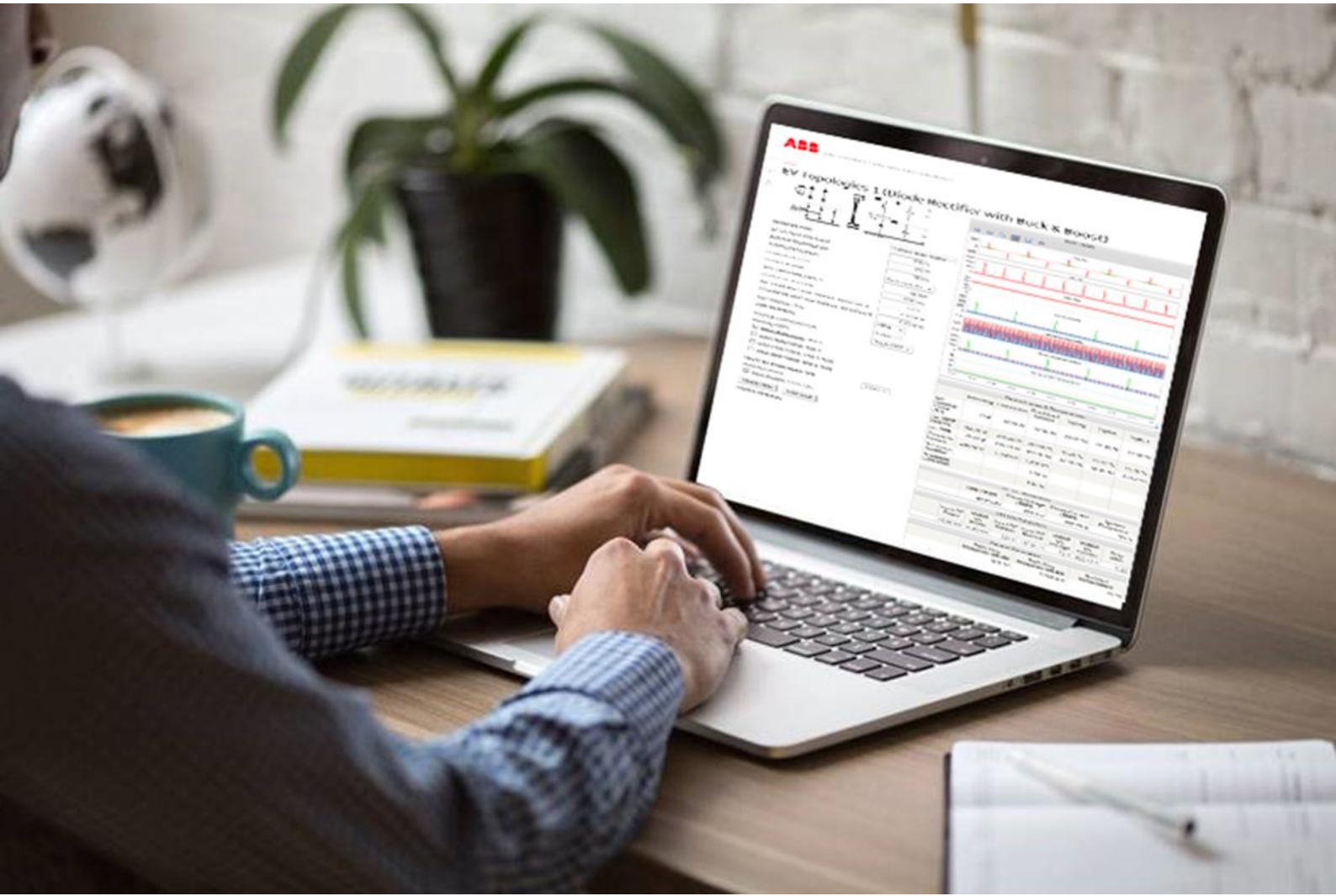
SEMIS Simulation Tool
Diode Based EV Charging Converters
User manual



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 the optimal selection of semiconductors for further investigations.

The SEMIS Simulation Tool is a user-friendly online application found on ABB Semiconductors website www.abb.com/semiconductors/semis

SEMIS users select from a substantial selection of topologies. By assigning the circuit parameters and selecting the desired switching device, multiple ABB 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 ABB Semiconductors website and use them for their simulations. For more specific topologies ABB offers customized converter simulations for non-standard topologies with PLECS simulation software on a project basis.

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1. DIODE BASED EV CHARGING CONVERTERS

Electric vehicle chargers are typical AC-DC converters based on diodes, IGBTs or thyristors at the first stage and DC-DC converters at the second stage to suit the battery charging voltage and to improve the power quality. The first stage of the converters used in this model is diode-based:

- 1 phase diode bridge rectifier
- 3 phase diode bridge rectifier

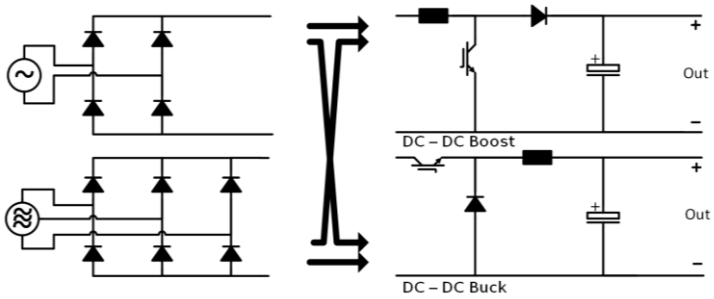
The DC-DC converters used are non-isolated:

- Buck converter
- Boost converter.

ABB offers the following power electronic topologies for thermal analysis simulation in Diode based EV charging converters

- 1 phase diode bridge rectifier + Buck converter: Domestic low voltage single phase of 230V is stepped down to values as low as 30V
- 3 phase diode bridge rectifier + Boost converter: Domestic low voltage three-phase voltage of 415V is stepped up to 1kV DC.

2. OVERVIEW



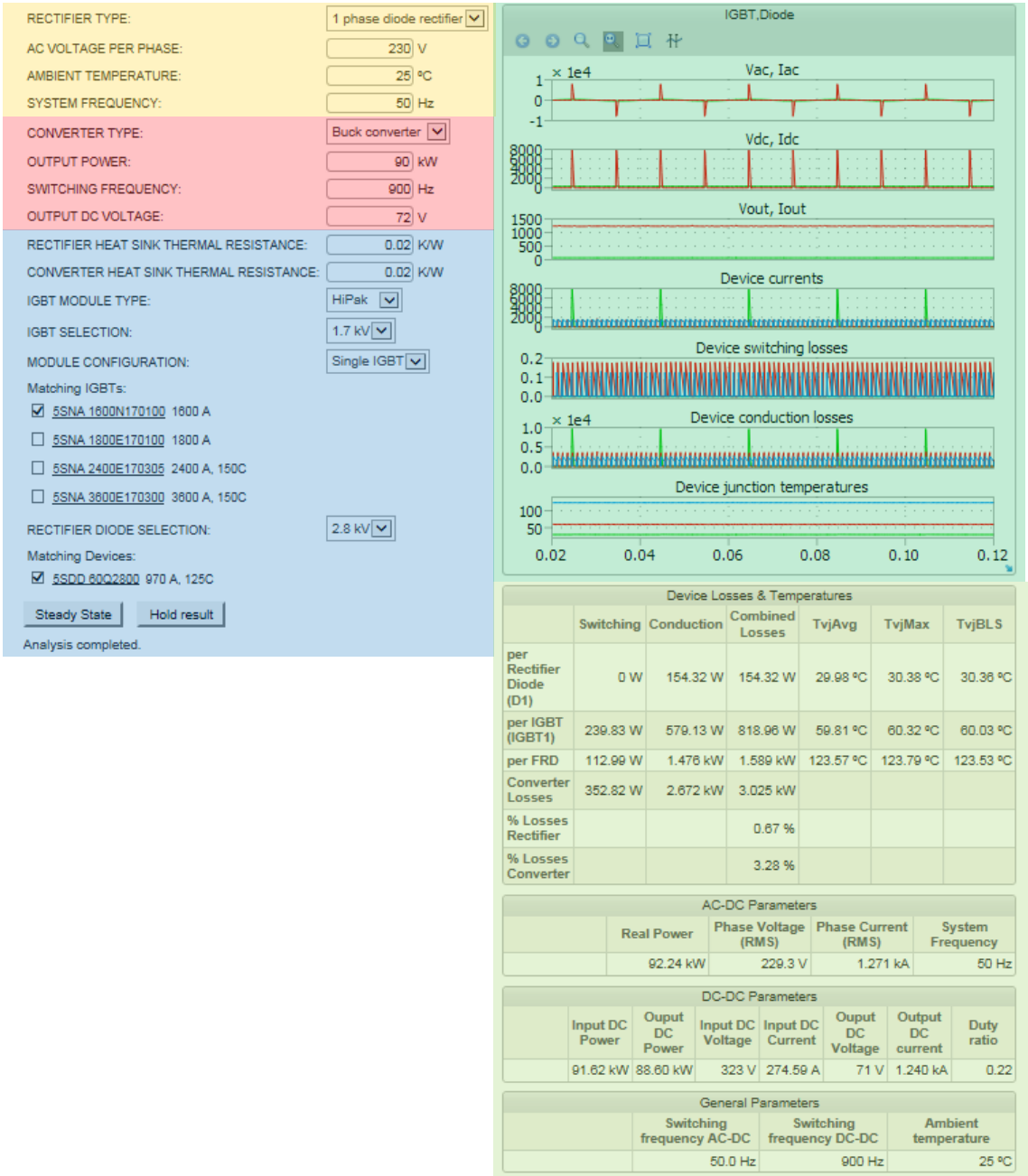


Figure 1: Page layout of Diode based EV charging converter in the ABB semiconductors website.

Rectifier settings

Converter settings

IGBT, Diode selection

Results graphs

Results tables

3. SIMULATION SETTINGS

3.1.1 Rectifier settings

The user can choose between the 2 types of rectifiers that are mentioned in section 3.1.1. The user may input the RMS value of the AC voltage per phase for both 3 phase and 1 phase source. The supply frequency can be changed – this usually is either 50Hz or 60Hz.

Figure 2 Rectifier settings input blocks

RECTIFIER TYPE	Choose between 1ph diode or 3ph diode bridge	Selection
AC VOLTAGE PER PHASE	AC voltage input	Range 230 .. 240 V
AMBIENT TEMPERATURE	Definition of environmental temperature around the converter for temperature / cooling calculations	Range -25 .. 90 °C
FREQUENCY	Frequency of the AC input voltage	50Hz/60Hz

3.1.2 Converter settings

The user can choose between the 2 types of converters here. The user shall select the buck converter for stepping down the output voltage of the rectifier. The user shall select boost operation if the output voltage of the rectifier must be stepped-up. These converters are modeled to operate in Continuous Conduction Mode (CCM), one shall change the user inputs as shown in Figure 3 Converter settings input blocks to operate the converters in CCM.

