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Thermal modeling & Reliability Test of Semiconductor devices

Anil Kumar Chaudhary

Asst. Professor *(EC Deptt.) in BIT GIDA Gorakhpur, U.P 273209, India; E-mail: chaudharyanil@live.com.*

Abstract— **This paper the reliability of switching components in hybrid electric vehicles (HEVs) is assessed in this research along with the presentation of thermal models. Evaluating the reliability of power electronic components is becoming more and more important as their use in automotive applications grows. The study computes switching element power losses and examines how they change with temperature. In order to analyse power loss dynamics and determine the waveform of Power Loss Variation with Temperature in Switching Devices, the methodology uses simulations based on MATLAB. The study also looks at thermal and electrical modelling methods for figuring out component junction temperatures under brief mission scenarios. Predicting system behaviour, improving design, cutting production costs, and raising overall reliability all depend on accurate thermal simulations.**

Key words: Reliability, Inverter, IGBT, Diode, Electrical Vehicle, Switching, Temperature.

I. INTRODUCTION

Ensuring the dependability of switching devices has become essential due to the increasing dependence on power electronics in automotive systems, especially in Hybrid Electric Vehicles (HEVs), where malfunctions caused by power electronics might result in serious issues [1]. IGBTs and other power semiconductor devices are essential components of energy conversion systems, motor drives, and switching power supply. However, precisely calculating power losses and junction temperatures has become a major difficulty as device capacities increase [2]. Every stage of the design process needs to take reliability into consideration [9–10]. The parts-count approach might be used in the conceptual stage when specific stress conditions are not established. Without a thorough stress analysis, this method calculates system dependability using generic failure rates, environmental variables, and component quality [3].,

D. Hirschmann et al. [1] created a sophisticated modelling program that can determine component temperatures in a three-phase converter across prolonged mission profiles in order to improve reliability prediction. More precise reliability evaluations were made possible by their work, which developed a novel algorithm to locate crucial temperature cycles within thermal curves. They also examined losses in DC-link capacitors and semiconductors in three-phase bridge arrangement. Fast-switching semiconductors with low turn-on/off losses are required by the drive for higher converter frequencies in power electronics. By drastically lowering power dissipation, faster switching speeds can increase overall efficiency.

II. LITERATURE REVIEW

Simulations are becoming increasingly significant in power electronics because they save money and time. Look-up tables are used by fast system simulation tools to calculate the switching and conduction losses of power semiconductor devices during converter operation. Temperature, voltage, and current are monitored both before and after a switching event. The energy associated with the identified operating point is read from the three-dimensional database when a switching transition takes place [5]. The primary goal of power electronics and power device societies is to reduce carbon dioxide emissions by increasing power conversion efficiency and reducing power loss in power conversion systems [6].

Electrical power must be controlled via power electronic converters. They can be used to convert variable frequency (360–800 Hz) in the next generation of civil aircraft to a constant frequency supply bus for a variety of loads, and they are required for motor drive controllers in electrically driven actuators. Given the growing importance of converter drives in safety-critical aircraft systems, it is evident that their dependability needs to be predicted and compared. The military handbook for reliability prediction of electronic equipment, MIL-HDBK-217F, has been used to analyse the dependability of five distinct converter topologies [3].

III. Research Methodology

Based on physical models, lifetime prediction assumes that a component will endure a specific level of stress before failing. As a result, every identical part will malfunction at precisely the same moment. Therefore, the lifespan of a system will be determined by its weakest component. The relationship between a chemical reaction's rate and temperature T is provided by the Arrhenius equation [9] [10].

. The lifespan is calculated by [1].

$$L = L_0 . B^{\left(\frac{T_{max} - T_a}{10}\right)} \qquad \text{……………..} (1)$$

Here L is lifetime to be estimated L0 is base lifetime

B < 1 temperature acceleration factor T_{max} Maximum rated temperature

T_a Ambient temperature

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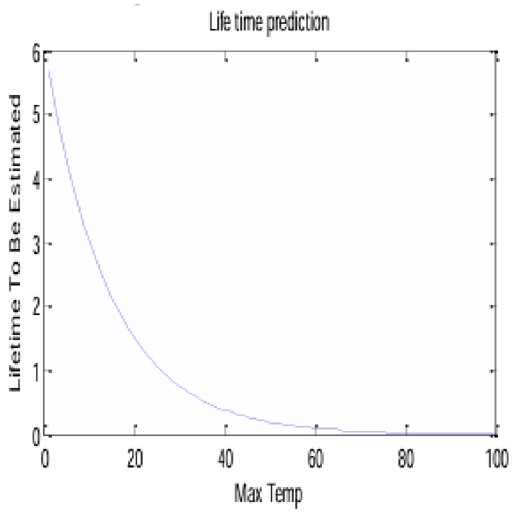

