WHY IS IT NECESSARY FOR A POWER CONVERTER TO COMPLY WITH THE EN 50155 RAILWAY CERTIFICATION?

PREFACE

The railway civilization, having evolved for more than two centuries, not only serves as a testament to its pivotal role in the history of land transportation, but also lays a crucial foundation for the modernization of nations worldwide. As technology continues to progress at an unprecedented pace, railway trains are propelled to ever-increasing speeds, giving rise to a growing demand for passenger safety. As a result, ensuring the simultaneous prioritization of safety and efficiency in railway-related equipment remains a paramount concern for equipment manufacturers.

The modernization of railways has given rise to a multitude of electronic devices that serve various functions, such as sensor systems for monitoring railway operation safety, air conditioning equipment, lighting devices, door control systems, railway communication systems, and highly-sensitive sensors, among others. These electronic devices rely on power provided by batteries installed on the railway.

Due to the prolonged exposure to railway vibration, all electronic devices face unstable voltage for extended periods. Additionally, considering the substantial safety concerns involved, all railway electronic equipment must adapt to adverse environmental conditions such as varying altitudes, humidity levels, presence of oil and gas, impact, vibration, temperature, and voltage. Such equipment must provide optimized performance to meet the strict requirements of railway applications.

However, the vehicle battery system is typically located at the front or rear of the train, necessitating the transmission of voltage through long cable lines to the electronic devices or systems. During the transmission process, electromagnetic interference is prone to occur, including transient voltage spikes caused by nearby lightning and fluctuations in power lines. The train battery must also drive starter motors, pumps, compressors, drivers, relay coils, switch devices, AC generators, generators, transformers, and other high-power load equipment. These factors often result in an unstable, highly fluctuating, and noisy power supply, which can lead to electrical shock and potential hazards, such as transient voltage spikes, mechanical damage, ignition, fires, as well as gaps, arcing, and short circuits in the PCB circuitry due to grounding loops. Since it exposes electronic equipment or systems to significant impact and failures, it becomes evident that railway electronic equipment and systems require high-performance, reinforced insulation, robust, and reliable railway DC-to-DC power modules as essential prerequisites for ensuring the long-term stable operation of trains.

Based on the aforementioned requirements, EN 50155 is the European standard specifically developed for electronic equipment used in railways. Most countries choose to make reference to this regulation as the testing standards cover various aspects, including input voltage, I/O isolation voltage, insulation voltage, electromagnetic compatibility (EMC), mechanics, and reliability tests for harsh environments. These reliability tests include working temperature, cooling, humidity, vibration, and shock testing.

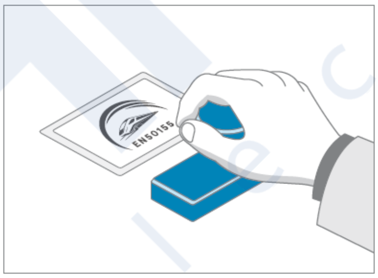
MINMAX not only provides suitable products, but also offers comprehensive services to earn the trust and support of end-users. This includes providing analysis and verification required by customers during the development process using MINMAX products or offering special designs based on customer requirements. MINMAX is dedicated to serving you wholeheartedly and facilitating close collaboration between your company and your customers.

Figure 1-MINMAX's complete range of railway-certified products are all compliant with EN 50155

FIGURE 1. MINMAX'S COMPLETE RANGE OF RAILWAY-CERTIFIED PRODUCTS ARE ALL COMPLIANT WITH EN 50155

To save weight and maximize space utilization in modern and high-speed railways, the batteries on the railway are often charged to 24V, 72V, or 110V. However, most electronic equipment and systems on the railway require input voltages of 5, 12, 15, 24, or 54VDC. Therefore, a railway-certified DC-to-DC power converter is required between the railway battery system and the electronic equipment to convert the DC voltage of 24V, 72V, or 110V to the DC voltages of 5, 12, 15, 24, or 54VDC, which are then supplied to numerous electronic systems.

Taking the railway-certified DC-to-DC power converter for instance, the input side must be connected to the railway battery. Therefore, this standard specifies that the input voltage of the converter must comply with the operating voltage of the railway battery to ensure the normal system operation. Additionally, the testing of transient voltage is also performed to ensure the insulation and resilience of the power module to extreme voltage fluctuation, thereby ensuring the safety of long-term operation.



Regarding the primary insulation barriers for railway DC power architecture, the required DC input voltages of 24V, 28V, 36V, 48V, 72V, 96V, and 110V are all supplied by the railway battery (Vn). Generally, railway batteries do not have voltage stabilizing devices. Therefore, MINMAX's railway-certified DC-to-DC power modules must withstand the following three conditions during operation:

- Voltage fluctuations from 0.7 Vn to 1.25 Vn (refer to Figure 2).
- Voltage drops to 0.6 Vn in 0.1 seconds (refer to Figure 3).

- Transient voltage spike of 1.4 Vn lasting for one second during battery startup process (refer to Figure 3).

