Reliability Tests and Thermal Modelling for Inverter in Hybrid Electrical Vehicles

Anil Kr. Chaudhary, S. K. Singh, Sanjay Singh, Fuzail Ahmad

Abstract— This paper presents thermal models and describe the reliability of switching component of inverter used in Hybrid Electrical Vehicles. Inverters are made up of semiconductors and capacitors, so it is important to assure the reliability of these components. The use of power electronic components in automobile applications is increasing day-by-day. Due to this it becomes important to determine the reliability of power electronic components used in automotive applications. Paper will compare reliability of IGBT and diode. This paper deals with the electrical and thermal modelling of three phase IGBT inverter which is capable of determining the junction temperature of the components over short mission profiles. Thermal simulations of systems and to accurately predict a system's response becomes essential in order to reduce the cost of design and production, increase reliability.

.**Index Terms**— Reliability, Inverter, IGBT, Diode, Electrical Vehicles , Switching , Temperature .

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1. INTRODUCTION

UE Due to the increasing importance of power electronic components in automobiles, it becomes necessary to consider their reliability. This applies especially to hybrid electrical vehicles (HEV) where a malfunction of the power electronics may prevent [1]. The numerous advantages of Insulated Gate Bipolar Transistor (IGBT) power modules and their ongoing development for higher voltage and current ratings make them interesting for traction applications. These applications imply high reliability requirements. One important requirement is the ability to withstand power cycles. Power semiconductor devices, especially IGBTs are widely used in many fields, such as motor drivers, switching supplies and other power conversion systems. The estimation of the power loss and junction temperature of semiconductor devices has become a major issue with the increase of the capacity of devices [2]. Reliability of electronic equipment should be considered in all design phases. In the conceptual design phase, where the specific stress cannot be determined exactly, the parts-count method can be applied. This method only considers the component quality and environmental conditions to determine the reliability of all components The number of components has to be determined and multiplied by a generic failure rate of each component [3].

D. Hirschmann, D.Tissen, S. Schroder, and R. De Doncker[1] presented the development of an advanced simulation tool which is capable of determining the component temperature of a three-phase converter over long mission profiles. A novel algorithm, detecting all relevant temperature cycles within the computed temperature curve is developed. The applicability and significance of the presented reliability prediction methods is assessed. The losses in the semiconductors and in the dc-link capacitors of a simple three-phase bridge are determined. The rise of the converter frequency in power electronics requires fast semiconductor switches with low losses during the turn-on and off switching transients. By increasing the switching speed, it is possible to reduce the power dissipation of a power device in an application. Today, IGBTs present interesting characteristics combining both MOS and Bipolar structures to achieve a voltage driven device with low on-state losses, low switching losses and high current density. These devices are increasingly used in many applications, but their optimum performances are often restricted by other elements (diode reverse recovery, parasitic capacitance, and stray inductance [4]. The necessary simplifications and their impacts on the results are explained in detail [1]. An accurate average power loss calculation based on PWM reconstruction technique is proposed and presents the estimation of power losses, thermal considerations, junction temperature and power cycling considerations for IGBT and intelligent power modules. [2]. The thermal model created in this paper represents the thermal model that the vendor states approximates the thermal response of the system. The solution to the thermal model has many assumptions worth mentioning. First, it ignores the thermal losses between the inverter case and the heat sink. Normally, a thermal model would be generated to account for the thermal losses due to the thermal paste that is applied between the inverter case and the heat sink. The vendor in the application notes indicates that the thermal losses due to the thermal paste boundary are insignificant compared to the other thermal losses. Second, the thermal coupling between the IGBT and the Diode due to there close proximity is ignored because the vendor states that the thermal coupling is minimal in the application notes. Instead

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of coupling, the application notes suggest to use the hottest modeled semiconductor device junction temperature to be the junction temperature of both devices. The relevancy and accuracy of these assumptions will be further discussed in the simulations and conclusions chapters. In order to compute the junction temperature using the thermal model developed in this chapter the power losses must be computed.

