Rensselaer Polytechnic Institute

Thermal Analysis of an Integrated Power Electronics Module

MANE-6980 Tentative Project Proposal Draft

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Abstract

Integrated power electronics such as IGBT’s are widely used to efficiently deliver electrical power in electrical drive systems in transportation, home electronics, and electrical grid applications. Applying integrated power electronics to electric drive systems is causing the need to improve volumetric requirements, ruggedness, weight, reliability, noise levels, and thermal heat dissipation. Modern integrated power electronics have a much higher power density compared to past technologies and companies continue to innovate. The limiting factor in these electronic components is heat removal. In order to achieve adequate cooling at current power densities, design engineers are forced to look beyond standard forced-convection air cooling. Liquid cooling has become an accepted and necessary form of heat dissipation for integrated power electronic modules. Two notable cooling technologies that have evolved into efficient and reliable means to dissipate heat are cold plates and heat pipes.

Introduction

Integrated power electronic modules consist of components such as insulated gate bipolar transistors (IGBTs), rectifying diodes, snubber capacitors, direct current (DC) link capacitors, resistors, gate driver boards and many other components based on the application. However, IGBTs are the main source of waste heat loads. The IGBT is a semiconductor power conversion device which can achieve a high power density while performing its fundamental role of electrical power processing, known as switching, at high frequencies. IGBT power losses are divided into three groups: conduction losses, switching losses and blocking losses (which are normally disregarded). Conduction losses deal with a series connection of DC voltage source of the on-state zero current of the collector-emitter voltage and resistance. Switching losses deal with turn-on energy losses in the IGBT taking into account the switch-on energy and the switch-on energy
caused by the reverse-recovery of the free-wheeling diode; switching losses in the IGBT are the product of switching energies and the switching frequency.

With the intent of creating a highly power dense integrated power electronic modules cold plates have matured into a common cooling technique. Unless properly designed, high rates of heat generation result in high operating temperatures for electronic equipment, which then jeopardizes its safety and reliability. In order to promote the needed heat transfer and improve temperature distribution within the power devices cold plates must be designed with the correct attributes for efficient heat transfer and dissipation. Cold plates act as an indirect cooling system where there is no contact between the cooling medium and the component. The heat generated by the IGBT is transferred from the case to the heat sink block which has imbedded piping containing a circulating cooling medium. The heated liquid is then cooled by an external heat exchanger. Desirable characteristics of cooling liquids include high thermal conductivity, high specific heat, low viscosity, high surface tension, and high dielectric strength. Required heat removal rates can be achieved by varying inlet temperature, flow rate, flow type (laminar or turbulent), thermal contact boundaries, and materials used for both pipe and heat sink.

There are many ways to cooling integrated power electronic modules. Cold plates have many benefits to their implementation but there are other technologies that can adequately compete. Making use of a heat pipe for cooling integrated power electronic modules could be a viable alternative.

**Problem Description**

The limiting factor for designing integrated power electronic modules is the ability to removal a sufficient amount of heat. The design of the cold plate must adhere to strict requirements based on the application it is being used in. Into today’s applications of cold plates, restrictions are placed on many attributes that affect the effectiveness of heat dissipation. The packaging of these power dense components within the integrated power
electronic modules impacts the capability of this technology to obtain a higher switching frequency. A higher switching frequency is desired of these devices because it translates directly into better power quality; however higher switching frequency results in a poor power efficiency (increased losses in the form of heat).

**Methodology / Approach**

First objective is to determine the operating voltages and currents for the IGBTs within the integrated power electronics module. Once the operating conditions are known, a calculation must be done to determine the total losses of the integrated power electronics module. Once losses are determined the design and analysis of a cold plate can begin. Materials, flow rate, pressure drop and all application based inputs must be addressed during this phase. Calculations will be completed to determine heat spreading, effectiveness of force convection fluid cooling, and develop an understanding of performance based attributes. Once standard calculations are complete the goal is to perform a COMSOL Multi-physics analysis of the cold plate design to compare calculated results and obtain a better understanding of cold plate operation. Following the computer analysis, alternate forms of cooling will be looked into with emphasis on heat pipes. The objective is to design a heat pipe which has a comparable ability to cool the integrated power electronics module.

**Resources Required**

Based on the scope of work, the following is a list of resources required to complete the project: SolidWorks / AutoCad Modeling Software for the design of the cold plate models, COMSOL Multi-physics for the thermal analysis of the cold plate dissipating heat from the IGBTs, Microsoft Office, and the Cole Library for literature resources.
Expected Outcomes

The primary objective of this project is to design a working cold plate that can successfully remove heat from the integrated power electronics module. In order to design a cold plate, losses of the integrated power electronics module must be determined. Goal is to refine the original cold plate design with hope of meeting various requirements (i.e., ambient temperature, inlet water temperature, fluid velocity limitations, material limitations, etc.). Following the cold plate design and analysis, goal is to perform an analysis with COMSOL Multi-physics software to confirm and compare the desired results of the cold plate design. Secondary objectives consist of exploring alternate forms of cooling technologies, and developing a possible heat pipe design which could successfully cool the integrated power electronics module.
## Milestones / Project Schedule

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References

Below is a list of potential technical references for this project: