ISOLATED DC-DC POWER CONVERTERS FOR RAILWAY CERTIFICATION: AN IN-DEPTH ANALYSIS OF UNCOMPROMISING PERFORMANCE (PART 1&2)

PREFACE

EN 50155 is a standard established in Europe for electronic equipment used in railways. Most countries choose to take reference to this regulation, which encompasses various testing standards such as input voltage, I/O isolation voltage, insulation voltage, electromagnetic compatibility (EMC), mechanics, and rigorous reliability testing for harsh environments, taking into account testing factors like operating temperature, cooling, humidity, vibration, and shock.

Having successfully obtained the EN 50155 certification, MINMAX's railway-certified DC-DC converters support a power range from 3 watts to 150 watts and come in various international packaging options such as DIP, 2" x 1", and quarter bricks. These converters also feature wide input voltage range, extended operating temperature range, reinforced insulation, deviation management, remote on/off control, output voltage trimming capability, output voltage monitoring, and more. Furthermore, they have met fire protection testing standard (EN45545-2), railway electromagnetic compatibility (EMC) standard (EN50121-3-2), vibration and shock reliability testing standard (EN61373), environmental testing standard (IEC 60068-2-1-2-30), international safety regulations (IEC 62368-1 certification), and carry the CE mark.

With optimized PCB layout design and thermal management, MINMAX's products maintain a high level of stability in overall efficiency, power loss, and heat generation, regardless of drastic fluctuations in input voltage, output current, and environmental temperature. Furthermore, our products can even meet 100% of the current and power requirements of the backend load system right at the moment of startup, rapidly supplying the rated output voltage and satisfying the optimized system load driving capability.

MINMAX not only provides suitable products but also offers comprehensive services to earn the trust and support of end users. These services include

providing analysis and verification required by customers during the development process when using MINMAX products, as well as offering special designs tailored to customer needs. We are dedicated to serving you and ensuring that your customers closely cooperate with you.

WIDE INPUT VOLTAGE RANGE

The voltage distribution in railway DC systems ranges from 24V, 28V, 36V, 48V, 72V, 96V, to 110V. To accommodate transient conditions, the voltage range must cover 0.6 to 1.4 times the rated center voltage.

MINMAX's railway-certified DC-DC converters mostly support a wide input voltage range of 4:1, with the actual ranges covering 9-36, 18-75, and 40-160VDC, allowing them to meet the voltage requirements of all railway equipment. Additionally, MINMAX has developed an input voltage specification of 36-160VDC specifically for applications that require low-voltage startup.

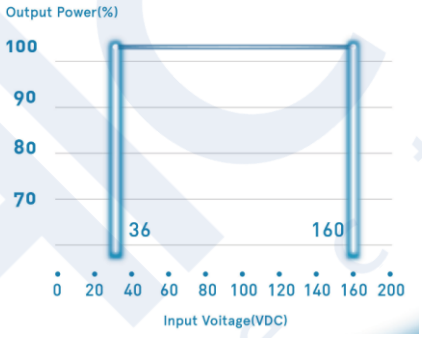


Figure 1 - Ability to Provide 100% Output Power within the Rated Input Range

HIGH-PRECISION OUTPUT VOLTAGE

Typically, railway batteries do not have voltage stabilization devices. Therefore, MINMAX's railway-certified DC-DC power modules must withstand the following three conditions of railway batteries during operation:

- Voltage fluctuations ranging from 0.7 Vn to 1.25 Vn
- Voltage drops of 0.6 Vn within 0.1 seconds
- Surge voltage of 1.4 Vn for one second during battery startup

To prevent any negative impact on railway operation systems caused by

uncertainties in input voltage, output load current, and surrounding temperature, MINMAX's railway-certified products adopt a special design that ensures ultra-high precision output voltage.

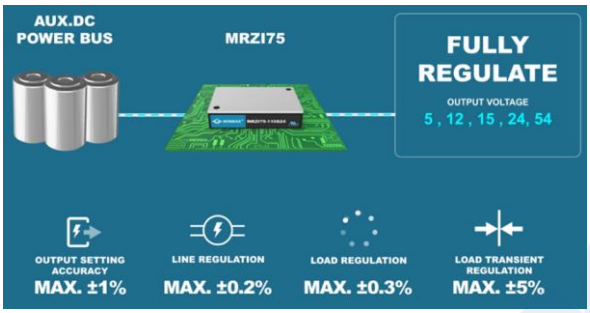


Figure 2 - Stable and Precise Output Voltage Accuracy is Essential

HIGH ISOLATION VOLTAGE WITH REINFORCED INSULATION SYSTEM

MINMAX's railway-certified products feature reinforced insulation, an isolation voltage of 2KVAC, and a fully encapsulated design to create a robust insulation barrier that withstands high voltage levels. This ensures the protection of sensitive system circuits from noise, electromagnetic interference, power bus fluctuations, electrical shocks, surges, transient voltage spikes, insulation breakdown, mechanical damage, fire hazards, and the risks of gaps, arcs, and short circuits in PCB circuit boards. These features provide optimal safety assurance for railway equipment operating over the long run.