2. LITERATURE REVIEW

In power electronics, simulations become more and more important since they save both time and cost. Fast system simulation programs use look-up tables in order to determine switching and conduction losses of power semiconductor devices during converter operation. Current and voltage before and after a switching event are recorded, and so is the temperature. When a switching transition occurs, the energy belonging to the detected operating point is read from the three-dimensional table [5]. Increase in power conversion efficiency and reduction of power loss in power conversion systems are the most important mission of power electronics and power device societies to contribute to the reduction of carbon dioxide emission [6]. Power electronic converters are required to control electrical power. They are necessary for motor drive controllers in electrically powered actuators, and can be used to convert variable frequency (360—800 Hz) in the next generation of civil aircraft to a constant frequency supply bus for various loads. As converter drives play an ever increasing role in safety critical aircraft systems, there is a clear need to predict and compare their reliability. The reliability of five different converter topologies has been analyzed using the military handbook for reliability prediction of electronic equipment MIL-HDBK-217F [3]. It is well known that power semiconductor devices are going through a rapid evolution now. The so-called modern power devices such as insulated gate bipolar transistors (IGBT), static induction thyristors (SITH), MOS-controlled thyristors (MCT), base resis- tance controlled thyristors (BRT), and emitter switched thyristors (EST) have been rapidly developed in the past decade, playing an im- portant role in the evolution of power elec- tronics [9][10]. In fact, among these innovative power devices mentioned above, only IGBT modules are getting more acceptance and are increasingly used in the power electrical indus- tries as high power and high voltage switching components.

3. RESEARCH METHODOLOGY

Lifetime prediction is based on physical models and makes the assumption that a component will withstand a certain amount of stress and then fail. Therefore, all identical components will fail at the exactly same time. As a result, the weakest component in a system will determine the lifetime of the whole system. The Arrhenius equation gives the dependence of the rate of a chemical reaction on the temperature T. Normally rate of a chemical reaction can be accelerated by increasing the temperature. The relation between the system temperature and the reaction rate is described quantitatively by the Arrhenius equation. A rule of thumb says that increasing the ambient temperature for about 10 °C will halve the lifetime. The lifespan is calculated by [1] The power loss of the device depends on the junction temperature. 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].

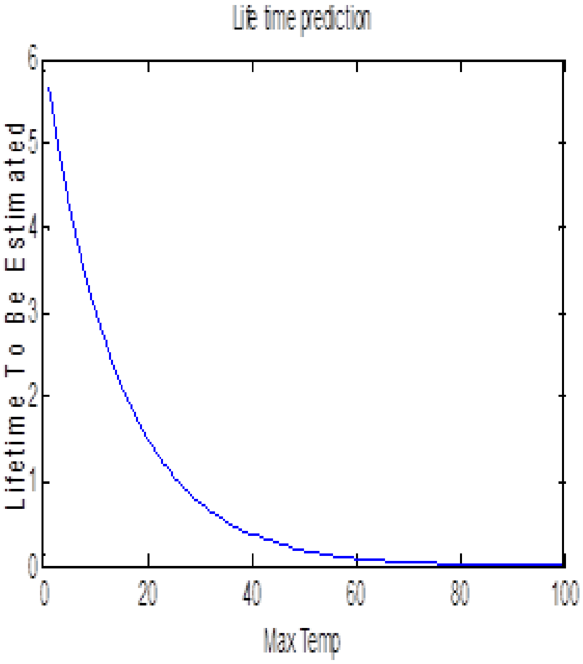

Fig.2 Life time estimation

In the fig.1 it will describe of life of switching element used in the inverter. This shows that when we increase the junction temperature life of switching device will goes decrease in same manner. When the life of switching element will lesser then system will less reliable. Above estimation will base on the equation.