Figure 3 Converter settings input blocks

CONVERTER TYPE	Converter is operated as Buck or Boost	Selection
OUTPUT POWER	Power demand of the load	Range 10 .. 150 kW
OUTPUT DC VOLTAGE	The constant DC output voltage on the load	Range 60 .. 1500V
SWITCHING FREQUENCY	Frequency at which the IGBT is turned ON/OFF	Range 200 .. 5000 Hz

3.2 IGBT settings

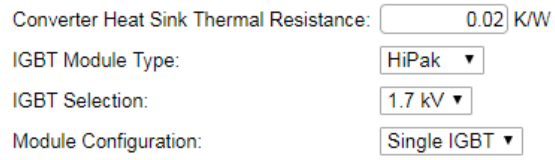


Figure 4 Thermal settings and device selection

Heat Sink Thermal Resistance	Definition of thermal resistance of the cooling system applied.	Range 0.0001 .. 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 is shown in the electrical configuration schematic of the IGBT module datasheet. Therefore, if a user selects a dual switch module, the Rth should be multiplied with a factor of 2 to differentiate from the single switch case, if the same heatsink would be used in both cases. The selected Rth is also accounted for the diode position for which same consideration applies to its electrical configuration.	
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

3.2.1 Matching IGBTs

Once the previous IGBT properties are selected, the matching IGBT option appears. By clicking on the product code name the user may access the datasheet from the ABB website.

Figure 5 Matching IGBTs for selection

Users can select the desired IGBTs product names for simulation.

Up to 4 elements can be selected simultaneously and simulated. If one or more elements produce results exceeding the safe operating area (SOA) then they will return no results. In this case, the user should run the simulation again with changed parameters and/or product selection to enable results within SOA operating conditions.

3.2.2 Matching Diodes

Once the IGBT's are selected, the user can do the Rectifier Diodes selection for the front end rectifier based on the voltage rating chosen. By clicking on the product code name the user may access the datasheet from the ABB website.

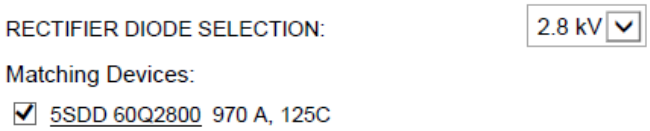


Figure 6 Matching Rectifier Diodes for selection

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 a number of calculated Jacobian.
Abort	Stops the simulation; No results generated
Hold results	To compare multiple simulations, results can be held for later viewing By selecting the button, results are held after the simulation has finalized for later comparison with succeeding simulations

Figure 7 Start of simulation

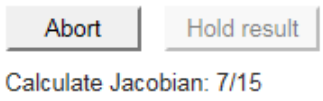


Figure 8 Simulation progress and termination

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

4.1 Graphical Output – Waveforms

When the simulation finishes the semiconductor and DC side waveforms are appearing as follows:

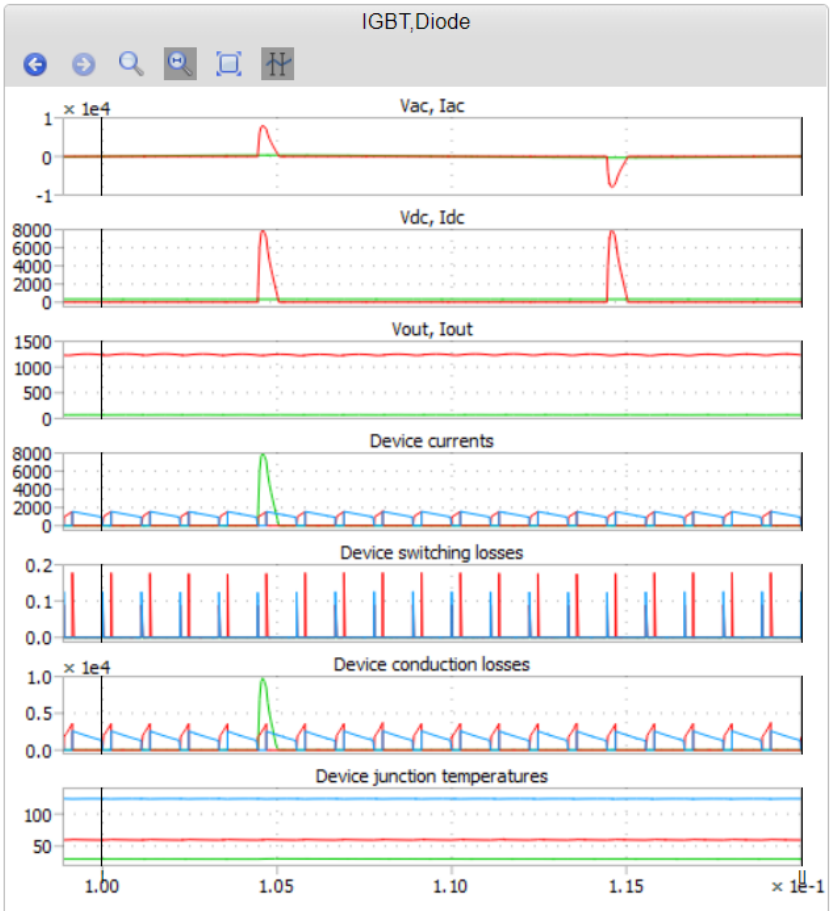


Figure 9 Graphical results of 1 phase diode rectifier + Buck converter

4.1.1 Control

For an 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

Hold result	Hide selectively waveforms of products
	Rest zoom to full view
	Activate cursors and to show parameter values table according to the cursor position
	Zoom selectable rectangle
	Zoom horizontal or vertical band

4.1.2 Parameters values indication

Tabular indication of graphical waveforms values according to the cursor position selected. Values are indicated for each parameter with the corresponding color of the waveform. The third column shows the difference between the two cursors per parameter.

