycloconverter with SiC Transistor and IGBT with Different Control Strategies

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***Abstract*—Silicon Carbide (SiC) MOSFET devices exhibiting several advantages, including high blocking voltage, lower conduction losses, and lower switching losses, when compared to silicon-based devices have become commercially available, enabling their adoption into power supply products. This paper presents a novel approach to designing a cycloconverter using SiC MOSFETs as opposed to the conventional usage of IGBT. A comparative study is attempted between the two with respect to power loss, system efficiency, leakage current etc. Furthermore, different closed loop control strategies are used to control the speed of an induction motor using the SiC cycloconverter model designed in this paper. MATLAB/Simulink models and simulations are used to analyze the results for the above.**

***Keywords—*Cycloconverters, IGBT, Silicon Carbide MOSFET, PID controller.**

# INTRODUCTION

Wide-bandgap (WBG) based semiconductors such as Silicon Carbide (SiC) or Gallium Nitride (GaN) are ready to carve out a niche in applications that demand the ability to work at high voltages and temperatures while demonstrating high efficiency and relatively smaller dimensions owing to their intrinsic properties. These WBG based semiconductors offer several advantages over the equivalent silicon devices available in the market today, few of which include, lower leakage current, significantly higher operating temperatures, better conduction and switching properties. For these reasons, the WBG devices have been identified to have a promising future in the power semiconductor industry.

Here the focus is only on the Silicon Carbide based Power devices and its applications. There has been a tremendous amount of research effort on developing power semiconductor devices with Silicon Carbide (SiC) in the pursuit of higher efficiency and smaller dimensions [1,2]. The availability of SiC wafers on a commercial basis has led to the demonstration of many types of metal-oxide semiconductor (MOS)-gated devices that exploit its unique properties. These emerging Silicon Carbide (SiC) MOSFET power devices promise to displace Silicon IGBTs from the majority of challenging power electronics applications by enabling superior efficiency and power density, as well as capability to operate at higher temperatures [3]. Reference [4] focuses on the comparison of a SiC based DC/DC converter and an IGBT based DC/DC converter and thus concludes that the efficiency of an SiC converter is greater than that of the IGBT converter over an output power range. An electro-thermal analysis of an automotive traction inverter platform based on SiC MOSFET and SiC IGBT technology is discussed in [5] and the results show that there is a higher total loss reduction in the SiC MOSFET model compared to the IGBT model. For all these reasons, in this paper, we are designing a cycloconverter using a SiC MOSFET as opposed to the usage of IGBT in doing the same.

In a cycloconverter, a constant voltage and frequency AC waveform is converted into another AC waveform of lower frequency without using DC link in the conversion process thus making it highly efficient [6]. A single-phase to single-phase cycloconverter consists of two full wave converters that are linked back to back. There has been extensive research carried out to explore the several possibilities for realizing an AC variable speed drive with cycloconverter. Reference [7] presents the different solutions and compares the performance of the cycloconverter in rolling mill drive applications. The speed control of induction motor plays an important role in industries, this can be made efficient by using various methods to control the action of the cyclo-converter which will control the motor performance [8], this paper uses the Silicon Carbide based cycloconverter for the speed control of a single phase induction motor using PID control strategy.

The objective of this paper is to design an efficient cycloconverter using SiC MOSFET and compare the performance of that with a cycloconverter designed using IGBT. The forthcoming sections give a better understanding of the above. SiC MOSFET is modelled using MATLAB/Simulink and a novel approach to design a cycloconverter using the same is presented. An analysis of all the simulation results and comparison of the performance of the SiC MOSFET and IGBT pertaining to various characteristics such as power loss, system efficiency, leakage current etc. is dealt with upon in the later sections Thereafter all the main results are concluded.

# SIMULINK MODEL

## Cycloconverter Design using IGBT

A cycloconverter for converting power at supply frequency to a lower frequency is modelled using IGBT as the switching element in Simulink. The converter has back to back connection of two full-wave rectifiers. The two-bridge type-controlled rectifiers are connected in anti-parallel direction via 4 ideal switched as represented in Fig. 1. As can be observed the conventional cycloconverter using uses 2 separate converters called the P-converter and the N-converter; each performing like an H-bridge inverter. The below model is used as a standard of comparison for the SiC model which is designed in this paper.