4. RELIABILITY COMPARISON BETWEEN IGBT AND DIODE

We are calculation the reliability of switching component based on their failure rate and life time of switch element .The reliability comparison of between IGBT & DIODE will shown in figure 2.

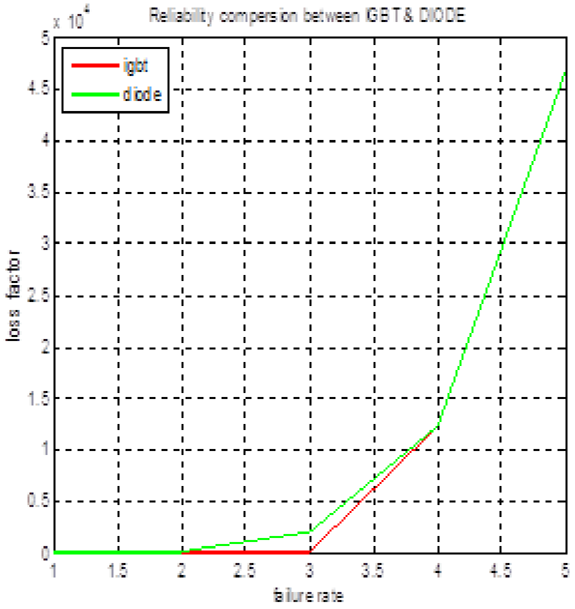

FIG.2 RELIABILITY COMPARISON BETWEEN IGBT & DIODE

When the loss factor goes increase failure rate of diode will higher than the IGBT that will result reliability of IGBT will higher than the diode. So that IGBT based inverter will more reliable than diode based. Life time of IGBT will also higher than diode. Above result will be calculated based Matlab programming

5. PROPOSED WORK

The losses in IGBT i.e. conduction loss and switching loss is calculated and fed to the thermal model. Here it should be noted that switching losses in an IGBT can be found by using datasheets. The thermal model gives the junction temperature as an output, which is later used in calculating reliability of the devices. Fig.1 will give basic mode of calculation of reliability of inverter in Vehicles under different switching pattern. In power electronics, the component temperature and temperature variations influence significantly reliability due to thermally induced stress, caused by differential thermal expansion of materials. Therefore, a program was developed, which computes the component temperature over a whole driving cycle. The simulation procedure will be explained briefly explanation can be found in [1]. Now the paper is not revised and new components like IGBTs are not considered here the values are too conservative for available devices. Some manufacturers gives information of finding reliability through information that only continue to finding switching losses and total power losses, very few of them gives the thermal model of the devices. The information of calculating the power losses and thermal modeling is presented in the proposed model. The reliability of a component is the probability that this component will perform its intended function after a time t in a given working condition. The Global reliability of the system is the product of all reliabilities

$$R_{tot}(t) = \prod_{i=1}^{n} R_i(t) \ \ldots\ldots\ldots\ldots\ldots(1)$$

Here n is the no. of components and It means adding component reduces reliability [1].