Name	Cursor 1	Cursor 2	Delta
Time	0.1	0.12	0.02
Vac, Iac			
Switch6:1	-6.589e-13	-4.780e-13	-1.809e-13
Switch6:2	0.000	0.000	0.000
Vdc, Idc			
Capacitor voltage	322.8	322.8	1.705e-13
Measured current	0.000	0.000	0.000
Vout, Iout			
Resistor voltage	71.02	71.02	-2.132e-13
Resistor current	1233	1233	-3.865e-12
Device currents			
Diode currents	0.000	0.000	0.000
IGBT currents	927.5	936.7	-9.183
Diode currents	9.183	0.000	9.183
Device switching losses			
Diode switching losses	0.000	0.000	0.000
IGBT switching losses	0.08912	0.09000	-0.0008824
Diode switching losses	0.1250	0.1262	-0.001237
Device conduction losses			
Diode conduction losses	0.000	0.000	0.000
IGBT conduction losses	1726	1743	-17.09
Diode conduction losses	12.61	0.000	12.61
Device junction temperatures			
Diode junction temperatures	29.91	29.91	-5.400e-13
IGBT junction temperature	59.57	59.57	-0.001064
Diode junction temperature	123.8	123.8	-0.001471

Figure 10 Tabular indication of cursor position graph values

Remark:
The numerical values of Phase Voltage/Current at the position of respective cursors are shown in the Table. The numerical values of IGBT current/Diode Current along with their Switching loss, Conduction loss, and Junction temperatures 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 the PLEXIM PLECS software principle through the reference of the lookup table and linear interpolation of the actual device current, voltage, and junction temperature.

The losses per rectifier diode are tabulated. The rectifier losses are arrived at by multiplying the per rectifier losses by 4 and 6 for 1 phase rectifier topology and 3 phase rectifier topology respectively. The cumulative losses for the topology are calculated as the sum of the losses of the rectifier and the converter and tabulated under Converter Losses.

Device Losses & Temperatures

Device Losses & Temperatures						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per Rectifier Diode (D1)	0 W	154.17 W	154.17 W	30.00 °C	30.39 °C	30.38 °C
per IGBT (IGBT1)	239.83 W	579.17 W	819.00 W	59.81 °C	60.32 °C	60.10 °C
per FRD	112.99 W	1.476 kW	1.589 kW	123.58 °C	123.79 °C	123.64 °C
Converter Losses	352.82 W	2.672 kW	3.024 kW			
% Losses Rectifier			0.67 %			
% Losses Converter			3.28 %			

Figure 11 Device Losses & Temperatures

Switching Loss	Single IGBT or Diode Losses during turn on and turn off events (dynamic)
Conduction loss	Single IGBT or Diode Losses during on state (static)
Combined losses	Sum of single IGBT or Diode switching and conduction loss.
Converter losses	Sum of all 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 the simulation period
Junction Temperature BLS	Junction temperature at the time point just before the switching, after which the maximum junction temperature is achieved

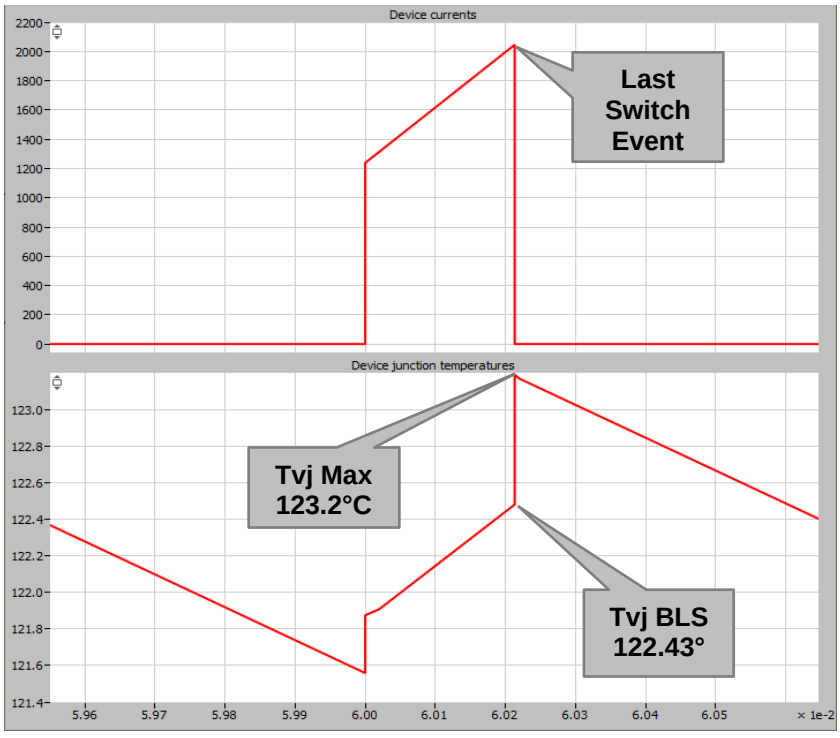


Figure 12 Definition of Tvj before the last switch

AC-DC parameters

AC-DC Parameters				
	Real Power	Phase Voltage (RMS)	Phase Current (RMS)	System Frequency
	92.24 kW	230.0 V	1.285 kA	50 Hz

