

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

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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 four simulation applications available: 3-phase inverter, H-bridge inverter, PFC + 3-phase inverter, and PFC boost.

IPM Simulation Tool: <https://www.infineon.com/cms/en/tools/landing/ipm.html>

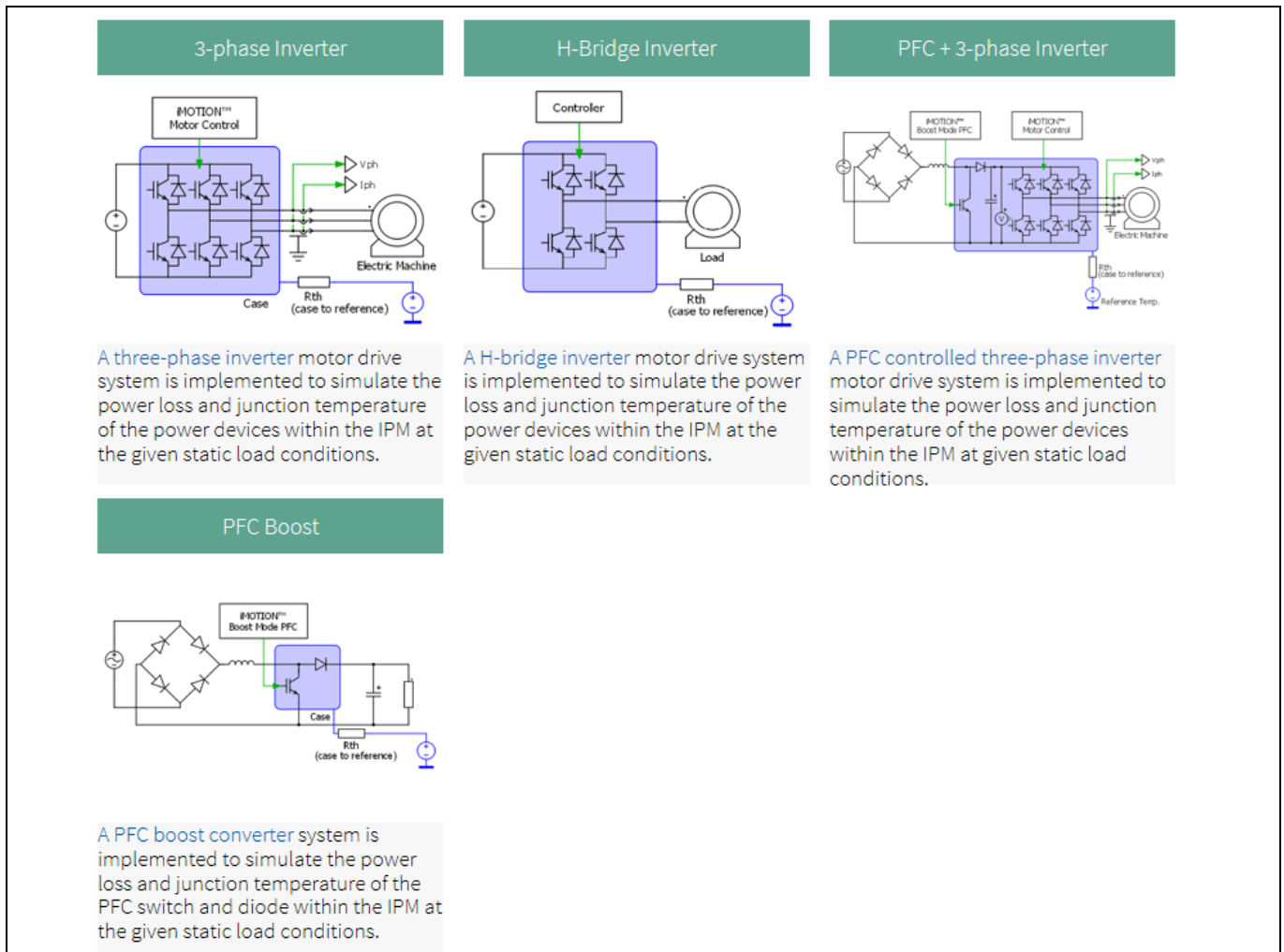


Figure 1 Simulation applications

Each simulation application page consists of four main sections: simulation schematic, parameter entry, 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 application webpage.

Please note that 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 3-phase inverter simulator

The CIPOS™ IPM 3-phase inverter 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.

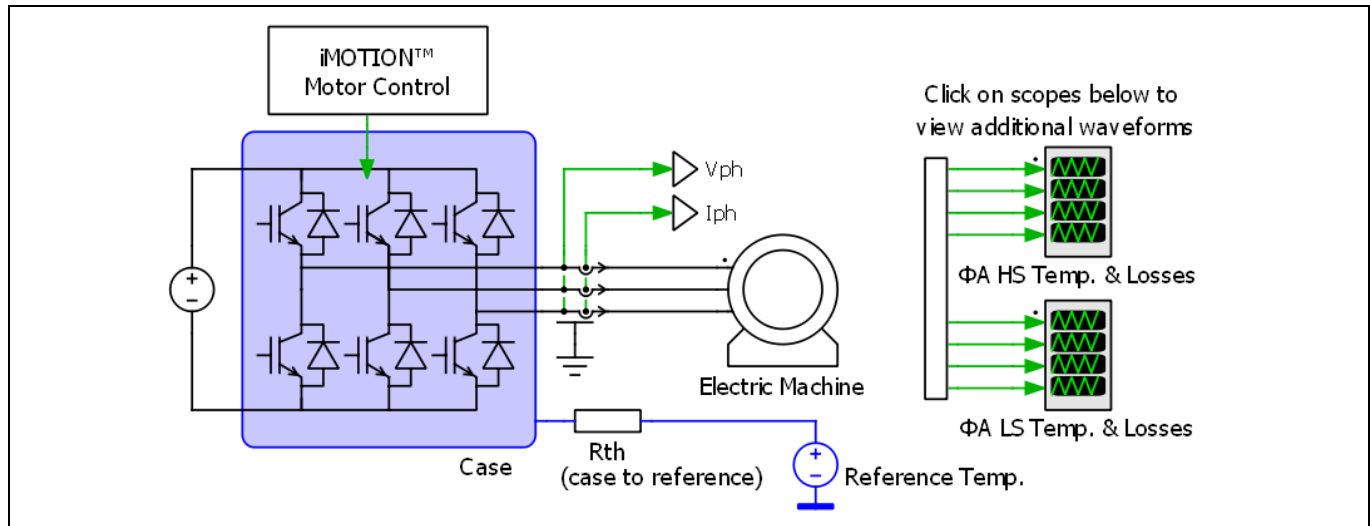


Figure 2 3-phase inverter schematic

2.1 Input parameters

The IPM 3-phase inverter 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	See section 2.1.1 for more detailed information	Options: ▪ Sine PWM ▪ iMOTION™ SVPWM ▪ SVPWM (2-phase 60°) ▪ Trapezoidal 120° ▪ SVPWM 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

