IP1 TRACTION TD1– PHASE 3 and HVAC TD8

D12.1 Final report reliability and availability improvement

Environmental requirement specification including harmful gas requirements

Public Version

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PINTA3

EXECUTIVE SUMMARY

Reliability of traction converter - especially SiC power semiconductor devices - are closely linked with the robustness against environmental loads. A precise specification with requirements derived from real Rolling Stock operation is the basis for a high quality and long lifetime of the devices.

The PINTA project concluded a measurement campaign all over Europe on different types of Rolling Stock, which is the basis for the environmental requirement specification. The measurement campaign

- encompasses tramways, Metro, regional and high-speed trains,
- encompasses water-cooled, natural-cooled and forced air-cooled systems,
- includes all relevant installation spaces for converters like roof, underfloor and machine room and
- covers moderate as well as Mediterranean climatic conditions

The measurement period for each train covers appr. 1 year operation to receive data for each season. With a standardized data evaluation tool developed by the PINTA WP4/12 working group data, covering several months of operation of each train, are analyzed and transformed as well as extrapolated to environmental requirements. The specification is updated accordingly.

In addition, PINTA successfully established a joined working group which consists of PINTA members and power semiconductor suppliers. This working group is hosted by ECPE (European Center for Power Electronics). The cooperation ensures an adoption of the PINTA project results by the European market. The requirement specification D12.1 is used to define appropriate tests for the innovative SiC devices. A first test specification prepared by the ECPE working group dedicated to the robustness against device internal aluminum corrosion was issued. A second test specification is in preparation regarding robustness against device internal condensation.

Other reliability characteristics of SiC power semiconductor devices are considered within the PINTA scope by the cooperation with the RECET4Rail project and an adjacent ECPE project carried out by the Fraunhofer Institute dedicated to harmful gas requirements caused by sulfur or chloride elements.

ABBREVIATIONS AND ACRONYMS

Si	Silicon
SiC	Silicon Carbide
RH	Relative Humidity
AH	Absolute Humidity
ECPE	European Centre for Power Electronics
PSRRA	Power Semiconductor Reliability for Railway Application working group within ECPE
T	Temperature
T_j	Junction Temperature
SC	Semiconductor

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1. SCOPE

1.1. OBJECTIVES OF THE DELIVERABLE

The document is subdivided into 5 technical chapters. The first two technical chapters focus on measurement campaigns (Chapter 2) and the resulting final environmental requirements valid for the power semiconductors validated using said campaigns (Chapter 3). It defines the thermal and humid operational conditions for the devices.

Use Cases for rollong stock specific operation are listed in Chapter 4. Meaningful for the power semiconductors environmental requirements are the numbers of incidents of specific operational load conditions. The use cases data are often separated into typical and maximum values.

Chapter 5 is dedicated to the rolling stock operation time. Data shown in this chapter are intended to be used for lifetime calculation. For the thermal and humid operation conditions of the power semiconductor devices three operation modes are relevant. Typical and generic distributions over the lifetime and the daily operation are described.

In chapter 6 “Operational Isolation Voltages” the required voltage levels (Terminal to ground / housing) of power semiconductor module are defined.

1.2. TECHNICAL SCOPE OF THE DOCUMENT

The climate requirement specification defines the thermal and humid operation conditions for power semiconductor devices used in traction converters installed on Rolling Stock. In addition to existing standards the requirements in this specification are defined for interfaces in the close neighbourhood of the power semiconductor device.

Three interfaces are considered:

1. Surrounding of the device housing, air close to the housing
2. Surface of the Heatsink
3. Main Terminals (Load and DC Link)

The numbers 1, 2, 3 in Figure 1 define the location of the interfaces for a power semiconductor device in a typical multi-chip housing. The interfaces are external locations of the housing. The requirements remain therefore valid for the different internal housing technologies. The specification applies for semiconductor dies covered either with pure silicone gel, silicone gel combined with hard epoxy resin as well as moulded devices with pure hard epoxy resin.

The advantage of this specification over basic environmental standards are the definition of the requirements for the power semiconductor devices considering the transformation of the external climate into the microclimate conditions for the devices. The transformation changes the relative and absolute humidity as well as the thermal conditions. Self-heating of the converter unit due to internal losses are considered.