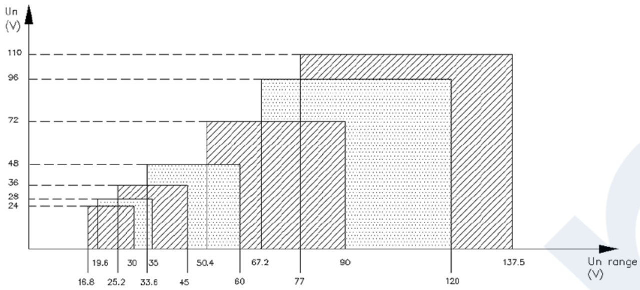


Figure 2-DC Power Supply Voltage

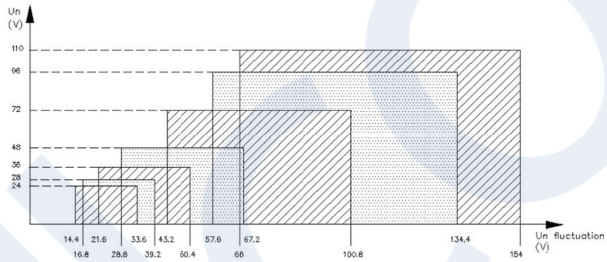


Figure 3-Fluctuation Requirements for Temporary DC Power Supply Voltage

The table below shows that the power tests for MINMAX's railway-certified DC-to-DC power converters include input voltage, undervoltage, transient variations, and voltage spikes. Moreover, MINMAX's testing standards go beyond EN 50155 by establishing equivalent or more stringent testing conditions to ensure the long-term stability of the power modules in railway electronic equipment systems.

Type of Test	EN 50155: 2017 (Source of Reference)	
	Standard Test Levels	MINMAX Test Levels
A. Supply Variations	**EN 50155 13.4.3.2 / EN 50155 5.1.1.3**	
	Test Voltage / Time: 1.4 V_N / 0.1sec.	Test Voltage / Time: 1.4 V_N / 10min. Test Voltage / Time: 1.4 V_N /

Type of Test	EN 50155: 2017 (Source of Reference)	
	Standard Test Levels	MINMAX Test Levels
	Test Voltage / Time: 1.4 V_N / 1sec	60min. Test Number: repeated 10 times
B. Temporary supply dips	**N 50155 13.4.3.3 / EN 50155 5.1.1.3**	
	Test Voltage / Time: 0.6 V_N / 0.1sec.	Test Voltage / Time: 0.6 V_N / 10min. Test Number: repeated 10 times
C. Supply Interruptions	**EN 50155 13.4.3.4 / EN 50155 5.1.1.4**	
	Class S1: 100% V_N / 0mS Class S2: 100% V_N / 10mS Class S3: 100% V_N / 20mS	Class S1: 100% V_N / 0mS Class S2: 100% V_N / 10mS* Class S3: 100% V_N / 20mS Test Number: repeated 10 times
D. Supply Change Over	**EN 50155 13.4.3.5 / EN 50155 5.1.3**	
	Class C1: Dip 40% V_N / 100mS Class C2: Interruptions 100% V_N /30mS	Class C1: Dip 40% V_N / 100mS & 10min. Class C2: Interruptions 100% V_N /30mS* Test Number: repeated 10 times

*Note: If additional components are required to meet the above conditions, please contact MINMAX for more information.

A. Supply Variations

Testing should be conducted to prove that the system operates properly under the rated power supply voltage and within the specified upper/lower limits.

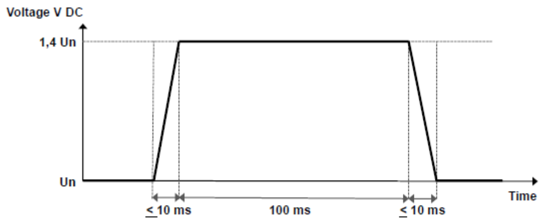


Figure 6 — Temporary supply overvoltages (a)

→If the equipment remains functionally operational without any deviation when subjected to a voltage up to 1.4 times the rated supply voltage for a duration not exceeding 0.1 seconds, it shall meets Performance Standard A.

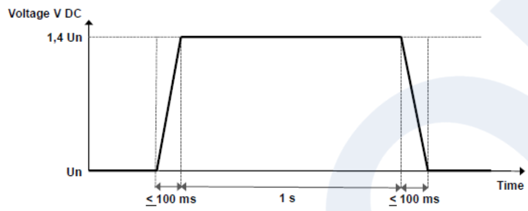
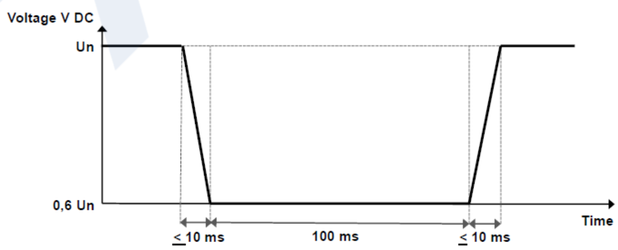


Figure 7 — Temporary supply overvoltages (b)

→If the equipment remains functionally operational without any deviation when subjected to a voltage up to 1.4 times the rated supply voltage for a duration not exceeding 1 second, it shall meets Performance Standard B.

B. Temporary supply dips

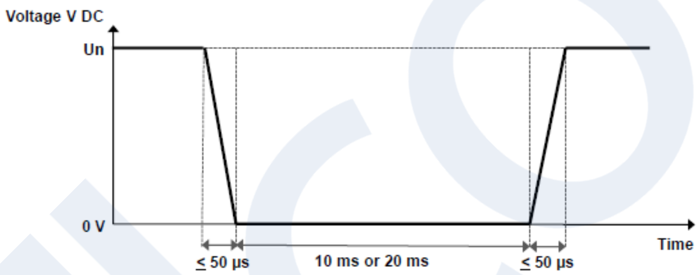
Voltage dips in the power supply primarily occur due to faults in the DC distribution system or sudden load changes. The testing method involves reducing the supply voltage to 0.6 times the rated voltage (0.6Un) and ensuring that it does not cause any functional deviations within a duration not exceeding 0.1 seconds. If the equipment remains functionally operational without any deviation under these conditions, it meets Performance Standard A.



C. Supply Interruptions

In the event of a short circuit in the DC power distribution circuit, the input voltage may briefly drop to 0V or exhibit a low impedance condition. Interruptions can be categorized into three types:

S1: In cases of voltage interruption, no performance criteria are required. However, the converter should continue to operate as specified after the voltage interruption to meet the S1 specification.
S2: If the voltage interruption lasts for 10 milliseconds without causing any deviation in the converter's functionality, it meets the S2 specification.
S3: If the voltage interruption lasts for 20 milliseconds without causing any deviation in the converter's functionality, it meets the S3 specification.