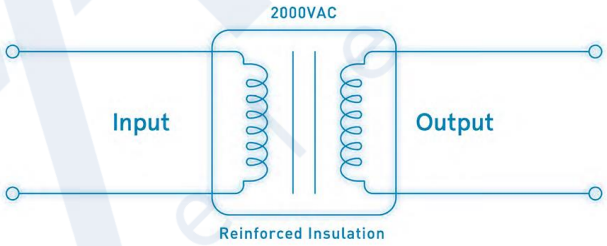


Figure 3 - MINMAX's Railway-Certified Products Pass the 2KVAC Isolation Voltage Test with Reinforced Insulation

EXCELLENT THERMAL DESIGN

Through optimized thermal structure design, such as high thermal conductivity adhesives, low thermal resistance components, and optimized PCB layout, we ensure improved thermal performance and long-term heat dissipation

capability. This design provides the best safety and reliability assurance for railway equipment operating in harsh environments over extended periods.

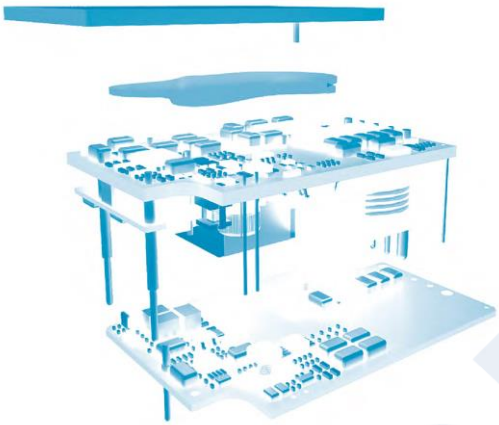
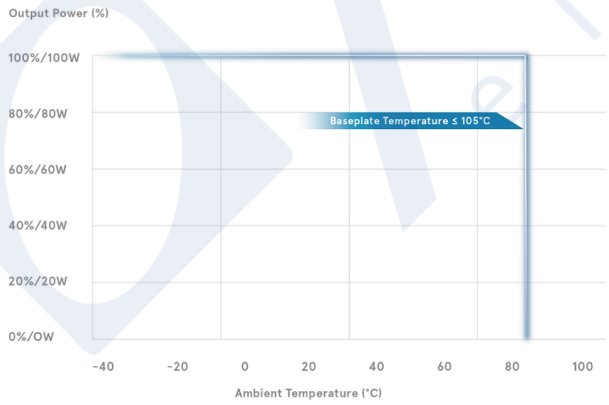


Figure 4 - Adoption of Optimized Thermal Design

WIDE OPERATING TEMPERATURE RANGE

In many railway applications, temperatures can reach extremely high levels at +60°C or even higher in summer and plummet to extremely low levels at -30°C or even lower in winter.

Therefore, expanding the operating temperature range of products is an important challenge. MINMAX's railway-certified products have passed optimized overall electrical and thermal design, supporting a temperature range of -40°C to +85°C to meet the stringent requirements of railway applications in various environmental conditions.



EFFECTIVE THERMAL DISSIPATION MECHANISM

The majority of MINMAX's railway-certified products offer a selection of three different heights of heat sinks to cater to various operating temperature requirements.

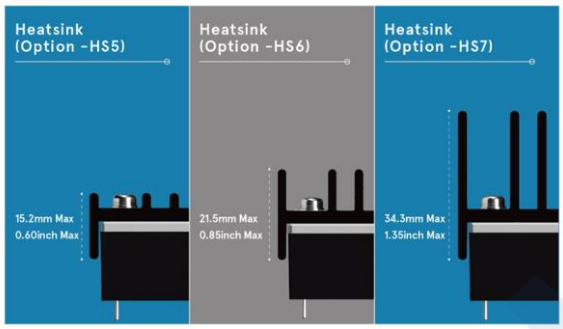


Figure 5 - Flexible Selection of Heat Sink Options

EXCELLENT EMC PERFORMANCE

MINMAX's railway-certified products exhibit excellent EMC performance through enhanced noise filtering technology. This helps reduce electromagnetic interference from power modules in the system, thereby improving the system's conductive and radiative EMI performance, as well as its electrostatic discharge (ESD), surge, electrical fast transients (EFT), conducted susceptibility (CS), radiated susceptibility (RS), and power frequency magnetic field tolerance (PFMF) in terms of EMS performance.