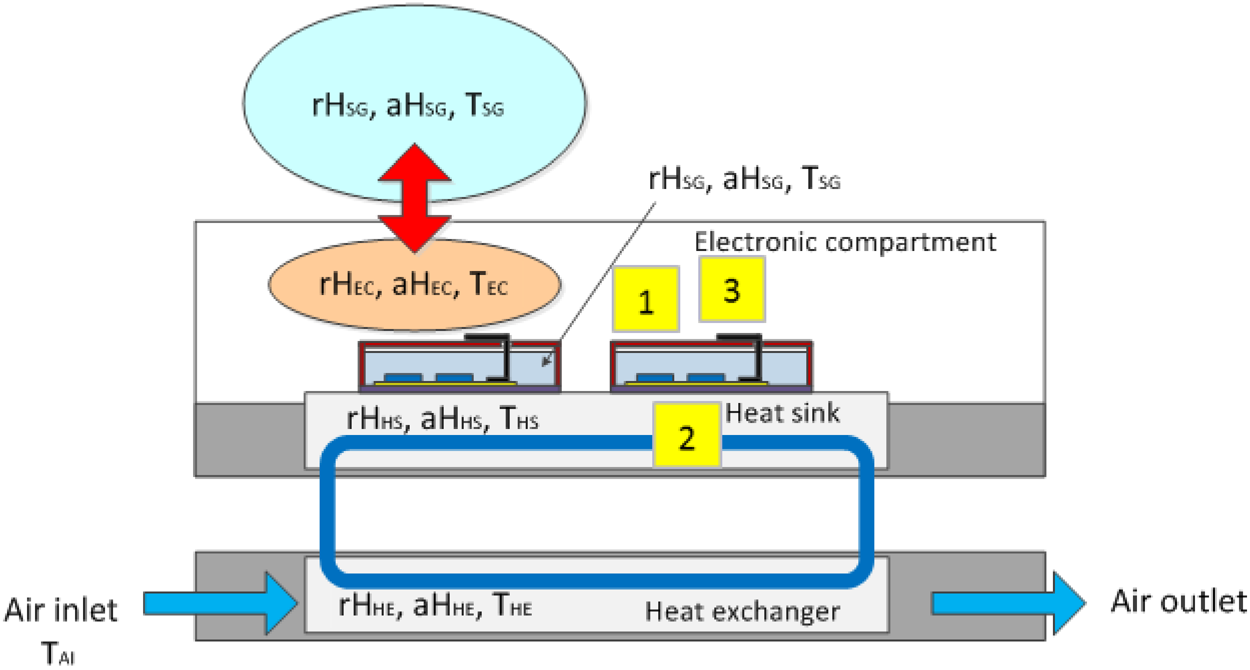

Figure 1: Typical converter unit with water cooling system. Interfaces 1, 2 and 3 close to the neighbourhood of the power semiconductor device are used for the requirement definition

The requirements in this specification apply for any power semiconductor technology in a multi-chip type housing used in traction converters. I.e. the specification is valid for Si and SiC devices. Semiconductor devices in a disc type housing are excluded from this specification.

Figure 1 shows the principal converter architecture of a water-cooled unit. Nevertheless, the requirements are valid as well for forced air cooled or natural cooled converter units.

As the lifetime of semiconductor modules also strongly depends on the voltages at the terminals, the scope of this document encompasses voltage specifications as well. The specifications are given for general converter applications and consider intermediate voltage levels.

2. MEASUREMENT CAMPAIGNS

Within the PINTA3 WP4/12 Working Group, eight different campaigns were launched on different vehicles, gathering valuable data on the microclimate inside converter cabinets. All measurement campaigns used dataloggers from the suisse company MSR. The same kind of sensor equipement was chosen and installed in similar fashion. For evaluation, a Matlab script was developed by all partners to ensure comparability of the results.

In the measurement campaigns, data was taken on three defined positions.

1. The Air next to the module (→Interface 1)
2. On Top of the Heatsink close to the module (→ Interface 2)
3. Outside the converter Cabinet (ambient condition of the Train)

The Interfaces 1 & 2 according to Figure 1 can thus be investigated by the measurement campaign, the values for Interface 3 can only be indirectly determined by e.g. estimating the baseplate temperature of the module which serves as a good approximation for the temperatures of the main terminals.

All measurement Campaigns are summed up in the following table.

Type of rolling Stock	Country	Converter type	Cooling type	Converter Location			Measured Positions			Track characteristics		Add. Data	
				Roof	Underfloor	Machine Room	Close to module	Heatsink	Outside of Cabinet	Tunnel sections	Operational Altitude	Vehicle Status Data	GPS
Regional, Intercity	Austria	DC/DC & Motor inverter	Water	X			X	X	X	X		X	X
Intercity	Germany	Motor inverter	Water		X		X	X	X	X		X	X
Regional	France	Motor inverter	Water	X			X	X	X			X	
Regional, double Deck	Switzerland	Line Converter	Water			X	X	X	X	X		X	
Regional	Spain	Motor inverter	Natural cooled		X		X	X	X	X	X	X	
Metro	Austria	Auxilliary Inverter	Force cooled		X		X	X	X	X		X	
Tram	Munich	Motor inverter	Force cooled	X			X	X	X			X	
Tram	Spain	Motor inverter	Natural cooled	X			X	X	X			X	

Table 1: Overview of Campaigns

2.1. DYNAMIC HUMIDITY

It is worthwhile noting that during the measurements, dynamic humidity was observed inside the converter cabinets in multiple campaigns. When the temperature inside the converter rose, the absolute humidity increased as well. That can be explained by e.g. humidity diffusion in plastics or humidity adsorption on walls (not necessarily wet condensation). This may lead to a higher humidity level than ambient, which was not taken into account by previous releases of this document. During measurements, more than 30 g/m³ were observed, which was given as the highest value in the last release.

This effect has been previously observed in controlled lab environments [REF 01] and could be described by humidity diffusion simulation. The observation of the effect of dynamic humidity in the PINTA measurement campaigns was presented in a conference paper at the EPE conference in 2021 [REF 02]. In this publication the authors describe the effect and present a methodology to simulate dynamic humidity in power converters for railway applications. Figure 2 is taken from this publication and illustrates the effect. Figure 3 illustrates the overall differences in climatic conditions using a bivariate histogram.

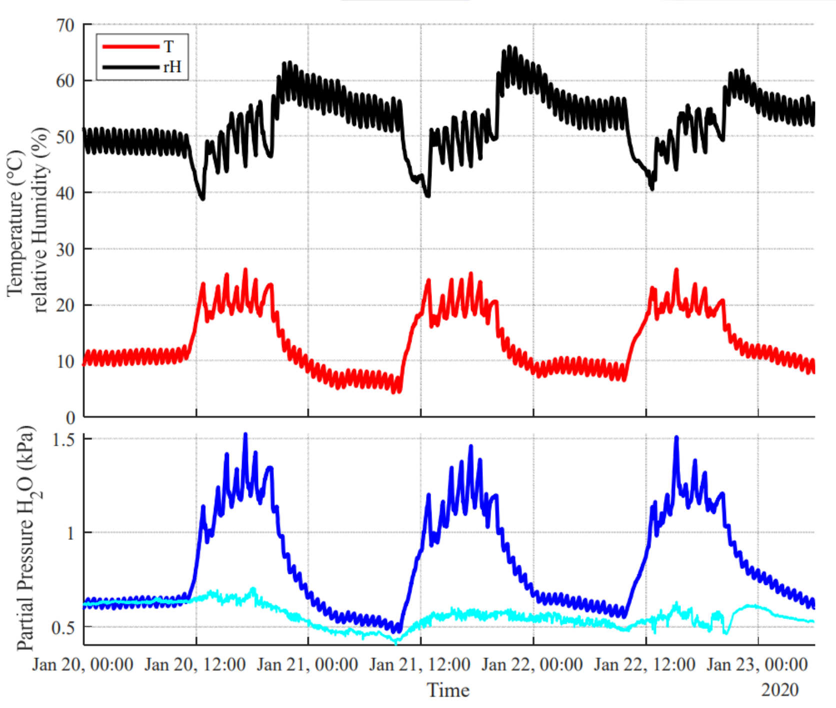

Figure 2: Temperature (red) and relative Humidity (black), The partial pressure (blue) rises under operation compared to ambient conditions (cyan). Figure taken from [REF 02].