D. Supply Change Over

The equipment should be capable of smooth operation under the following conditions:

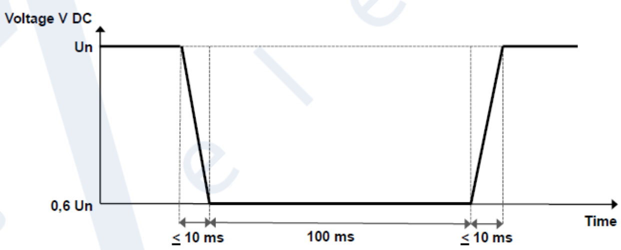


Figure 10 — Supply change-over Class C1

If the rated supply voltage drops to 0.6 Un for a duration of 100 milliseconds without causing any deviation in the functionality of the converter, it shall meets performance standard A.

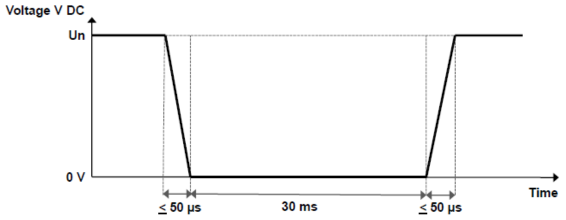


Figure 11 — Supply change-over Class C2

If the rated supply voltage decreases to 0V for a duration of 30 milliseconds without causing any deviation in the functionality of the converter, it shall meets performance standard B.

EN 50155:2017 ISOLATION VOLTAGE AND WITHSTANDING VOLTAGE TESTING

The isolation and withstanding capability of power modules is an important specification that must be taken into account by manufacturers. Using isolated power modules can protect personnel from physical and electrical harm as well as safeguard the backend load equipment and systems. It is an effective method to prevent the spread of faults and plays a crucial role in railway electronic equipment where safety is of utmost importance. Therefore, EN 50155 includes isolation voltage testing as one of the basic test items. Nonetheless, MINMAX internally adopts even higher testing standards to ensure that the product's safety performance meets the higher requirements of customers.

MINMAX's railway-certified power converters have all passed the enhanced 2000VAC isolation/withstanding voltage testing, which is also used to verify the required design in terms of creepage distance, air clearance, and insulation levels of the power modules. The aforementioned standards comply with the limited leakage current under normal/single fault conditions and serve to protect sensitive system circuits from hazards such as noise, electromagnetic interference, power bus fluctuations, electric shocks, surge voltages, transient spikes, insulation breakdown, mechanical damage, fire, clearances, arcs, and short circuits during railway operations.

Type of Test	EN 50155: 2017 (Source of Reference)	
	Standard Test Levels	**MINMAX Test Levels**
Isolation / Withstanding Voltage Test	**EN 50155 13.4.9**	
	Test Voltage / Time: 1500VAC / 60sec.	Test Voltage / Time: 2000VAC / 60sec.

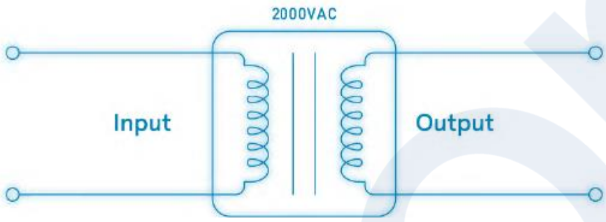


Figure 4-All MINMAX's railway-certified products have passed the enhanced insulation & withstanding voltage testing of over 2000VAC.

EN 50155:2017 ELECTROMAGNETIC COMPATIBILITY (EMC) TESTING

Under the influence of modernization, a wider range of electronic devices consisting of numerous electronic components are installed on trains. In pursuit of miniaturization and lightweight design, integration has become an indispensable capability for electronic device manufacturers. Therefore, ensuring that the devices are not susceptible to interference or do not affect the performance of other equipment becomes crucial, particularly in confined spaces.

As electromagnetic compatibility (EMC) is a significant category in the EN 50155 certification, MINMAX's railway-certified DC-DC power modules adhere to the European Union standard EN 50121-3-2, "Railway Applications - Electromagnetic Compatibility - Part 3-2: integration of apparatus into rolling stock." This standard declares that the conducted and radiated disturbances of the power modules must not exceed the specified limits. Additionally, the modules should remain unaffected by external radiation, surges, electrostatic discharge (ESD), and electrical fast transients (EFT) with a certain level of self-protection capability.

EMC	Type of Test	EN 50155: 2017 (Source of Reference)	
		Standard Test Levels	Standard Test Levels
EMI	Conducted Emission	EN 50155 13.4.8 / EN 50121-3-2, EN 55016-2-1	
		Frequency / level: 0.15~0.5MHz / 99 dBuV Frequency / level: 0.5~5MHz / 93 dBuV Frequency / level: 5~30MHz / 93 dBuV	Frequency / level: 0.15~0.5MHz / 66 dBuV* Frequency / level: 0.5~5MHz / 60 dBuV* Frequency / level: 5~30MHz / 60 dBuV*
	Radiated Emission	EN 50155 13.4.8/ EN 50121-3-2, EN 55016-2-1	
		Frequency / level: 30~230MHz / 40 dB(uV/m) Frequency / level: 230~1000MHz / 47 dB(uV/m) Frequency / level: 30~230MHz / 40 dB(uV/m)*	Frequency / level: 30~230MHz / 40dB(uV/m)* Frequency / level: 230~1000MHz / 47 dB(uV/m)*
EMS	ESD Immunity Test	EN 50155 13.4.8 / EN 50121-3-2, EN 61000-4-2	
		Air Discharge: ±8KVDC Contact Discharge: ±6KVDC Indirect Discharge HCP & VCP: ±6KVDC	Air Discharge: ±8KVDC Contact Discharge: ±6KVDC Indirect Discharge HCP & VCP: ±2/4/6KVDC
	Radio-Frequency, Electromagnetic Field Immunity Test	EN 50155 13.4.8 / EN 50121-3-2, EN 61000-4-3	
		Frequency / Field: 80~1000MHz/20 V/m Frequency / Field: 1400~2000MHz/10	Frequency / Field: 27~80MHz/20 V/m Frequency / Field: 80~1000MHz/20 V/m

EMC	Type of Test	EN 50155: 2017 (Source of Reference)	
		Standard Test Levels	Standard Test Levels
		V/m Frequency / Field: 2000~2700MHz/5 V/m Frequency / Field: 5100~6000MHz/3 V/m	Frequency / Field: 1400~2000MHz/20 V/m Frequency / Field: 2000~2700MHz/10 V/m Frequency / Field: 2700~5000MHz/10 V/m Frequency / Field: 5100~6000MHz/10 V/m
	Electrical Fast Transient/Burst Immunity Test	**EN 50155 13.4.8 / EN 50121-3-2, EN 61000-4-4**	
		Line, Neutral, Line+Neutral: ±2KVDC	Line, Neutral, Line+Neutral: ±2KVDC*
	Surge Immunity Test	**EN 50155 13.4.8 / EN 50121-3-2, EN 61000-4-5**	
		Line to Line: ±1KVDC	Line to Line: ±2KVDC*
	Radio-Frequency, Conducted Disturbances Immunity Test	**EN 50155 13.4.8 / EN 50121-3-2, EN 61000-4-6**	
		Frequency : 0.15 to 80MHz Field: 10 Vrms	Frequency : 0.15 to 80MHz Field: 10 Vrms
	Power Frequency Magnetic Field Immunity Test	**EN 61000-4-8**	
		No Needed	Frequency: 50Hz Field: 30/100/1000 A/m
		EN 61000-4-10	

EMC	Type of Test	EN 50155: 2017 (Source of Reference)	
		Standard Test Levels	Standard Test Levels
	Damp Oscillatory Magnetic Field Immunity Test	No Needed	Frequency: 0.1 & 1 MHz Field: 30 A/m

WHY IS IT NECESSARY FOR A POWER CONVERTER TO COMPLY WITH THE EN 50155 RAILWAY CERTIFICATION?

EN 50155:2017 ENVIRONMENTAL TESTING

REQUIREMENTS FOR OPERATING TEMPERATURE

Railway applications often face challenging environmental conditions, such as high-altitude plateaus, hot and dry deserts, and cold and humid tundra. They may also be subjected to prolonged high temperatures in enclosed spaces or prolonged exposure to the elements alongside the tracks. Despite the unpredictable and ever-changing nature of surrounding railway environments, EN 50155 establishes stringent standards for measuring the operating temperature. This ensures that railway equipment continues to operate reliably under extreme environmental conditions.

EN 50155 is primarily divided into four categories to define different severe environmental conditions, as presented in Table 1 below. When designing a railway-certified DC-to-DC power module, it is crucial to consider whether temperature issues may arise during the system startup process.

Table 1 - Operating Temperature

Level	Device Operating Temperature (°C)
OT1	-25°C to +55°C
OT2	-40°C to +55°C
OT3	-25°C to +70°C
OT4	-40°C to +70°C
OT5	-25°C to +85°C
OT6	-40°C to +85°C

- OT1 and OT2 apply to passenger compartments and driver's cabins, where the long-term temperature must be maintained at +25℃. The temperature in these spaces may affect the lifespan of materials used.
- OT3 and OT4 should be applicable to equipment in cabinets, with a long-term reference temperature of +45℃. The ambient temperature in these spaces also affects the lifespan of materials used.
- OT5 and OT6 categories may not serve as a general specification for the vehicle temperature requirement (e.g., but may be applicable to semiconductor drive units (SDUs), engine control components, etc.).

Figure 1: Trains frequently operate in harsh climate conditions

Figure 2: Wide operating temperature range enables coping with severe climates

During the design process, it is necessary to consider the indoor temperature rise to ensure that components do not exceed their specified rated temperature. For instance, the ambient air temperature around the PCB may increase by approximately 15℃ (this temperature rise largely depends on the power consumption of the PCB itself and the adjacent PCBs, as well as natural or forced airflow). When designing the Printed Board Assembly (PBA), whether at a single PBA level or in a vertical stack or subrack configuration, the supplier should take into account the specific requirements arising from the particular onboard installation.

In certain exceptional circumstances, such as the influence of compartments, sunlight, or the closure of auxiliary cooling systems, additional operational checks on startup equipment under short-term hot conditions should be carried out according to ST1 or ST2 as outlined in Table 2 below.

Table 2 - Extended Operating Temperature - Startup State

Level	Extended Operating Temperature - Startup State (Interval: 10 minutes)	Dry Heat Test
ST0	No Extended Operating Temperature - Startup State	Cycle A
ST1	OTx + 15℃	Cycle B
ST2	OTx + 15℃	Cycle C

※OTx +15℃ represents the maximum operating temperature (OTx) plus an additional +15℃.
※Levels ST1 and ST2 are not applicable to OT5 and OT6 as per Table 1.
※Unless otherwise specified, Level ST1 must be executed.

When trains pass through tunnels, the temperature often undergoes drastic changes. This significant temperature difference may lead to the formation of water droplets, moisture, and humidity, which have unforeseen effects on equipment. To address these issues, all MINMAX power modules are fully encapsulated to effectively resist the impact of external environmental factors. Furthermore, EN 50155 sets forth specifications for the expected performance of electronic devices in such environments. MINMAX's testing standards go beyond those defined by EN 50155, ensuring equivalent or even stricter testing conditions. For detailed information, please consult Table 3.

