Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Importance of thermal radiation from heat sink in cooling of three phase PWM inverter kept inside an evacuated chamber

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ARTICLE INFO

Article history:
Received 14 April 2016
Revised 23 May 2016
Accepted 7 June 2016
Available online xxxx

Keywords:
IGBT
Thermal radiation
Heat sink
SPWM technique
Junction temperature

ABSTRACT

The paper describes a thermal analysis of a three-phase inverter operated under a Sinusoidal Pulse Width Modulation (SPWM) technique which used three sine waves displaced in 120° phase difference as reference signals. The IGBT unit is assumed to be placed with a heat sink inside an evacuated chamber and the entire heat has to be transferred by conduction and radiation. The main heat sources present here are the set of IGBTs and diodes which generates heat on a pulse basing on their switching frequencies. Melcosim (a well-known tool developed by Mitsubishi Electric Corporation) has been used to generate the power pulse from one set of IGBT and diode connected to a phase. A Scilab code is written to study the conduction and thermal radiation of heat sink and their combined effect on transient growth of the junction temperature of IGBT unit against complex switching pulses. The results mainly show that how thermal radiation from heat sink plays a crucial role in maintaining the junction temperature of IGBT within a threshold limit by adjusting various heat sink parameters. As the IGBT heat generation rate becomes higher, radiative heat transfer of the heat sink increases sharply which enhances overall cooling performance of the system.

1. Introduction

In recent years, effort to spread the use of renewable energy sources with depleting layers of hydrocarbon fuels has been increased. To utilize these renewable energy resources, an inverter is essential which converts DC to AC as most of the renewable energy is found in DC form. The inverter mainly consists of IGBT (i.e. voltage controlled power transistor) that is used while voltage requirement increases. IGBT (Insulated Gate Bipolar Transistor) improves dynamic performance, efficiency and dissipates heat in the form of conduction as well as switching losses. A heat sink attached to IGBT cold plate drives the heat away from the module to external ambient. Kojima et al. [1] describes a novel electro-thermal coupling simulation technique for analysing automotive IGBT modules. The transient temperature response obtained using the proposed model was validated with FEM model and the experimental results. In their approach, they could successfully capture the lateral thermal spreading and thermal interferences occurring at IGBT module. Popovic et al. [2] conducted a thermal analysis of the half bridge IGBT power module mounted on a heat sink. They approached with FEM and verified that temperature rise of the system for different cases of power dissipation and forced cooling condition. Finally, they found good agreement between their model and the experiments. Ke Ma et al. [3] highlighted the discrepancies of Foster type of RC network in addressing the thermal impedances of heat sink and thermal grease. They proposed a new thermal model which gave a better result for both junction and case temperature compared to the earlier model. Schnell [4] numerically calculated switching and conduction losses under the assumption of sinusoidal output currents. Static and transient temperature rise in the module with specific heat sink is calculated inside the program. Losses in the IGBT and companion freewheeling diode are iteratively adjusted to temperature rises. Angira et al. [5] used a float metal concept to reduce RF overlap area between the movable structure of capacitive shunt RF-MEMS switch and central conductor of CPW for improving the insertion loss of the device without affecting the down state response. Pal et al. [6] has performed an analytical study of dual material surrounding Gate MOSFET (DMSG) by solving Poison equation. In their results they have revealed that DMSG MOSFET provides higher efficacy to prevent short channel effects as compared to conventional MOSFET. Moaiyeri et al. [7] have simulated 32 nm CNTFET model and demonstrated improvements in terms of speed and power delay product as compared to the cutting edge CNTFET based

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Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.06.004
2215-0986/