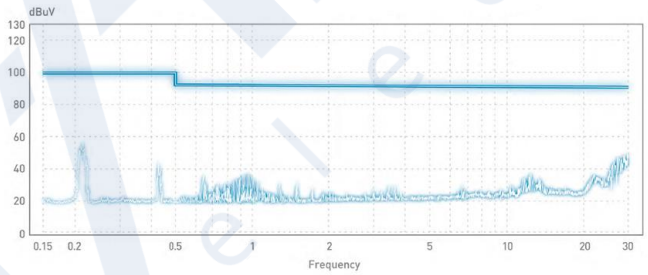


Figure 6 - Conducted EMI compliant with EN 50121-3-2 standard

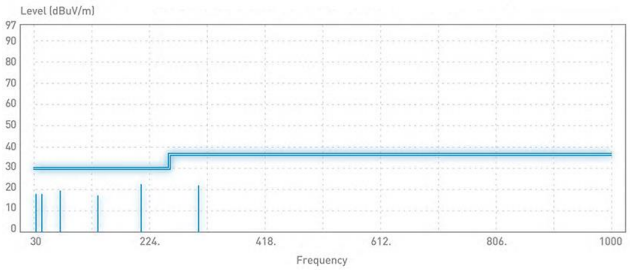


Figure 7 - Radiated EMI compliant with EN 50121-3-2 standard

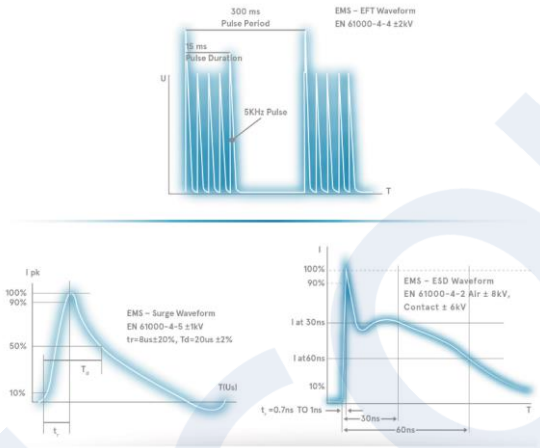


Figure 8 - Compliance with various EMS testing standards of EN 55024

ISOLATED DC-DC POWER CONVERTERS FOR RAILWAY CERTIFICATION: AN IN-DEPTH ANALYSIS OF UNCOMPROMISING PERFORMANCE (PART 2)

ROBUST MECHANICAL AND THERMAL SHOCK DESIGN

The application environment of railways is highly variable, requiring consideration of multiple conditions such as climate, temperature, humidity, terrain, and power supply methods. In one hour, it could be scorching hot in a desert, while the next hour might be extremely cold in a frozen tundra. Therefore, the performance of power converters in harsh environments must be viewed from the most rigorous perspective. You can refer to the following standards:

- Low-temperature startup test : EN 50155 13.4.4 / EN 60068-2-1
- Dry heat test : EN 50155 13.4.5 / EN 60068-2-2
- Low-temperature storage test : EN 50155 13.4.6 / EN 60068-2-1
- Damp heat cyclic test : EN 50155 13.4.7 / EN 60068-2-30
- Functional random vibration test : EN 50155 13.4.11 / EN 61373 (EN 60068-2-6)
- Enhanced random vibration test : EN 50155 13.4.11 / EN 61373 (EN 60068-2-6)
- Shock test : EN 50155 13.4.11 / EN 61373 (EN 60068-2-27)

MINMAX's railway-certified products meet all the above test requirements, providing customers with the most reliable solutions in the face of harsh environmental conditions.

Figure 8: MINMAX provides durable, robust, and reliable railway-certified products

PASSING RIGOROUS TEMPERATURE CYCLING TESTS

To verify long-term reliability, MINMAX's railway-certified products undergo temperature cycling tests of over 500 cycles. Within each cycle, the products must rapidly rise to a high temperature of +125°C and then descend to a low temperature of -40°C at a rate of 20°C per minute. This creates a temperature difference of up to 165°C. MINMAX adopts the most stringent testing approach to ensure that the products meet the demanding requirements of railway systems.