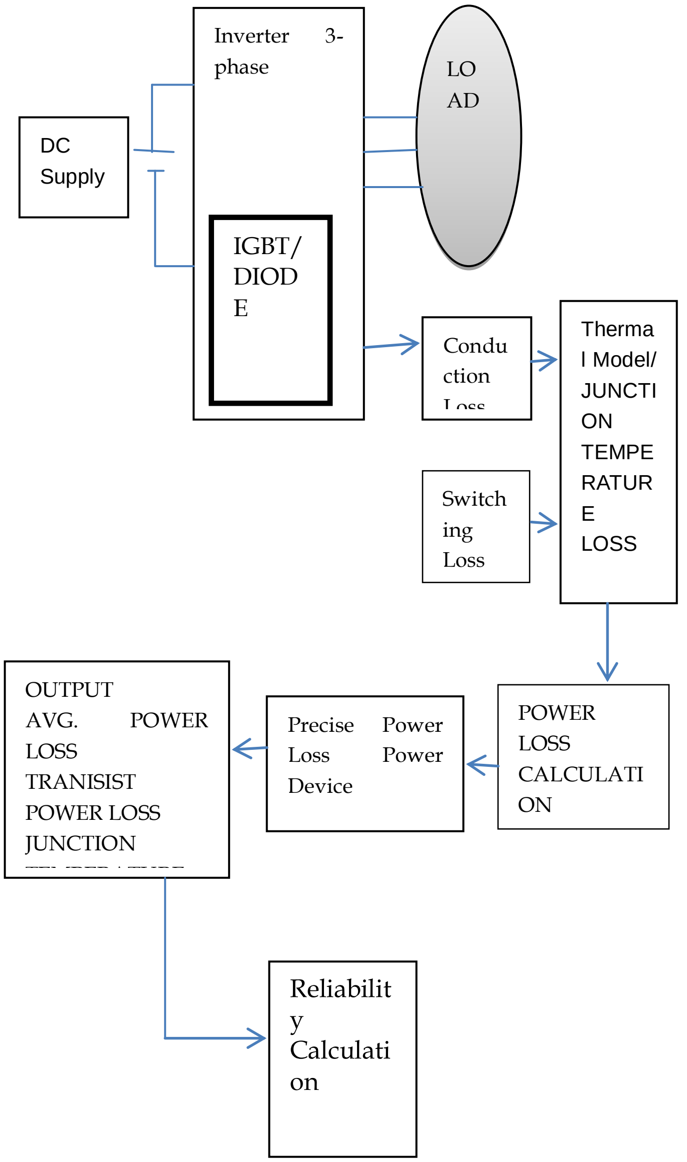

Fig.3Block Diagram Representation of Proposed Mode

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 starting point in reliability analysis is the evaluation of reliability of a device or a component. This is generally done from the available failure data. That is, a large number of identical components are subjected to identical operating conditions and the frequency of their failures is tabulated(1)

