CIPOS IPM Simulation Tool

User Manual

About this document

Scope and purpose

This document provides details on how to use the IPM Simulation Tool

Intended audience

This document is intended for all users of the IPM Simulation Tool

Table of Contents

1 Introduction

The IPM Simulation Tool allows the user to simulate and compare Intelligent Power Modules (IPMs) under user-specified application conditions to help determine which IPM will best suit their needs. Currently, there are two simulation applications available: 3-phase inverter motor drive, and PFC boost.

IPM Motor Drive Simulation Tool: https://plex.infineon.com/plexim/ipmmotor.html

IPM PFC Boost Simulation Tool: https://plex.infineon.com/plexim/ipmpfcboost.html

Each application page of the tool consists of four main sections: simulation schematic, parameters, part selection, and results. This document goes into detail on how to use the IPM Simulation Tool, and also provides additional information about each simulation webpage.

Please note, all simulations involve steady-state analysis. While losses are calculated for the IPM, all other components in the schematic are ideal, and do not add losses to the system.

All IPM simulation models are comprised of an electrical and thermal model. Both models are derived from actual characterization of the IPMs, and hence the models align with parameters found in the respective IPM datasheets. Electrical models are based on typical characteristics taken at two temperatures: 25°C and 150°C, and linearly interpolated for all other simulated temperatures. Thermal models are single $Z_{th(J-C)}$ maximum characterization, and correspond at steady state to the maximum $R_{th(J-C)}$ value given in each part's datasheet. If $R_{th(J-C)}$ maximum is not specified in the datasheet, $R_{th(J-C)}$ typical *1.2 is used. For all CIPOS™ Nano IPMs, thermal models use $Z_{th(J-CB)}$ characterization where CB is the case bottom.

2 IPM Motor Drive Simulator

The CIPOS™ IPM Motor Drive Simulator was designed for the user to simulate and compare IPM parts under user-specified, three-phase motor operating conditions to determine which part best suits their needs. This tool shows the expected temperature of the selected IPM, the approximate power losses of the IPM, and waveforms corresponding to the inverter output voltage, output current, junction temperature, and power losses.

