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LOSSES CALCULATION OF PWM INVERTER

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ABSTRACT

A crucial criterion for the dimensioning of converters is the cooling of the power semiconductors and thus determination of power dissipation in the semiconductors at certain operating points. Estimation of its temperature rise of power electronics devices are generally evaluated based on its thermal equivalent circuit. These equivalent circuit models typically composed to thermal RC networks, to the calculated power losses. Methods for the calculation and simulation of semiconductor losses in the converters are well known. In this paper an attempt has been made to calculate power semiconductor losses for Pulse with Modulation(PWM) Inverter. Conduction losses as well as switching losses are included in the calculation using a simplified model, based on power semiconductor data sheet information. Proposed simulation scheme calculates losses with minimum efforts, high accuracy and does not slow down the numerical simulation. It can be embedded directly in any circuit simulator employing ideal switches. Results of the calculation are shown for PWM inverter. As an example, a PWM Inverter is connected to drive a simple resistive load, where the losses calculations are based on datasheet values. Based on these calculations, result of temperature rise of semiconductor devices shown.

Keywords: Switching Losses, Conduction Losses, Electro-Thermal Model, PWM Inverter, IGBT

INTRODUCTION

The electrical characteristics of the power semiconductor devices that are the main components of power IGBT modules (IGBTs and Diodes), depend strongly on their junction temperature. An electro-thermal simulation technique is therefore required to estimate the electrical and thermal behavior of the power IGBT modules. The proposed simulation scheme calculates total the losses including conduction and switching losses. Loss calculations are based on datasheet values of the power module IXDR35N60BD1 as shown in Figure.1 [1].

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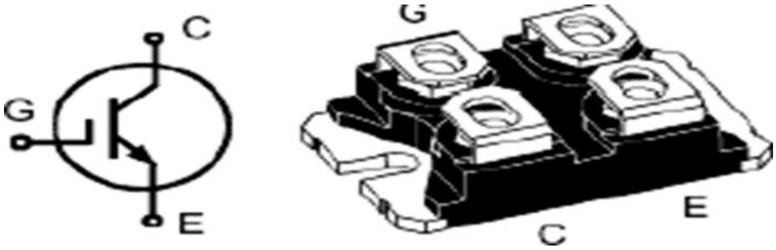

Figure 1: Power module IXDR35N60BD1

The availability of an electro-thermal model is a very important step towards its goal to have a model available for the design of power circuits. Various dynamic electro-thermal simulation methods that can handle this interaction between electrical and thermal phenomena have been introduced. Thermal analysis of a power IGBT consists of three tasks

(1) Developing the thermal characterization of the IGBT
(2) Generating the thermal model
(3) Running a thermal simulation using MATLAB or a similar platform.

In this paper, first the methodology to estimate the conduction and switching losses is described. Second, RC parameter extraction method for the electrical IGBT module is presented. Third, implementation of buck converter using the above models to calculate losses and junction temperature of semiconductor device with the help of using pie thermal model. Finally the results of the proposed circuit topology are presented.