Figure 13 Converter AC-DC Parameters

Real power	Active power supplied by the source including the thermal losses
Phase Voltage (RMS)	AC voltage per phase at the source
Phase current (RMS)	AC current drawn at the source by the load
Input Frequency (Hz)	Frequency of the source voltage

DC-DC parameters

DC-DC Parameters							
	Input DC Power	Ouput DC Power	Input DC Voltage	Input DC Current	Ouput DC Voltage	Output DC current	Duty ratio
	91.62 kW	88.60 kW	323 V	274.58 A	71 V	1.240 kA	0.22

Figure 14 Converter DC-DC Parameters

Input DC power	Active power supplied by the source including the thermal losses
Output DC power	Load power set by the user as explained in section 3.1.1.
Input DC voltage	DC voltage supplied at the input of the converter (Usually the output of a rectifier)
Output DC voltage	DC voltage output set by the user as explained in section 3.1.1.
DC Current	DC current is drawn by the load at the power set by the user.
Duty ratio	Duty ratio is calculated and displayed as per section 6.

General parameters

General Parameters			
	Switching frequency AC-DC	Switching frequency DC-DC	Ambient temperature
	50.0 Hz	900 Hz	25 °C

Figure 15 General Parameters

Switching Freq.	According to the definition
Ambient Temp.	According to the definition

5. ALERTS & FEATURES

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

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

Parameter	DC Blocking voltage
Verification	If the voltage rating of the IGBT and/or diode is less than the DC blocking voltage, the alert message is displayed
Warning message	For the selected device voltage rating, the operating range of the device is displayed

Parameter	Duty ratio
Verification	Range of Duty ratio is 0 to 1. If the duty ratio is out of these limits and an alert message is displayed
Warning message(s)	-Output voltage should be less than the input voltage for Buck operation -Output voltage should be greater than the input voltage for Boost operation

6. APPLIED CALCULATIONS

6.1 Input Parameter Definitions

V_{DC}	Input DC voltage/Rectifier output
V_{OUT}	Output DC voltage
V_{ph}	Single phase RMS voltage
Pout	Load power
F_Hz	AC side frequency (50/60Hz)
Fc_Hz	Control PWM switching frequency

6.2 DC output voltage of the Rectifier

1 phase diode bridge rectifier: $V_{DC} = \sqrt{2} * V_{ph}$

3 phase diode bridge rectifier: $V_{DC} = \sqrt{2} * \sqrt{3} * V_{ph}$

6.3 Output capacitance of the rectifier

The output capacitance is designed based on the ripple percentage with reference to the peak voltage (V_{DC}). The ripple factor is calculated as a product of ripple percentage which is considered as 1 %.

The following equation holds for I_{DC}: $I_{DC} = Pout * 1000/(V_{DC} - (0.01 * V_{DC} * 0.5))$

1 phase diode bridge rectifier: $C_d = I_{DC}/(2 * 0.01 * V_{DC} * F_{Hz})$

3 phase diode bridge rectifier: $C_d = I_{DC}/(6 * 0.01 * V_{DC} * F_{Hz})$

6.4 Duty ratio of the converter

The output of the rectifiers serves as input to the DC-DC converters. The following calculations have been used in the model to calculate the duty ratio:

For Buck converter: $D = \frac{V_{OUT}}{V_{DC}}$

For Boost converter: $D = 1 - \frac{V_{DC}}{V_{OUT}}$

6.5 Load side

The resistive load is formulated based on the following equations for each of the converters:

P_{OUT}	DC power / real power at the load
D	Duty cycle as per section 6.2
Rout	Resistive load of the converter

For Buck converter: $R_{OUT} = \frac{D^2 * V_{DC}^2}{P_{OUT}}$

For Boost converter: $$R_{OUT} = \frac{1}{(1-D)^2} * \frac{V_{DC}^2}{P_{OUT}}$$

6.6 Design of the inductance for Continuous Conduction Mode (CCM) of the converter

For Buck converter: $$L_b = \frac{R_d*(1-D)}{2*Fc\_Hz}$$

For Boost converter: $$L_b = \frac{R_d*D*(1-D)^2}{2*Fc\_Hz}$$

6.7 Converter output smoothing capacitor expressions

For Buck converter: $$C_s = \frac{(1-D)}{8*Lb*0.02*Fc\_Hz^2}$$

For Boost converter: $$C_s = \frac{(D)}{0.02*R_d*Fc\_Hz}$$

7. VALIDATION OF PLECS RESULTS WITH PSCAD

To ensure supplied simulation results are reliable, each of the Diode rectifier models in combination with either buck or boost on the secondary is validated with another simulation platform.

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 2 pulse + buck, 2 pulses + boost, 6 pulses + buck, and 6 pulses + boost with loss and temperature estimation in PSCAD and to validate the steady-state results obtained through EV charging topology based on Diode web simulation model.