6. THERMAL MODELING AND CALCULATION OF JUNCTION TEMPERATURE

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

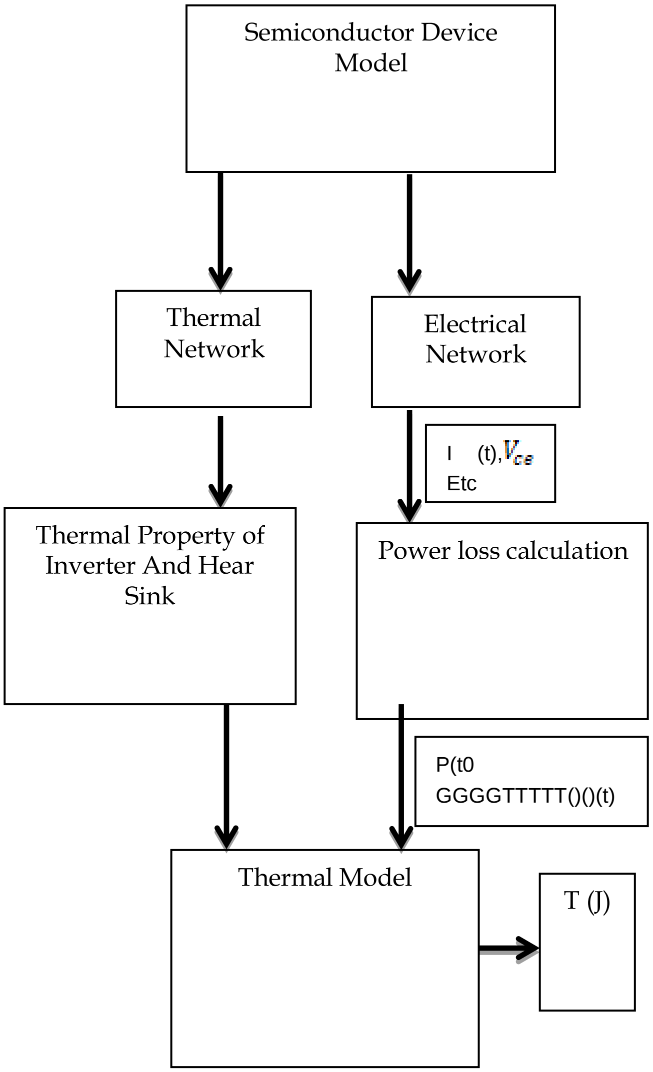

Fig.4Electro-thermal Semiconductor Device Model

The mounting of the device and the heat sink become important in determining the heat removal performance and, hence, must be modeled accurately. Fig. 4 is a diagram of the structure of the electro-thermal semiconductor device models indicating the interaction with the thermal and electrical networks through the electrical and thermal terminals, 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. The input required in the thermal model was the average power output of the semiconductor devices on the VSI module. In order to simulate the average power output of the semiconductor devices, a power loss model of the Semikron VSI module was created in Simulink. The power loss model input variables were set to obtainable lab conditions.. The losses in IGBT i.e. conduction loss and switching loss is calculated and fed to the thermal model. Here it should be noted that switching losses in an IGBT can be found by using datasheets. The thermal model gives the junction temperature as an output, which is later used in calculating reliability of the devices.

7. DETECTION OF TEMPERATURE

A matlab program is developed based on this method. In the first of all extremas are detected. Each time the gradient changes from negative to positive a minimum is detected and each time the slope changes from positive to negative a maximum is detected. This leads to a large amount of extreme values

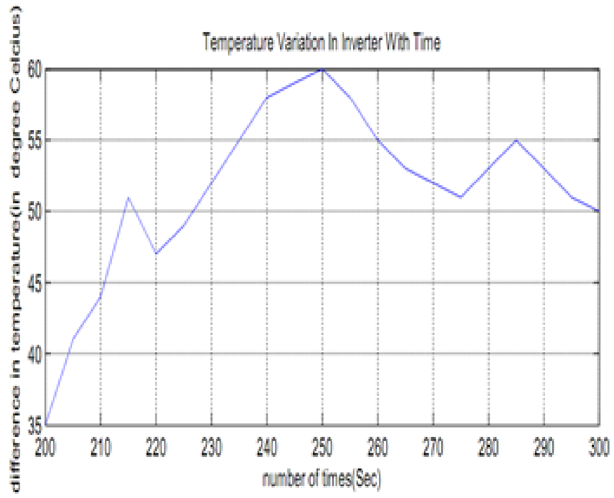

Fig 5.Temperatutre Variation In Inverter

The model consists of an electrical model and a thermal model. The device model, where electrical characteristics of IGBTs or diodes are defined, is connected to the thermal model. The instantaneous value of the device power loss is applied to the thermal model, in which the thermal characteristics of the module are defined. Then, the instantaneous device temperature is generated by the thermal model, and the temperature dependent device model parameters are determined using this instantaneous device temperature. These calculations are performed simultaneously using a circuit simulator. As described above, the device model and the thermal model are essential components of an electro-thermal simulation.

8. CONCLUSION

For calculate reliability of power semiconductors failure-rate catalogs, temperature cycles are importance. Different switching device have been compared to calculate the system reliability based on the generated data. The devices considered here were the IGBT and the diode, the procedure is easily calculated to most other power electronic components like MOSFETs, GTOs etc. To reduce the cost of design and production, increase reliability, quantify the accuracy of the estimated thermal impedance of an IGBT module, predict the maximum switching frequency without violating thermal limits, and to quantify the characteristics of the heat-sink needed to dissipate the heat under worst case conditions. This information is then used in conjunction with detailed device switching models, to describe the heat-source terms for a thermal solver, this allows electro-thermal performance of the inverter to be predicted over long periods of real time. This simulation methodology brings together accurate models of the electrical systems performance conclusion—these should be referenced in the body of the paper.

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