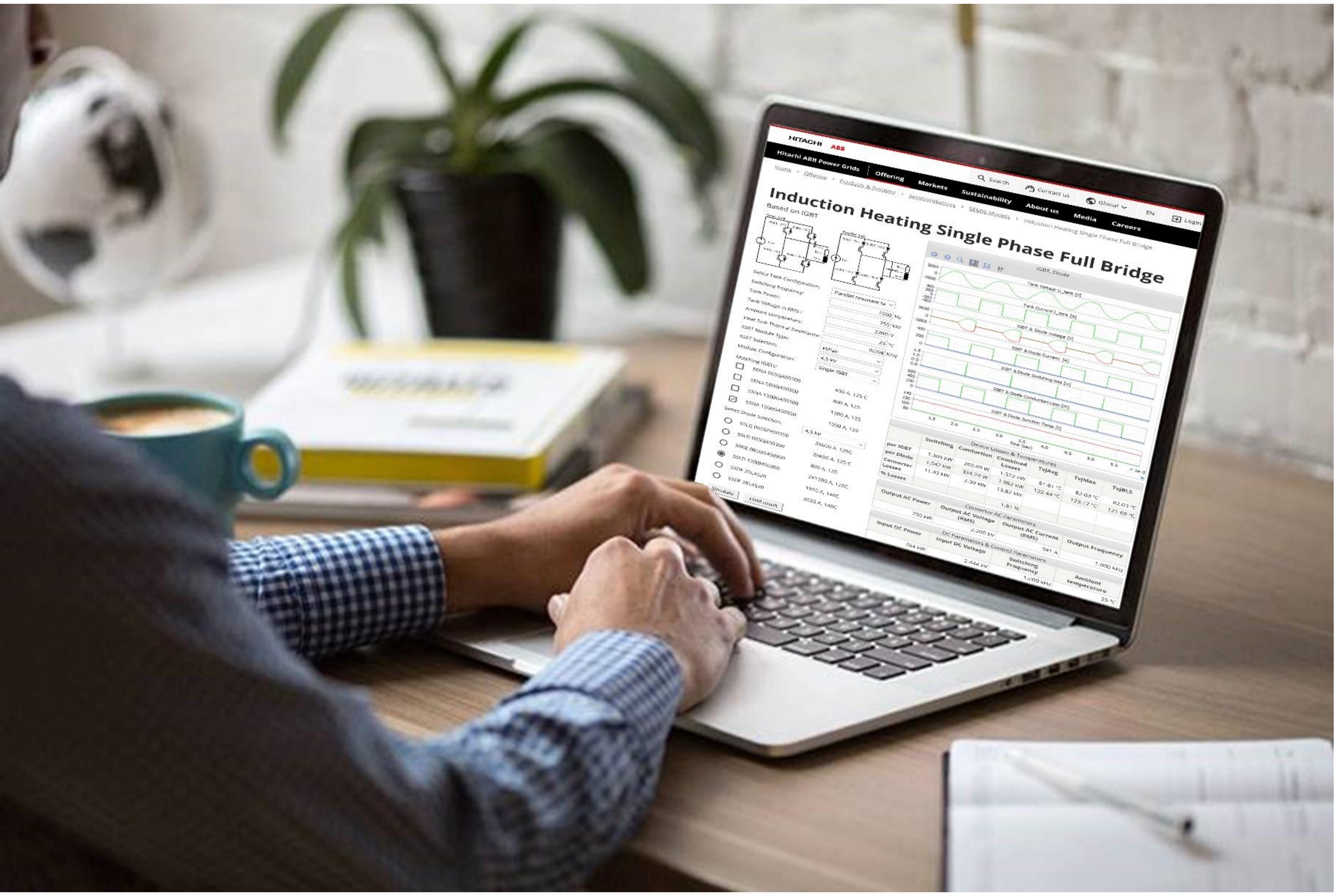
SEMIS Simulation Tool
Induction heating IGBT
User Manual



HITACHI ABB POWER GRIDS

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Introduction

SEMIS is a web-based semiconductor simulation tool providing a thermal calculation of the semiconductor losses for common converter circuits. The simulation simplifies significantly the selection of the switching device and enables optimal selection of semiconductors for further investigations.