The junction temperature affects the device's power loss. The life of the switching element utilised in the inverter is described in fig. 1. This demonstrates how the life of a switching device will decrease in a similar way when the junction temperature rises. The system will become less dependable as the switching element's lifespan decreases.

Generally speaking, raising the temperature can speed up a chemical reaction. The Arrhenius equation provides a quantitative description of the relationship between the system temperature and the reaction rate. According to a general rule, raising the ambient temperature by roughly 10 °C will cut the lifespan in half. Equation 1 will serve as the foundation for the above estimation. Therefore, electro-thermal coupling simulation techniques, where the estimation of power loss and the calculation of the junction temperature should be combined, become important for predicting the dynamic power loss and Junction temperature [8].

Because of thermally induced stress brought on by the differential thermal expansion of materials, component temperature and temperature changes have a substantial impact on dependability in power electronics. Consequently, a program that calculates the component temperature over the course of a driving cycle was created. A basic explanation of the simulation process may be found in [1]. The document has not been updated, and new elements such as IGBTs are not taken into account because the values are too conservative for the devices that are now on the market. Few manufacturers provide the thermal model of their devices; others simply provide information on switching losses and overall power losses when attempting to determine dependability. The suggested model presents the data for power loss calculations and thermal modelling. diode. MATLAB programming will be used to calculate the above result.

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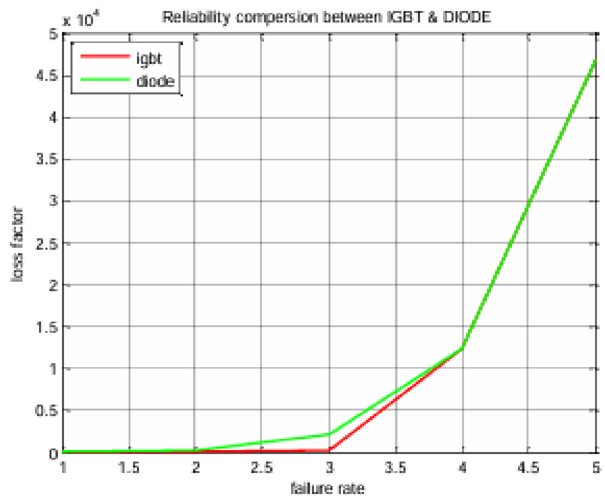


Fig.2 Reliability Comparison between Different Switching Devices

Figure 2 will display the reliability comparison between IGBT and DIODE. As the loss factor rises, the diode's failure rate will surpass that of the IGBT, causing the IGBT to be more reliable than the diode. in order for IGBT-based inverters to be more dependable than diode-based ones. IGBT will also last longer than a

V. Thermal Modelling and Power Loss Variation in Switching Device

Based on the failure rate and lifespan of the switch element, we are calculating the dependability of the switching component. The reliability (t) of a component is the probability that this component will perform its intended function after a time t in $R_{tot}(t) = \prod_{i=1}^{n} R_i(t)$ (2)