Two different rectifier diode models and two different IGBTs have been chosen for the process of validation. The XML data of both these Diodes and IGBTs which were created from the device datasheets for SEMIS simulations is modified to individual .txt files for switch turn-on energy (E_{on}), switch turn-off energy (E_{off}), diode reverse recovery energy (E_{rec}), on-state voltage drop of IGBT (V_t), and on state voltage drop of the diode (V_d) 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 Diodes and IGBTs have been captured from the device datasheet while the Heat sink to ambient thermal resistance Rth(h-a) is assumed as 2K/kW with different ambient temperatures.

3 cases each for the 4 topologies are simulated in PSCAD and SEMIS by varying different parameters like input phase voltage, device, Load current, Load power, Switching frequency, etc.

Results analysis according settings

Topology	SEMIS 25 - 1Ph Diode Rectifier + Buck/Boost
Tester:	Sravan Durga
Date	April 8, 2020
Device used (.xml)	SSNE 0800M170100, SSNA 1600N170100, SSDD 60Q2800, SSDD 50N550
Limit acceptance level Green / Orange / Red	0% / 2% / 5%
Instructions	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 %

Description of Settings Set	Set 1			Set 2			Set 3			Set 4			Set 5			Set 6		
Parameter	**SEMIS**	**PSCad**	**Difference**	**SEMIS**	**PSCad**	**Difference**	**SEMIS**	**PSCad**	**Difference**	**SEMIS**	**PSCad**	**Difference**	**SEMIS**	**PSCad**	**Difference**	**SEMIS**	**PSCad**	**Difference**
Absolute average difference [%]			0.25%			0.89%			0.45%			0.36%			0.40%			0.35%
Max difference [%]			0.69%			1.65%			1.33%			1.76%			1.76%			1.92%
Device Losses & Temperatures (Rectifier)																		
Conduction Loss per Diode (W)	5.63	5.62	+ 0.18%	39.3	38.77	+ 1.35%	58.79	58.02	+ 1.31%	125.23	124.7	+ 0.42%	150.32	149.98	+ 0.23%	150.65	150.86	- 0.14%
Combined Loss per Diode (W)	5.63	5.62	+ 0.18%	39.3	38.77	+ 1.35%	58.79	58.02	+ 1.31%	125.23	124.7	+ 0.42%	150.32	149.98	+ 0.23%	150.65	150.86	- 0.14%
Junction Temperature Avg Diode (°C)	40.14	40.13	+ 0.02%	41.02	41.05	- 0.07%	41.52	41.56	- 0.10%	43.24	43.44	- 0.46%	44	44.04	- 0.09%	44	44.07	- 0.16%
Rectifier Losses (W)	22.52	22.48	+ 0.18%	157.2	155.08	+ 1.35%	235.16	232.08	+ 1.31%	500.92	498.8	+ 0.42%	601.28	599.92	+ 0.23%	602.6	603.44	- 0.14%
Losses Efficiency																		
Device Losses & Temperatures (Converter)																		
Conduction Loss per IGBT (W)	40.29	40.13	+ 0.40%	122.22	121.2	+ 0.83%	152.5	151.6	+ 0.59%	190.59	190	+ 0.31%	190.59	190	+ 0.31%	184.4	184.6	- 0.11%
Switching loss per IGBT (W)	27.56	27.5	+ 0.22%	183.58	182.6	+ 0.53%	57.82	57.6	+ 0.38%	108.41	108	+ 0.38%	108.41	108	+ 0.38%	354.58	355.9	- 0.37%
Combined loss per IGBT (W)	67.85	67.63	+ 0.32%	305.8	303.8	+ 0.65%	210.32	209.2	+ 0.53%	299	298	+ 0.33%	299	298	+ 0.33%	538.98	540.5	- 0.28%
Conduction Loss per Diode (W)	86.96	86.59	+ 0.43%	49.64	48.82	+ 1.65%	154.72	154.31	+ 0.26%	114.59	113.75	+ 0.73%	114.58	113.7	+ 0.77%	77.01	76	+ 1.31%
Switching loss per Diode (W)	11.06	11.03	+ 0.27%	70.47	69.6	+ 1.23%	21.79	21.7	+ 0.41%	46.95	46.7	+ 0.53%	46.95	46.7	+ 0.53%	136.84	139	- 1.58%
Combined Loss per Diode (W)	98.02	97.62	+ 0.41%	120.11	118.42	+ 1.41%	176.51	176.01	+ 0.28%	161.54	160.45	+ 0.67%	161.53	160.4	+ 0.70%	213.85	215	- 0.54%
Junction Temperature Avg IGBT (°C)	46.37	46.35	+ 0.04%	62.29	62	+ 0.47%	52.47	52.52	- 0.10%	62.67	62.59	+ 0.13%	62.67	62.59	+ 0.13%	67.18	67.6	- 0.63%
Junction Temperature Avg Diode (°C)	51.57	51.5	+ 0.14%	58.63	58.34	+ 0.49%	55.16	55.1	+ 0.11%	62.81	62.65	+ 0.25%	62.81	62.65	+ 0.25%	64.05	64.31	- 0.41%
Converter Losses (W)	165.87	165.25	+ 0.37%	425.91	422.22	+ 0.87%	386.83	385.21	+ 0.42%	460.54	458.45	+ 0.45%	460.53	458.4	+ 0.46%	752.83	755.5	- 0.35%
Total Converter Losses (W)	188.39	187.73	+ 0.35%	583.11	577.3	+ 1.00%	621.99	617.29	+ 0.76%	961.46	957.25	+ 0.44%	1061.81	1058.32	+ 0.33%	1355.43	1358.94	- 0.26%
Losses Efficiency																		
AC Parameters																		
Real Power (kW)	10.10	10.06	+ 0.38%	30.31	29.86	+ 1.50%	40.27	40.06	+ 0.53%	75.11	74.95	+ 0.22%	75.67	75.05	+ 0.82%	75.51	75.51	- 0.00%
Phase Voltage RMS (V)	229.2	230	- 0.35%	230	230	+ 0.00%	230	230	+ 0.00%	230	230	+ 0.00%	229.5	230	- 0.22%	230	230	+ 0.00%
Phase Current RMS (A)	171.53	171.72	- 0.11%	473.69	480.67	- 1.47%	622.47	628	- 0.89%	1077	1096	- 1.76%	1077	1096	- 1.76%	1091	1112	- 1.92%
System frequency (Hz)	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%
DC Parameters & Control Parameters																		
Input DC Power (kW)	10.07	10.04	+ 0.38%	30.16	29.70	+ 1.50%	40.04	39.83	+ 0.53%	74.61	74.45	+ 0.22%	75.07	74.45	+ 0.83%	74.90	74.91	- 0.00%
Output DC Power (kW)	9.908	9.87	+ 0.38%	29.73	29.28	+ 1.51%	39.65	39.44	+ 0.53%	74.15	73.99	+ 0.22%	74.61	73.99	+ 0.83%	74.15	74.15	+ 0.00%
Input DC Voltage (V)	324	323.8	+ 0.06%	324	323.8	+ 0.06%	324	323.8	+ 0.06%	324	323.7	+ 0.09%	324	323.7	+ 0.09%	324	323.7	+ 0.09%
Input DC Current (A)	30.61	30.53	+ 0.26%	91.83	90.6	+ 1.34%	122.46	121.89	+ 0.47%	229.11	228.7	+ 0.18%	229.11	228.7	+ 0.18%	229.11	229.46	- 0.15%
Output DC Voltage (V)	72	71.5	+ 0.69%	199	197.5	+ 0.75%	149	148.98	+ 0.01%	746	745	+ 0.13%	746	745	+ 0.13%	994	994.5	- 0.05%
Output DC Current (A)	138.24	137.98	+ 0.19%	149.31	148.2	+ 0.74%	265.49	264.78	+ 0.27%	99.43	99.3	+ 0.13%	99.43	99.3	+ 0.13%	74.57	74.5	+ 0.09%
Duty	0.22	0.22	+ 0.00%	0.61	0.61	+ 0.00%	0.46	0.46	+ 0.00%	0.56	0.56	+ 0.00%	0.56	0.56	+ 0.00%	0.67	0.67	+ 0.00%