The SEMIS simulation tool is a user-friendly online application found on Hitachi ABB Power Grids' semiconductors website www.hitachiabb-powergrids.com/offering/product-and system/semiconductors/semis.

SEMIS users select from substantial selection of topologies. With assigning the circuit parameters and selecting the desired switching device, multiple Hitachi ABB Power Grids semiconductor products can be simulated at the same time. Once a simulation is run, SEMIS returns comprehensive results on semiconductor losses as well as on the electrical parameters in the input and output of the circuit. The results are shown in both graphical (waveforms) and numerical (tables) way.

The SEMIS tool is based on the PLECS simulation software. PLECS users can download our product models in the XML file format from the Hitachi ABB Power Grids' semiconductors website and use them for their own simulations. For more specific topologies Hitachi ABB Power Grids offers customized converter simulations for non-standard topologies with PLECS simulation software on a project basis.

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1. INDUCTION HEATING IGBT BASED

Induction heating provides contactless efficient heating of conductive materials. An AC source is used to supply an alternating voltage to an induction heating coil. The coil generates an alternating magnetic field, in which the load is immersed. Hence, the load is heated due to eddy current and hysteresis loss.

In this model a converter to transform DC power at the source to AC power at the load is discussed. The load side is modeled as a resonant tank circuit with user specifying the output voltage and power.

ABB offers the following induction heating topologies for thermal analysis simulation with

- Induction heating thyristor based
- Induction heating IGBT based
- Voltage-fed series resonant inverters (VFSRI)
- Current-fed parallel resonant inverters (CFPRI)