Type of Test	EN 50155 : 2017(Source of Reference) / MINMAXTesting Level
A. Low Temperature Start-up Test	**EN 50155 13.4.4 / EN 60068-2-1** Test Curve Follow by EN 50155 : 2017 with: • Operating Temperature Class : OT4 • Continuous Operation Checks Period: 8 HRs
B. Dry Heat Test	**EN 50155 13.4.5 / EN 60068-2-2** Test Curve Follow by EN 50155 : 2017 with: • Operating Temperature Class: OT4 • Switch-on Extended Operating Temperature Range Class: ST2 • Thermal Test Cycle: C • Continuous Operational Checks Period: 8 HRs
C. Low Temperature Storage Test	**EN 50155 13.4.6 / EN 60068-2-1** Test Curve Follow by EN 50155 : 2017 with: • Temperature / Dwell Time: 16HRs in storage
D. Cyclic Damp Heat Test	**EN 50155 13.4.7 / EN 60068-2-30** Test Curve Follow by EN 50155 : 2017 with: • Test Temperature (TTEST) under Equip. Switched ON: +70°C • Continuous Operation Checks Period under Equip. Switched-on: 24HRs • Test Temperature (TTEST) of Recovery Period under Equip. Switched-off: +70°C

A. Low Temperature Start-up Test

To assess whether the product can start up properly at low temperatures, the testing will be conducted according to the low temperature levels specified in Table 1. The test procedure, as depicted in Figure 3, involves checking the functionality at room temperature before gradually lowering the temperature to the specified level. The stabilization period should last at least 2 hours. Subsequently, the equipment will be powered on for operational checks for 1 hour. Once the checks are completed, the equipment will be allowed to return to room temperature and remain at that temperature for 1 hour before undergoing another round of functionality checks upon restarting. Throughout the testing period and thereafter, the equipment can be deemed to have met Performance Standard A if it functions as expected and operates within its specified range.

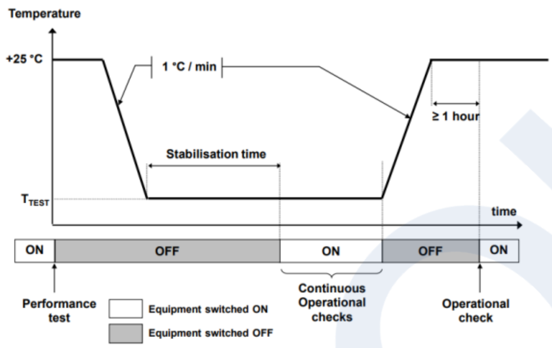


Figure 3 A. Low Temperature Start-up Test

B. Dry Heat Test

To evaluate the performance of the product under high-temperature and dry heat conditions, the testing will be conducted using the high-temperature levels specified in Table 1 and the extended temperatures provided in Table 2, taking into account different external conditions. After selecting Cycle A/B/C, the corresponding test procedures are outlined in Figures 4/5/6. The stabilization period during the test should last for a minimum of 2 hours. If the equipment operates as expected and within its specified range both during and after the testing period, it can be deemed to have met Performance Standard A.

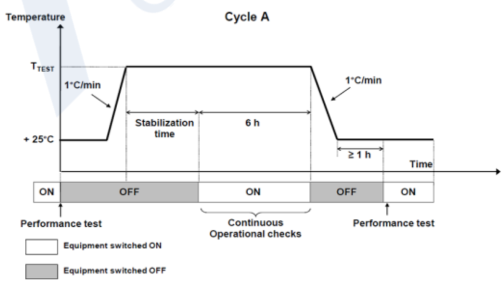


Figure 4. Dry Heat Test - Cycle A

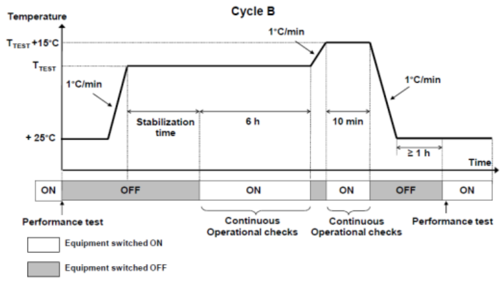


Figure 5 Dry Heat Test - Cycle B

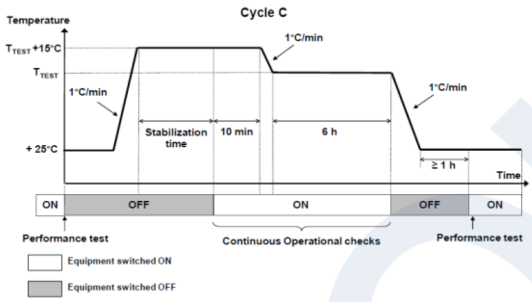


Figure 6 Dry Heat Test - Cycle C

C. Low Temperature Storage Test

To assess the product's ability to withstand low-temperature storage environments, the product will be placed in a test chamber without any power supply. The test temperature should be set to -40℃ and maintained for at least 16 hours. After returning to room temperature, functional verification will be performed. If the product operates normally within its specified range, it can be deemed to have met Performance Standard A.

D. Cyclic Damp Heat Test

The purpose of this test is to assess the product's ability to withstand variations in operating temperature and humidity. The test conditions are as follows:

- Temperature : +25℃ & +55℃
- Number of cycles : 2 cycles
- Duration : 2 x 24 hours

If the equipment operates as expected and within its specified range throughout the testing period and thereafter, it can be deemed to have met Performance Standard A.