Here

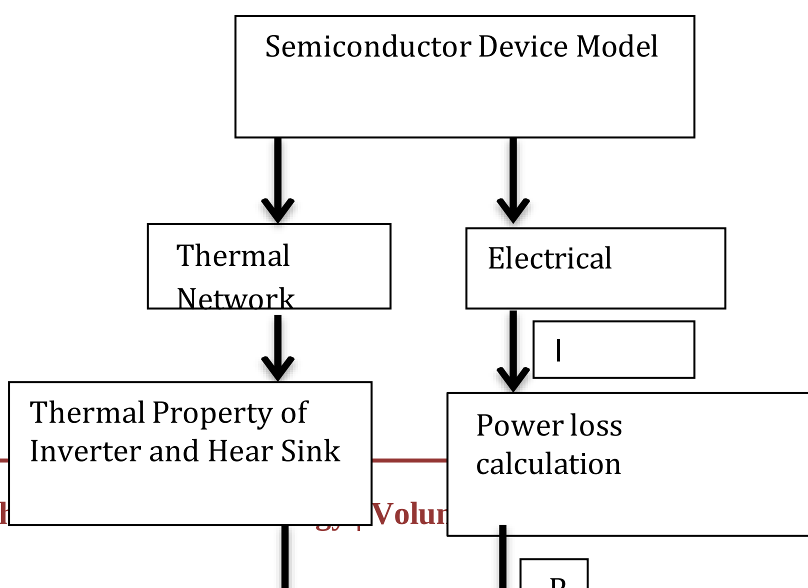
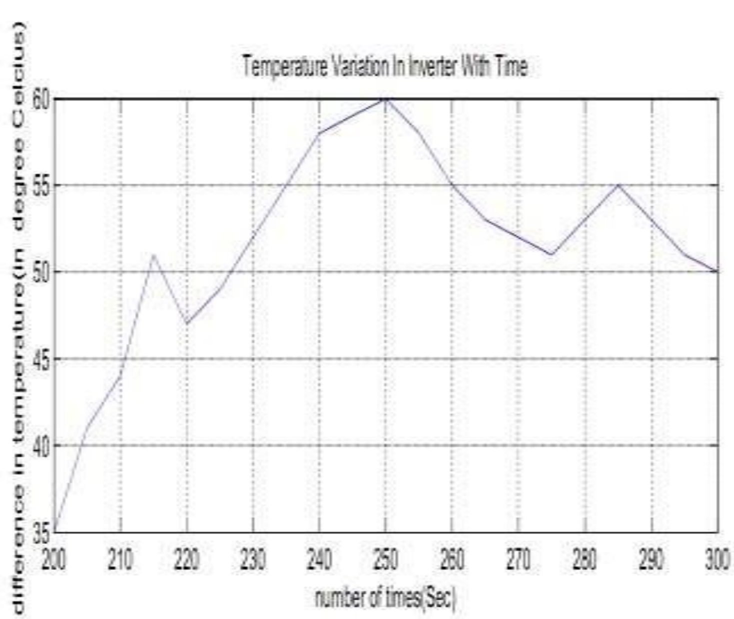


Fig.3 Electro-Thermal Semiconductor Device Model Reliability involves four elements, namely:(1) probability,(2) intended functions,(3) operation time, and(4) operating environment. In other words, reliability is the probability of a device performing its intended function for a specified period of time under the specified operating environment. This concept of reliability as a probability, typically quantified by assessing the mean time to failure (MTTF), implies that field failures are inevitable. In today‟s very competitive electronic products market, a commitment to product reliability is a necessity [7]. The thermal model of the system was characterized by using the vendor application notes and data sheets. Once the thermal model was defined, a mathematical model representation of the system was created and solved. The mathematical model was then implemented in a Simulink Model.

The vendor's application notes and data sheets were used to characterise the system's thermal model. Following the definition of the thermal model, the system was represented mathematically and solved. A Simulink model was then used to implement the mathematical model.

The Accurate modelling is necessary because the mounting of the device and the heat sink play a significant role in determining the heat removal performance. The topology of the electro-thermal semiconductor device models is shown in Fig. 3, which also shows how the electrical and thermal terminals interact with the thermal and electrical networks, respectively. The simplest method to calculate the component temperature is to build an equivalent electrical network where each component is represented



by a single thermal resistance. In this equivalent circuit, the power corresponds to current and temperature to voltage

Fig 4.Temperatutre Variation In Inverter

Conduction and switching losses in IGBT are computed and supplied to the thermal model. It should be mentioned here that datasheets can be used to determine the switching losses in an IGBT. The junction temperature, which is subsequently used to determine the devices' reliability, is an output of the thermal model.

This approach is used to create a MATLAB application. Extremes are discovered in the beginning of all cases. A minimum is found whenever the gradient shifts from negative to positive, while a maximum is found if the slope shifts from positive to negative. This results in a significant number of extreme values. Figure 4 illustrates how the temperature changes over time.