2. OVERVIEW

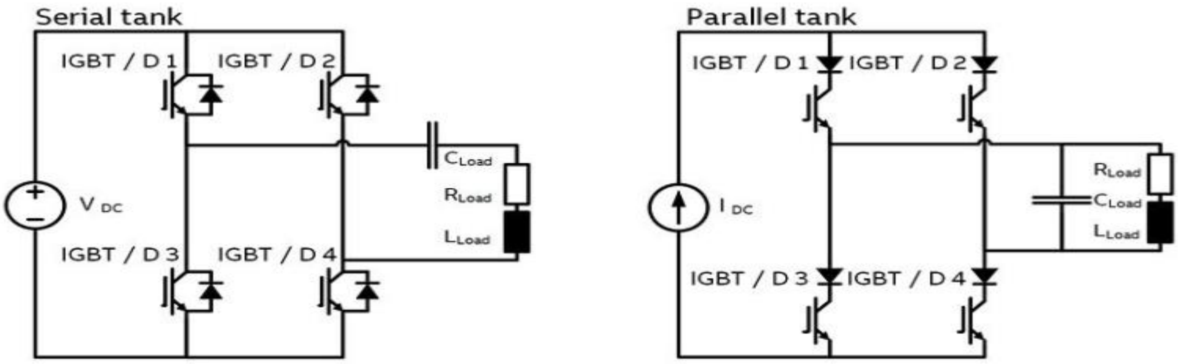
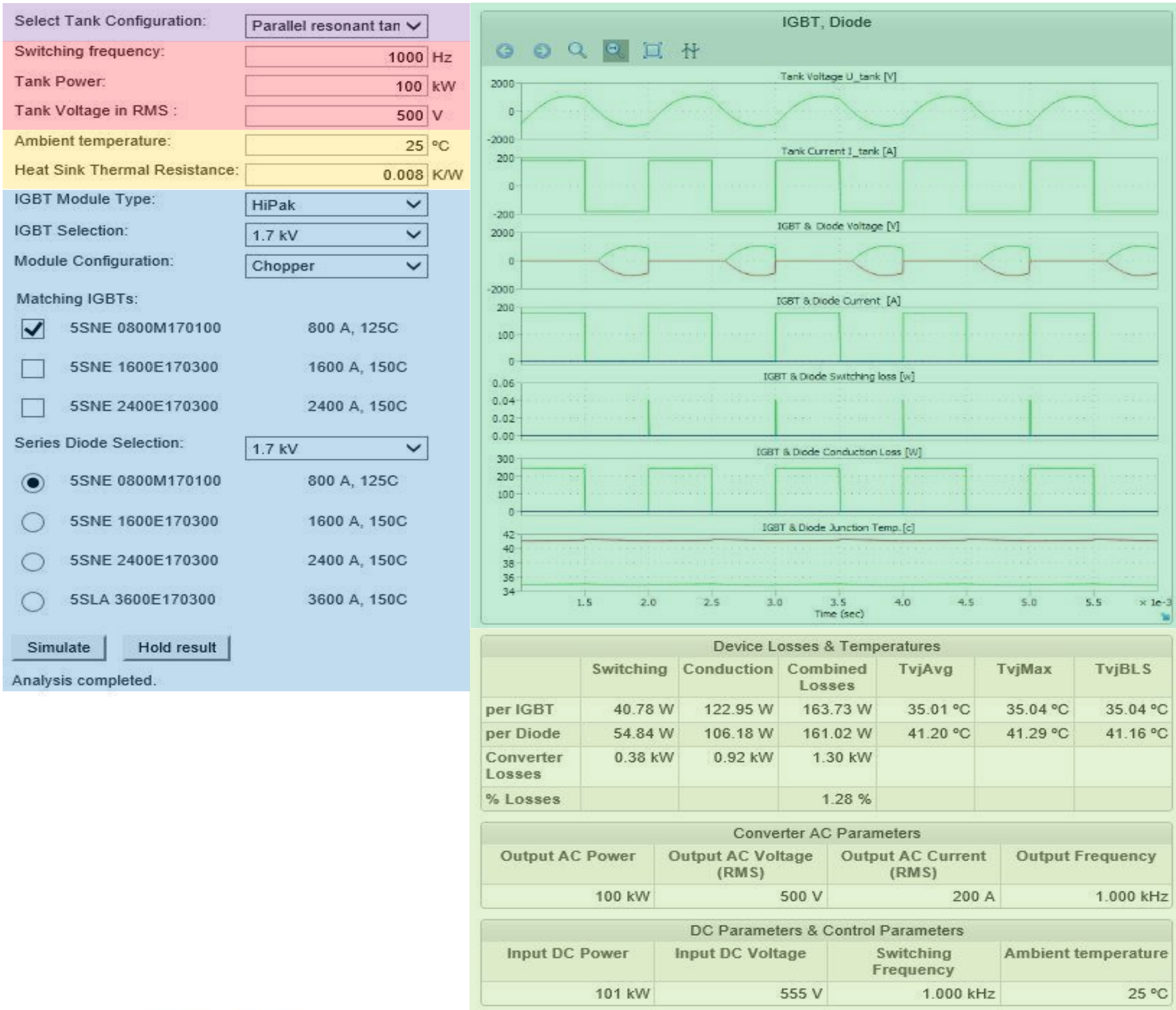


Figure 1. IGBT based Induction Heating Inverters VFSRI & CFPRI



Simulation powered by PLECS using WebSIM patented technology

Select Inverter & Tank Configuration	Results graphs
Load Tank Parameters	Results tables
IGBT & Series Diode Selection	General Settings

3. SIMULATION SETTINGS

3.1 Circuit parameters

3.1.1 Inverter Selection (VSI/CSI)

Figure 2 Inverter selection VSI/CSI

Select Inverter Type	Inverter type can be selected either as VSI or as CSI Inverter based on the resonant tank configuration.
	Voltage Source Inverter 1. VSI fed Series Resonant Inverter

Current Source Inverter 2. CSI fed Parallel Resonant Inverter

3.1.2 Tank Circuit Configuration

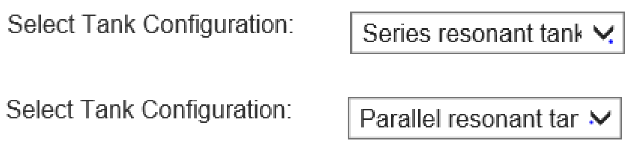


Figure 3 Tank Circuit Selection series/parallel

Select Tank Configuration	Tank Circuit type can be selected either as Series resonant tank or as Parallel resonant tank configuration.