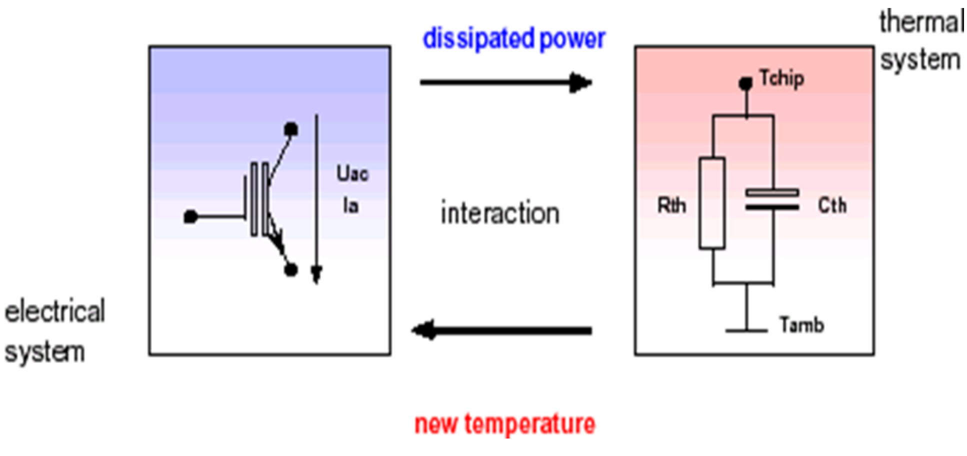

Figure 2: Interaction between the electrical and thermal sub-systems

POWER LOSSES

Power losses are important in several respects. Besides the efficiency of a converter, they determine heat sink and cooling method along with the rating of power semiconductors required. Power losses occur in several ways, explained as follows.

Conduction Losses

Conduction losses are caused by the forward voltage drop when the power semiconductor switches been turned on. Conduction losses of power semiconductors are often calculated by inserting a voltage UF representing the voltage drop and a resistor ron representing the current dependency in series with the ideal device. In this way, the non- linear characteristic of the current-voltage dependency is modeled in a simple way. Adding the ability to measure conduction losses this way means partly rebuilding a system in the circuit simulator. The characteristic describing the relationship between voltage drop VCE and collector current IC of the IGBTs as given in the datasheet is shown in Figure.3(a). We propose to multiply the current IC with the according voltage VCE directly in the datasheet to get the conduction power loss PVCOND dependent on the current IC as shown for two operating temperatures in Figure.3(b).The advantage of this procedure is that the curves in Figure.3(b) and can be approximated very accurately with second order polynomial fitting curves (dashed lines in Figure.3(b)), generally be described by Equation (1).

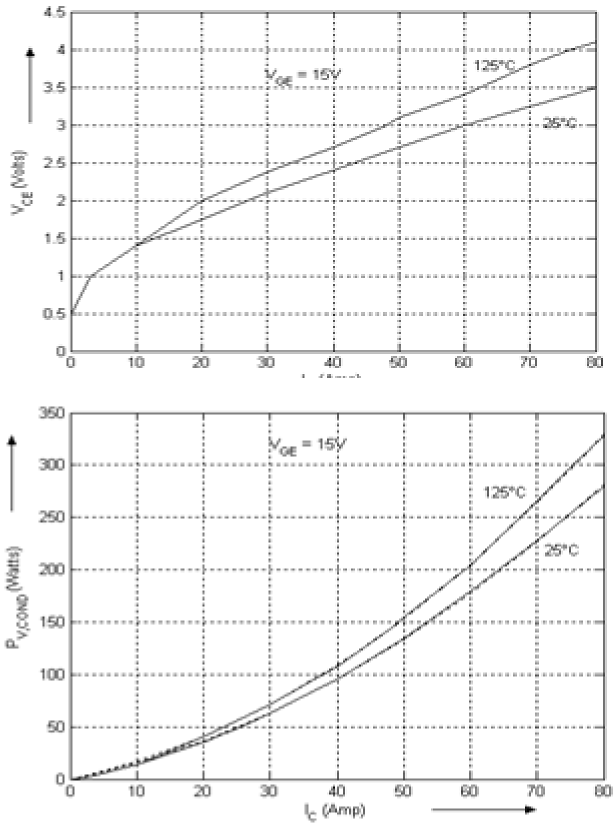

Figure 3(a): V-I characteristic of the IGBTs inside the module IXDR35N60BD1 as given in the datasheet (b): Conduction loss dependent on current for two temperatures

Here from equations (5) & (6) C1 << Co and d1 << do • Therefore (1) can be set up temperature-independent for the highest acceptable junction temperature, e.g. T=125°C. If the junction temperature time behavior simulated under this assumption remains below

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125°C, the assumption is verified and there is even some thermal safety margin built into the design.