IPM 3-phase inverter simulator

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
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
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
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

IPM 3-phase inverter simulator

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

For trapezoidal modulation scheme,
$$\text{Voltage to motor } (V_{peak}) = M_i \cdot V_{DC}$$

For sinusoidal modulation schemes,
$$\text{Voltage to motor } (V_{rms}) = \frac{\sqrt{3}}{\sqrt{2} \cdot 2} M_i \cdot V_{DC}, \text{ where } V_{rms} \text{ is referencing the RMS voltage of the first harmonic.}$$

All input parameters must be filled in 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]
Mounting Option:	Mounted heatsink
Ambient Temperature:	100 °C
Heatsink Thermal Resistance:	2 °C/W
Thermal Interface Material:	Yes
Thermal Interface Resistance:	0.1 °C/W
Family and Package:	All Packages

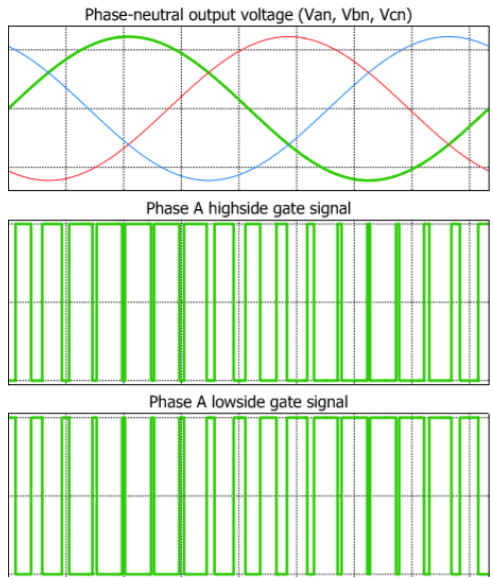
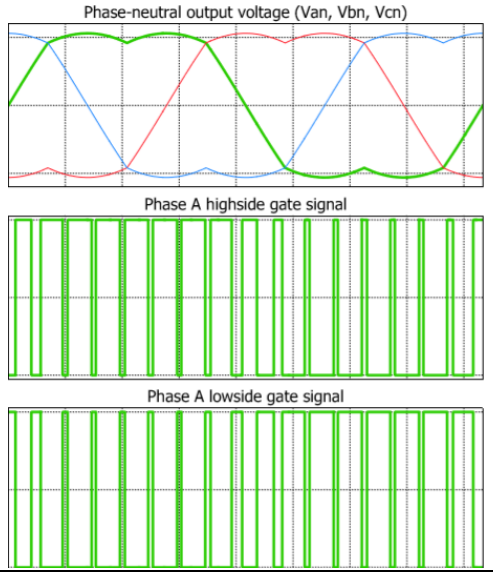
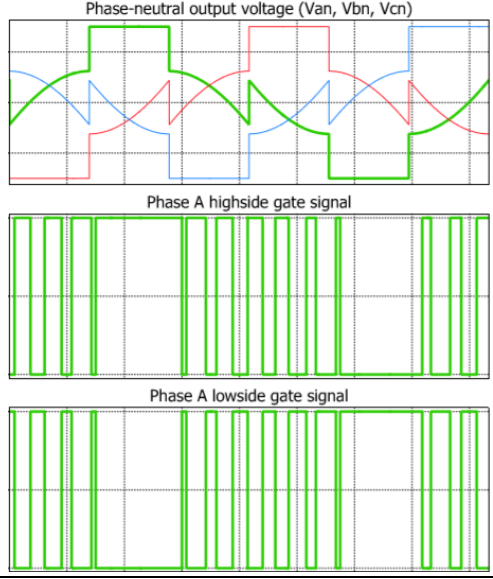
Figure 3 Input parameters

2.1.1 Modulation schemes

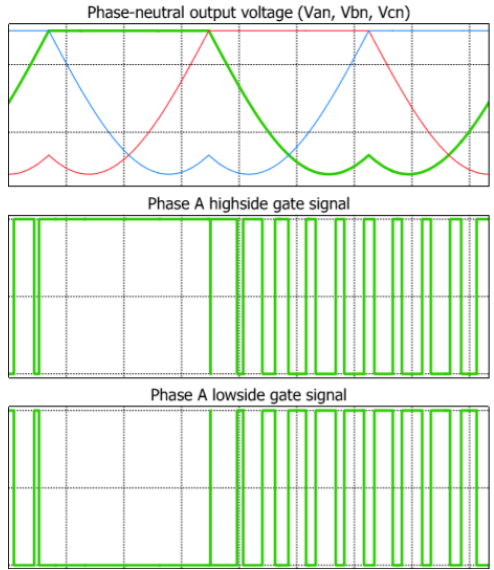
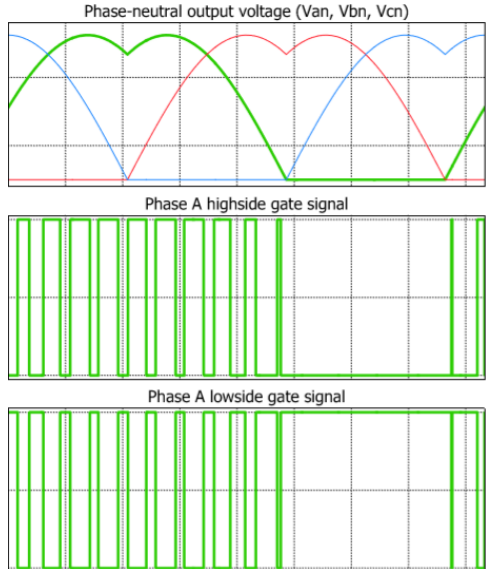
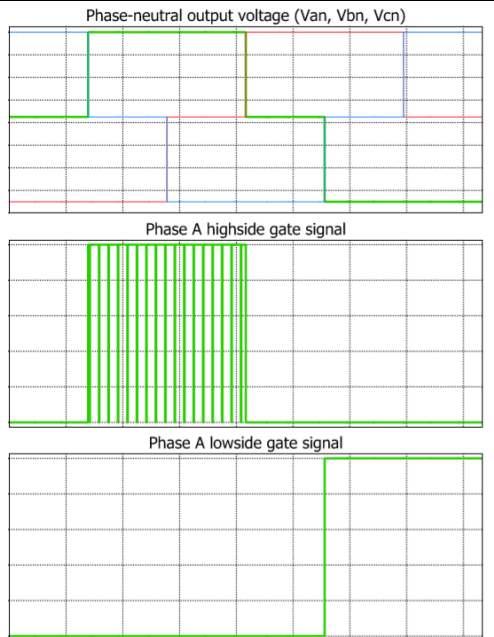
There are several modulation schemes available for sine-wave current operation and square-wave current operation in the simulation tool. Sine-wave current operation can be classified into two groups: continuous and discontinuous. Normally, discontinuous PWM scheme is used for reducing switching losses at the cost of higher harmonics in the output current. Available modulation schemes are detailed in Table 2.

Table 2 Modulation schemes description

IPM 3-phase inverter simulator

Name	Current output	Description	PWM scheme and signal
Sine PWM	Sinusoidal	Alternative names: - SPWM 3-Phase Sinusoidal PWM	
iMOTION™ SVPWM	Sinusoidal	Alternative names: - SVPWM 3-Phase Continuous Space Vector PWM	
SVPWM (2-phase 60°)	Sinusoidal	Alternative names: - SVPWM60 - SVPWM discontinuous symmetrical	

IPM 3-phase inverter simulator

Name	Current output	Description	PWM scheme and signal
SVPWM high-side clamp	Sinusoidal	Alternative names: - SVPWM120HS 3-phase 120° discontinuous SVPWM (high-side fully on)	
iMOTION™ SVPWM low loss, low-side clamp	Sinusoidal	Alternative names: - SVPWM low-side clamp - SVPWM120LS 3-phase 120° discontinuous SVPWM (low-side fully on)	
Trapezoidal 120°	Square	Alternative names: - PWM BLDC 120 2-ph PWM with lowside 120° fully on High-side switch modulates the duty cycle while the low-side switch conducts the current continuously for a 120° duration.	

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 3-phase 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.

☐	IRSM515-065DA	1.3Ω - Micro DIP 29x12F
☐	IRSM515-065PA	1.3Ω - Micro SOP 29x12F
☐	IRSM506-076DA	4A - Micro DIP 29x12F
☐	IRSM506-076PA	4A - Micro SOP 29x12F
☐	IRSM516-076DA	4A - Micro DIP 29x12F
☐	IRSM516-076PA	4A - Micro SOP 29x12F
☐	IM393-S6E	6A - Tiny DIP 34x15
☐	IM393-S6F	6A - Tiny SIP 34x15
☐	IM393-M6E	10A - Tiny DIP 34x15
☐	IM393-M6F	10A - Tiny SIP 34x15

Figure 4 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.

Result History		
☒	IM393-S6E, Trace 2, @4Arms results	-
☒	IM393-M6E, Trace 2, @4Arms results	-
☒	IM393-S6E, Trace 1, @3Arms results	-
☒	IM393-M6E, Trace 1, @3Arms results	-

Figure 5 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 3 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 the majority of IPMs is 150°C but the simulation will show results up to 200°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 the majority of IPMs is 150°C but the simulation will show results up to 200°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

The IPM inverter simulation outputs a total of 11 graphs in 3 scopes for the user to view. These include inverter output waveforms, highside temperature and losses, and lowside 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.

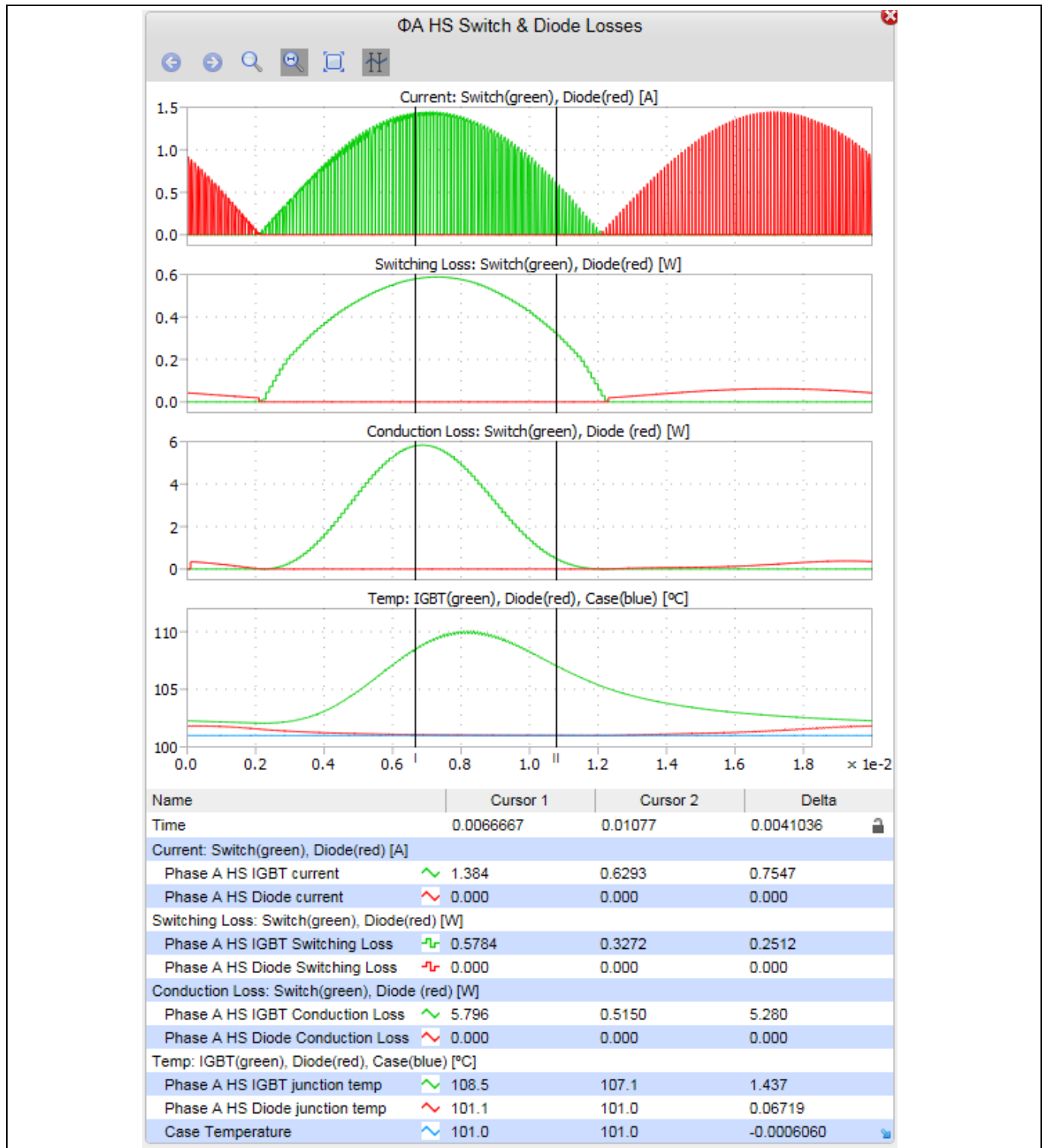


Figure 6 ΦA HS scope example

2.5 Results tables

The result table for inverter losses 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 7 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 H-bridge inverter simulator

The CIPOS™ IPM H-bridge inverter simulator was designed for users to simulate and compare IPM parts under user-specified, two-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.

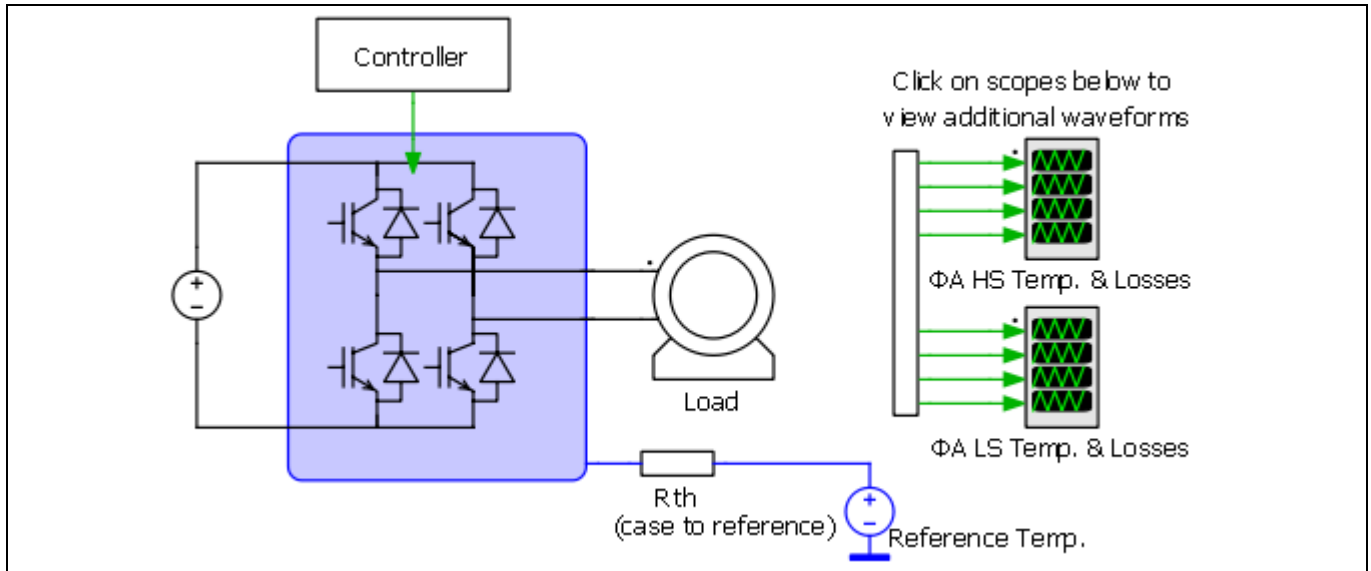


Figure 8 H-bridge inverter schematic

3.1 Input parameters

The IPM H-bridge simulator allows the user to enter 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 out the IPMs 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 4 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	See section 3.1.1 for more detailed information	Options: ▪ Bipolar PWM ▪ Unipolar PWM ▪ Reduced loss unipolar PWM
DC bus voltage	Input voltage This selection is used to filter parts	Between 10 V and 1200 V
Voltage to motor, line to line	Output AC voltage See note below Table 1*	Limited by DC bus voltage V_{rms}
Motor drive phase current RMS	Output single phase RMS current	Between 0.0001 A and 50 A

IPM H-bridge inverter simulator

Parameter	Description	Allowed selection
Power factor		Between -1 and 1
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
Thermal interface material		Options: ▪ Yes ▪ No
Thermal interface resistance	Thermal resistance of grease, silicon pad, etc. Will only display if thermal interface material is used	Between 0°C/W and 10°C/W
Family and package	This selection is used to filter parts	Options: ▪ All packages ▪ Nano QFN 7x8 ▪ Nano QFN 8x9 ▪ Mini DIP 36x21

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

$Voltage\ to\ motor\ (V_{rms}) = \frac{1}{\sqrt{2}} Mi \cdot V_{DC}$, where V_{rms} is referencing the RMS voltage of the first harmonic.

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

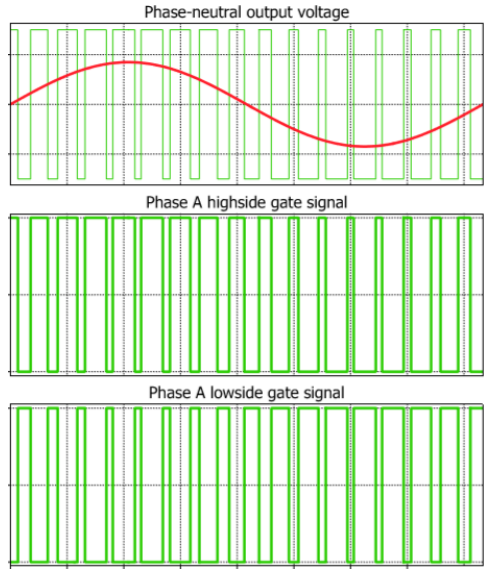
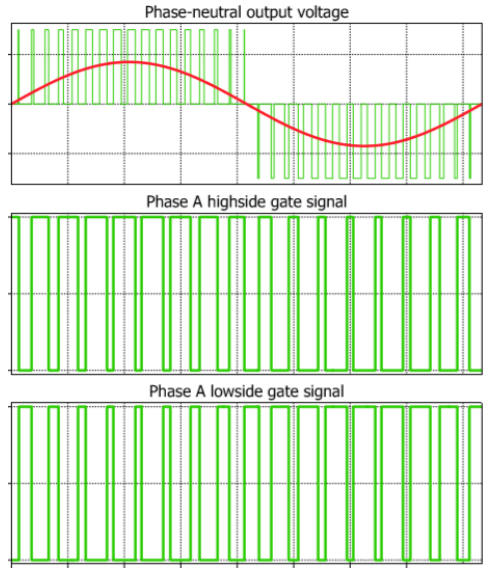
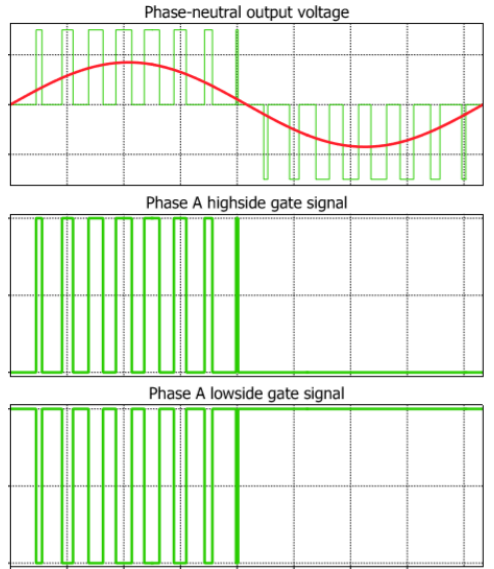
System Frequency:	50 Hz
PWM Frequency:	10 kHz
Modulation Scheme:	Bipolar PWM ▾
DC Bus Voltage:	300 V
Voltage to motor:	147 Vrms
Motor Drive Current:	1 Arms
Power Factor:	0.8 [-1, 1]
Mounting Option:	Mounted heatsink ▾
Ambient Temperature:	25 °C
Heatsink Thermal Resistance:	2 °C/W
Thermal Interface Material:	Yes ▾
Thermal Interface Resistance:	0.1 °C/W
Family and Package:	All Packages ▾

Figure 9 **Input parameters**

3.1.1 **Modulation schemes**

Available H-bridge modulation schemes are detailed in the table below:

Table 5 **Modulation schemes description**

Name	Current output	Description	PWM scheme and signal
Bipolar PWM	Sinusoidal		
Unipolar PWM	Sinusoidal		
Reduced loss unipolar PWM	Sinusoidal	Alternative names: Hybrid unipolar PWM Low-side or high-side switch turns on continuously for half of the output frequency	

3.2 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 the 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 H-bridge simulation tool includes single-phase (half-bridge) and 2-phase (h-bridge) IPMs. When simulating a half-bridge IPM such as IRSM807-105MH, simulations consider two IPMs operating a 2-phase motor drive.

☐	IRSM807-045MH	1.7Ω - Nano QFN 8x9
☐	IRSM807-105MH	0.8Ω - Nano QFN 8x9
☐	IRSM808-105MH	0.8Ω - Nano QFN 8x9
☐	IM512-L6A	10A - Mini DIP 36x21

Figure 10 Example of parts' list

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/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.

Result History		
☒	IRSM807-045MH, Trace 2, @2Arms results	
☒	IRSM807-105MH, Trace 2, @2Arms results	
☒	IRSM807-045MH, Trace 1, @1Arms results	
☒	IRSM807-105MH, Trace 1, @1Arms results	

Figure 11 Result History example

3.3.1 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 6 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.

Error message	Explanation
IGBT is running over its maximum junction temperature! Please adjust your simulation parameters or choose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for the majority of IPMs is 150°C, but the simulation will show results up to 200°C.
Diode is running over its maximum junction temperature! Please adjust your simulation parameters or choose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for the majority of IPMs is 150°C, but the simulation will show results up to 200°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. In some cases this warning may appear instead.
Analysis exceeded a maximum runtime of x seconds.	This error occurs when the simulation takes 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.

3.4 Simulation results

The IPM H-bridge simulation outputs a total of 10 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 located at 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 zooms 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.

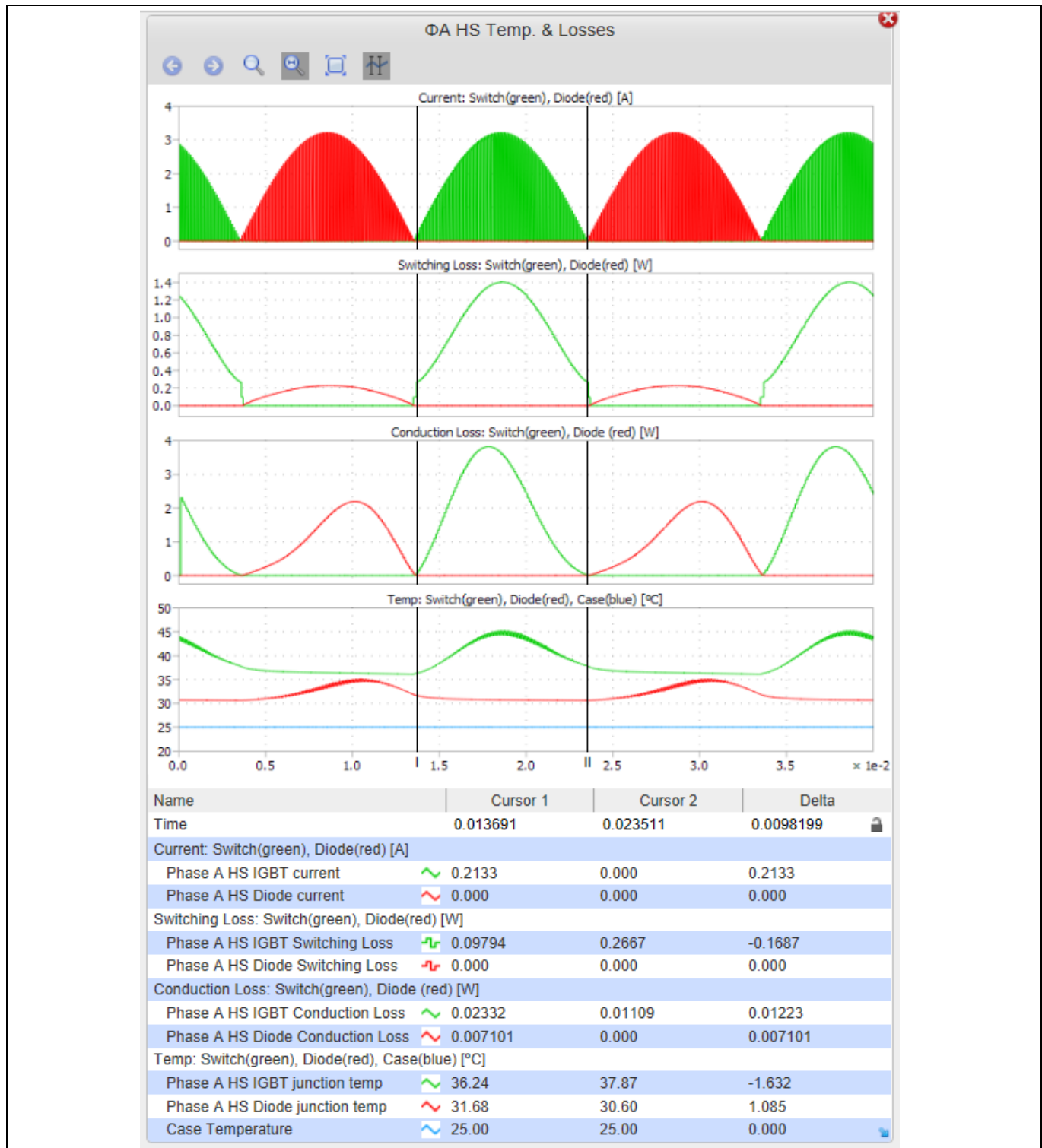


Figure 12 ΦA HS scope example

3.5 Results tables

The results table for inverter losses displays the total losses for the switch, diode, and the entire 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	IM512-L6A	4.41 W			
All Diodes	IM512-L6A	1.94 W			
Inverter	IM512-L6A	6.35 W	99.14 %	735.0 W	25.00 °C

Phase A High Side Device Losses and Junction Temperatures							
	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IM512-L6A	0.64 W	0.03 W	0.66 W	0.44 W	31.68 °C	32.21 °C
Diode	IM512-L6A		0.18 W	0.18 W	0.31 W	31.68 °C	32.21 °C

Phase A Low Side Device Losses and Junction Temperatures							
	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IM512-L6A	0.63 W	0.03 W	0.66 W	0.44 W	31.67 °C	32.21 °C
Diode	IM512-L6A		0.18 W	0.18 W	0.31 W	31.67 °C	32.21 °C

Figure 13 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.

4 IPM PFC + inverter simulator

The CIPOS™ IPM PFC + inverter simulator was designed for users 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.

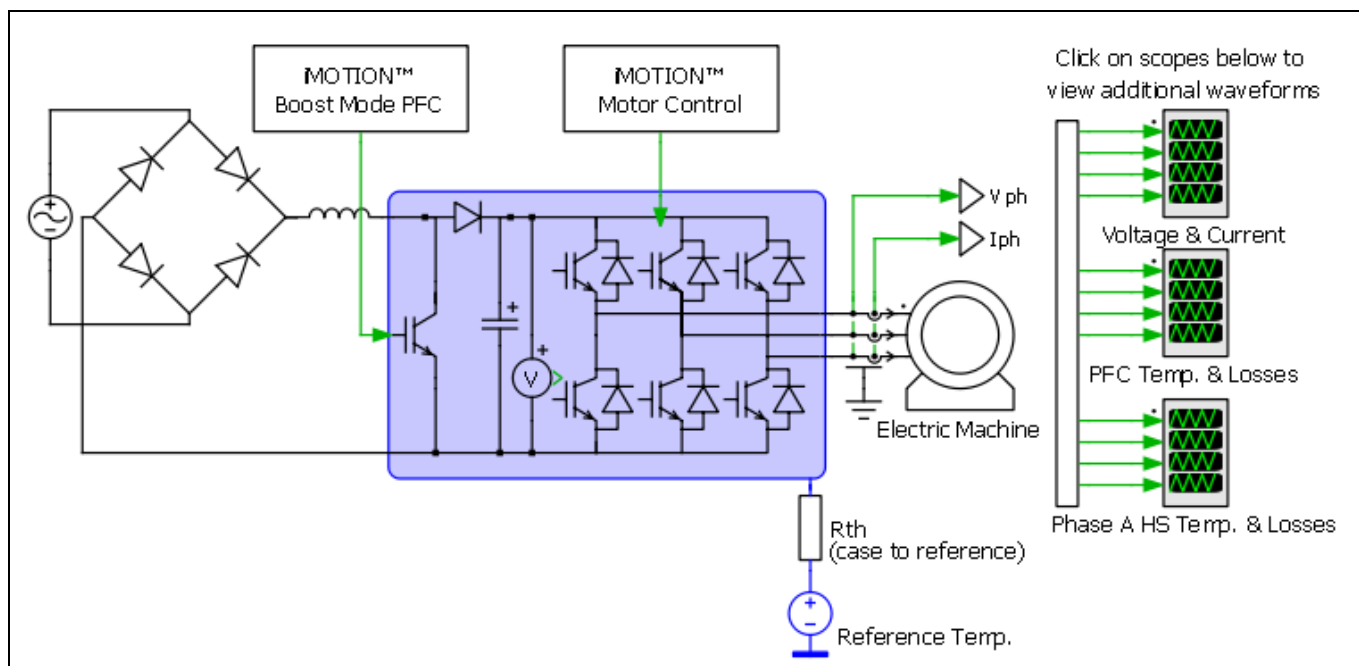


Figure 14 Motor drive schematic

4.1 Input parameters

The IPM PFC + inverter simulator allows the user to enter parameters for AC input voltage and frequency, PFC PWM frequency, DC bus voltage, inverter modulation scheme and PWM frequency, output system frequency, voltage and current, power factor and thermal parameters. Family and package options can be used to filter IPMs. The DC bus voltage input is also used to filter out the IPMs 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 7 Allowed input parameters

Parameter	Description	Allowed selection
Input AC voltage		Between 85 V _{rms} and 300 V _{rms}
Input AC frequency	Input fundamental frequency	Between 0.1 Hz and 100 Hz
PFC modulation scheme		PFC continuous conduction mode
PFC PWM frequency	PFC pulse-width modulation frequency	Between 0.1 kHz and 150 kHz
DC bus voltage	Input voltage This selection is used to filter parts	Between 10 V and 450 V

IPM PFC + inverter simulator

Parameter	Description	Allowed selection
Inverter modulation scheme	See section 2.1.1 for more detailed information	Options: ▪ Sine PWM ▪ iMOTION™ SVPWM ▪ SVPWM (2-phase 60°) ▪ Trapezoidal 120° ▪ SVPWM high side clamp ▪ iMOTION™ SVPWM low loss, low side clamp
Inverter PWM frequency	Pulse-width modulation frequency	Between 0.1 kHz and 100 kHz
Output system frequency	Inverter output fundamental frequency	Between 0.1 Hz and 1000 Hz
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
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
Thermal interface material		Options: ▪ Yes ▪ No
Thermal interface resistance	Thermal resistance of grease, silicon pad, etc. Will only display if thermal interface material is used	Between 0°C/W and 10°C/W
Family and package	This selection is used to filter parts	Options: ▪ All Packages ▪ Mini DIP 36x21D

IPM PFC + inverter simulator

***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,

$$\text{Voltage to motor } (V_{peak}) = Mi \cdot V_{DC}$$

For sinusoidal modulation schemes,

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

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

Input AC voltage:	220 Vrms
Input AC frequency:	60 Hz
PFC modulation scheme:	PFC Continuous Conduction Mode
PFC PWM frequency:	20 kHz
DC bus voltage:	400 V
Inverter modulation scheme:	Sine PWM
Inverter PWM frequency:	10 kHz
Output system frequency:	50 Hz
Voltage to motor, line to line:	147 Vrms
Motor Drive phase current RMS:	1 A
Power factor:	0.8 [-1, 1]
Mounting option:	Mounted heatsink
Ambient temperature:	100 °C
Heatsink thermal resistance:	2 °C/W
Thermal interface material:	Yes
Thermal interface resistance:	0.1 °C/W
Family and package:	All Packages

Figure 15 Input parameters

4.2 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 the 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.

☐	IFCM10P60GD	10A - Mini DIP 36x21D
☐	IFCM10S60GD	10A - Mini DIP 36x21D
☐	IFCM15P60GD	15A - Mini DIP 36x21D
☐	IFCM15S60GD	15A - Mini DIP 36x21D
☐	IM564-X6D	20A - Mini DIP 36x21D

Figure 16 Example of parts' list

4.3 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.

Result History		
☒	IM393-S6E, Trace 2, @4Arms results	-
☒	IM393-M6E, Trace 2, @4Arms results	-
☒	IM393-S6E, Trace 1, @3Arms results	-
☒	IM393-M6E, Trace 1, @3Arms results	-

Figure 17 Result History example

4.3.1 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 8 Common simulation errors

Error message	Explanation
V_{dc} parameter too low. Minimum value must be $(\text{Input AC } V_{rms}) \cdot \sqrt{2}$	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.
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 choose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for the majority of IPMs is 150°C, but the simulation will show results up to 200°C.

Error message	Explanation
Diode is running over its maximum junction temperature! Please adjust your simulation parameters or choose another device.	Parameters entered are too extreme for the device selected. Maximum junction temperature (T_J) for the majority of IPMs is 150°C, but the simulation will show results up to 200°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 takes 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.

4.4 Simulation results

IPM PFC + inverter simulator outputs a total of 12 graphs in 3 scopes for the user to view. These include input AC voltage and current, inverter output waveforms, PFC temperature and losses, and high-side temperature and losses. 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 located at 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 zoom 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.