3.1.3 Load Tank Parameters

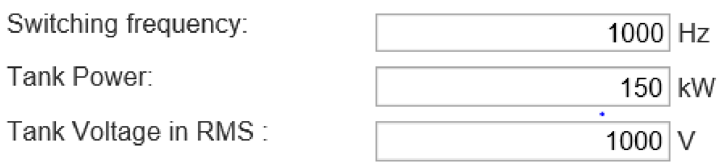


Figure 4 Load Tank Circuit Parameters

Switching Frequency	Definition of switching frequency	Range 100 to 10000 Hz
Tank Power	Define Tank Circuit Power in kW	Range 5 kW to 1000 kW
Tank Voltage in RMS	Define Tank Circuit Voltage in RMS	Range 200 V to 4.5 kV

3.2 Device Settings

3.2.1 Ambient

Figure 5 Thermal settings

Ambient temperature	Definition of environmental temperature around the converterfor temperature / cooling calculations	Range -25 to 90 °C
Heat Sink Thermal Resistance	Definition of thermal resistance of cooling system applied.	Range 0.0001 to 0.5 K/W

Remark:

Include the thermal resistance of case to heatsink to ensure correct simulation results. The value entered is attributed to each individual switch shown in the electrical configuration schematic of the IGBT module data sheet. Therefore, if user selects a dual switch module, the Rth should be multiplied with a factor of 2 to differentiate from the single switch case, if same heatsink would be used in both cases. Same applies for the case of full bridge modules.

The selected Rth is also accounted for the antiparallel diode position for which same consideration applies for its electrical configuration.

3.2.2 Switch settings

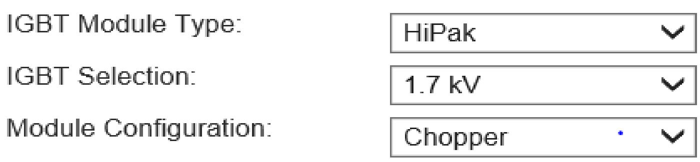


Figure 6 IGBT selection

IGBT module type	Select housing type of IGBT for filtering	Selection
IGBT selection	Select voltage class of IGBT for filtering	Selection
Module configuration	Select topology of IGBT module for filtering	Selection

3.2.3 Matching Devices

Once the IGBT voltage rating is selected, the matching IGBT option is populated with device. By clicking on the product code name, the user may access the data sheet from Hitachi-ABB website.

Figure 7 Matching IGBTs for selection

User can select the desired IGBT product names for simulation.

All the elements can be selected and simulated simultaneously. If one or more elements produce results exceeding the safe operating area (SOA), no results will be returned. In this case the user should run the simulation again with changed parameters and/or product selection to enable results within SOA operating conditions.

3.2.4 Matching Series Diodes

Once the IGBT is selected, then the user can select the matching Series Diode for Parallel tank Configuration based on the voltage and current ratings. By clicking on the product code name, the user may access the data sheet from the Hitachi-ABB website.

This section/figure is not visible when the selected topology is Series resonant tank configuration.

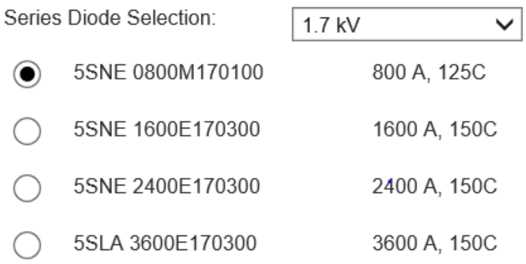


Figure 8 Matching Series Diodes for selection

3.3 Selection of articles / Start simulation

To simulate one or more articles, select from the list by activating the checkbox

Simulate	Starts the simulation; The progress of the simulation is shown with number of calculated Jacobian.
Abort	Stops the simulation; No results generated
Hold Result	To compare multiple simulations, results can be hold for later viewing. By selecting the button, result are hold after simulation has finalized for later comparison with succeeding simulations

Figure 9 Start of simulation

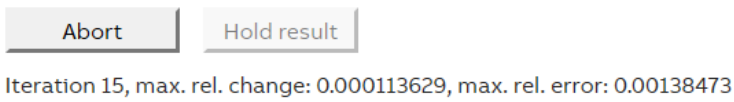


Figure 10 Simulation progress and termination

4. SIMULATION RESULTS

The simulation results are displayed in two different ways for all selected articles simulated.

To hide curves of selected articles, unselect in the table “Results History”

Graphical results – Waveforms	Visual analysis of waveforms for fast and efficient detection of most significant sources
Numerical / Tabular results	Numeric indication of all simulations values for direct comparison

4.1 Graphical Output – Waveforms

When the simulation finishes the semiconductor device waveforms are appearing as follows:

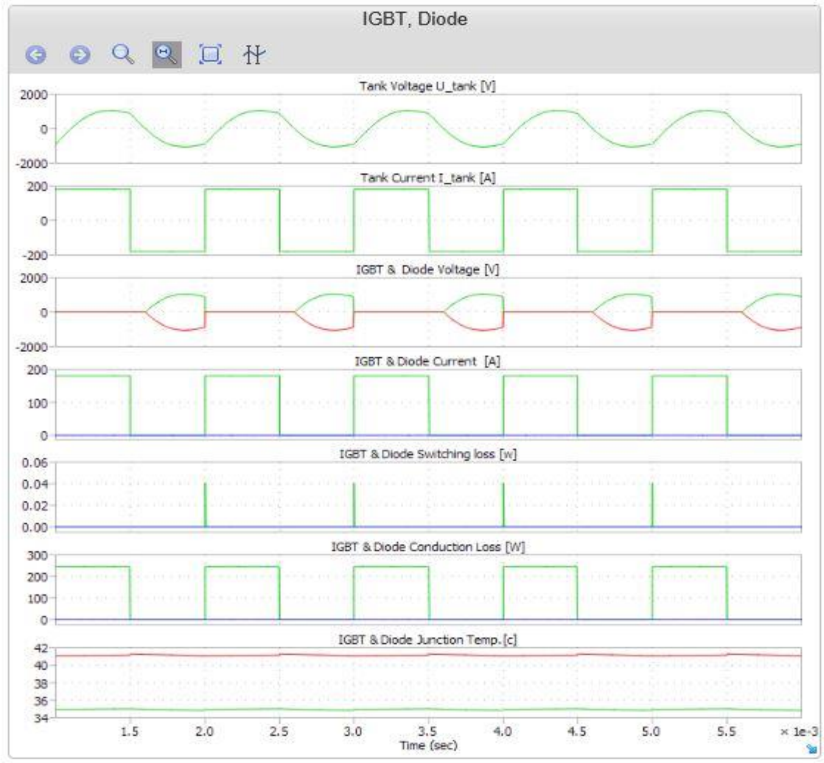
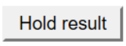


Figure 11 Graphical results of Induction Heating converters

4.1.1 Control

For indication of values within the graph a cursor can be activated to show curve values in a table.

Sections of graphs can be zoomed in by click, move and release mouse button for more details



Hide selectively waveforms of products

Rest zoom to full view

Activate cursors and to show parameter values table according to cursor position

Zoom selectable rectangle

Zoom horizontal or vertical band

4.1.2 Parameters values indication

Tabular indication of graphical wave forms values according cursor position selected.

Values are indicated for each parameter Color of wave form is indicated. Third column shows difference of two cursors per parameter.

Name	Cursor 1	Cursor 2	Delta
Time	0.0026667	0.0043333	0.0016667
Tank Voltage U_tank [V]			
Measured voltage	-472.3	1037	-1509
Tank Current I_tank [A]			
Measured current	-180.1	180.1	-360.1
IGBT & Diode Voltage [V]			
IGBT Voltage	472.3	0.000	472.3
Diode Voltage	-472.3	0.000	-472.3
IGBT & Diode Current [A]			
IGBT Current	0.000	180.1	-180.1
Diode Current	0.000	0.000	0.000
IGBT & Diode Switching loss [w]			
IGBT Switching loss	0.000	0.000	0.000
Diode Switching loss	0.000	0.000	0.000
IGBT & Diode Conduction Loss [W]			
IGBT Conduction loss	0.000	245.9	-245.9
Diode Conduction loss	0.000	0.000	0.000
IGBT & Diode Junction Temp.[c]			
IGBT Junction temp.	34.97	35.02	-0.05001
Diode Junction temp.	41.22	41.14	0.07931

Figure 12 Tabular indication of cursor position graph values

Remark:

The numerical values of Voltage/Current at the position of respective cursors are shown in the Table.

