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Estimation of Junction Temperature and Power loss of IGBT used in VVVF Inverter using Numerical Solution from Data sheet Parameter

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***Abstract*--Numerical solution of junction temperature measurement is performed by setting up mathematical model of power semiconductor device using data sheet parameter. Calculating or estimating accurately conduction losses and, especially, switching losses has been discussed in the literature but seems to be not well known among many engineers. Therefore, in this paper we will give an overview of this topic and propose improvements of the procedure of loss estimation in power IGBT. The proposed scheme calculates conduction losses and switching losses with minimum effort, high accuracy. Loss calculations are based on datasheet values and/or experimental measurements. As an example, a 90kW-inverter connected to a Variable Frequency drive is set up with each bridge leg realized by a power module, where the characteristic parameters for the loss calculation scheme are extracted from datasheet diagrams and calculated result is verified with "MELCOSIM" which is power loss simulator software developed by MITSUBISHI corporation for proper selection of IGBT module in inverter within its maximum junction temperature limit.**

***Index Terms*—conduction losses, IGBT Junction temperature estimation by mathematical model in PSIM, switching losses, Three phase PWM inverter loss calculation**

I. INTRODUCTION

The insulated gate bipolar transistor (IGBT) is popularly used in high power, high frequency power-electronic applications such as pulse width modulated (PWM) inverters. These applications require well designed thermal management systems to ensure the protection of IGBTs, which operate with smaller safety margins due to economic considerations. Hence, tools for accurate prediction of device power dissipation and junction temperature become important in achieving optimized designs. At high switching frequencies, switching losses constitute a significant portion of the device power dissipation. Therefore, accurate calculation of switching losses is an important step in the thermal management system design [1]. system design guidelines in general and, increasingly, reliability issues put emphasis on the thermal analysis of power electronic systems.Numerical simulation of the junction temperature time behavior in a circuit simulation is possible by setting up a thermal model of power semiconductors and cooling systems, and connecting these thermal equivalent circuits, typically composed of RC networks and/or analytical equations, to the calculated power losses of the semiconductors. Calculating or estimating accurately conduction losses and, especially, switching losses has been discussed in the literature but seems to be not well known among many engineers doing research and development in power electronics. Therefore, in this paper we will give an overview of this topic and propose some improvements in the procedure of loss estimation.

In the following the time behavior of the total losses of the semiconductors of the power module CM400DY-24NF will be discussed and calculated.

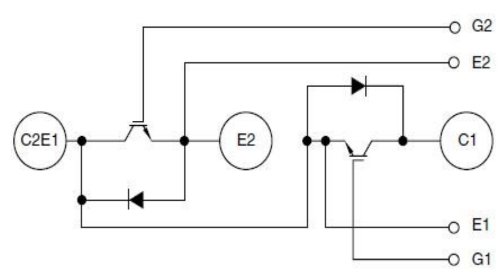

Fig. 1 Circuit diagram of CM400DY-24NF Dual IGBTMOD™ NF-Series 400 Amperes/1200 Volts [2]

The proposed Mathematical scheme calculates total losses with minimum effort, high accuracy and does not slow down the numerical calculation in a significant way. It can be embedded directly in any circuit simulator. Loss calculations are based on datasheet values and/or experimental measurements. [5]

II.VVVF (Variable voltage variable frequency) Inverter loss calculation [3]

One common application of power modules is the variable voltage variable frequency (VVVF) inverter. In VVVF inverters, PWM modulation is used to synthesis sinusoidal output currents. In this application the IGBT current and duty cycle are constantly changing making loss estimation very difficult. The following equations can be used for initial estimation in VVVF applications. Actual losses will depend on temperature, sinusoidal output frequency, output current ripple and other factor. Fig.2 shows typical VVVF inverter circuit. [3]

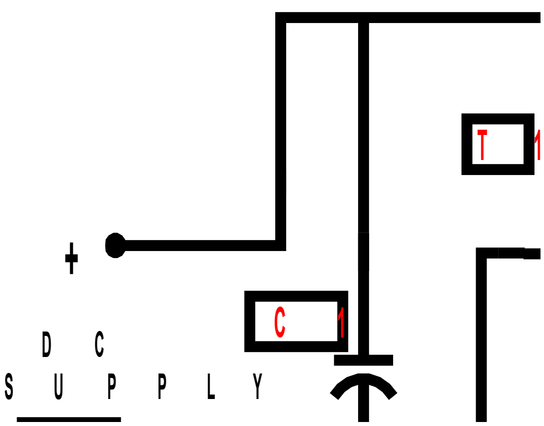

Fig. 2 Circuit diagram of VVVF inverter

III. Estimating power losses of IGBT

The first step in thermal design is the estimation of total power loss. In power electronics circuit using IGBTs the two most important sources of power dissipation that must be considered are conduction losses and switching losses.