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Fig. 1. Cycloconverter model using IGBT

The supply input to the cycloconverter is a 100V signal alternating at 50 Hz as in Fig. 2. The corresponding step-down output corresponds to a signal of 100V, alternating at a frequency of 5 Hz as shown in Fig. 3.

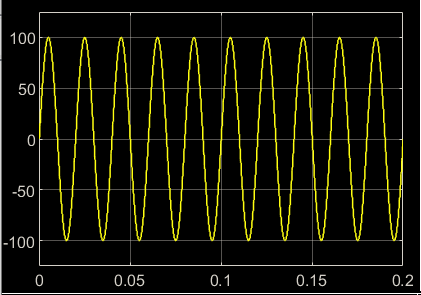


Fig. 2. Cycloconverter input

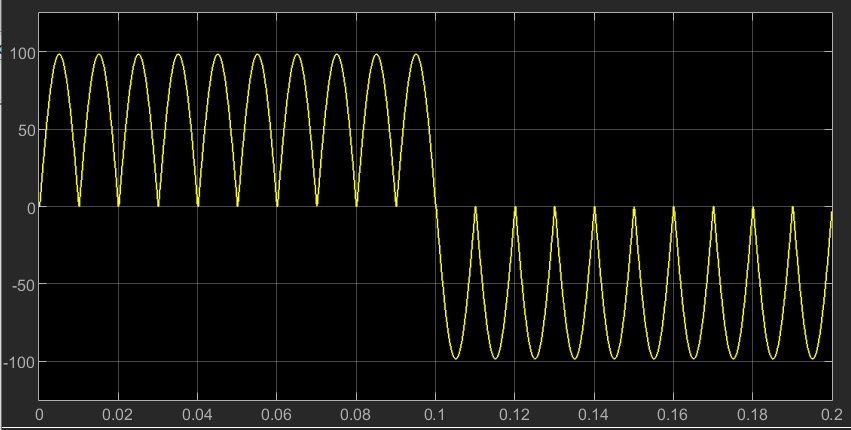


Fig. 3. Cycloconverter output

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*a**b* 

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# References

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| [1] | J. Biela, M. Schweizer, S. Waffler and J. W. Kolar, "SiC versus Si—Evaluation of Potentials for Performance Improvement of Inverter and DC–DC Converter Systems by SiC Power Semiconductors," *IEEE Transactions on Industrial Electronics,* vol. 58, no. 7, pp. 2872-2882, 2011. |
| [2] | L. D. Stevanovic, K. S. Matocha, P. A. Losee, J. S. Glaser, J. J. Nasadoski and S. D. Arthur, "Recent advances in silicon carbide MOSFET power devices," in *Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, Palm Springs, CA, 2010. |
| [3] | J. McBryde, A. Kadavelugu, B. Compton, S. Bhattacharya, M. Das and A. Agarwal, "Performance comparison of 1200V Silicon and SiC devices for UPS application," in *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society*, Glendale, 2010. |
| [4] | R. Ø. Nielsen, L. Török, S. Munk-Nielsen and F. Blaabjerg, "Efficiency and cost comparison of Si IGBT and SiC JFET isolated DC/DC converters," in *IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society*, Vienna, 2013. |
| [5] | A. Kempitiya and W. Chou, "An electro-thermal performance analysis of SiC MOSFET vs Si IGBT and diode automotive traction inverters under various drive cycles," in *34th Thermal Measurement, Modeling & Management Symposium (SEMI-THERM)*, San Jose, 2018. |
| [6] | M. A. K. A. Biabani and M. A. Pasha, "Performance analysis of step up and step down cyclo converter," in *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, Chennai, 2016. |
| [7] | R. Hagmann, "AC-cycloconverter drives for cold and hot rolling mill applications," in *Conference Record of the 1991 IEEE Industry Applications Society Annual Meeting, Dearborn*, Michigan, 1991. |
| [8] | B. Brindha, T. Porselvi and R. Ilayaraja, "Speed Control of Single and Three Phase Induction Motor Using Full Bridge Cycloconverter," in *2018 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)*, Chennai, 2018. |