4.2 Numerical / Tabular results

The following parameters are given in a tabular format in multiple sections. All calculations and simulation results are based on datasheet typical values.

All types of semiconductor losses are calculated according to PLEXIM PLECS software principle through reference of look up table and linear interpolation of the actual device current, voltage, and junction temperature.

As converter losses the aggregated losses in all devices are accounted. The losses per device are tabulated, the combined loss is calculated by adding the losses of each IGBT or Diode.

Device Losses & Temperatures						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per IGBT	40.78 W	122.95 W	163.73 W	35.01 °C	35.04 °C	35.04 °C
per Diode	54.84 W	106.18 W	161.02 W	41.20 °C	41.29 °C	41.16 °C
Converter Losses	0.38 kW	0.92 kW	1.30 kW			
% Losses			1.28 %			

Figure 13 Device Losses & Temperatures

Switching Loss	Single IGBT or Diode Loss during turn on and turn off events (dynamic)
Conduction loss	Single IGBT or Diode Loss during on state (static)
Combined losses	Sum of single IGBT or Diode switching and conduction loss.
Converter losses	Sum of all the IGBT and Diode losses

% Losses	Defined as the (%) ratio of calculated combined converter losses with respect to the total output power and losses i.e., total apparent power flow.
Junction Temperature Avg	Junction temperature average during the simulation period
Junction Temperature Max	Maximum junction temperature during simulation period
Junction Temperature BLS	Junction temperature at timepoint just before the switching, after which the maximum junction temperature is achieved.

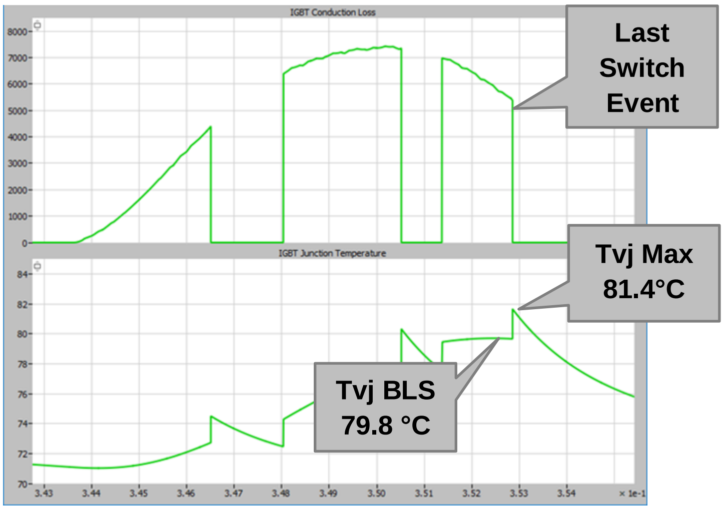


Figure 14 Definition of Tvj before last switch

Converter AC Parameters

Converter AC Parameters			
Output AC Power	Output AC Voltage (RMS)	Output AC Current (RMS)	Output Frequency
100 kW	500 V	200 A	1.000 kHz

Figure 15 Converter AC Parameters

Output AC Power	Output Real power across the Tank
Output AC Voltage (RMS)	RMS value of the output voltage across the Tank
Output AC Current (RMS)	RMS Value of the output current across the Tank
Output Frequency	Frequency at the output side

DC Parameters & Control Parameters

DC Parameters & Control Parameters			
Input DC Power	Input DC Voltage	Switching Frequency	Ambient temperature
101 kW	555 V	1.000 kHz	25 °C

Figure 16 DC Parameters & Control Parameters

Input DC Power	Real power at the input side including the effect of inverter losses
Input DC Voltage	Inverter Input DC Voltage
Switching Frequency	Converter switching frequency considered 50% duty cycle
Ambient temperature	Temperature around the converter

5. ALERTS & FEATURES

The system verifies results and generated warning messages in case of limits are violated.