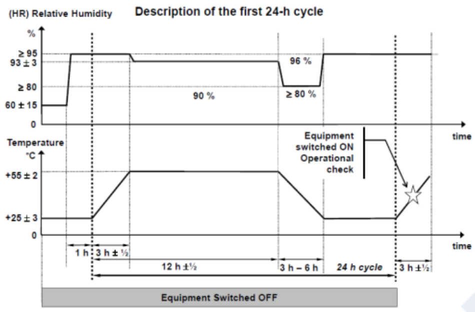


Figure 7 Cyclic Damp Heat Test - Start of the 24-hour cycles for the first and second time

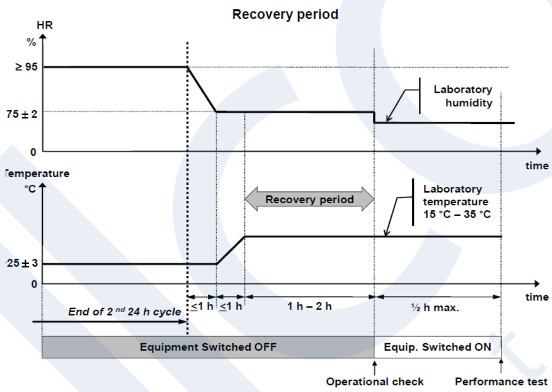


Figure 8 Cyclic Damp Heat Test - End of the second cycle and recovery period

Figure 9 Full encapsulation potting aids in the converter's resistance to external environmental factors

EN 50155:2017 MECHANICAL TESTING

In the operation of high-speed trains, all equipment is subjected to continuous vibration, particularly as the speed continues to increase with technological advancements. However, along with these advancements come risks. Therefore, ensuring that equipment can withstand intense impact, vibration, and collisions while maintaining stable output or normal operation is a crucial concern for equipment manufacturers.

The EN 50155 certification explicitly states that the railway-grade DC-to-DC power converters installed on vehicles must meet the vibration and shock testing requirements of EN 61373. Therefore, strict control must implemented during the manufacturing process to ensure consistency in performance. MINMAX's railway-certified DC-to-DC power converters are specifically designed to meet high-impact and high-vibration tolerance, as well as to ensure stability and minimize the occurrence of faults during long-term operation, as per the EN 61373 vibration and shock standards.

Table 4 – Mechanical Testing

Type of Testing	EN 50155 : 2017 (Source of Reference)	
	Standard Testing Levels	Standard Testing Levels
A. Functional Random Vibration Test	EN 50155 13.4.11.4 / EN 61373 (EN 60068-2-6)	
	Category 1, Class B, Body Mounted Frequency Range: 5Hz~150Hz Grms Value: 0.103 Grms (1.01m/s²) for Vertical Axis Grms Value: 0.046 Grms (0.45m/s²) for Transverse Axis Grms Value: 0.071 Grms (0.70m/s²) for Longitudinal Axis Dwell Time: 10min/axis in Storage	Category 1, Class B, Body Mounted Frequency Range: 5Hz~250Hz Grms Value: 0.2 Grms (2.0m/s²) for Each Axis Dwell Time: 10min/axis in Operation
	EN 50155 13.4.11.2 / EN 61373 (EN 60068-2-6)	

Type of Testing	EN 50155 : 2017 (Source of Reference)	
	Standard Testing Levels	Standard Testing Levels
B. Increased Random Vibration Test	Category 1, Class B, Body Mounted	Category 1, Class B, Body Mounted
	Frequency Range: 5Hz~150Hz	Frequency Range: 5Hz~250Hz
	Grms Value: 0.583 Grms ($5.72m/s^2$) for Vertical Axis Grms Value: 0.260 Grms ($2.55m/s^2$) for Transverse Axis Grms Value: 0.404 Grms ($3.96m/s^2$) for Longitudinal Axis	Grms Value: 1.2 Grms ($12m/s^2$) for Each Axis Dwell Time: 5 HRs/axis in Operation
	Dwell Time: 5 HRs/axis in Storage	
C. Shock Test	**EN 50155 13.4.11.3 / EN 61373 (EN 60068-2-27)**	
	Category 1, Class A&B, Body Mounted Wave Form: Half-Sine Acceleration Peak: 3.060 Grms ($30m/s^2$) for Vertical Axis Acceleration Peak: 3.060 Grms ($30m/s^2$) for Transverse Axis Acceleration Peak: 5.102 Grms ($50m/s^2$) for Longitudinal Axis Dwell Time: 30mS in Storage Shock/Bump Times: 3 Times for Each Direction	Category 3, Axle Mounted Wave Form: Half-Sine Acceleration Peak: 100 Grms ($1000m/s^2$) for Each Axis Dwell Time: 6mS in Operation Shock Times: 3 Times for Each Direction
D. Bump Test	**No Reference / No Reference (EN 60068-2-29)**	
	No Needed	Wave Form: Half-Sine

Type of Testing	EN 50155 : 2017 (Source of Reference)	
	Standard Testing Levels	Standard Testing Levels
		Acceleration Peak: 5.102 Grms (50m/s²) for Each Axis
		Dwell Time: 30mS in Operation
		Acceleration Peak: 10 Grms (100m/s²) for Each Axis
		Dwell Time: 11mS in Operation
		Bump Times: 2000 Bumps for Each Direction

A. Functional Random Vibration Test

First, we select the installation position of the testing equipment, which is divided into Body Mounting Class A, Body Mounting Class B, Bogie Mounting, and Axle Mounting. The equipment is then tested according to the related root mean square (RMS) values and frequency ranges given in Table 5. In cases where the actual direction of the equipment is uncertain or unknown, the test should be conducted with RMS values in the vertical direction on all three axes. Under the basic testing conditions of Body Mounting Class B, MINMAX increases the "vibration frequency" and "RMS acceleration" parameters to provide customers with greater reliability assurance.