A thermal model and an electrical model make up the model. The thermal model is linked to the device model, which defines the electrical properties of IGBTs or diodes. The thermal model, which defines the module's thermal properties, is subjected to the instantaneous value of the device power loss. After that, the thermal model generates the instantaneous device temperature, which is then used to calculate the temperature-dependent device model parameters.

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The voltage, current, and temperature all affect the semiconductor losses in a particular assembly. The electrical simulation provides the phase voltages and currents, but the thermal model's output must be used to extract the temperatures. Conduction and switching losses are the two categories into which semiconductor losses may be separated.

A. Conduction Losses

These losses are the ones that happen while the IGBT is conducting current and turned on. Multiplying the on-state saturation voltage by the on-state current yields the overall power dissipation during conduction.
By multiplying the datasheet Vfm by the anticipated average diode current, one can estimate free-wheel diode losses.

$$P_{cond=}\ f_{SW} * \{V_{ce(on)} * I_c\} \qquad \text{.........} (3)$$

Where

$$I_c = I_0 \times (e^{\frac{V_D}{n\times k\times T}})$$

f_{SW} is switching frequency

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$V_{(ce(on))}$ Collector to emitter voltage I_c is the collector current

A. Switching Losses

Power loss during the turn-on and turn-off switching transitions is known as switching loss. PWM switching losses at high frequencies can be significant and need to be taken into account when designing thermal systems. The conventional definition of switching energy is turn-on (E(SW(on)) and turn-off (E(SW(off) .By adding together E(SW(on)) and E(SW(off)) and dividing by the switching time T, one can calculate the average switching power loss in situations where the running current and applied DC bus voltage are constant, meaning that E(SW(on)) and E(SW(off)) are the same for each turn-on and turn-off event. The simplest formula for average switching power loss is obtained by dividing by the switching period, which is equivalent to multiplying by the frequency:

$P_{SW=} f_{SW} * \{(E_{SW(on)}) + (E_{SW(off)})\}\ldots$ (4) Where:

f_{SW} is switching frequency

$E_{SW(on)}$ is turn-on switching energy. $E_{(SW(off))}$ is turn-off switching energy

The manufacturer's datasheets are the most reliable source of information about switching losses in an IGBT. IXER 35N120D1 is utilised for this model. This datasheet

$$E_{(SW(on))}=5.4 \text{ mJ}$$

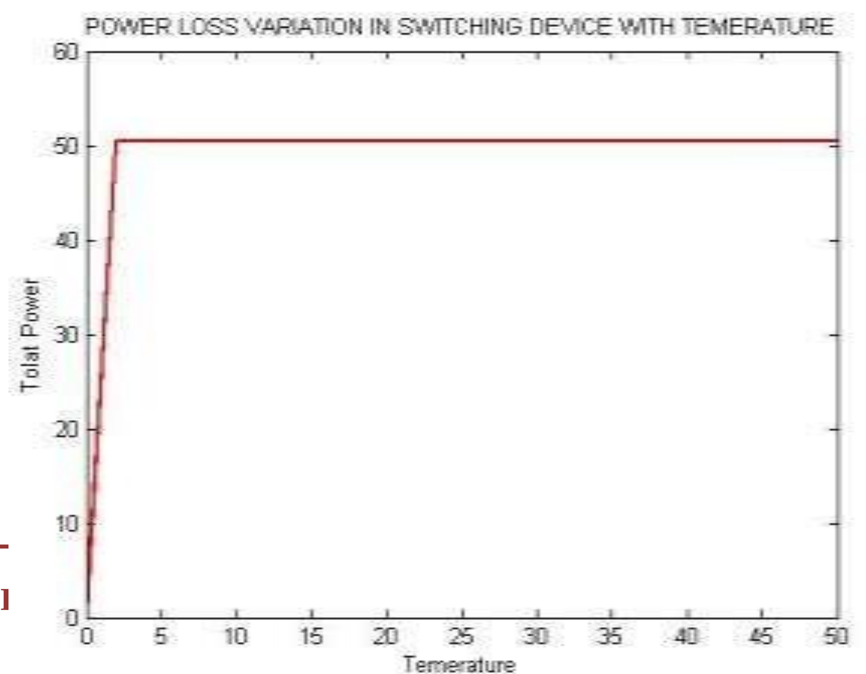
$$E_{(SW(off))}=2.6 \text{ mJ}$$

$$P_{cond=} f_{SW} * \{_{(on)} * I_c\}\ldots\ldots\ldots\ldots(5)$$

$$P_{SW=} f_{SW} * \{(E_{SW(on)}) + (E_{SW(off)})\}\ldots(6)$$

$$P_{TOTAL} = Psw + P_{cond} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

This approach is used to create a Matlab program. Extremes are discovered in the beginning of all cases.