5.1 Junction Temperature

Parameter	Junction temperature
Verification	If the junction temperature BLS of IGBT and/or Diode is above its maximum junction temperature limit, alert message is displayed
Warning message	IGBT and/or Diode temperature out of safe operating area

5.2 Tank Voltage

Parameter	Tank Voltage in RMS
Verification	If the tank voltage is greater than safe operating voltage rating of IGBT, alert message is displayed
Warning message	For the voltage rating 1.7kV, Vdc min = 200V & Vdc max = 1100V

6. APPLIED CALCULATIONS

Input Parameter Definitions

P_{Tank}	Tank circuit power in kW
U_{Tank}	Tank circuit voltage in RMS
V_{DC}	Selected DC link voltage for VSI
I_{DC}	Selected DC link current for CSI

6.1 Real Power

P_{DC}	DC power from the Input DC side of VSI/CSI
P_{AC}	Real / Active power transferred to Induction heating converter output
$P_{LossConverter}$	Total converter losse
$U_{\_Tank\_RMS}$	True phase voltage RMS AC output
I_{Tank_RMS}	True phase current RMS AC output
η	Power conversion efficiency
Z_1	Load impedance across the workpiece
R_{eq}	Load resistance across the workpiece

For single-phase full bridge inverter RMS value of output voltage,

$$U_{tank} = \frac{4*V_{DC}}{\pi*\sqrt{2}}$$

For single-phase full bridge inverter RMS value of output current,

$$I_{tank} = \frac{4*I_{DC}}{\pi*\sqrt{2}}$$

In case of series resonance tank configuration: (xl=xc)

$$I_{tank\_rms} = \frac{Utank}{R_{eq}}$$

In Case of parallel resonance tank configuration: (xl=xc)

$$I_{tank\_rms} = \frac{Utank}{Z_1}$$

Power delivered to load P_{Tank} in watts at resonant (xl=xc) condition,

$$P_{tank} = I^2{}_{tank} * R_{eq}$$

This must be equal to the power PDC delivered by the source,

$$P_{DC} = V_{DC} * I_{DC}$$

It includes all harmonic components NOT ONLY 1st order of output frequency.

According to:

$$I_{DC} = \frac{2\sqrt{2} * I_{tank}}{\pi}$$

For Inverter series or parallel mode, the DC power definition P_{DC} can be computed as

$$P_{DC} = P_{AC} + P_{LossConverter}$$

6.2 Tank Circuit Parameters

R_{Load}	Tank Circuit Resistor,	[Ω]
C_{Load}	Tank circuit Capacitor,	[F]
L_{Load}	Tank circuit Inductor	[H]
f_{res}	Resonance frequency	[Hz]
V_{DCPeak}	Peak DC Voltage	[V]

$$R_{Load} = \frac{U_{Tank}}{I_{Tank}}$$

$$C_{Load} = \frac{I_{DC}}{2 * \pi * f_{res} * V_{DCPeak}}$$

$$L_{Load} = \frac{1}{(2 * \pi * f_{res})^2 * C_{Load}}$$

7. VALIDATION OF PLECS RESULTS

To ensure supplied simulation results are reliable, 1- phase Induction heating Inverter model is validated with another simulation platform or compared to real measurement data.

The circuit topology is reconstructed in PSCAD to validate the results obtained from the SEMIS web simulation tool. The objective of the work is to develop a 1-phase Induction heating inverter with loss and temperature estimation in PSCAD and to validate the steady-state results obtained through web simulation model.

The XML data of the IGBT and diode which were created from the device datasheets for SEMIS simulations are modified to individual .txt files to capture the on-state voltage drop of the IGBT (Vce at different temperatures, to make the data readable in PSCAD.

The PSCAD and SEMIS circuit models are made as identical as possible to prevent any errors in validation due to the dissimilarities. Junction to Case and Case to Heat sink thermal resistances for the Thyristor have been captured from the device datasheet.