By applying the actual current through the IGBT to the 2nd order polynomial fitting curve

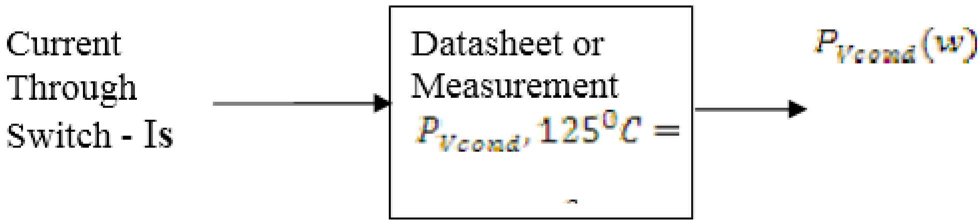

Figure 4: Implementation of conduction loss calculation block

Figure.3(b), the time behavior of the conduction loss PVCOND(t) of the IGBT can be directly calculated in a numerical circuit simulation. Now, equation (1) can be used in the circuit simulation that uses the current through the switch as input value and gives the time behavior of the conduction loss of the IGBT as output during the simulation. In Figure.4 the temperature independent implementation is shown in general form. The block in Figure.4 can be easily added to any ideal circuit simulation with no need to rebuild the power circuit or change the switch models(Vasanthy and Jeganathan 2007, Vasanthy et.al., 2008,Raajasubramanian et.al., 2011, Jeganathan et.al., 2012, 2014, 2020 & 2021 , Sridhar et.al., 2012, Gunaselvi et.al., 2014& 2020, Premalatha et.al., 2015, Seshadri et.al., 2015, Shakila et.al., 2015, Ashok et.al., 2016, Satheesh Kumar et.al., 2016 & 2019).

Switching Losses

In power electronics switching losses typically contribute a significant amount to the total system losses. IGBTs are designed for use in switching converters and not linear operation. This means switching time intervals are short compared to the pulse durations at typical switching Frequencies. This can be seen from their switching times, such as fall time tf and rise time tr in the data sheets[1]. Switching losses occur during these switching intervals. For IGBTs they are specified as an amount of energy for a certain switching operation.

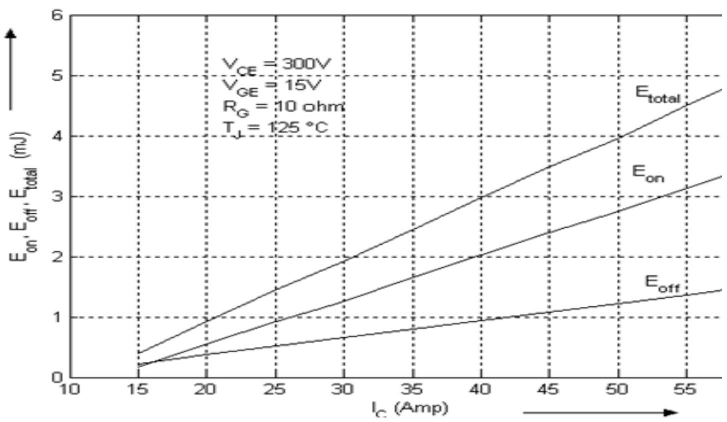

Figure 4: Current-dependent switching energy loss of the IGBT of the module IXDR35N60BD1 for TJ = 125°C.