A. Conduction losses:

Conduction losses are the losses that occur while the IGBT is On and conducting current. The total power dissipation during conduction is computed by multiplying the On state saturation voltage by the On state current. In PWM application the conduction losses should be multiplied by the duty factor to obtain the average power dissipated. A first approximation of conduction losses can be obtained by multiplying the IGBT's rated Vce(sat) by the expected average device current. Conduction losses can be evaluated from following equation in the case of VVVF inverter application

$$Pcond = Ic \times Vce(sat) \times \frac{1}{2\pi} \left(\frac{1}{8} + \frac{D}{3\pi} \cos \emptyset\right) [1] \quad (1)$$

B. Switching losses:

Switching loss is the power dissipated during the turn On and turn Off switching transitions. In PWM switching losses can sustainable and must be considered in thermal design. To estimate average switching power losses read the Esw(on) and Esw(off) values from the curve at the expected average operating current. Average power dissipation is then given by

$$Psw = Fsw \times \frac{(Esw(on) + Esw(off))}{\pi} [1] \quad (2)$$

The main use of the estimated power loss calculation is to provide a starting point for preliminary device selection. The final selection must be based on the rigorous power and temperature rise calculation.

C. *Total loss per IGBT:*

$$Ptotal = Pcond + Psw \quad (3)$$

I V. COMPUTING POWER LOSS OF FREEWHEELING DIODE

A. Steady state loss per Diode

$$Pdc = Ic \times Vf \times \left(\frac{1}{8} - \frac{D}{3\pi} \cos \emptyset\right) [1] \quad (4)$$

B. Recovery loss per Diode

$$Prr = 0.125 \times Irr \times Trr \times Vce(pk) \times Fsw [1] \quad (5)$$

C. *Total Losses Per Arm (Half Module)*

Pa = PIgbt + Pdiode = Pcond +Psw+Pdc+Prr (6)

V. ESTIMATION OF AVERAGE JUNCTION TEMPERATURE

When operating the power device contained in IGBT and intelligent power modules will have conduction and switching power losses. The heat generated as a result of these losses must be conducted away from the power chips and in to the environment using a heat sink.

If an appropriate thermal system is not used the power device will overheat which could result in failure. In many applications the maximum useable power output of module will be limited by the system thermal design. So it is very important to design very accurate system for getting maximum output from the device.

D. Calculation of case temperature:

$$Tc = Tf + Ptotal \times Rth\,(c-f) \quad [1] \qquad (7)$$

E. Calculation of IGBT junction temperature:

$$Tj_{IGBT} = Tc + PtIGBT \times Rth\,(j-c) \quad [1] \qquad (8)$$

F. Calculation of diode junction temperature:

$$Tj_{diode} = Tc + Ptdiode \times Rth\,(j-c) \quad [1] \qquad (9)$$

Table1. Description of symbol used in Equation

Symbol	Description
Esw(on)	IGBT turn on switching energy @ Ic and T=125
Esw(off)	IGBT turn off switching energy @ Ic and T=125
Fsw	PWM switching frequency
Ic	Peak value of sinusoidal output current
Vce(sat)	IGBT saturation voltage drop @ Ic & T=125
Vf	FWD forward voltage drop @ Ic
D	PWM duty Factor
ϕ	Phase angle between output Voltage & current
Irr	Diode Peak recovery current @ Ic
Trr	Diode reverse recovery time @ Ic
Vce(pk)	Peak voltage across the fwd at recovery
Rth(c-f)	Thermal impedance between case to fin
Rth(j-c)IGBT	Thermal impedance between junction to case
Rth(j-c)fwd	Thermal impedance between junction to case

VI. DERIVATION OF POWER LOSS USING LINEAR POLYNOMIAL EQUATION FOR CM400 DY-24NF IGBT MODULE USED IN 90KW VVVF DRIVE

In this calculation we assume that practically we have known the value of output current(Ic), switching frequency(Fsw) , PWM Modulation rate(D),Power Factor (cosΦ). And we have the data sheet parameter so we can easily find the power losses and hence the Junction Temperature using above derived equation[2] as follow,

Conduction losses of power semiconductors are often calculated by inserting a voltage Vce(sat) 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. [4]