Five cases each have been simulated in PSCAD and SEMIS by varying different parameters like tank power and voltage, switching frequency and tank configuration, etc.

SEMIS 34 - Induction Heating Model with IGBT		
Patturaja C		
July 13, 2021		
5SNA 1200G330100, 5SNE 0800G450300		
0%	2%	5%

1. Enter all values according the final results table in the column SEMIS
2. Enter all values according the final results from the PSCAD in the column PSCad
3. Verify the relative difference; Results must not vary more than 2 %

Series Tank Configuration

Set 1 SEMIS	Set 1 PSCad		Set 1 Difference	Set 2 SEMIS	Set 2 PSCad		Set 2 Difference	Set 3 SEMIS	Set 3 PSCad		Set 3 Difference
			0.30%				0.22%				0.25%
			2.15%				1.86%				1.84%
253.470	252.1023	+	0.54%	450.730	449.3430	+	0.31%	704.75	702.3276	+	0.34%
967.020	964.2756	+	0.28%	536.620	535.6109	+	0.19%	238.92	238.5779	+	0.14%
1220.490	1216.3955	+	0.34%	987.350	984.9450	+	0.24%	943.66	940.8097	+	0.30%
71.130	69.5973	+	2.15%	65.180	63.9680	+	1.86%	64.07	62.8883	+	1.84%
4880.000	4865.4007	+	0.30%	3950.000	3939.7802	+	0.26%	3770.00	3763.5438	+	0.17%
0.540	0.5384	+	0.30%	0.520	0.5200	+	0.00%	0.75	0.7527	-	0.36%
900.000	900.145	-	0.02%	750.000	750.067	-	0.01%	500	499.994	+	0.00%
1200.000	1200.096	-	0.01%	1500.000	1500.0674	-	0.00%	1800	1799.9908	+	0.00%
750.000	750.056	-	0.01%	500.000	500.0224	-	0.00%	278	277.776	+	0.08%
1000	1000	+	0.00%	1500	1500	+	0.00%	2000	2000		0.00%
905	905.010	-	0.00%	754	754.007	-	0.00%	504	503.758	+	0.05%
1333	1333	+	0.00%	1666	1666	+	0.00%	1999	1999.000	+	0.00%
40	40	+	0.00%	40	40	+	0.00%	40	40	+	0.00%

Parallel Tank Configuration

Set 4 SEMIS	Set 4 PSCad		Set 4 Difference	Set 5 SEMIS	Set 5 PSCad		Set 5 Difference
			0.59%				0.77%
			2.80%				2.84%
777.22	780.2721	-	0.39%	641.00	636.4146	+	0.72%
401.83	400.4111	+	0.35%	295.00	293.2602	+	0.59%
1179.00	1180.6832	-	0.14%	936.00	929.6748	+	0.68%
855.46	835.5761	+	2.32%	730.00	715.5264	+	1.98%
503.00	502.8647	+	0.03%	373.00	373.6885	-	0.18%
1358.00	1338.4408	+	1.44%	1103.00	1089.2149	+	1.25%
77.00	76.8517	+	0.19%	82.00	79.8494	+	2.62%
122.00	118.5898	+	2.80%	117.00	113.6799	+	2.84%
1015.00	1008.0708	+	0.68%	816.00	807.8297	+	1.00%
1.99	2.0162	-	1.32%	1.01	1.0095	+	0.05%
500	499.983	+	0.00%	800	800.0262	-	0.00%
1200	1199.9797	+	0.00%	2400	2400.038	-	0.00%
417	416.6567	+	0.08%	333	333.339	-	0.10%
1000	1000	+	0.00%	500	500	+	0.00%
510	510.064	-	0.01%	808	808.1035	-	0.01%
1333	1330	+	0.23%	2666	2693	-	1.01%
25	25	+	0.00%	40	40	+	0.00%

8. USER MANUAL REVISION HISTORY

Rev.	Page	Change Description	Date / Initial
1.0	All	Initial version	2021-05-21 PGGI/CP

9. SIMULATION SOFTWARE RELEASE HISTORY

Rev.	New topic	Fixed defects	Tvj influence	Date
1.0	Initial version	-	-	2021-05-21 PGGI/CP

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