Category	Orientation	RMS m/s^2	Frequency range
1 Class A Body mounted	Vertical Transverse Longitudinal	0,750 0,370 0,500	Figure 2
1 Class B Body mounted	Vertical Transverse Longitudinal	1,01 0,450 0,700	Figure 3
2 Bogie mounted	Vertical Transverse Longitudinal	5,40 4,70 2,50	Figure 4
3 Axle mounted	Vertical Transverse Longitudinal	38,0 34,0 17,0	Figure 5

Table 5 - Intensity and Frequency Range of Functional Random Vibration Test

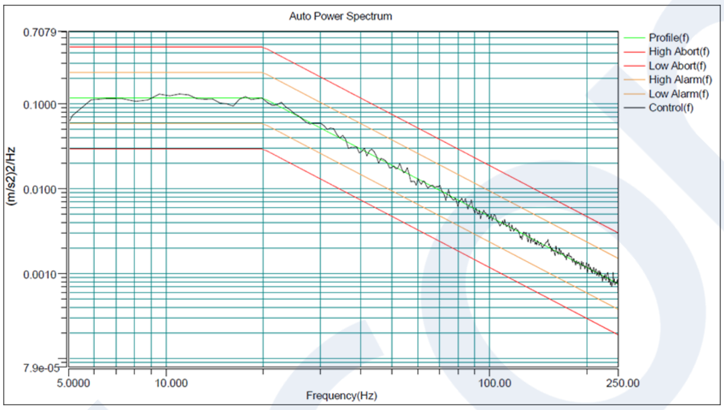


Figure 10 - Horizontal Axis - Illustration of Functional Random Vibration Test Results (MINMAX Enhanced Version)

B. Increased Random Vibration Test

First, we select the installation position of the testing equipment, which is divided into Body Mounting Class A, Body Mounting Class B, Bogie Mounting, and Axle Mounting. The equipment is then tested according to the related root mean square (RMS) values and frequency ranges given in Table 6. In cases where the actual direction of the equipment is uncertain or unknown, the test should be conducted with RMS values in the vertical direction on all three axes. All types of equipment should undergo a total of 15 hours of testing, with 5 hours of testing conducted separately on each of the three mutually perpendicular axes.

Category	Orientation	RMS 5 h test period m/s^2	Frequency range
1 Class A Body mounted	Vertical Transverse Longitudinal	4,25 2,09 2,83	Figure 2
1 Class B Body mounted	Vertical Transverse Longitudinal	5,72 2,55 3,96	Figure 3
2 Bogie mounted	Vertical Transverse Longitudinal	30,6 26,6 14,2	Figure 4
3 Axle mounted	Vertical Transverse Longitudinal	144 129 64,3	Figure 5

Table 6 - Intensity and Frequency Range of Increased Random Vibration Test

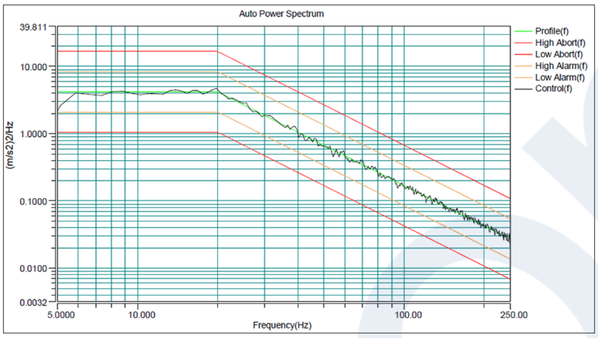


Figure 11 - Horizontal Axis - Illustration of Increased Random Vibration Test Results (MINMAX Enhanced Version)

C. Shock Test

First, we select the installation position of the testing equipment, which is divided into Body Mounting Class A/B, Bogie Mounting, and Axle Mounting. The tested equipment is subjected to 18 shock impulses, with three tests each performed in the positive and negative directions of the horizontal, vertical, and longitudinal axes. Please refer to Table 7 for the test conditions.

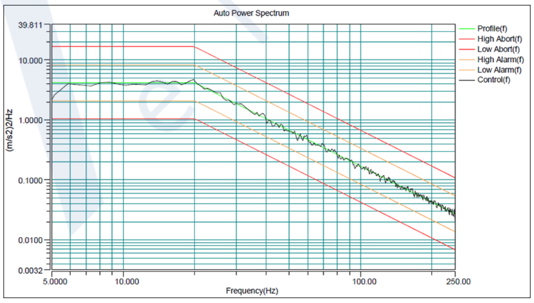


Table 7 - Directions, Intensity, and Duration of the Shock Test

Category	Orientation	Peak acceleration A m/s²	Nominal duration D ms
1 Class A and class B Body mounted	Vertical Transverse Longitudinal	30 30 50	30 30 30
2 Bogie mounted	All	300	18
3 Axle mounted	All	1 000	6

Figure 12 - Positive Horizontal Axis - Shock Test (MINMAX Enhanced Version, 10Grms, 11ms)

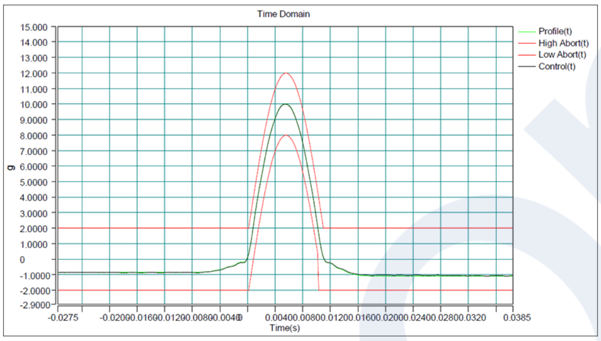


Figure 13 - Positive Horizontal Axis - Shock Test (MINMAX Enhanced Version, 100Grms, 6ms)