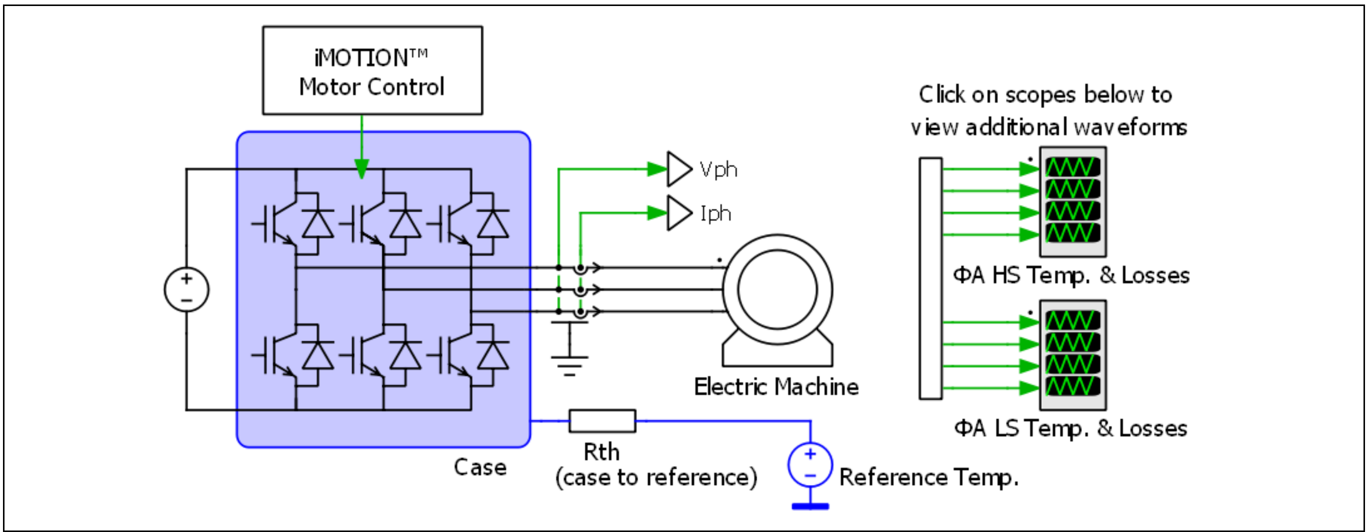


Figure 1 Motor drive schematic

2.1 Input parameters

The IPM motor drive simulator allows the user to input parameters for system and PWM frequency, modulation scheme, input and output voltage, current, power factor, thermal interface material, mounting option, thermal resistance, and reference temperature. Family and package options can be used to filter IPMs. The DC bus voltage input is also used to filter IPMs to only those that can operate at the required voltage. Default values are auto-filled, and the users can overwrite them with their own parameters as needed. The input parameters have range limits to prevent unrealistic outputs. These range limits are as follows:

Table 1 Allowed input parameters

Parameter	Description	Allowed selection
System frequency:	Inverter output fundamental frequency	Between 0.1 Hz and 1000 Hz
PWM frequency:	Pulse-width modulation frequency	Between 0.1 kHz and 100 kHz
Modulation scheme:		Options: ▪ Sine PWM ▪ iMOTION™ Space-Vector PWM ▪ Space-Vector PWM (2-phase 60°) ▪ Trapezoidal 120° ▪ Space-vector PWM high side clamp ▪ iMOTION™ SVPWM low loss, low side clamp
DC bus voltage:	Input voltage **This selection is used to filter parts**	Between 10 V and 1200 V

Parameter	Description	Allowed selection
Voltage to motor, line to line:	Output AC voltage **See note below Table 1***	Limited by DC bus voltage V_{rms}, (V_{peak} for trapezoidal)
Motor drive phase current RMS:	Output single phase RMS current	Between 0.0001 A and 50 A
Power factor:		Between -1 and 1
Thermal interface material:		Options: ▪ Yes ▪ No
Thermal interface resistance:	Thermal resistance of grease, silicon pad, etc. **Will only display if thermal interface material is being used**	Between 0°C/W and 10°C/W
Mounting option:		Options: ▪ Mounted heatsink ▪ In free air ▪ Fixed reference
Temperature:	Will display as ambient or reference temperature depending on mounting option	Between -40°C and 150°C
Thermal resistance	Will display as heatsink, case to ambient, or none depending on mounting option	Between 0°C/W and 100°C/W for all cases
Family and package:	**This selection is used to filter parts**	Options: ▪ All packages ▪ Nano QFN 7x8 ▪ Nano QFN 8x9 ▪ Nano QFN 12x12 ▪ Micro DIP 29x12F ▪ Micro SOP 29x12F ▪ Micro DIP 29x12 ▪ Micro SOP 29x12 ▪ Tiny DIP 34x15 ▪ Tiny SIP 34x15 ▪ Mini DIP 36x21D ▪ Mini DIP 36x21 ▪ Maxi DIP 36x23D

***Note:** If the modulation index (Mi) is known instead of voltage to motor, the following equations can be used to calculate voltage to motor:

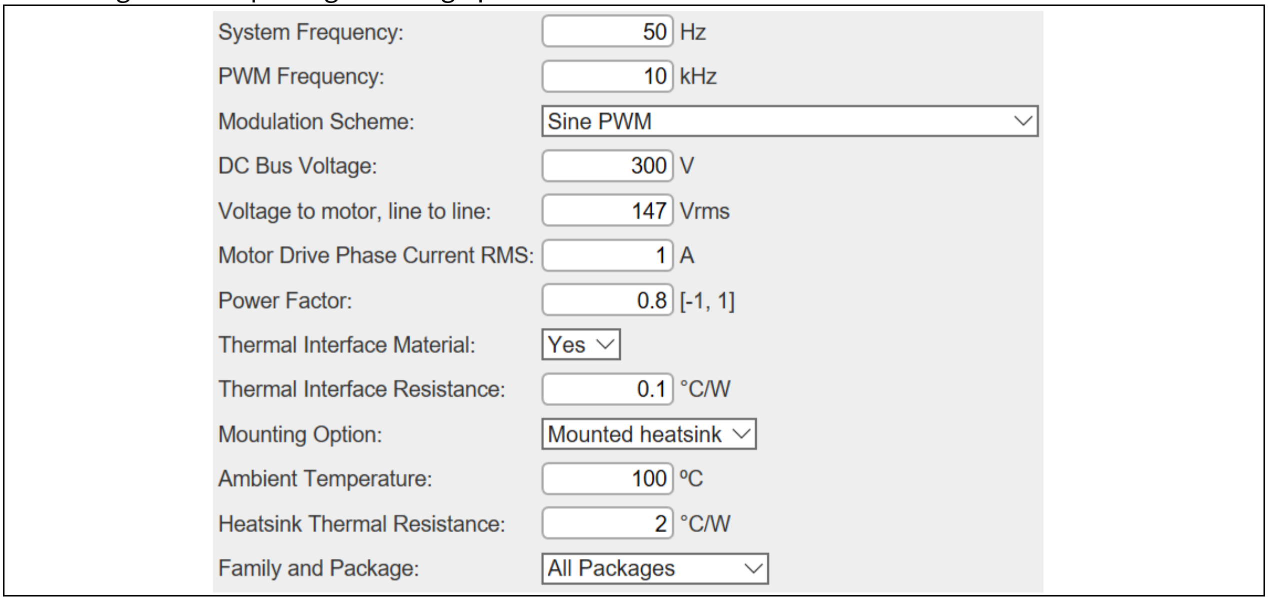
For trapezoidal modulation scheme,

$$Voltage\ to\ motor\ \left(V_{peak}\right) = Mi \bullet V_{DC}$$

For sinusoidal modulation schemes,

$$Voltage\ to\ motor\ (V_{rms}) = \frac{\sqrt{3}}{\sqrt{2*2}} Mi \bullet V_{DC},$$ where V_{rms} is referencing the RMS voltage of the first harmonic.

All input parameters must be filled out before parts are selected, as the available parts list is determined by DC bus voltage and the package filtering option.



System Frequency:	50	Hz
PWM Frequency:	10	kHz
Modulation Scheme:	Sine PWM	
DC Bus Voltage:	300	V
Voltage to motor, line to line:	147	Vrms
Motor Drive Phase Current RMS:	1	A
Power Factor:	0.8	[-1, 1]
Thermal Interface Material:	Yes	
Thermal Interface Resistance:	0.1	°C/W
Mounting Option:	Mounted heatsink	
Ambient Temperature:	100	ºC
Heatsink Thermal Resistance:	2	°C/W
Family and Package:	All Packages	

Figure 2 Input parameters

2.2 Selecting parts

Once all input parameters have been entered, the user can now select a part. The list of parts available depends on the input parameters the user has entered. Highlighted in blue is the part number; clicking on the part number will direct the user to the part's datasheet. Next to the part number is the rated current for IGBT IPMs or the rated $R_{DS(ON)}$ for MOSFET IPMs and its package name. As many parts as desired can be selected, but simulation time will increase with the number of IPMs selected, and graphs may become overcrowded.

The IPM Simulation Tool includes IPMs in configurations other than 3-phase IPMs. The parts list includes single phase (half-bridge), 2-phase (h-bridge), and PFC-integrated IPMs. When simulating a half-bridge IPM such as IRSM807-105MH, simulations consider three IPMs operating a 3-phase motor drive. For 2-phase (h-bridge) IPMs, results are shown as if one part and a single phase of another part are operating. Lastly, for PFC-integrated IPMs, simulations only consider the inverter portion of the IPM. These results can be de-rated for PFC + inverter performance.

Figure 3 **Example of parts' list**

2.3 Running a simulation

Once parts have been selected, the simulation can be started by clicking Get Result at the bottom of the parts list. Once clicked, the simulation will begin to run and will read "Calculating Jacobian: X/41" below the button. Once finished, Analysis Completed will appear in its place. Pressing the Get Result button before the analysis is completed will abort the calculation. The user can save the current simulation by pressing the Hold Result button. This will open a Result History log at bottom to show all traces saved. Clicking the (-) next to the part will remove its simulation results. Clicking a (+) next to the part will hold the simulation results until removed. Held results are indexed with a trace number. The trace number is auto-incremented as additional simulation results are held. By clicking on the name in the trace, the user can rename as desired. This is beneficial as the user can add information from the input parameters to represent each trace.