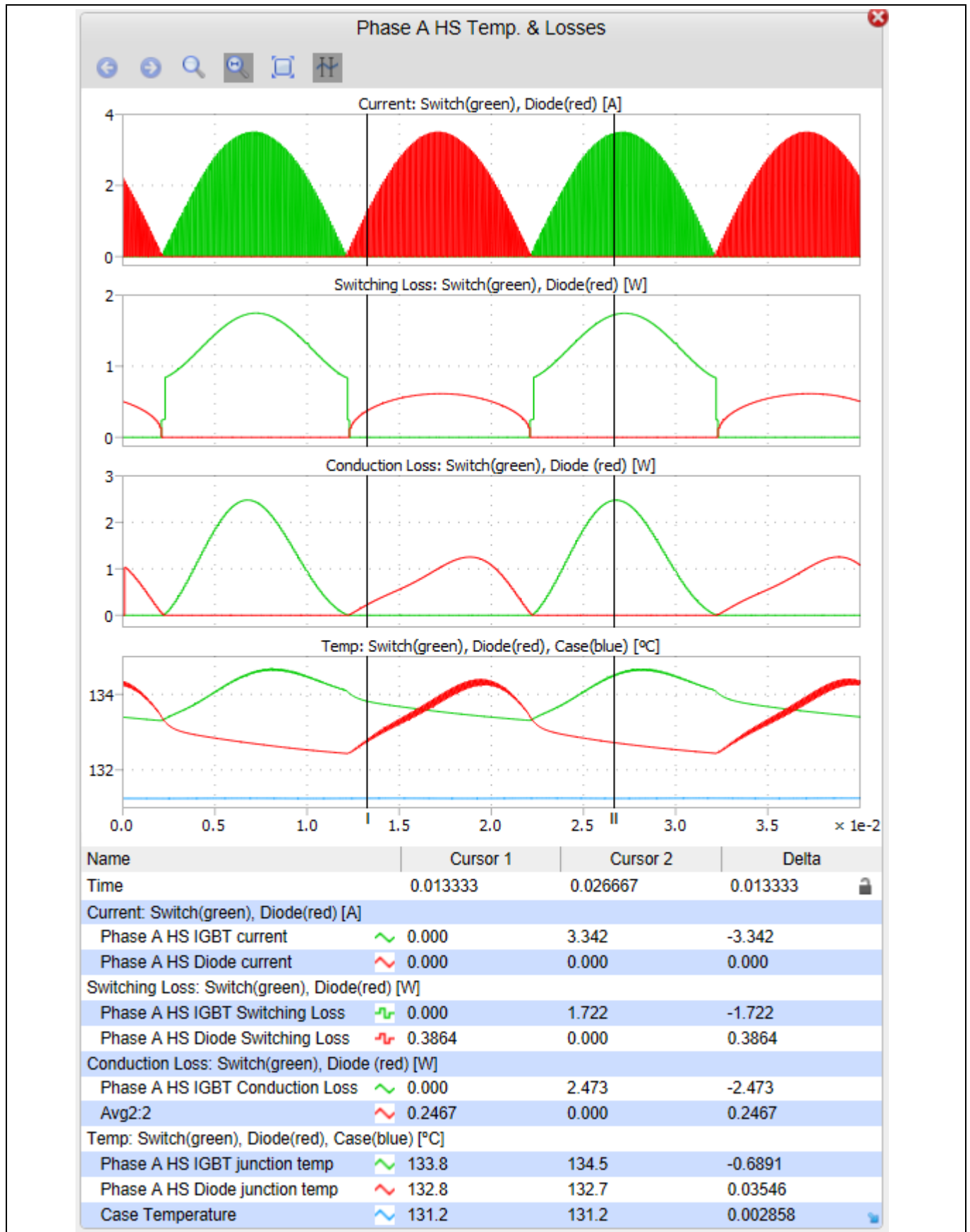


Figure 18 ΦA HS scope example

4.5 Results tables

The results table for PFC + inverter losses displays the total losses for the IPM, output power, and average case temperature. The result table for PFC losses and junction temperature shows a loss breakdown between switching and conduction losses, average temperature and maximum temperature of both the PFC switch and diode inside the IPM. The result table for inverter losses and junction temperature shows a loss breakdown between switching and conduction losses, average temperature and maximum temperature of the hottest switch and diode inside the IPM. Inverter efficiency is also displayed.

PFC + Inverter IPM							
	Part Name	Total Losses	Output Power	Avg. Case Temp.			
IPM	IM564-X6D	14.96 W	509.22 W	131.2 °C			
PFC Losses and Junction Temperature							
	Part Name	Switching Losses	Conduction Losses	Total Losses	Avg. Junction Temp.	Max Junction Temp.	
PFC Switch	IM564-X6D	1.40 W	0.20 W	1.60 W	133.5 °C	133.5 °C	
PFC Diode	IM564-X6D	0.76 W	1.02 W	1.78 W	135.4 °C	135.9 °C	
PFC	IM564-X6D			3.38 W			
Inverter Losses and Junction Temperatures							
	Part Name	Switching Losses	Conduction Losses	Total Losses	Efficiency	Avg. Junction Temp.	Max Junction Temp.
Inverter Switches	IM564-X6D	4.03 W	3.99 W	8.01 W		133.9 °C	134.7 °C
Inverter Diodes	IM564-X6D	1.43 W	2.13 W	3.56 W		133.2 °C	134.4 °C
Inverter	IM564-X6D			11.58 W	97.73 %		

Figure 19 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 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.

5 IPM PFC Boost Simulator

The CIPOS™ IPM PFC Boost Simulator was designed for the user to simulate and compare the PFC switch and diode of an IPM under user-specified 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 input and output voltage and current, junction temperature, and power losses.

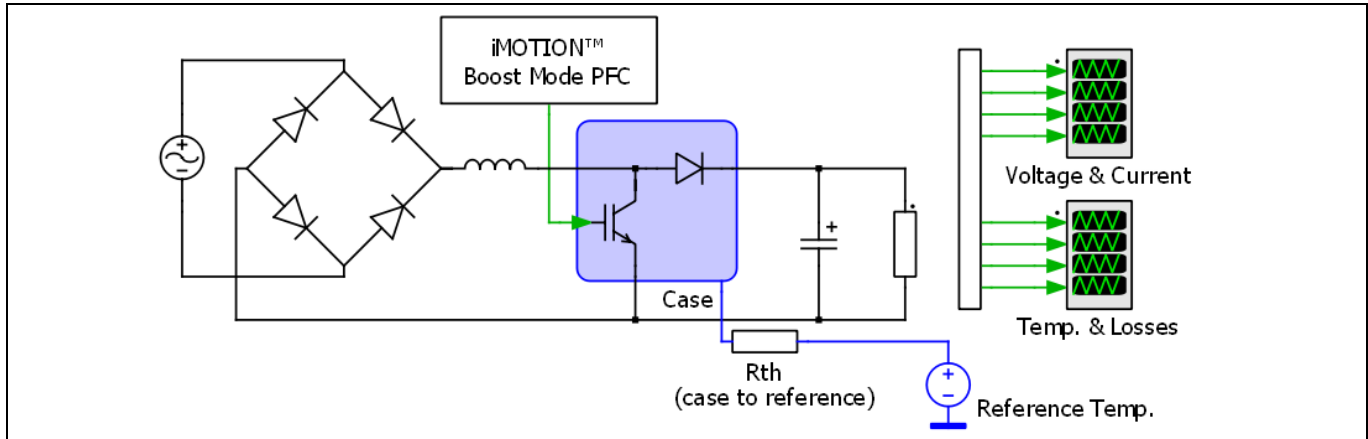


Figure 20 PFC boost schematic

5.1 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 9 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
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