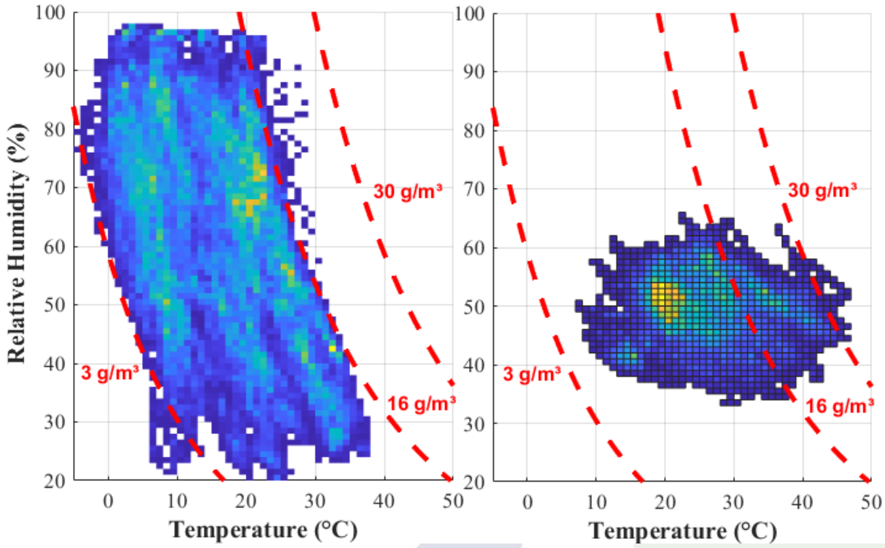

Figure 3: Bivariate Histograms of a full year of data taken outside the cabinet (left) and inside a DC/DC converter (right). Only days with actual operation are considered. Figure taken from [REF 02].

These findings clearly show that using ambient humidity conditions as the basis for requirement specifications for power semiconductors would definitely underestimate the stress by the environment. A similar observation is encoded in IEC standard 60721-3-5 5K2. Here, the maximum absolute humidity value is given as 60 g/m³, which is way higher compared to realistic ambient conditions. In the standard, the cause for this is given as e.g. “evaporation of water from wet surfaces”, which is also a reservoir of humidity that can be thermally activated.

2.2. IMPACT OF WATER COOLING ONTO MICROCLIMATE

Leaving a warm, humid tunnel into a cold environment is commonly expected to produce condensation in railway application. For this reason, signifcant efforts were made to include vehicles that are exposed to significant temperature changes that are produced by tunnel operation. Most notably, one of the vehicles under observation regularly passed through the Gotthard-Tunnel. With a length of 57 km and a maximum rock overlay of 2450m, the Gotthard Tunnel was expected to have a significant impact on the microclimate of the converter.

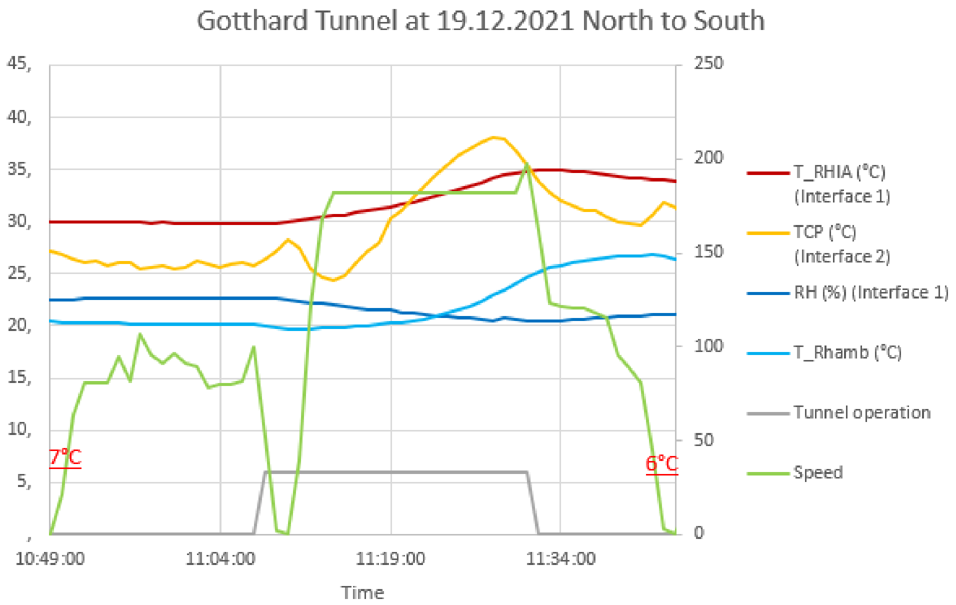

Figure 4: Measured Temperatures inside the converter cabinet when passing through the Gotthard Tunnel on a cold day. Note: The ambient measurement (T_Rhamb) does not follow the ambient conditions due to the placement of the sensor.

Contrary to expectation, the impact was insignificant. The temperature inside the Gotthard Tunnel is expected to be higher than 40°C in Summer, but unfortunately the ambient temperature measurement was strongly influenced by the cooling water temperature and could thus not be used. The change in the temperatures as seen in Figure 4 can be fully explained by the control of the cooling system and acceleration of the train. No sudden temperature change at both entry and exit of tunnel was observed throughout the seasons. This is attributed to the large thermal time mass of the whole cooling system. If the corresponding thermal time constant was significantly larger than the time it takes to pass the tunnel in its entirety, no drastic effect can be observed.

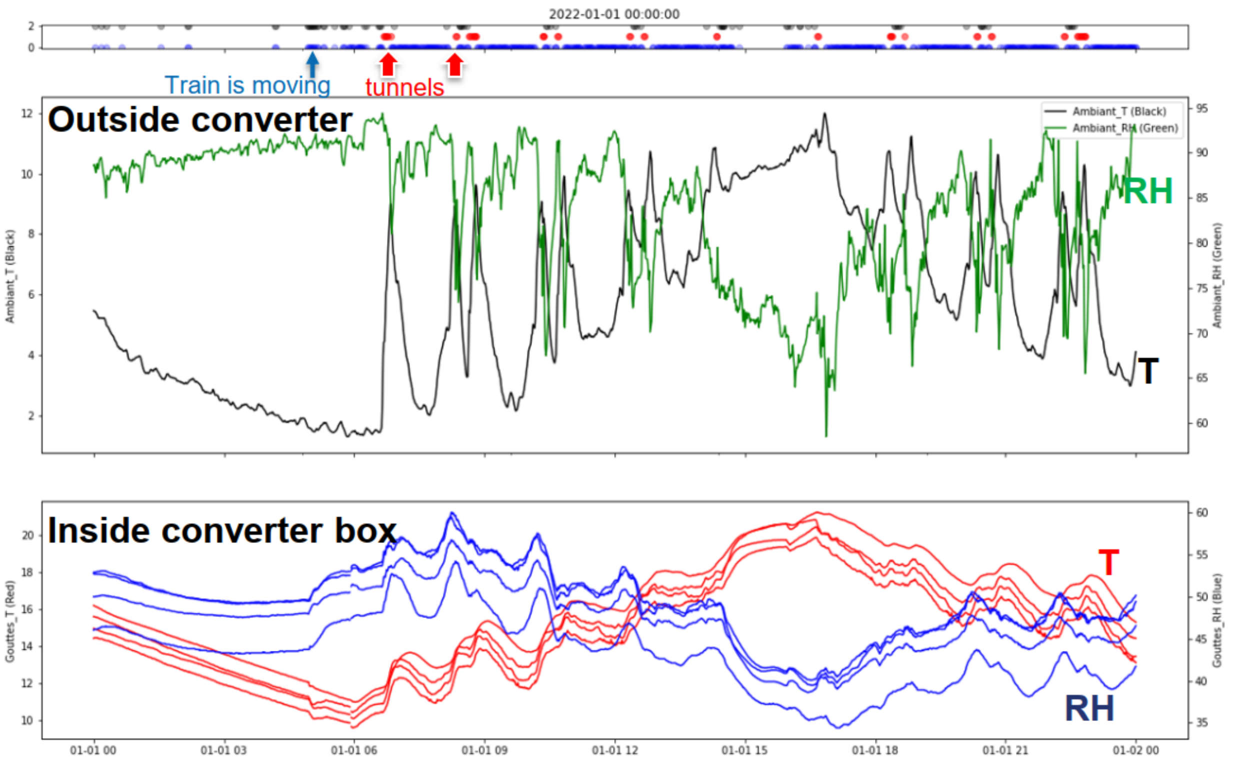

Figure 5: Multiple short tunnels in a round trip: Strong increase in ambient temperature only translates to a dampened effect inside the water cooled converter.

Results from another measurement campaign (also water-cooled converter) illustrate a similar situation. In the upper subplot of Figure 5 the ambient conditions are shown, the black T curve shows domininant peaks, when the vehicle is passing through a tunnel (indicated by the red markers at the very top). The effect of these strong temperature peaks onto the climate inside the converter box (lower subplot) is damped by the thermal time constant of the cooling system. The different relativ humidity and temperature measurements are taken at different positions in the converter cabinet and show comparable absolute humidity.

For water cooled systems, the greatest impact on the microclimate is posed by the control of the cooling system. For all observed water-cooled converters, the signature of the control was the dominating influence, most prominently the change of the efficiency of the cooling system (e.g. switching on/off).

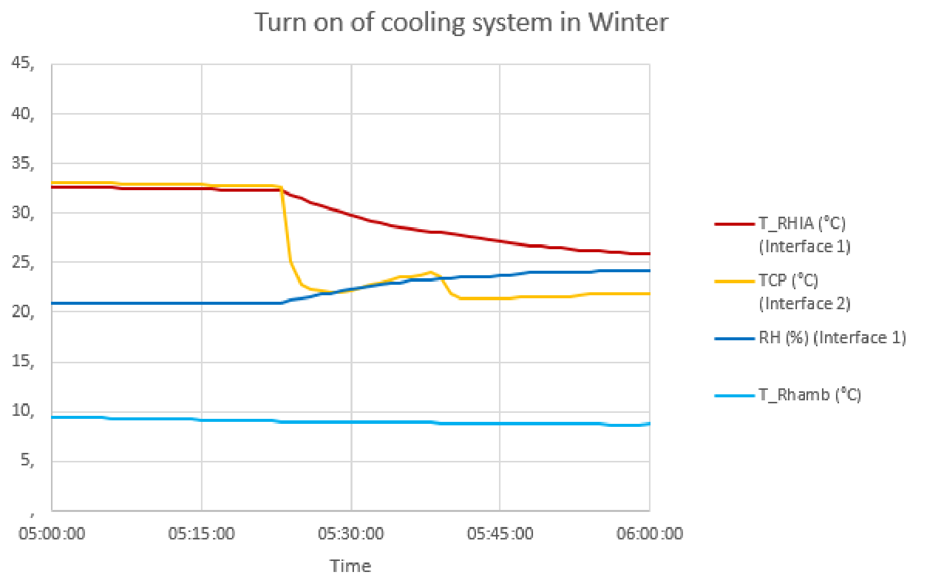

Figure 6: Temperature change when switching on the (water) cooling system in winter: Quick changes in temperature are observed

The influence of switching on the cooling system can be clearly seen exemplary in Figure 6 above. The temperature of Interface 2 (yellow curve) quickly (max dT/dt = 7.5 K/min) drops by 10 K, while the temperature of Interface 1 takes much longer.