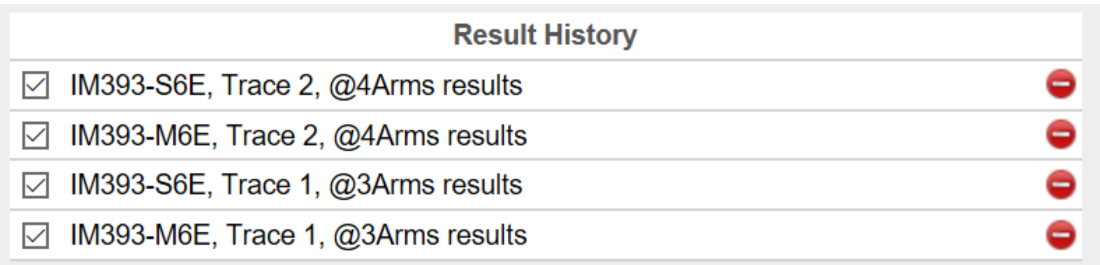


Figure 4 **Result History example**

2.3.1 Simulation errors

If the simulation experienced any issues while running, an error message will be displayed below the Get Result button. Common errors that may be displayed are as follows:

Table 2 **Common simulation errors**

Error message	Explanation
Enter into over-modulation range.	This tool does not support over-modulation conditions. For sinusoidal modulations, value must be between 0 and 1. For all other modulations, value must be between 0 and 1.15.
IGBT is running over its maximum junction temperature! Please adjust your simulation parameters or chose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for all IPMs is 150°C.

Error message	Explanation
Diode is running over its maximum junction temperature! Please adjust your simulation parameters or chose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for all IPMs is 150°C.
Steady-state analysis failed to converge after 20 iterations.	This error normally occurs when parameters are too extreme for the selected device. Usually in this case, the user will receive an over-temperature warning as discussed above. For some cases this warning may appear instead.
Analysis exceeded a maximum runtime of x seconds.	This error occurs when the simulation is taking too long to solve. Normally, this error may be seen when a very low system frequency is entered. If you receive this error, please refresh the simulation page and try again. If the error still occurs, please contact technical assistance.

2.4 Simulation results

IPM Motor Drive Simulator outputs a total of 11 graphs in 3 scopes for the user to view. These include inverter output waveforms, high side temperature and losses, and low side temperature and losses for both the switch and diode. The inverter output graph is shown automatically, and the other graphs can be viewed by clicking their corresponding waveform scopes in the schematic. These scopes can be reordered by dragging the title bars. They can also be resized by dragging the small blue arrow in the bottom of each scope. The simulation offers many tools for analysis located on the title bar of each of the three scopes. Free zoom and fixed zoomed can be used to better view each graph. The cursor tool allows the user to move two cursors to measure voltage, current, losses, and temperature at any given time in the scope.