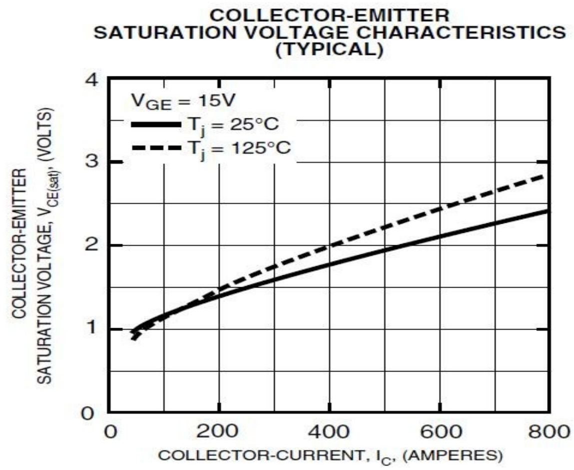

Fig 3.Vce(sat)-Ic Characteristic

The characteristic describing the relationship between voltage drop Vce(sat) and collector current *IC* of the IGBTs as given in the datasheet is shown in **Fig3**.[2] This nonlinear dependency is often modeled in a rough approximation as voltage source and resistor in series with an ideal switch. We propose to multiply the current *IC* with the according voltage Vce(sat) directly in the datasheet to get the conduction power loss *Pcond* dependent on the current *IC* as shown for two operating temperatures in Fig.3.

G. Conduction losses of IGBT using polynomial Equation

The advantage of this procedure is that the curves in Fig.4 can be approximated very accurately with linear polynomial fitting curve and generally be described in a form,

$$Vce(sat) = a + b \times Ic \qquad (10)$$

where the coefficients *a* and *b* are derived by curve fitting. A linear polynomial approximation of the curves shown in Fig.4 gives the parameter values at Tj=125'c

$$Vce(sat) = 0.8978 + 0.002705 \times Ic \qquad (11)$$

From equation (1) we get the conduction loss of IGBT by substitute the value of Vce(sat) calculated by equation (11).

For example we show the comparison table 2 of calculated value and melcosim (power simulator software) result.

*H.**Switchin***
Equation

The curves in Fig.4 can be approximated very accurately with linear polynomial fitting curve and generally be described in a form,

$$Etotal\,(sw) = 0.007473 + 0.0002824 \times Ic \qquad (12)$$

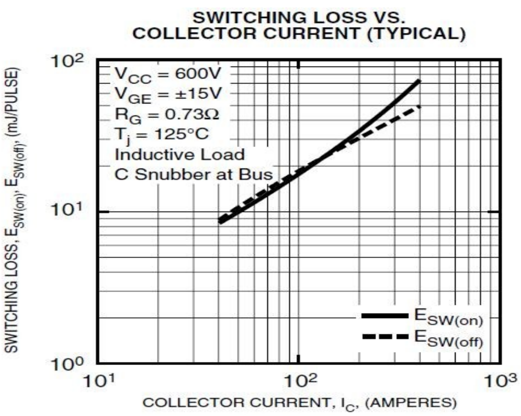

Fig 4.E(sw) -Ic Characteristic from data sheet

From equation (2) we get the switching loss of IGBT by substitute the value of Esw(total) calculated by equation (12).

VII. DIFFERENT PARAMETER VALUE TAKEN IN THE FOLLOWING COMPARISON RESULTS

1. D= 1.0
2. cosΦ= 0.8
3. Fsw= 2khz
4. Vce(pk)= 1200 volt
5. Tf= 90'c (heat sink Temp.)
6. Rth(c-f)= 0.02'c/Watt [2]
7. Rth(j-c)IGBT=0.034'c/watt [2]
8. Rth(j-c)DIODE=0.062'c/watt [2]

TABLE 2. COMPARISION OF CALCULATED RESULT

Output Current Ic A Peak value	TOTAL LOSS/IGBT calculated	Melcosim Result [4] Actual loss	Difference in Value
175	85.579	87.22	1.640
192.5	95.793	97.95	2.156
210	106.394	109	2.605
227.5	117.383	120.24	2.856
245	128.759	131.75	2.990
297.5	165.213	168.12	2.906
315	178.140	180.89	2.749
332.5	191.454	194	2.545

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I. Dc losses of FWD using polynomial Equation