Overall, one of the key learnings is that for water cooled systems, fast changes in the ambient conditions are significantly dampened due to the long thermal time constant of the whole cooling system. Another key learning is that the control of the cooling system can be considered a major influence onto the temperatures inside the converter cabinet, which may even lead to condensation.

2.3. MODERATE TEMPERATURES DURING NORMAL OPERATION

Comparing the measurement results (and the subsequent extrapolation) to the educated guesses given in the very version of the document, it became obvious, that the temperatures and the changes thereof were significantly lower than expected. This discrepancy is attributed to the piling up of worst case situations that necesarrily need to be considered in development and design of a converter. Some examples that show how the observations have impacted the view on the temperatures can be seen in the Table 2 below.

Description of Item	Old Value based on estimation	New Value
High air temperature (max), Interface 1	95 °C	75 °C
High air temperature (max), Interface 2	100 °C	80 °C

Table 2: Comparison of old and updated specified high temperatures in converters for railway applications

2.4. ASSESSMENT OF RISK OF CONDENSATION

Fast changes of temperatures in an air cooled system (natural or forced) will translate to fast changes of temperature on Interface 2. As one measurement campaign experienced many such drops when leaving the warm depot at the start of operation, an investigation of the risk of condensation on top of the heatsink was done.

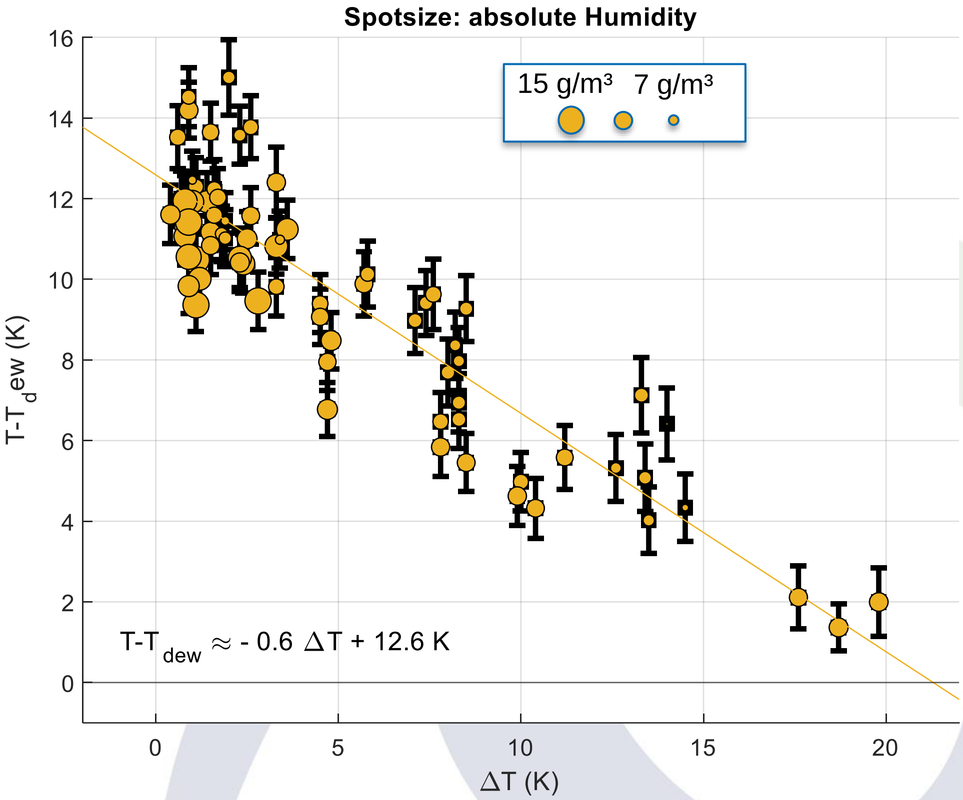

Figure 7: Estimation of risk of wet condensation by leaving a warm depot: linear fit predicts ca 20 K for low to moderate humidity

Figure 7 shows a scatterplot of the observed drops in temperature.The x-axis gives the amplitude of the temperature drop, the y-axis denotes the corresponding minimum difference to the dew point on the surface of the heatsink. In order to assess the risk of wet condensation forming on the heatsink a linear function was fitted to the data. The resulting linear function predicts the event of $T = T_{dew}$ at a Temperature drop of 21 K. The amount of absolute humidity at the moment of temperature change (indicated by marker sizes) does not influence the result significantly. It is worth adding that the amount of absolute humidity observed in this campaign is considered low to moderate.

Considering all this, sudden temperature drops of more than 20 K are likely to produce condensating conditons on the top of the heatsink.

But even if no condensation on the heatsink may be visible, a decrease in temperature might still produce condensation inside the power semiconductor module: Combining the key result of dynamic humidity inside the converter cabinet and the fact that the absolute humidity inside the module can be modeled by a lowpass filter with long time constants (e.g. 24 hours) we conclude that the amount of absolute humidity close to the chip can indeed be higher, than the absolute humidity next to the module. This key learning was included in the requirement specifications by considering the max. mean values of absolute humidity for different time windows, representing different humidity intrusion behaviors of different power semiconductor modules.

2.5. TRANSFORMING MEASUREMENTS TO SPECIFICATIONS

In order to extrapolate the measurement towards realistic worst case scenarios, reference to the expected worst-case outside conditions must be made. As the climatic conditions in the immediate vicinity of the converter cabinet can differ from wheather data significantly, the specfied temperature of the container is defined as the highest ambient temperature to be expected .

The appropriate way of extrapolation is plotting the measured ambient temperatures versus the temperatures of the investigated Interface and extrapolating towards the defined condition.

Table 3 lists the way of extrapolation for all items of the requirement specifications.