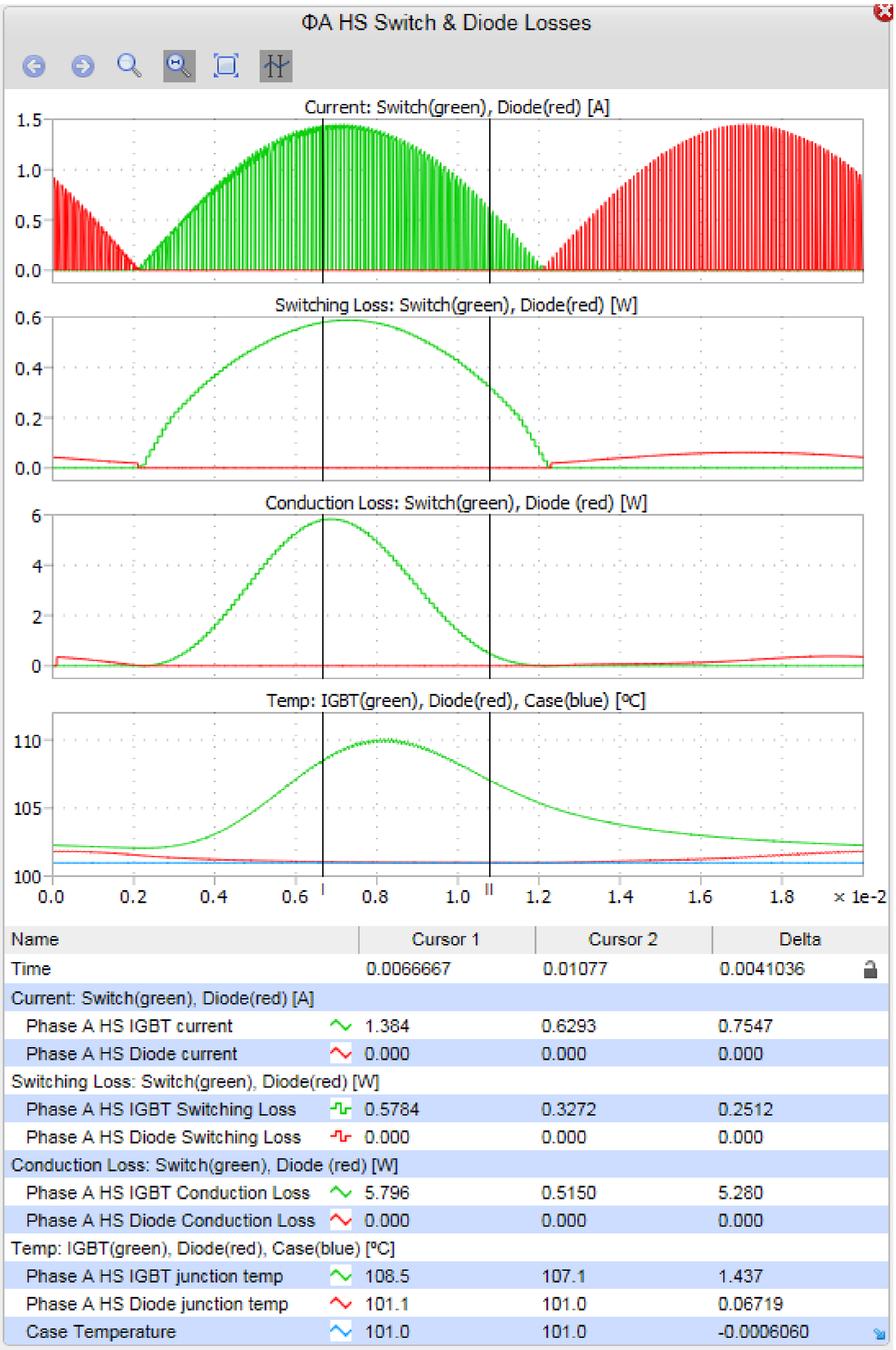


Figure 5 ΦA HS scope example

2.5 Results tables

The inverter losses result table displays the total losses for the switch, diode, and the whole IPM part under the given conditions. Also included in this table is the efficiency, output power, and average case temperature. The phase-A high side and low side result tables show switching losses, conduction losses, average temperature and maximum temperature of both the switch and diode inside the IPM.

Inverter Losses					
	Part Name	Total	Efficiency	Output Power	Avg. Case Temp.
All Switches	IKCM15H60GA	27.15 W			
All Diodes	IKCM15H60GA	6.07 W			
Inverter	IKCM15H60GA	33.21 W	96.85 %	1053 W	94.74 °C

Phase A High Side Device Losses and Junction Temperatures							
	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IKCM15H60GA	0.66 W	0.82 W	1.48 W	3.05 W	117.2 °C	126.6 °C
Diode	IKCM15H60GA		0.23 W	0.23 W	0.78 W	100.7 °C	104.0 °C

Phase A Low Side Device Losses and Junction Temperatures							
	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IKCM15H60GA	0.66 W	0.82 W	1.48 W	3.04 W	117.2 °C	126.6 °C
Diode	IKCM15H60GA		0.23 W	0.23 W	0.78 W	100.7 °C	104.0 °C

Figure 6 Results table example

In the case of IGBT-based IPMs, the IGBT losses are listed under "Switch" while the diode losses are listed under "Diode".

In the case of IPMs containing RC-IGBTs (reverse conducting IGBTs), the split is similar although the IGBT and diode are located on the same physical chip.

