Fluid-Thermal Analysis of an Inverter with Air Cooling

R. V. Arimilli[1], A. H. Nejad[1], K. Ekici[1]

[1]The University of Tennessee, Knoxville, TN, USA

Abstract

The development of power electronics devices with wide-band gap (WGB) materials (e.g., SiC) made it possible to operate them at higher temperatures than similar Si-based devices. These devices include diodes and IGBTs (Insulated-Gate Bipolar Transistors). Their stability at higher temperatures provides an opportunity to design heat sinks that can be cooled with air instead of liquids. Tawfik [1, 2] designed a 55-kW cylindrical flow air-cooled power inverter (refer the papers) for hybrid electric and plug-in electric transportation vehicles . The complete inverter will be composed of nine power modules, each module has a mid-plane symmetry and therefore one-half of a module can be used to simulate the performance. In each half-module, there are four diodes and four IGBTs. The performance parameter of significance to power inverters for automotive use is the power-to-volume ratio. The air-cooled design by Tawfik was shown to meet the performance values for liquid-cooled inverters under turbulent flow conditions. However, other arrangement of modules are possible.

In this study we considered an alternate linear arrangement of the modules, as opposed to a cylindrical arrangement, using modules of same size and power dissipation. The half of one module is utilized in this study and henceforth will be referred as the "module" in this paper. The present analysis is based on conjugate heat transfer with laminar flow in COMSOL Multiphysics®. The performance parameter is not a serious limitation for a linearly-arranged inverter because it is expected to be positioned below or in place of the vehicle radiator. Therefore, the fin arrangement has to be redesigned for use under laminar flow conditions and this was done.

Figures 1 and 2 show the geometric details of the design configuration and modeled domains. The overall energy balance error (OEBE) was defined as the ((net out flow of total normal energy flow rate ÷ total power input to the system) -1) expressed as a percentage. For this stationary solution, OEBE should approach zero value as the mesh refinement is improved. Figure 3 shows OEBE decreasing with improved mesh refinement for all the Reynolds numbers (based on inlet conditions) considered. However, OEBE increases with increasing Reynolds number. For all inlet Reynolds numbers considered, the Reynolds number for flow within the air passages (based on average velocity and hydraulic diameter) is substantially lower. So we can be sure that the flow everywhere is laminar. At the higher Reynolds numbers much finer mesh is needed to achieve better OEBEs, which is beyond the scope of the resources available to us. In Figure 4 the variation in maximum temperature is far less sensitive to the mesh refinement, and it

decreases with increasing Reynolds number.

Reference

1. Tawfik, Jonathan A., Thermal Feasibility and Performance Characteristics of an Air-Cooled Axial Flow Cylindrical Power Inverter by Finite Element Analysis, M.S. Thesis, The University of Tennessee, Knoxville, May 2011.

2. Chinthavali, Madhu , Tawfik , Jonathan A, and Arimilli, Rao V., Design and Analysis of a 55-kW Air-Cooled Automotive Traction Drive Inverter, Energy Conversion Congress and Exposition (ECCE), 2011 IEEE, PID1930289.pdf.

Figures used in the abstract

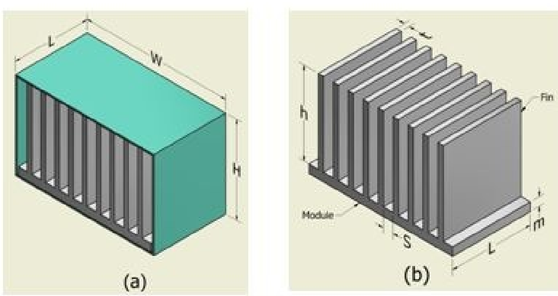

Figure 1: Sketch of the heat sink configuration design.

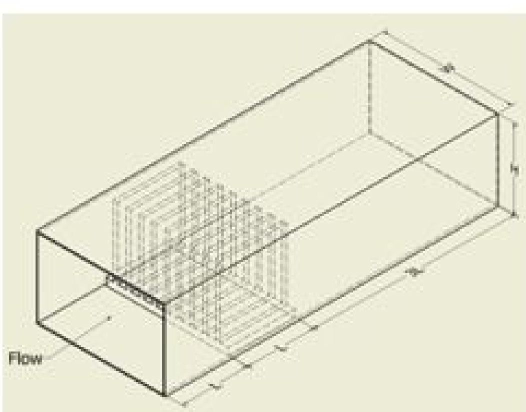

Figure 2: Sketch of the heat sink configuration analyzed in COMSOL showing upstream and downstream flow passage system.

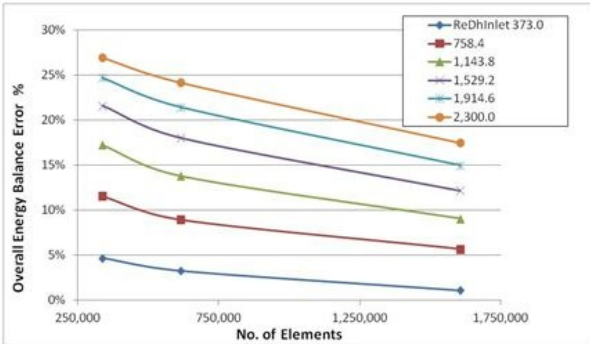

Figure 3: Overall energy balance error as a function of mesh refinement.

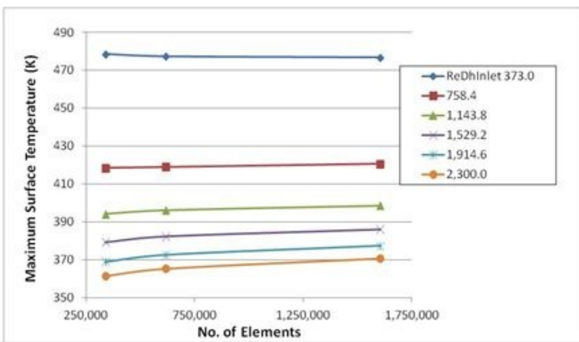

Figure 4: Maximum temperature as a function of mesh refinement.