The curves in Fig.5 [2] can be described very accurately with linear polynomial fitting curve and generally be described in a form,

$$Vf\,(\,Tj = 25) = 1.242 + 0.003005 \times Ic \qquad (13)$$

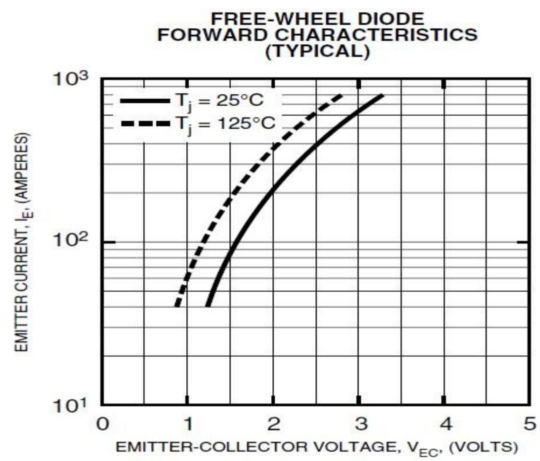

Fig.5 Ic-Vf Characterstic from data sheet

From equation (3) we get the dc loss of FWD by substitute the value of Vf calculated by equation (13).

J. Switching losses of FWD using polynomial Equation

The curves in Fig.6 [2] can be described very accurately with linear polynomial fitting curve and generally be described in a form,

$$Irr = 218.8 + 0.3163 \times Ic \qquad (14)$$

And Trr can be described in a form,

$$Trr = 7.508e - 08 + 1.29e - 10 \times Ic \qquad (15)$$

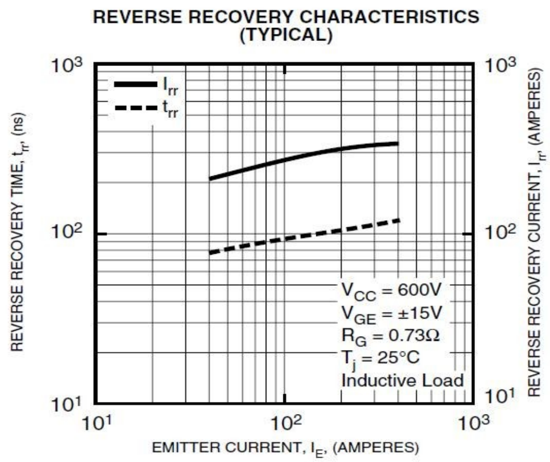

Fig. 6 Irr,Trr Vs Ie characteristic from data sheet

TABLE 3. COMPARISION OF CALCULATED RESULT WITH POWER SIMULATOR SOFTWARE

Output Current Ic A Peak value	TOTAL LOSS/Diode calculated	Melcosim Result Actual loss	Difference in Value
175	20.443	20.84	0.396
192.5	22.442	23.15	0.707
210	24.523	25.5	0.976
227.5	26.684	27.87	1.185
245	28.927	30.28	1.352
262.5	31.252	32.75	1.497
280	33.657	35.28	1.622
297.5	36.144	37.85	1.705
315	38.713	40.46	1.746
332.5	41.362	43.11	1.747

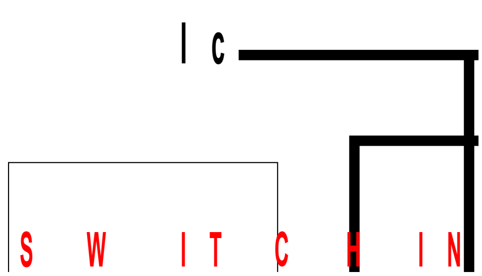

Fig.7: Implementation of the loss calculation scheme

TABLE 4. COMPARISION OF CALCULATED RESULT WITH POWER SIMULATOR SOFTWARE

Output Current Ic Peak value	Calculated Tj IGBT AVG	Melcosim Result Actual	Difference in Value
175	95.030	95.13	0.10
192.5	95.621	95.75	0.12
210	96.235	96.4	0.16
227.5	96.872	97.05	0.17
245	97.531	97.72	0.18
262.5	98.213	98.41	0.19
280	98.917	99.11	0.19
297.5	99.644	99.84	0.19
315	100.393	100.58	0.18
332.5	101.165	101.34	0.17

Output Current Ic Peak value	Calculated Tj DIODE AVG	Melcosim Result [4] Actual	Difference in Value
175	93.38	93.45	0.06
192.5	93.75	93.86	0.10
210	94.13	94.27	0.13
227.5	94.53	94.69	0.15
245	94.94	95.12	0.17
262.5	95.37	95.56	0.18
280	95.81	96.01	0.19
297.5	96.26	96.47	0.20
315	96.73	96.94	0.20
332.5	97.21	97.42	0.20

VIII.NUMERICAL SCHEME IMPLEMENTED IN PSIM

Fig 8 shows the Calculation of power loss and junction temp. for 90 kw inverter drive which has a peak amplitude current(Rated current) of 175 amp. Using linear polynomial Equation in PSIM with the help of Mathematical blocks.