In the case of IPMs containing MOSFETs, the forward conduction losses, E_{on} and E_{off} are grouped under "Switch" while the reverse conduction losses and reverse recovery losses are grouped under "Diode". For MOSFET products, the "Switch" and "Diode" temperatures are the same as the diode is the intrinsic body diode of the MOSFET structure.

3 IPM PFC Boost Simulator

3.1 Input parameters

The IPM PFC Boost Simulator allows the user to enter parameters for input AC voltage, current, and frequency, PWM frequency, DC output voltage, thermal interface material, mounting option, thermal resistance, and reference temperature. Default values are auto-filled; the users can overwrite them with their own parameters as needed. The input parameters have range limits to prevent unrealistic outputs. These range limits are as follows:

Table 3 Allowed input parameters

Parameter	Description	Allowed selection
Input AC voltage:		Between 90 V_{rms} and 300 V_{rms}
Input AC current:		Between 0.1 A_{rms} and 50 A_{rms}
AC frequency:	Input fundamental frequency	Between 0.1 Hz and 100 Hz
Modulation scheme:		PFC continuous conduction mode
PWM frequency:	Pulse-width modulation frequency	Between 0.1 kHz and 100 kHz
DC output voltage	Value must be larger than peak of input AC voltage	Between 127 V and 900 V
Thermal interface material:		Options: ▪ Yes ▪ No
Thermal interface resistance:	Thermal resistance of grease, silicon pad, etc. **Will only display if thermal interface material is being used**	Between 0°C/W and 10°C/W
Mounting option:		Options: ▪ Mounted heatsink ▪ In free air ▪ Fixed reference
Temperature:	Will display as ambient or reference temperature depending on mounting option	Between -40°C and 150°C
Thermal resistance	Will display as heatsink, case to ambient, or none depending on mounting option	Between 0°C/W and 100°C/W for all cases
Family and package:	**This selection is used to filter parts**	Options: ▪ All packages ▪ Mini DIP 36x21D