Item	Explanation	Interface	Way of Extrapolation	Reasoning
3.1	Operation temperature lower limit value	1	Lowest expected ambient condition	Vehicle starting from cold state.
3.2	Operation temperature upper limit value	1	Extrapolating $T_{Ambient}$ vs. T_1 data using appropriate functions (polyn. Deg. 1 or 2) towards specified ambient conditions of the container only using Data when the vehicle is in operation.	In a first approximation, the temperature at the respective interface will be given by $T_{ambient}$ plus some ΔT that is given by heating of internal air due to the load. Since this ΔT is heavily influenced by e.g. control of the cooling system, the ΔT for high ambient Temperatures may differ significantly from the on at low ambient temperatures, it is important to plot and understand the said influences prior to performing the extrapolations.
4.1	High Air Temperature	1	See 5.2, except now all data is taken into account.	See Item 3.2
4.1	High Air Temperature	2	See 5.2, except now all data is taken into account and Ambient vs. T_2 is used.	See Item 3.2
5.1	Change of the surrounding air temperature at interface 1, negative temperature change (high --> low)	1	T_1-$T_{workshop}$	Assuming the air at Interface 1 is at its specified high temperature (Item 5.2) and the container is opened in a workshop with ambient conditions of 25°C, the difference of both temperatures will give a maximum of negative temperature change.
5.2	Change of the surrounding air temperature at interface1, positive temperature change (low→high)	1	$T_{workshop}$-$T_{Item\ 5.1}$	Assuming the air at Interface 1 is at its specified low temperature (Item 5.1) and the container is opened in a workshop with ambient conditions of 20°C, the difference of both temperatures will give a maximum of positive temperature change.
9	High absolute Humidity	1	IEC 60721-3-5: 5K2	Dynamic humidity by thermal activation of humidity reservoirs has been observed in the measurement campaigns. IEC 60721-3-5 5K2 gives 60 g/m³ as highest absolute humidity due to e.g. evaporation of water from wet surfaces.
11	Max. Absolute Humidity (6hr mean, 24hr mean, 1 Week mean)	1	Scale Dataset to the value given in Item 9: $AH_{scaled}(t) = AH_1(t) \cdot \frac{AH_{Item\ 9}}{\max(AH_1)}$ The values for item 11 are then calculated using a moving mean filter with different time windows.	Dynamic humidity is observed in various campaigns. Scaling data with prominent dynamic humidity towards worst case absolute humiditiy, the obtained worst-case data as function of time can be used.

Table 3: Methods of extrapolation starting from measurement results

Symbols:

T_x, RH_x, AH_x : T, RH, AH at Interface x

$T_{Item\ x}$, $RH_{Item\ x}$, $AH_{Item\ x}$: T, RH, AH specified in Item x

3. ENVIRONMENTAL REQUIREMENTS

Item	Standard reference	Converter requirement	Unit	Interface specific data			Explanation/Remark
				1	2	3	
Altitude							
1	IEC 60721-3-5 IEC 62498-1	Altitude	m	3000			Higher Values need to be discussed within projects
Temperature							
2	IEC 62498-1	Operation temperature lower limit value	°C	-40			Valid for all Interfaces
3.1	PINTA2 technical note [REF 03]	Storage temperature lower limit value	°C	-50			Valid for all Interfaces
3.2	IEC 60571	Storage temperature upper limit value	°C	85			Valid for all Interfaces
4.1	IEC 60721-3-5 (Revised by measurement)	High temperature (max.) at different interfaces in compartments, except engine compartments, for 125°C Tj SCs	°C	75	85	120	Interface 3.:Value obtained from type-tests
4.2	IEC 60721-3-5 Extrapolated from measurement	High temperature (max.) at different interfaces in compartments, except engine compartments, for 175°C Tj SCs	°C	125	135	150	The values given in this item are estimations and might be revised in the future
5.1	(IEC 60721-3-5) (Revised by extrapolated data)	Change of the surrounding air temperature at interface 1, negative temperature change (high → low)	K	50	n/a	n/a	Explanation see Table 3
5.2	(IEC 60721-3-5) (Revised by extrapolated data)	Change of the surrounding air temperature at interface 1, negative temperature change (low → high)	K	60	n/a	n/a	Explanation see Table 3

Item	Standard reference	Converter requirement	Unit	Interface specific data			Explanation/Remark
				1	2	3	
6	(IEC 60721-3-5) (Revised by measurement)	Change of temperature during daily operation at the specific interface	K	typ 20 max 45	typ 25 max 45	n/a	The values describe a complete temperature cycle of a length of several hours, that consists of the daily ambient temperature cycle, internal losses and solar irradiance.
Humidity							
7	IEC 60721-3-5	Relative humidity, not combined with rapid temperature changes, except in engine compartments of vehicles powered by internal combustion engines	% °C	Storage: 45 °C / 95 % Operation : 70 °C / 30 %	n/a	n/a	Other combinations of temperature and rel. Humidity can occur assuming a const., absolute humidity
8	IEC 60721-3-5	Relative humidity, combined with rapid temperature changes, air/air at high relative humidity (except in engine compartments of vehicles powered by internal combustion engines)	% °C	This requirement is defined by item 6 and item 7			
9	IEC 60721-3-5	High Absolute Humidity	g/m³	60	n/a	n/a	
10	IEC 60721-3-5	Low relative humidity	% °C	10 30	n/a	n/a	
11	(IEC 60721-3-5) (Revised by extrapolated data)	Max. Absolute Humidity	Peak value 6hr mean 24hr mean 1 Week mean	60 g/m³ 50 g/m³ 40 g/m³ 30 g/m³	n/a	n/a	Based on measurements that showed prominent humidity increase during operation. Extrapolation towards IEC 60721-3-5 was done according to Table 3.
Air movement, air pressure							
12	IEC 60721-3-5	Movement of surrounding medium air (max.)	m/s	5	n/a	n/a	Remark : Specified Value limited to operation