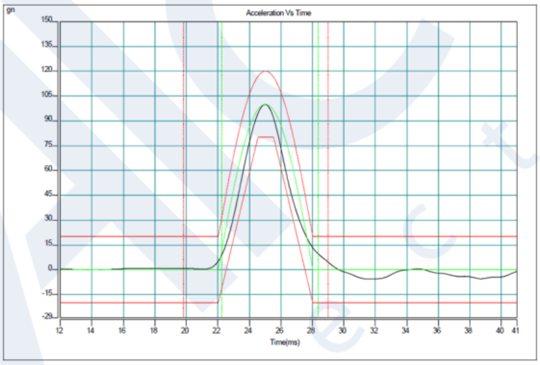


Figure 14 - Ensuring Long-Term Reliability through Mechanical Testing

EN 45545-2 FIRE PROTECTION TESTING

The railway transportation industry widely requires that power module materials meet the relevant requirements of fire protection testing specified in EN 45545-2. In the EN 45545-2 standard, different tested materials are classified and defined based on categories R1-R26, which specify the "fire performance parameters and test conditions."

Testing includes:

1. Functional description of fire safety objects
2. Grading and requirement levels for homogeneous materials
3. Internal structural materials

The assessment of fire performance involves the following key parameters:

1. Heat release rate
2. Combustibility
3. Toxicity testing
4. Smoke density

- Different tested materials are evaluated for their fire protection testing level (HL Level) based on the final test results of the "fire performance parameter."
- In railway rolling stock, the fire protection testing level required for the materials used is determined based on the operating environment of the vehicle and the classification of different vehicle categories, as per classification table provided below (Table 4 - Hazard Classification).

Table 4 - Hazard Classification

Operation category	Design category			
	N: Standard vehicles	A: Vehicles forming part of an automatic train having no emergency trained staff on board	D: Double decked vehicles	S: Sleeping and couchette vehicles
1	HL1	HL1	HL1	HL2

Operation category	Design category			
	N: Standard vehicles	A: Vehicles forming part of an automatic train having no emergency trained staff on board	D: Double decked vehicles	S: Sleeping and couchette vehicles
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

MINMAX conducts fire protection testing on the plastic housing, printed circuit board (PCB), and potting compound for all its railway-certified power modules. These materials are tested based on the final "fire performance parameter" results to assess their fire protection level (HL Level) and ensure the safety of railway vehicle operations.

EN45545-2

APPLICATION OF RAILWAY VEHICLES

The requirements for railway equipment are adjusted based on different railway types, purposes, and installation positions. Please refer to Figure 15 for a further understanding of the typical equipment positions on railway vehicles:

1. Different Types of Railway Vehicles

Different types of railway vehicles, such as urban mass transit, underground transit, high-speed passenger trains, or freight trains, may lead to specific usage conditions.

2. Railway Vehicles with Different Purposes

The intended use of railway vehicles is influenced by geographical destinations and whether they operate underground or above ground. The specific conditions of the equipment may vary, depending on the intended purpose (e.g., the equipment mounting on bogies that are subjected to rapid temperature changes at the tunnel entrances/exits).

3. Equipment Positions on Railway Vehicles

Figure 15 illustrates the typical equipment positions on railway vehicles, such as Position 4 (underneath or on the roof of the vehicle), Position 5 (between vehicles), Position 6 (bogies), and Position 7 (axles), which are subjected to different conditions of use based on their design in different positions. Table 5 provides an overview of the equipment positions and the corresponding requirements.

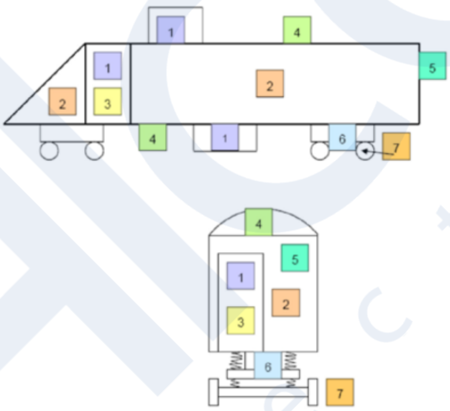


Table 5 - Examples of Typical Equipment Positions on Railway Vehicles

Position	Definition	Definition	Expected Outcome
1	**Enclosed electrical operator**	Internal vehicle compartments (with wind and rain protection External vehicle compartments (with wind and rain protection)	Working temperature and/or impact level depend on the installation position.

Position	Definition	Definition	Expected Outcome
		Under the frame or on the roof	
2	**Driver's cabin and interior**	Passenger compartments and driver's cabin	Only international protection certification with lower levels is required. (low dust and chemical pollution in the air)
3	**Enclosed electrical operator with forced filtered fresh air ventilation**	Mechanical compartment	Higher working temperature in the engine (or power converter) room or resistance to fuel and liquids.
4	**Outdoor static application**	Underbody, roof underside (non-weather-protected positions)	• Higher international protection certification • Resistance to light (UV) • Ozone resistance of rubber and plastic components
5	**Outdoor dynamic application**	Between vehicles	• Higher international protection certification in non-weather-protected positions • Resistance to light (UV) • Ozone resistance of rubber and plastic components • Higher mechanical resistance
6	**Outdoor high dynamic application**	Bogie	• Higher international protection certification in non-

Position	Definition	Definition	Expected Outcome
			weather-protected positions • Resistance to light (UV) • Ozone resistance of rubber and plastic components • Higher mechanical resistance • High vibration and impact limits • Resistance to fuel and liquids
7	**Outdoor high dynamic application**	Axle	• Higher international protection certification in non-weather-protected positions • Resistance to light (UV) • Ozone resistance of rubber and plastic components • Higher mechanical resistance • Very high vibration and impact limits • Resistance to fuel and liquids