Figure 16: Validation of results for for 1 Ph Diode Rectifier + Buck & Boost

Results analysis according settings

Topology	SEMIS 25 - 3Ph Diode Rectifier + Buck/Boost
Tester:	Sravan Durga
Date	April 8, 2020
Device used (.xml)	SSNE 0800M170100, SSNA 1600N170100, SSDD 60Q2800, SSDD 50N550
Limit acceptance level Green / Orange / Red	0% / 2% / 5%
Instructions	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 %

Description of Settings Set																						
Parameter	**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**		**Set 4 SEMIS**	**Set 4 PSCad**	**Set 4 Difference**		**Set 5 SEMIS**	**Set 5 PSCad**	**Set 5 Difference**		**Set 6 SEMIS**	**Set 6 PSCad**	**Set 6 Difference**	
Absolute average difference [%]			0.36%				0.19%				0.33%				0.23%				0.34%				0.32%	
Max difference [%]			1.18%				0.53%				1.40%				0.69%				1.46%				1.04%	
Device Losses & Temperatures (Rectifier)																								
Conduction Loss per Diode (W)	74.76	75.34	0.78%	-	22.72	22.78	0.26%	-	34.51	34.93	1.22%	-	75.21	75.57	0.48%	-	24.54	24.86	1.30%	-	84.93	85.67	0.87%	-
Combined Loss per Diode (W)	74.76	75.34	0.78%	-	22.72	22.78	0.26%	-	34.51	34.93	1.22%	-	75.21	75.57	0.48%	-	24.54	24.86	1.30%	-	84.93	85.67	0.87%	-
Junction Temperature Avg Diode (°C)	41.96	42.03	0.17%	-	40.59	40.61	0.05%	-	40.9	40.94	0.10%	-	41.96	42.02	0.14%	-	40.65	40.67	0.05%	-	42.28	42.3	0.05%	-
Rectifier Losses (W)	448.56	452.04	0.78%	-	136.32	136.68	0.26%	-	207.06	209.58	1.22%	-	451.26	453.42	0.48%	-	147.24	149.16	1.30%	-	509.58	514.02	0.87%	-
Losses Efficiency	0.30	0.30	1.18%	-	0.18	0.18	0.01%	+	0.21	0.21	1.40%	-	0.30	0.30	0.69%	-	0.20	0.20	1.46%	-	0.34	0.34	1.04%	-
Device Losses & Temperatures (Converter)																								
Conduction Loss per IGBT (W)	460.14	458.2	0.42%	+	230.3	230.1	0.09%	+	322.39	322.29	0.03%	+	176.87	176.39	0.27%	+	42.74	42.7	0.09%	+	97.1	97	0.10%	+
Switching loss per IGBT (W)	132.76	132.3	0.35%	+	296.27	295.58	0.23%	+	311.97	311.9	0.02%	+	167.13	166.8	0.20%	+	141.43	141.48	0.04%	-	77.15	77.8	0.84%	-
Combined loss per IGBT (W)	592.9	590.5	0.40%	+	526.57	525.68	0.17%	+	634.36	634.19	0.03%	+	344	343.19	0.24%	+	184.17	184.18	0.01%	-	174.25	174.8	0.32%	-
Conduction Loss per Diode (W)	140.77	140.36	0.29%	+	307.88	306.6	0.42%	+	868.86	867.15	0.20%	+	176.45	176	0.26%	+	76.28	76	0.37%	+	200.62	200.3	0.16%	+
Switching loss per Diode (W)	54.97	54.7	0.49%	+	143.75	143.38	0.26%	+	148.06	147.7	0.24%	+	78.58	78.3	0.36%	+	57.4	57.3	0.17%	+	30.35	30.6	0.82%	-
Combined Loss per Diode (W)	195.74	195.06	0.35%	+	451.63	449.98	0.37%	+	1016.92	1014.85	0.20%	+	255.03	254.3	0.29%	+	133.68	133.3	0.28%	+	230.97	230.9	0.03%	+