Item	Standard reference	Converter requirement	Unit	Interface specific data			Explanation/Remark
				1	2	3	
Rain							
13	EN 50125-1, 4.6	Rain		no	no	no	
14	IEC 60721-3-5	Precipitation, rain		n/a	n/a	n/a	
Snow and hail							
15	EN 50125-1, 4.7	Snow and hail		no	no	no	
16	EN 50125-1, 4.8	Ice (frozen condensed water)		n/a	Yes	n/a	
Solar radiation							
17	IEC 60721-3-5	Solar radiation	W/m²	1120 (for 100h of the lifetime)			
Pollution (Refer to EN50124, PD 3)							
18	IEC 60721-3-5	Chemically active substances		5C2			5C1 is not sufficient w/o salt mist
19	IEC 60721-3-5	Biological conditions		5B1			
20	IEC 60721-3-5	Dust, sand		5S2			e.g. Talcum
21	IEC 60721-3-5	Salt spray		5C2			w/o salt mist
22	IEC 60721-3-5	Contaminating fluids		5F1 + cooling fluid, thermal grease cleaning fluid			

Table 4: Environmental Requirements

4. USE CASES AND OPERATIONAL CONDITIONS

ID	Use case	Req. item	Unit	Value	Remark/ explanation
A1	Lhasa line (China/ Tibet)	1	altitude [m]	5100	
A2	Lima – Huancayo	1	altitude [m]	4830	
A3	Ferrocaril Central Andino	1	altitude [m]	4781	
A4	Rocky Mountaineer	1	altitude [m]	3000	
A5	Kapstadt - Johannesburg	1	altitude [m]	1800	
A6	Darjeeling Himalayan Railway	1	altitude [m]	2200	
A7	Kalka-Shimla Railway	1	altitude [m]	2000	
A8	Schweizer Alpen (Glacier Express)	1	altitude [m]	2033	
A9	Schweizer Alpen (Bernina)	1	altitude [m]	2253	
A10	Schweizer Alpen (Jungfraujoch)	1	altitude [m]	3454	

Table 5: Use Cases for altitude, typical operational scenarios of rolling stock

ID	Use case	Req. item	Value	Concerned interface	Temperature difference	Gradual change of temperature	Number of occurences per year	Remark/ explanation
TC1	opening of the container during maintenance starting with a warm converter	3,4,5	max	1	50 K (75°C … 25°C)	50 K / min	1	No direct transfer from air to air possible. The temperature drop is estimated to happen within one minute.
TC2	opening of the container during maintenance starting with a cold converter, entering a warm workshop	3,4,5	max	1	60 K (-40°C … 20°C	60 K / min	1	No direct transfer from air to air possible. The temperature drop is estimated to happen within one minute.
TC3	Temperature change caused by change of the environmental temperature		max.	2	20 K	0,2 K / min	60	Daily temperature change definition of the climates: IEC 60721-2-1"
TC4	Temperature change caused by change of the environmental temperature		typ.	2	10 K	0,1 K / min	365	Daily temperature change definition of the climates: IEC 60721-2-1"
TC5	Temperature change caused by starting the cooling system		max.	2	30 K	15 K/min	10	
TC6	Temperature change caused by starting the cooling system		typ.	2	20 K	10 K/min	2000	
TC7	Temperature change caused by entering or leaving tunnels (low --> high) or (high --> low)		extreme	2	40 K	20 K / min	20 x high to low 20 x low to high	
TC8	Temperature change caused by entering or leaving tunnels (low --> high) or (high --> low)		max.	2	30 K	15 K/ min	50 x high to low 50 x low to high	Based on publically available data of metro London [Ref 09]
TC9	Temperature change caused by entering or leaving tunnels (low --> high) or (high --> low)		typ.	2	20 K	10 K/ min	2000 x high to low 2000 x low to high	Based on publically available data of metro London [Ref 09]

TC10	Temperature change caused by entering or leaving workshops (low --> high) or (high --> low)		typ.	2	30 K	15 K / min	50 x high to low 50 x low to high	
TC11	Temperature change caused by entering or leaving workshops (low --> high) or (high --> low)		max.	2	60 K	30 K / min	1	

Table 6: Use Cases for condensation, typical operational scenarios of Rolling Stock

5. TYPICAL ROLLING STOCK OPERATION

5.1. LIFETIME REQUIREMENTS

Data category	Unit	Type	Regional		Suburban Paris		High Speed Trains DB	High Speed Trains SNCF	High Speed Trains SNCF	Remark/ explanation
			Max[1)]	Min[1)]	Max[1)]	Min[1)]	Typical[1)]	Typical[1)]	Max[1)]	
Number of operation days		Max.	330	310	335	310	330		350	
Daily operation (normal service)	h	Typ.	16	10	19	11	18	12	20	
Standstill time with electric power	h	Typ.	3	4	2	7	6	6		
Standstill time w/o electric power	h	Typ.	5	10	3	6				
Maximum speed	km/ h		160		140		300	> 320		
Equivalent mean speed under operation	km/ h			48,4		42,3				
Mean line length	km			70						
Daily mileage	km/ d				640	465	1.750	1.500	3.000	
Distance between two stops	km		7	1			20 - 200			
Number of starting operations per day of the traction system (short stop time)	1/ d	Typ.	774	69						Intermediate stops of regional train at end stations
Number of starting operations per day of the traction system (long stop time at end stations)	1/ d		11	7						
Service time	a	max	40	40	40		30	30	40	
km per Year	km				214.000	144.000	730.000	540.000	1.000.000	
			SNCF for Reliability studies		50% @ 25kV/50Hz 50% @ 1500VDC					input from 2016-07-12

Table 7: Rolling Stock operation, liftetime requirements

1) Trains of a fleet aren't operated with equal load profile. In order to distinguish operational severity levels they are rated into: Min, Typical, Max

5.2. GENERIC TRAIN OPERATION

Typical train operation varies in dependence of the type of Rolling Stock. For trains of the type Electric Multiple Unit (EMU) the operation schedule shown in Figure 8 can be used as a simple and general description of the sequence of operation modes considering the supply of the train and the operation of the traction and auxiliary power supply system.

