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***PSIM Software***

**IGBT Loss Calculation  
Using the Thermal Module**

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In this document, the process of calculating the IGBT power losses using PSIM's Thermal Module is described.

As an illustration, Semikon's 3-phase IGBT Module SEMiX151GD066HDs (600V, 150A) is used in the example.

The results from the Thermal Module will be compared with the results from SEMISEL, Semikron's own thermal calculation software.

### **System Operating Conditions:**

The system under study is a 3-phase voltage source inverter, as shown below:

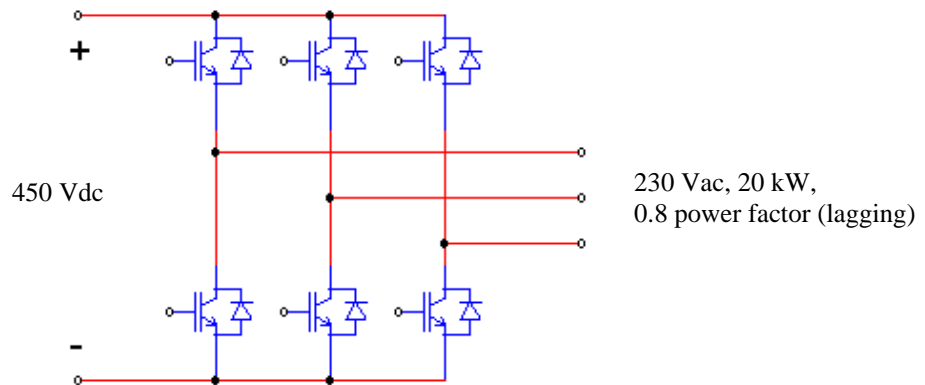


Fig. 1: A 3-phase voltage source inverter

The inverter operating conditions are:

DC Bus Voltage: 450 Vdc  
AC Output: 230 V (line-line, rms), 60 Hz, 20 kW, 0.8 power factor (lagging)  
Switching Frequency: 8 kHz

From the values above, the ac output current is calculated as:  $I_o = 62.75$  A.

### **IGBT Module in the Device Database:**

The first step is to add Semikon's IGBT Module SEMiX151GD066HDs into the device database in PSIM.

Below is the procedure to add this device into the device database.

- In PSIM, go to **Utilities -> Device Database Editor** to launch the Device Database Editor.

- One may choose to add the device to one of the existing device files that came with the PSIM software. But it is recommended that a separate device file be created. In this example, we will create a new device file called “Semikron.dev”, and we will place it in the \device sub-folder in PSIM.

Go to **File** -> **New Device File**, and under the PSIM device sub-folder, create the file “Semikron.dev”. This file will appear in the **File Name** list box at the upper left corner of the Device Database Editor.

- Highlight the file “Semikron.dev”, and go to **Device** -> **New IGBT** to create a new IGBT device. The new device created will be stored in the device file “Semikron.dev”.

Based on the Semikron datasheet for this device, the following will be specified for the new device:

Manufacturer:	Semikron
Part Number:	SEMiX151GD66HDs
Package:	6-Pack
Absolute Maximum Ratings:	
V <sub>ce,max</sub> (V):	600
I <sub>c,max</sub> (A):	150
T <sub>j,max</sub> (oC):	175

- Enter the transistor forward conduction characteristics:

The datasheet does not provide the curve of V<sub>ce(sat)</sub> v.s. I<sub>c</sub>. Only one test point is provided (I<sub>c</sub> = 150 A, T<sub>j</sub> = 150 °C, and V<sub>ce(sat)</sub> = 1.7 V), and this point will be added to the database.

Click on the **Edit** button of the “V<sub>ce(sat)</sub> v.s. I<sub>c</sub>” characteristics, and type (150, 1.7) in the edit field beneath the line “Enter values in the following format”. Note that I<sub>c</sub> is the X axis and V<sub>ce(sat)</sub> is the Y axis. Click on the **Conditions** tab, enter: gate voltage = 15, and junction temperature = 150 °C . These test conditions are obtained from the datasheet. Click on **OK** to close the dialog window.