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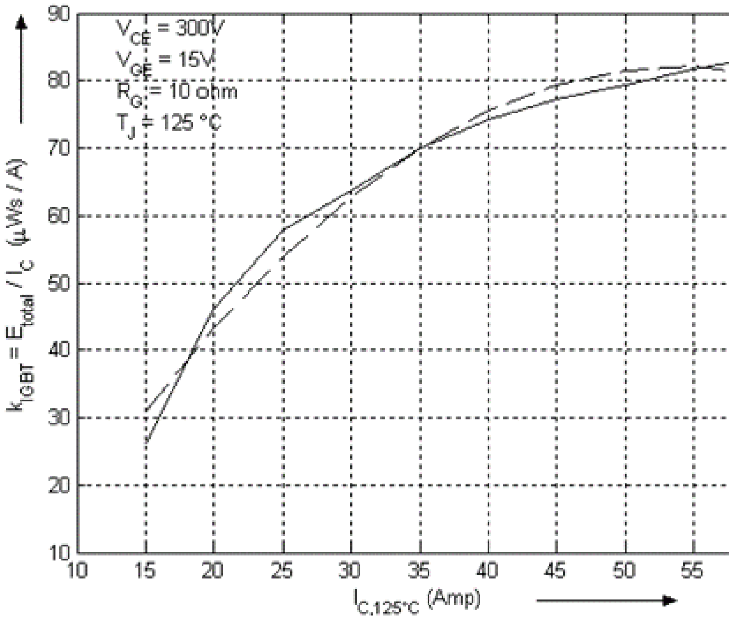

Figure5:The parameter kIGBT [µWs/A] v/s current IC

To calculate the junction temperature time behavior, it is necessary to accurately calculate the switching losses. The current-dependency of switching losses for the IGBT module under investigation as given in the datasheet is shown in Figure.5(a). The parameter KIGBT describing the ratio of the total switching losses and the switched current for the given temperature 125oC is shown in Figure.5(b). These losses are also dependent on the blocking voltage, the junction temperature, the gate resistor and the wiring stray inductance.

A general implementation of the scheme calculating the switching losses is shown in Figure.6. Whenever the switching signal detects a change of state of the ideal switch from OFF to ON, a pulse of height 1.0 is generated with a defined pulse width ΔT. Dividing this pulse through its width ΔT creates a pulse signal with unit [s-1] when multiplied with energy gives the switching loss.

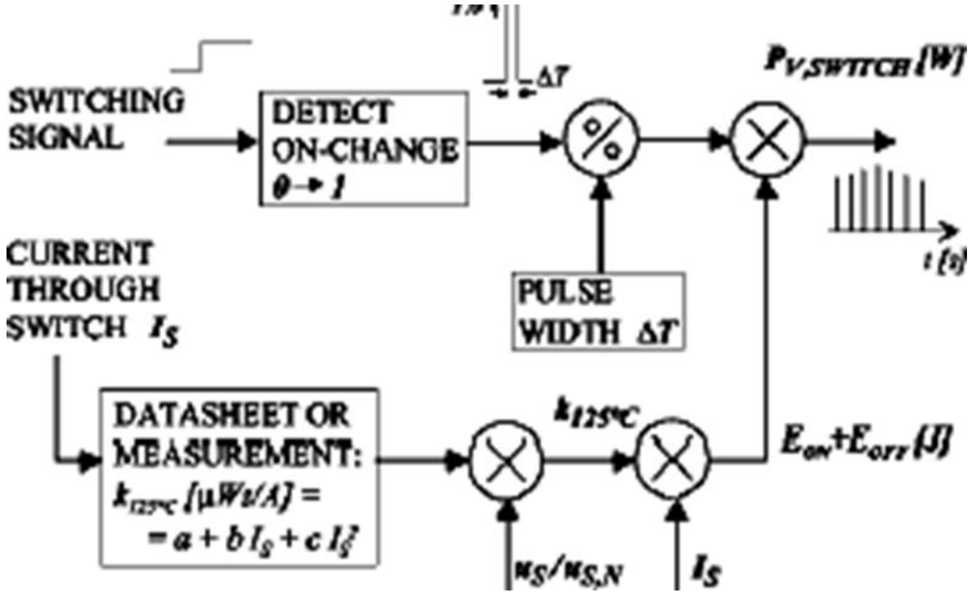

Figure 6: The general scheme for calculating switching losses

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The general scheme employs the current through the switch, the switching signal & the approximation of ratio k. Where, switching signal & the approximation of ratio k. The time-behavior of the current through the ideal switch is taken as the input value, and the switching loss factor k is calculated based on the second-order approximation from the Datasheet. If the blocking voltage uS is different from the one given in the datasheet (uS,N) [1], it can be adjusted by a linear approximation employing the factor (uS/uS,N). Multiplying the actual value of k with the current IS, the total energy loss for the actual current IS and the actual blocking voltage is derived(Manikandan et.al., 2016, Sethuraman et.al., 2016, Senthil Thambi et.al., 2016).