The following operation modes are considered:

- Daily operation (normal service): The train is supplied by the main electric systems provided by the substations of the grid, which feed the catenary or third rail. The traction system is in normal service accelerating, braking, coasting or in stand-still mode for entry / exit of passengers at regularly scheduled stops according to the train specific schedule.
- Stand-still time with electric power: Stand-still periods at end stations of a route or in a depot. The train is still connected to the main electric supply system. Auxiliary power supply system on the train as well as battery chargers are operable.
- Stand-still time w/o electric power: The train is disconnected from the catenary or third rail. The high voltage components and power electronic equipment of the train are disconnected from the supply system. The auxiliary supply and electronic components of the traction converter are switched off.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total [h]
Daily operation (normal service)																									16
Standstill time with electric power																									3
Standstill time w/o electric power																									5

Figure 8: Generic train operation, different operation modes in a daily sequence: the top row indicates the hours of the day

The generic train operation can be used to estimate the thermal characteristics of the converter units in the power electronic sections and the electronic compartments. The different operation modes are a first indication for losses generated in a converter cabinet. Temperature differences between ambient temperature outside of the vehicle and the converter interior can roughly be estimated.

Duration and sequence of the operation modes can be different between specific train types and the generic schedule depends on region, operator and train type.

6. OPERATIONAL ISOLATION VOLTAGES

Failure rates and lifetime limitations strongly depend on the voltages, which appear at the terminals of the power semiconductor devices. The following specification define for each terminal of the device to ground / device housing the voltage levels. The voltage curves and levels depend on the converter function and the earthing methodology of the intermediate circuit.

The defined voltages refer to the intermediate circuit voltage levels V_D and consider overvoltages caused by the switching characteristics of the semiconductor device.The average & maximum voltage requirements are defined for the generic converter functions and are given in Table 8.

The intermediate circuits can be either grounded at its minus pole, at its plus pole or floating with high impedance to ground.

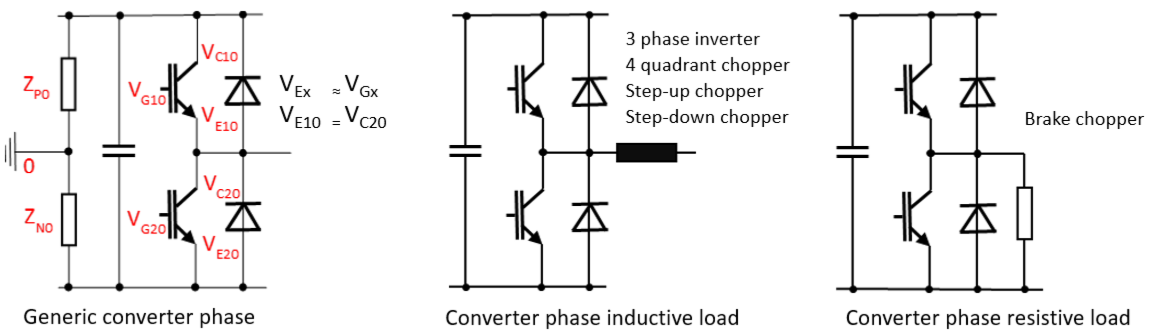

Figure 9: Definition of voltages for generic converter phases

	Z_{P0}	Z_{N0}	V_{C10av}	V_{E10av} (4QS & PWR)	V_{E10av} (DC/DC)	V_{E20av}	V_{C10max}	V_{E10max} (4QS & PWR)	V_{E10max} (DC/DC)	V_{E20max}
Floating Intermediate Circuit	$\gg 0$	$\gg 0$	$V_D / 2$	≈ 0	$\pm V_D/2$	$- V_D /2$	$V_D/2 +\Delta V$	$V_D/2 +\Delta V$	$V_D/2 +\Delta V$	$-V_D/2 -\Delta V$
Grounded Intermediate Circuit at minus pole	$\gg 0$	0	V_D	$V_D / 2$	$0 \dots V_D$	0	$V_D+\Delta V$	$V_D+\Delta V$	$V_D+\Delta V$	0
Grounded Intermediate Circuit at plus pole	0	$\gg 0$	0	$- V_D / 2$	$-V_D \dots 0$	$- V_D$	0	$-V_D-\Delta V$	$-V_D -\Delta V$	$-V_D -\Delta V$

Table 8: Operational average & maximum isolation voltages. ΔV: Overvoltage due to switching. ***max****: effects due to e.g. parasitic capacitances etc. neglected*

7. WORK WITHIN THE ECPE RAILWAY GROUP

The pre-standardization working group “Power-Semiconductor Reliability for Railway Applications” (PSRRA) hosted by the European Center for Power Electronics (ECPE) has started transforming the results of the PINTA working group into valuable test definitions and guidelines. Members of the PSRRA working group encompass the members of the PINTA group, Semiconductor suppliers and further experts in the field. The work done within the PINTA project is effectively disseminated into the industry and will thus help increasing the reliability of power semiconductors.

Up to now, PSRRA has released a Guideline for HV-H^3TRB Testing in December of 2019. Right now, the focus has shifted towards the definition of a condensation test for power semiconductor modules. Based on the measurement results and the expertise of both the PINTA Workgroup and semiconductor suppliers, within the PSRRA working group this complex topic is pushed forward and the resulting test will also be provided as an ECPE Guideline at first.

8. CONCLUSION

In this the document, a significant step towards improving the reliability for power semiconductor in railway applications was done: The generation of realistic environmental requirement specifications based on actual measurement campaigns throughout Europe, encompassing different vehicle types and all relevant installation spaces for converters.
All eight measurement campaigns were concluded and their results were presented. The requirement specifications were finalized by comparing and analyzing the results, and performing extrapolations towards the worst-case.

Additionally, the specification of operational isolation voltages depending on the converter type has been introduced to the document, now also including maximum values. As voltages levels at the terminals may also lead to lifetime limitations of power semiconductors, these specifications are a crucial addition.

In close cooperation with the ECPE and RECET4Rail a variety of related reliability topics of SiC power semiconductor devices are investigated. Worth mentioning is certainly the ECPE effort to determine harmful gas concentrations throughout Europe done by the Fraunhofer Institute.

The final environmental specifications are considered more realistic than the ones estimated at the start of PINTA. The temperature specifications were lowered according to the results of measurement & extrapolation – the humidity specifications were mapped to the tightness of semiconductor modules, a novel idea based on key observations in the measurement campaigns.

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