Junction Temperature Avg IGBT (°C)	82.47	82.28	0.23%	+	83.28	83.18	0.12%	+	87.3	87.5	0.23%	-	67.47	67.4	0.10%	+	54.65	54.64	0.02%	+	52.06	52.14	0.15%	-
Junction Temperature Avg Diode (°C)	72.26	72.1	0.22%	+	97.6	97.32	0.29%	+	115.79	115.61	0.16%	+	73.46	73.3	0.22%	+	57.62	57.55	0.12%	+	57.83	57.82	0.02%	+
Converter Losses (W)	788.64	785.56	0.39%	+	978.2	975.66	0.26%	+	1651.28	1649.04	0.14%	+	599.03	597.49	0.26%	+	317.85	317.48	0.12%	+	405.22	405.7	0.12%	-
Total Converter Losses (W)	1237.2	1237.6	0.03%	-	1114.52	1112.34	0.20%	+	1858.34	1858.62	0.02%	-	1050.29	1050.91	0.06%	-	465.09	466.64	0.33%	-	914.8	919.72	0.54%	-
Losses Efficiency	0.53	0.53	0.01%	-	1.30	1.29	0.53%	+	1.64	1.64	0.05%	-	0.40	0.40	0.04%	+	0.43	0.43	0.05%	-	0.27	0.27	0.29%	-
AC Parameters																								
Real Power (kW)	149.74	149.14	0.40%	+	75.48	75.69	0.28%	-	101.00	100.82	0.18%	+	149.45	149.13	0.21%	+	74.69	74.57	0.16%	+	149.34	149.10	0.16%	+
Phase Voltage RMS (V)	229.2	230	0.35%	-	230	230	0.00%	+	230	230	0.00%	+	230	230	0.00%	+	229.5	230	0.22%	-	230	230	0.00%	+
Phase Current RMS (A)	680.39	677.15	0.48%	+	346.9	346.16	0.21%	+	436.54	430.45	1.40%	+	674	670	0.59%	+	347.65	343	1.34%	+	663.81	667.6	0.57%	-
System frequency (Hz)	50	50	0.00%	+	50	50	0.00%	+	50	50	0.00%	+	50	50	0.00%	+	50	50	0.00%	+	50	50	0.00%	+
DC Parameters & Control Parameters																								
Input DC Power (kW)	149.29	148.69	0.40%	+	75.35	75.56	0.28%	-	100.79	100.61	0.18%	+	149.00	148.68	0.22%	+	74.54	74.42	0.16%	+	148.84	148.59	0.17%	+
Output DC Power (kW)	148.5	147.9	0.40%	+	74.37	74.58	0.28%	-	99.14	98.96	0.18%	+	148.4	148.08	0.22%	+	74.22	74.1	0.16%	+	148.43	148.18	0.17%	+
Input DC Voltage (V)	561	560.34	0.12%	+	561	560.5	0.09%	+	561	561	0.00%	+	561	561	0.00%	+	561	560.5	0.09%	+	561	560.5	0.09%	+
Input DC Current (A)	264.94	264.1	0.32%	+	132.54	132.65	0.08%	-	176.72	176.68	0.02%	+	264.59	264.37	0.08%	+	132.29	132.28	0.01%	+	264.58	264	0.22%	+
Output DC Voltage (V)	398	397.2	0.20%	+	199	199	0.00%	+	119	119.39	0.33%	-	995	994	0.10%	+	746	745.7	0.04%	+	796	795	0.13%	+
Output DC Current (A)	373.17	372.3	0.23%	+	373.4	373.13	0.07%	+	829.72	829.15	0.07%	+	149.21	149.01	0.13%	+	99.47	99.36	0.11%	+	186.52	186.4	0.06%	+
Duty	0.71	0.71	0.00%	+	0.345	0.345	0.00%	+	0.207	0.207	0.00%	+	0.436	0.436	0.00%	+	0.248	0.248	0.00%	+	0.295	0.295	0.00%	+

Figure 17: Validation of results for 3 Ph Diode Rectifier + Buck & Boost

8. USER MANUAL REVISION HISTORY

Rev.	Page	Change Description	Date / Initial
1.0	all	Initial version new design	2020-15-04 PGGI/SD

9. SIMULATION SOFTWARE RELEASE HISTORY

Rev.	New topic	Fixed defects	Tvj influence	Date
1.0	Initial version	-	-	2020-15-04 PGGI/SD

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