LOSS CALCULATION AND IMPLEMENTATION OF THERMAL MODEL IN PWM INVERTER

The implementation of the loss calculation scheme is shown in Figure. 12 for PWM Inverter shown in Figure.13 [5]. The power circuit is modeled employing ideal switches. The current is measured in the semiconductor device provides an input to the loss calculation scheme. The switching signal of IGBT is used to calculate the switching losses. The total losses of IGBT are fed into the thermal model of semiconductor to calculate the junction temperature time behavior of the device.

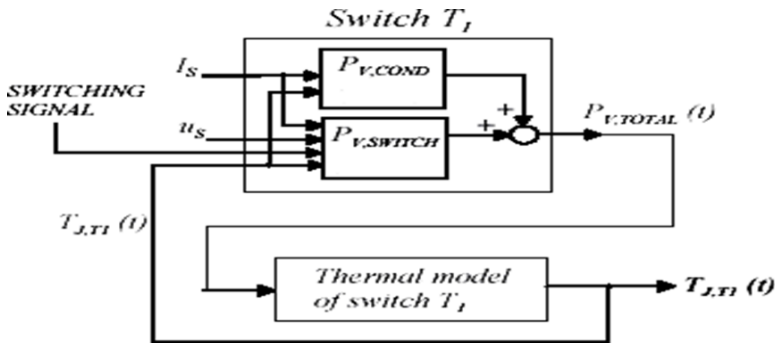

Figure 7: Implementation of the loss calculation scheme in a circuit simulator employing a circuit simulation with ideal switches.

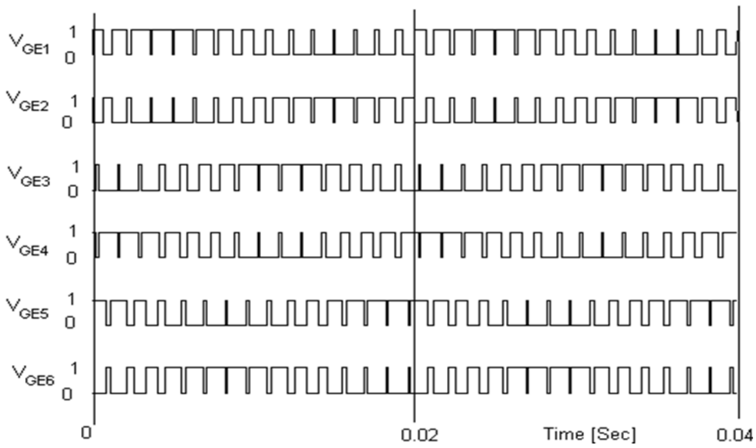

Figure 8: Inverter output voltage and Load voltage

In the above figures the time behavior of key waveforms of simulation is shown together with conduction losses, switching losses and total losses of the semiconductor chip realized by the

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power module IXDN35R60BD1 [1]. The conduction and switching loss characteristics are assumed for a constant junction temperature TJ =125°C.

CONCLUSION

A simple method of generating a thermal model for an IGBT has been presented. The paper discusses estimation of losses of power semiconductors in numerical circuit simulations. The proposed schemes are simple to implement in any circuit simulators. The estimation of the losses is as accurate as the loss data provided by datasheets. Therefore, the accuracy of the resulting total losses is principally not influenced by the proposed loss calculation scheme.

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