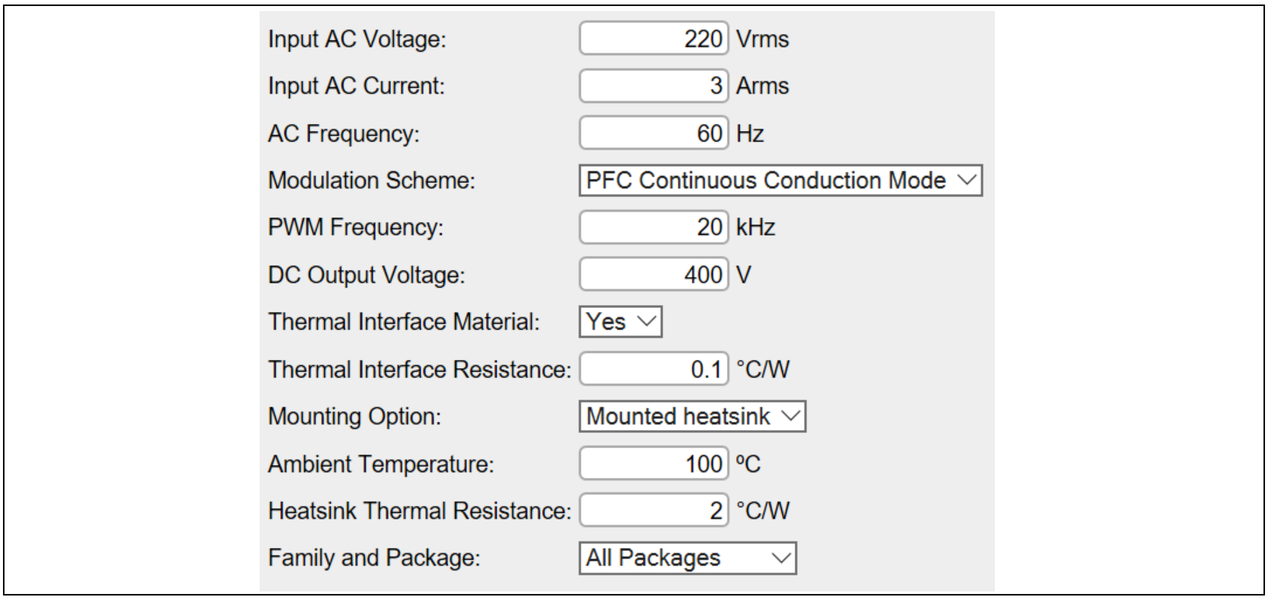


Figure 7 Input parameters

3.2 Selecting parts

Once all input parameters have been entered, the user can select a part. Highlighted in blue is the part number; clicking on the part number will direct the user to the part's datasheet. Next to the part number is the rated current for the IPMs and its package name. As many parts as desired can be selected, but simulation time will increase with the number of IPMs selected, and graphs may become overcrowded.

There are three IPM configurations that are included in the PFC boost simulation. These include: PFC-integrated, 2-phase interleaved, and 3-phase interleaved. For PFC-integrated IPMs, only the PFC portion is simulated. The inverter portion of the IPM can be simulated in the IPM Motor Drive Simulator.

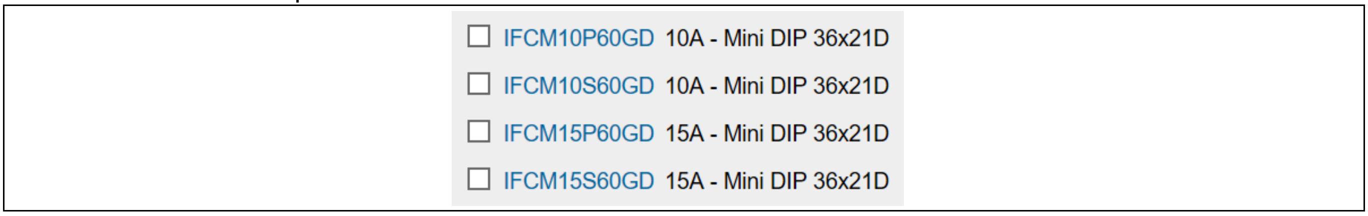


Figure 8 Parts' list example

3.3 Running a simulation

Once parts have been selected, the simulation can be started by clicking Get Result at the bottom of the parts' list. Once clicked, the simulation will begin to run and will read "Calculating Jacobian: X/22" below the button. Once finished, "Analysis completed" will appear in its place. Pressing the Get Result button before the analysis is completed will abort the calculation. The user can save the current simulation by pressing the Hold Result button. This will open a Result History log below to show all traces saved. Clicking the (-) next to the part will remove its simulation results. Clicking a (+) next to the part will hold the simulation results until removed. Held results are indexed with a trace number. The trace number is auto-incremented as additional simulation results are held. By clicking on the name in the trace, the user can rename as desired. This is beneficial as the user can add information from the input parameters to represent each trace.

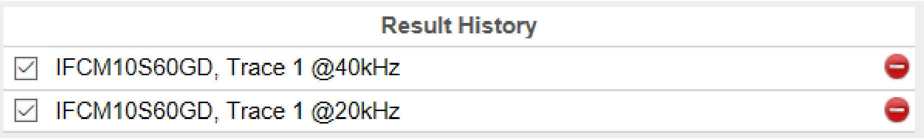


Figure 9 Results history example

3.3.1 Simulation errors

If the simulation experienced any issues while running, an error message will display below the Get Result button. Common errors that may be displayed are as follows:

Table 4 Common simulation errors

Error message	Explanation
V_{dc} parameter too low. Minimum value must be (Input AC V_{rms})*√2	V_{dc} value must be higher than the peak of the specified input AC voltage. If it is lower than this value, the simulation will stop and this message will appear.
IGBT is running over its maximum junction temperature! Please adjust your simulation parameters or chose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for all IPMs is 150°C.
Diode is running over its maximum junction temperature! Please adjust your simulation parameters or chose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for all IPMs is 150°C.

3.4 Simulation results

IPM PFC Boost Simulator outputs a total of eight graphs in two scopes for the user to view. These include input and output voltage and current, current through the switch and diode, as well as conduction losses, switching losses and junction temperature for both the switch and diode. These scopes can be reordered by dragging the title bars. They can also be resized by dragging the small blue arrow in the bottom of each scope. The simulation offers many tools for analysis located on the title bar of each of the three scopes. Free zoom and fixed zoomed can be used to better view each graph. The cursor tool allows the user to move two cursors to measure voltage, current, losses, and temperature at any given time in the scope.