Parameter	Description	Allowed selection
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
Family and package	This selection is used to filter parts	Options: ▪ All packages ▪ Mini DIP 36x21D

Input AC Voltage:	220 Vrms
Input AC Current:	3 Arms
AC Frequency:	60 Hz
Modulation Scheme:	PFC Continuous Conduction Mode ▾
PWM Frequency:	20 kHz
DC Output Voltage:	400 V
Mounting Option:	Mounted heatsink ▾
Ambient Temperature:	100 °C
Heatsink Thermal Resistance:	2 °C/W
Thermal Interface Material:	Yes ▾
Thermal Interface Resistance:	0.1 °C/W
Family and Package:	All Packages ▾

Figure 21 Input parameters

5.2 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 two IPM configurations that are included in the PFC boost simulation. These include: 2-phase interleaved, and 3-phase interleaved.

☐	IFCM20T65GD 20A - Mini DIP 36x21D
☐	IFCM20U65GD 20A - Mini DIP 36x21D
☐	IFCM30T65GD 30A - Mini DIP 36x21D
☐	IFCM30U65GD 30A - Mini DIP 36x21D

Figure 22 Parts' list example

5.3 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.

Result History	
☒ IFCM30U65GD, Trace 2 @40kHz	
☒ IFCM30U65GD, Trace 1 @20kHz	

Figure 23 Results history example

5.3.1 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 10 Common simulation errors

Error message	Explanation
V_{dc} parameter too low. Minimum value must be $(\text{Input AC } V_{rms}) \cdot \sqrt{2}$	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 the majority of IPMs is 150°C but the simulation will show results up to 200°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 the majority of IPMs is 150°C but the simulation will show results up to 200°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.

5.4 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.

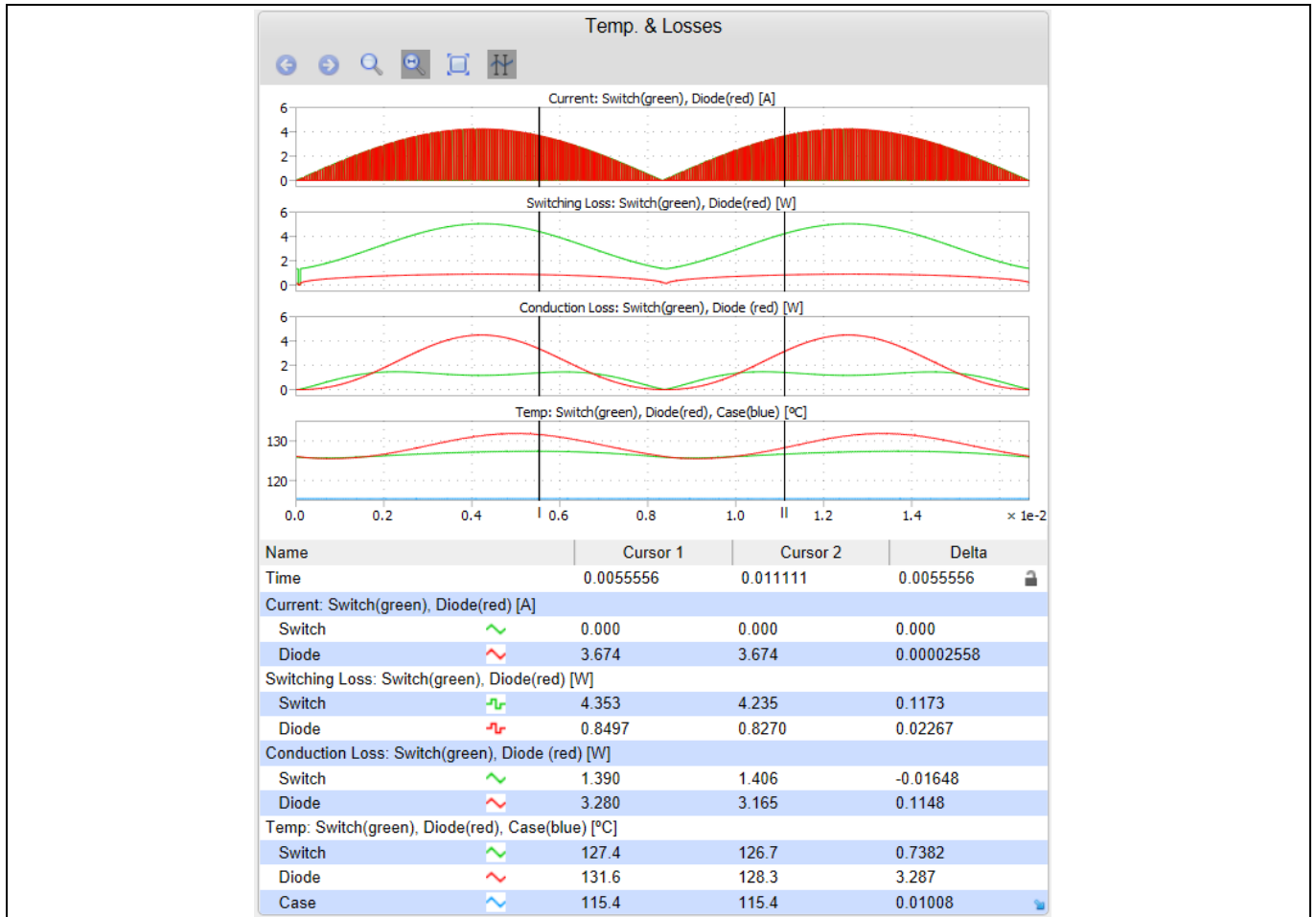


Figure 24 Temperature & losses scope example

5.5 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	IFCM30U65GD	6.19 W			
Diode	IFCM30U65GD	3.93 W			
PFC	IFCM30U65GD	10.12 W	98.47 %	649.9 W	121.3 °C

Loss Breakdown and Junction Temperatures							
	Part Name	EOn	EOff	Total Switching	Cond.	Avg. Junction Temp.	Max Junction Temp.
Switch	IFCM30U65GD	4.15 W	0.94 W	5.09 W	1.10 W	134.1 °C	134.6 °C
Diode	IFCM30U65GD		2.47 W	2.47 W	1.46 W	132.2 °C	133.1 °C

Figure 25 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.
2.1	05/01/2019	Documented parameter changes, added image of PFC boost schematic
3.0	1/23/20	Updated document to include PFC Inverter and H-bridge simulation. Manual also now includes details on modulation schemes.

[1]

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