- Enter the transistor switching energy losses characteristics:

Fig. 3 of the datasheet gives the transistor turn-on/turn-off energy losses E<sub>on</sub> and E<sub>off</sub> as a function of the current I<sub>c</sub>. One can use the Graph Wizard in the Database Editor to capture the curve. Here, for simplicity, we will define the curves by data points through visual inspection. From Fig. 3, we obtain the following energy losses at different current values:

I <sub>c</sub> (A)	E <sub>on</sub> (mJ)	E <sub>off</sub> (mJ)	Err (mJ)
100	4	3	3.75
150	6.2	3.75	5.8
200	8.3	5	7
250	10.8	6.6	8
300	13.3	8.3	8.1

Click on the **Edit** button of the “Eon v.s. Ic” characteristics. Enter the following points in the edit field beneath the line “Enter values in the following format”:

(100, 4) (150, 6.2) (200, 8.3) (250, 10.8) (300, 13.3)

In the dialog, in order to match the graph with Fig. 3 in the datasheet, set  $X0 = 0$ ;  $Xmax = 400$ ;  $Y0 = 0$ ; and  $Ymax = 15$ ; and in the pull-down button for the multiplier factor, choose “m” for the Y axis (this means that the Y axis values shall be multiplied by  $10^{-3}$ ).

Then, click on the **Conditions** tab, and enter the following test conditions obtained from Fig. 3 of the datasheet: dc bus voltage = 300 V; gate voltage from -8 V to 15 V; gate resistance = 4.5 Ohm; and junction temperature = 150 °C. Note that the test dc bus voltage is important as it is used in loss calculation.

Repeat the same process to define the “Eoff v.s. Ic” characteristics. The data points will instead be:

(100, 3) (150, 3.75) (200, 5) (250, 6.6) (300, 8.3)

The test conditions for Eoff are the same as for Eon.

- Enter the diode forward conduction characteristics:

The diode forward conduction characteristics are provided in Fig. 11 in the datasheet. Click on the **Edit** button of the “Vd v.s. IF” characteristics. Enter the following data points to define the curve that corresponds to  $T_j = 150$  °C:

(25, 0.75) (50, 0.9) (100, 1.25) (150, 1.55) (200, 1.77) (250, 2.1)

The curve for  $T_j = 150$  °C is selected as the temperature better reflects the condition that the device will most likely operate under.

In order to match the graph with Fig. 11 in the datasheet, set  $X0 = 0$ ;  $Xmax = 300$ ;  $Y0 = 0$ ; and  $Ymax = 3$ .

- Enter the diode switching characteristics:

The diode reverse recovery characteristics  $t_{rr}$ ,  $I_{rr}$ , and  $Q_{rr}$  v.s. the current  $I_F$  are not provided in the datasheet. Only the characteristics of the reverse recovery energy  $E_{rr}$  v.s. the current are provided in Fig. 3 of the datasheet.

Enter the following data points to define the curve of  $E_{rr}$  v.s.  $I_F$ :

(100, 3.75) (150, 5.8) (200, 7) (250, 8) (300, 8.1)

The unit of  $E_{rr}$  is mJ. The test conditions are: reverse blocking voltage  $V_R = 300$  V, rate of change of the current = 3000 A/us; and junction temperature = 150 °C.

This concludes the entry of the device information into the database. One may fill in the information for the thermal characteristics and the dimension and weight. But the information is not used in the losses calculation.

### Loss Calculation in PSIM:

Once the device is added into the device database, it can be used in PSIM for the loss calculation. To choose this device, in PSIM, go to **Elements** -> **Power** -> **Thermal Module** -> **IGBT (database)**, and place the discrete IGBT element in the schematic. Double click on the IGBT element to open the property dialog window. Click on the Browser button next to the “Device” input field, and choose the device “Semikron SEMiX151GD066HDs”. The IGBT image will change to a 6-pack inverter bridge. Continue to build the rest of the circuit.

The circuit below shows the completed inverter circuit using the IGBT Module SEMiX151GD066HDs. The load resistances and inductances and the modulation index are selected such that the circuit operates under the specified conditions (output of 230 Vac, 20-kW, 0.8 power factor (lagging)).