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Conduction loss plus switching loss add up to power loss in the switching part. With only a slight temperature difference, switching loss will be essentially constant. However, equation 3 illustrates how conduction loss changes with temperature. This will demonstrate that the overall loss will rise with temperature and stabilise at the threshold voltage.

Fig.7. Power Loss Variation with Temperature In Switching Device

We can calculate the power loss with temperature variation for different switching element. And finally we can calculate life time of switching element .After that reliability will calculate. Whole method of calculation done on the MATLAB and finally we find the waveform of Power Loss Variation with temperature In Switching Device by MATLAB programming

VI. Conclusions

The temperature effect fluctuation of switching devices is crucial for calculating the dependability of power semiconductor failure-rate catalogues. With the help of these models, engineers will be able to lower design and production costs, improve reliability, measure the accuracy of an IGBT module's estimated thermal impedance, forecast the highest switching frequency without going over thermal limits, and measure the properties of the heat-sink required to dissipate heat in the worst-case scenario. The heat-source terms for a thermal solution are then described using this data in combination with comprehensive device switching models, enabling the prediction of the inverter's electro-thermal performance over extended real-time periods.

References

[1] D. Hirschmann, D. Tissen, S. Schroder, and R. De Doncker, ― Reliability Prediction for Inverters in Hybrid Electrical Vehicles‖ , IEEE transactions on power electronics,vol.22,n0.6,nov 2007

[2] A. Morozumi, K. Yamada, T. Miyasaka, S. Sumi, and Y. Seki, ― Reliability of power cycling for IGBT power semiconductor modules, ‖ IEEE Trans. Ind. Appl., vol. 39, no. 3, pp. 665 – 671, May. 2003.

[3] Military Handbook (MIL-HDBK-217F), ‖ Dept.Defense, Dec. 1991, Ed.

[4] M. T. Rahimo, and D. J. Chamund „ANALYSIS OF THE IGBT / FREEWHEELING DIODE SWITCHING BEHAVIOUR DURING TURN-ON IN HARD SWITCHING APPLICATIONS" Power Electronics and Variable Speed Drives, 21-23 September 1998, Conference Publication No. 456 0 IEE 1998.

[5] Munk- Nielsen, S.; Tutelea, L.N.; Jæger, U.: Simulation with Ideal Switch Models Combined with Measured Loss Data Provides a Good Estimate of Power Loss Industry Applications Conference IEEE, 2000.

[6] Ambo, T. et al, "Power Electronics for Large Scale Wind PowerGeneration," IEEJ Journal, Vol. 129, No.5 (2009), pp. 291-294

[7] Anuj Goel, & Robert J. Graves- lectronic System Reliability:Collating Prediction Models' IEEE TRANSACTIONS ON DEVICE AND MATERIALS RELIABILITY, VOL. 6, NO. 2, JUNE 2006

[8]T. Kojima, Y. Nishibe, Y.Yamada, T. Ueta, K. Torii, S. Sasaki, and K. Hamada,"Novel electro-thermal coupling simulation technique for dynamic analysis of HV (hybrid vehicle) inverter," in Proc. 37th IEEE Power Electron.

Specialists Conf., 2006, PESC "06, Jun. 2006, pp. 1

[9] AK Chaudhary & S.K Singh- Reliability Tests and Thermal Modelling for Inverter in Hybrid Electrical Vehicles- International Journal of Scientific & Technology Research Volume 1 - Issue 4, May 2012 Edition - ISSN 2277-

8616.

[10]A.K Chaudhary& S.K Singh- Reliability Comparison of IGBT based Inverters in Hybrid Electrical Vehicles Under Different Switching Pattern INTERNATIONAL CONFERENCE on INNOVATIONS AND ADVANCEMENTS IN INFORMATION AND COMMUNICATION TECHNOLOGY -ICIAICT 2012= ISBN 978-93-81583-34-0