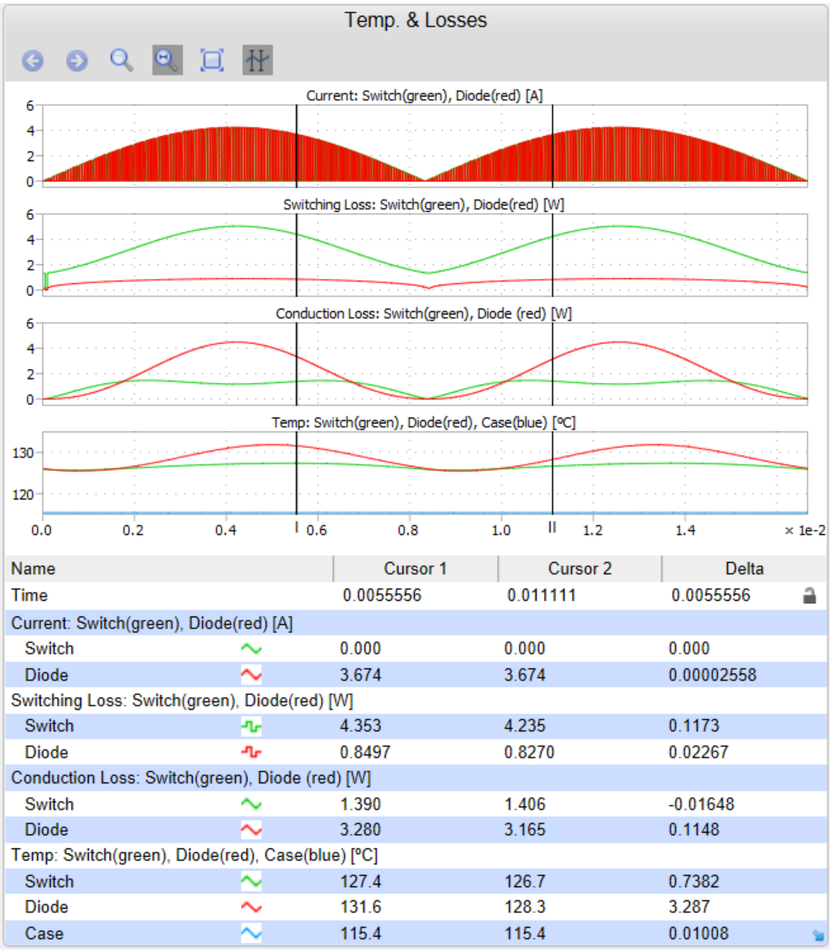


Figure 10 Temperature & losses scope example

3.5 Results tables

The PFC Losses result table displays the total losses for the switch, diode, and the PFC portion of the IPM under the given conditions. Also included in this table is the efficiency, output power, and average case temperature. Efficiency only accounts for the losses of the switch and diode, as all other components are ideal. The loss breakdown and junction temperatures result table shows switching losses, conduction losses, average junction temperature and maximum junction temperature of both the PFC switch and diode inside the IPM.

PFC Losses

	Part Name	Total	Efficiency	Output Power	Avg. Case Temp
Switch	IFCM15S60GD	2.92 W			
Diode	IFCM15S60GD	2.80 W			
PFC	IFCM15S60GD	5.72 W	0.99 %	654.3 W	117.7 °C

Loss Breakdown and Junction Temperatures

	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IFCM15S60GD	0.60 W	1.45 W	2.04 W	0.88 W	121.2 °C	122.4 °C
Diode	IFCM15S60GD		1.36 W	1.36 W	1.43 W	125.5 °C	126.7 °C

Figure 11 Results table example

Revision History

Document Version	Date of Release	Description of changes
1.0	08/07/2017	Initial document
1.1	11/27/2017	Updated to include new parameters and schematic
2.0	03/01/2019	Expanded document to include PFC Boost simulation along with minor revisions to sections.

[1]

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