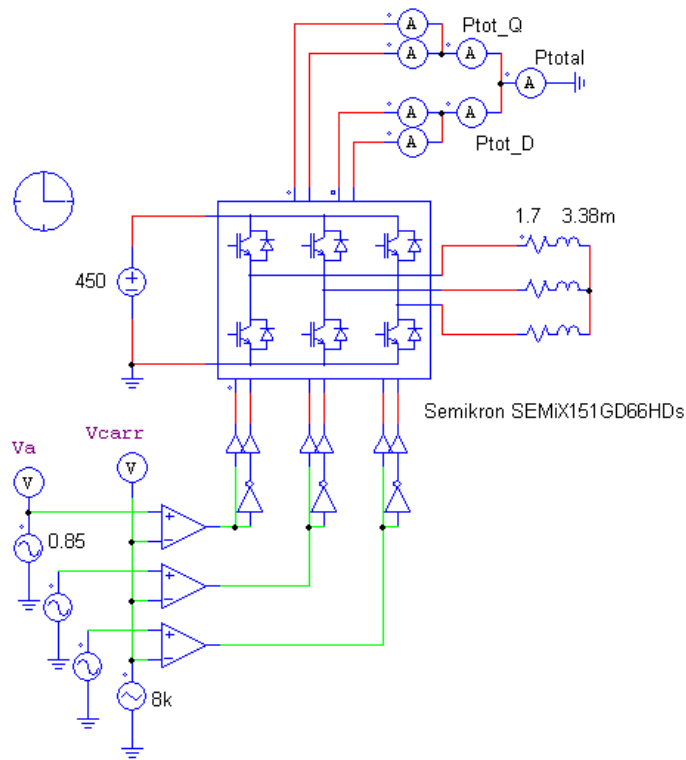


Fig. 2: The inverter circuit for the loss calculation of the IGBT SEMiX151GD066HDs  
(file: “loss calculation IGBT SEMiX151GD066HD.sch”)

The IGBT Module image shows 2 dc bus terminals on the left, 3 ac output terminals on the right, 6 gating signal nodes at the bottom, and 4 extra nodes on the top. These 4 nodes are for the power losses, and they are (from left to right): transistor conduction losses  $P_{cond\_Q}$ , transistor switching losses  $P_{sw\_Q}$ , diode conduction losses  $P_{cond\_D}$ , and diode switching losses  $P_{sw\_D}$ . These losses are for the whole Module (including all 6 IGBT switches). They are in the form of electric currents, and will flow out of these nodes. To measure the losses values, connect an ammeter to each node.

The parameters of the IGBT Module are defined as:

Frequency:	60
Pcond_Q Calibration Factor:	1
Psw_Q Calibration Factor:	1
Pcond_D Calibration Factor:	1
Psw_D Calibration Factor:	1

The frequency defines the interval under which the losses are calculated. For example, if the frequency is 60 Hz, the losses results are the average value for an interval of 16.67 ms. If the frequency is set to be the same as the switching frequency, the losses in each switching cycle are obtained.

The Calibration Factors are used to scale the calculation results against experimental results. For example, for a specific device, if the calculated losses are 10 W, but the measured losses from the experiments are 12 W, the calibration factor shall then be set to 1.2.

The following losses results are obtained from the PSIM simulation:

Diode Conduction Losses:	39.
Diode Switching Losses:	66.85
Diode Total Losses:	105.85
Transistor Conduction Losses:	212.12
Transistor Switching Losses:	153.84
Transistor Total Losses:	365.96
Total Losses per Module:	471.81

To simulate this circuit (schematic file: “loss calculation IGBT SEMiX151GD066HD.sch”), copy the file “Semikron.dev” into the \device sub-folder of the PSIM directory first. Then load the schematic file into PSIM, and run the simulation.

### **Loss Calculation in SEMISEL:**

The losses of the inverter are also calculated using Semikron’s on-line thermal calculation SEMISEL. The SEMISEL calculation is based on the following settings:

Circuit parameter:	
Input voltage:	450 V
Output voltage:	230 V
Cosinus phi:	0.8
Output power:	20 kW
Output current:	63 A
Switching frequency:	8 kHz
Output frequency:	60 Hz
Device:	SEMiX151GD066HD
Enter the calculation method:	use typical values
Enter the correction factor of the switching losses	
Transistor:	1

## IGBT Loss Calculation Using the Thermal Module

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Diode: 1

The following losses results (for the whole Module) are obtained from the SEMISEL calculation:

Diode Conduction Losses:	48
Diode Switching Losses:	72
Diode Total Losses:	120
Transistor Conduction Losses:	162
Transistor Switching Losses:	144
Transistor Total Losses:	306
Total Losses per Module:	426

The results from the Thermal Module compare well with the results from SEMISEL.