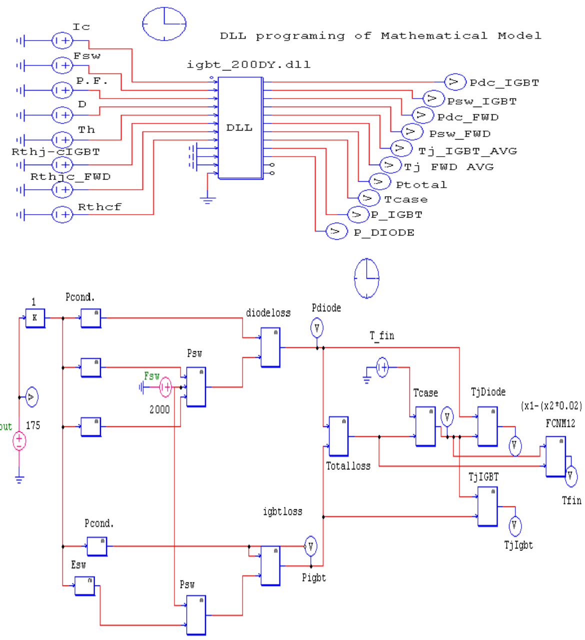

Fig.8 Mathematical solution in PSIM

As shown in above simulation, the Math Block in PSIM software used for solving the numerical equation. In our case the derived linear polynomial equations are solved by this MATH block of PSIM shown as rectangle box in Fig. 8. Below Fig 9 shows the Calculated result which are verify with the melcosim result and shown in table 2 to table 4.

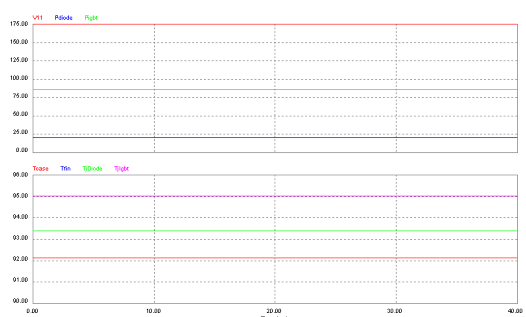

Fig 9.Calculated Result in PSIM

IX. CONCLUSION

The paper discusses loss estimation of power semiconductors using the simple numerical method. The proposed schemes are simple to implement, it doesn't slow down the numerical simulation time. The estimation of the losses, especially of the switching losses of the power semiconductors, is as accurate as the loss data provided by datasheets or experimental measurements. Therefore, the accuracy of the resulting total losses is principally not influenced by the proposed loss calculation scheme it is truly depend upon the datasheets or experimental measurements. From the comparison of both results we can conclude that this method is accurate and time saving for estimation of IGBT junction temperature.

X.REFERENCES

POWEREX, INC."IGBT and Intellimod™ Applications and Technical Data book" *1st edition, pp. A,18-25, October. 1994.*

MITSUBISHI Corporation: Datasheet of IGBT module "CM400 DY-24NF" published at http://www.mitsubishichips.com/

POWEREX, INC."IGBT and Intellimod™ Applications and Technical Data book" *1st edition, pp. A,18-25, October. 1994.*

"MELCOSIM IGBT POWER LOSS SIMULATOR VERSION 4.0.3" from http://www.mitsubishichips.com/Global/index.html

Uwe DROFENIK Johann W. KOLAR "A General Scheme for Calculating Switching- and Conduction-Losses of Power Semiconductors in Numerical Circuit Simulations of Power Electronic Systems". *Power Electronic Systems Laboratory (PES), ETH Zurich ETH-Zentrum / ETL H13, CH-8092 Zurich, Switzerland drofenik@lem.ee.ethz.ch , kolar@lem.ee.ethz.ch*

A.D. Rajapakse, A.M. Gole and P.L. Wilson, "Electromagnetic transient simulation models for accurate representation of switching losses and thermal performance in power electronic systems," *IEEE Trans. Power Delivery*, vol. 20, No.1, pp. 319-327, Jan. 2005.

U. Drofenik, "Embedding Thermal Modeling in Power Electronic Circuit Simulation," *ECPE Power Electronics Packaging Seminar (PEPS), Baden-Dättwil, Switzerland, June 7 – 8, 2004.*

U. Drofenik and J. W. Kolar, "A Thermal Model of a Forced-Cooled Heat Sink for Transient Temperature Calculations Employing a Circuit Simulator", *Proc. of the 5th International Power Electronic Conference(IPEC), Niigata, Japan, April 4 – 8, 2005.*