Nomenclature

A	exposed surface area to ambient (m^2)
B	ratio of fin thickness (t) to base thickness (t_b)
C_p	specific heat of copper (J/kg K)
F	view factor
f	frequency (Hz)
h	heat transfer coefficient (W/m^2 K)
H	height of the heat sink fin (m)
I	applied current (A)
k	thermal conductivity of copper (W/m K)
l	equivalent height of heat sink along the heat transfer direction (H/2) (m)
L	length of the heat sink fin (m)
M	modulation factor
n	number of fins of the heat sink
PF	power factor (cos φ)
P	power (W)
Q	heat transferred (W)
R	thermal resistance (K/W)
R'	electrical resistance (Ω)
S	gap between fins of the heat sink (m)′
t	thickness (m)
t'	time (s)
ts′	time to reach steady state condition (s)
T	absolute temperature (K)
V	operating voltage (V)
W	width of heat sink base (m)

Greek alphabets

ρ	density of copper (kg/m^3)
η	overall surface efficiency of heat sink fins
ε	emissivity of the heat sink surface
σ	Stefan–Boltzmann constant (5.67×10^{-8}) ($W/m^2 K^4$)
φ	phase angle (deg)

Subscripts

a	ambient
av	average
b	heat sink base
c	case
C	collector
CD	conduction
CE	collector-emitter
ch	heat sink channel
cs	case to sink
d	dissipation
G	gate
hs	heat sink
O	output
r	radiative
rr	reverse recovery
sa	sink to ambient
sat	saturated
SW	switching

ternary designs. Turkyilmazoglu [8] used water nanofluid for performance enhancement of a direct absorption solar collector by increasing the thermal efficiency. He developed analytical solutions of the temperature fields for the two dimensional steady state model to study the increase in temperature of the heat transferring nanofluid. In the above literatures the thermal radiation is considered negligible and hence become an interesting field to be researched for its effect on a IGBT under operating condition and hence the present study is focused to that.

2. Objective of research

In the present investigation, a three phase inverter is subjected to a voltage source that use PWM switching techniques having a DC input voltage of constant magnitude. The inverter job is to take this DC input to generate AC output, where the magnitude and frequency can be controlled. The entire unit has to be placed in an evacuated chamber where force cooling mechanism can't be adapted and hence huge amount of heat generated inside has to be removed to the atmosphere by means of conduction and radiation. Keeping in mind of above condition, the study has been conducted thoroughly to maximize radiation heat transfer of a plate fin heat sink which is further attached to this unit for removal of the total heat produced inside.

3. SPWM technique and input conditions applied

In this design the Sinusoidal Pulse Width Modulation (SPWM) technique has been used for controlling the inverter to produce desired output voltage and frequency. SPWM technique is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches. The inverter assembly consists of three IGBT (CM150DY-34A/Mitsubishi Electric) modules connected to three different output phases as shown in Fig. 1. Each module consists of two IGBT transistors which are attached to their freewheeling diodes, in turn making a total of six transistors and six diodes inside the whole assembly. The input conditions considered for this investigation are given below for the complete inverter assembly.

$V = 1000\,V, PF = 0.7, M = 1, f_{SW} = 3\,kHz, f_O = 60\,Hz, R'_G = 3.2\,\Omega,$

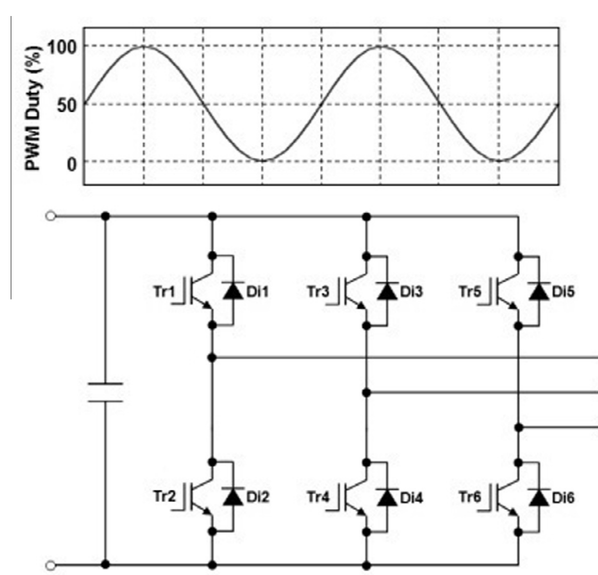

Fig. 1. IGBT transistors and freewheeling diode architecture inside three phase inverter.