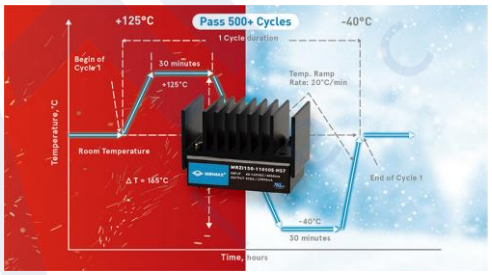


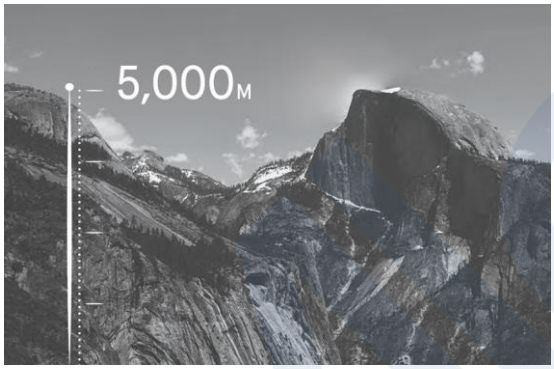
Figure 9: Passing temperature cycling tests of over 500 cycles

OPERATING AT AN ALTITUDE OF 5,000 METERS

To obtain necessary certifications, the specifications defined in IEC 62368-1 require compliance with operating conditions from sea level up to an altitude of 2,000 meters. However, this also means that equipment installed with these components can only be used within the altitude range of 2,000 meters.

Many cities in Europe, Asia, or the Americas are built at altitudes higher than 2,000 meters where the most modern electrical and electronic equipment markets exist. Europe is an example where many telecommunications base stations are placed at the highest possible locations to achieve maximum range and coverage. However, China has taken a step further in this field. For instance, the GB 4943.1-2011 standard already requires medical equipment to be suitable for applications at an altitude of 5,000 meters.

Therefore, MINMAX has subjected the majority of its railway-certified products to testing at an altitude of 5,000 meters. This helps to avoid short-circuiting issues caused by PCB track routing, air gaps, or arcing, thereby resolving the height limitations faced by railways operating at high altitudes.



COMPREHENSIVE RELIABILITY TESTING

In addition to EN 50155 certification, MINMAX's railway-certified products undergo even more careful and stringent testing to provide customers with high-quality and highly-reliable products.

Type of Test	Test Conditions
Reliability Testing of Developing Products	
Burn-in	Input Line: Nom. Line Output Load: Full Load Temperature: Room Temperature Duration: 1032 HRs

Type of Test	Test Conditions
Reliability Testing of Developing Products	
Highly Accelerated Life Test(HALT)	Thermal Step Stress Test Rapid Thermal Stress Test Vibration Step Stress Test Combined Environmental Stress Test
Temperature Cycling Test(TCT)	Temperature Change: -40℃ ~ +125℃ Steady State Duration: 30min Ramp Rate: 20℃/min Number of Cycles: 200+
Temperature & Humidity Storage Cycling Test (Non-Operation)	Temperature Change: Low to High Temperature Ramp Rate: 1-3℃/min Relative Humidity: +95% RH. Steady State Duration: 1 HR Number of Cycles: 5 Cycles
Power and Temperature Cycling Test(PTCT) (In Operation)	Input Line Change: Low/Nom./High Line Output Load Change: No or Min./Full Load Temperature Change: Low to High Temperature Relative Humidity: +95% RH. Duration for ON/OFF: 3 Sec Number of Cycles: 300 Cycles
Temperature, Humidity and Bias Test(THB) (In Operation)	Input Line: High Line Output Load: No or Min. Load Temperature: +85℃ Relative Humidity: +85% RH. Operating Duration: 1000 HRs
Low Temperature Test (In Operation)	Input Line: Nom. Line Output Load: Full Load

Type of Test	Test Conditions
Reliability Testing of Developing Products	
	Temperature: Low Temperature Duration: Achieve Thermal Equilibrium
High Temperature Test (In Operation)	Input Line: Nom. Line Output Load: Full Load Temperature: High Temperature Duration: Achieve Thermal Equilibrium
Vibration Test(Non-Operation)	Waveform: Random
	P.S.D Level: 10 Hz.1.04×10^{-3} g^2/Hz 30 to 200Hz.20.8×10^{-3} g^2/Hz 500 Hz.2.08×10^{-3} g^2/Hz
	Duration: 30 minutes
	Directions: X, Y and Z
Shock Test(Operation)	Waveform: Half-sine Acceleration: 30 g Duration: 11 ms Number of Shocks: 3 shocks for each ±axis
ESD Test	Contact Discharge: ±4KV Air Discharge: ±2/4/8KV
Soldering Heat Test	MIL-STD-202F Method 210E

Type of Test	Test Conditions
Reliability Testing of Developing Products	
RoHS	RoHS Directive 2011/65/EU
Extra Testing	
Drop Test	Drop Height: 66 cm
	Drop Sequence: 1 corner, 3 edges and 6 faces

MINMAX GREEN ENERGY DESIGN

HIGHER OVERALL CONVERSION EFFICIENCY

MINMAX's latest green energy design ensures that its railway-certified products maintain high conversion efficiency regardless of variations in output current, input voltage, or ambient temperatures. It also reduces the efficiency variation under different conditions to achieve energy savings, improved heat management, and addressing concerns related to temperature increase.

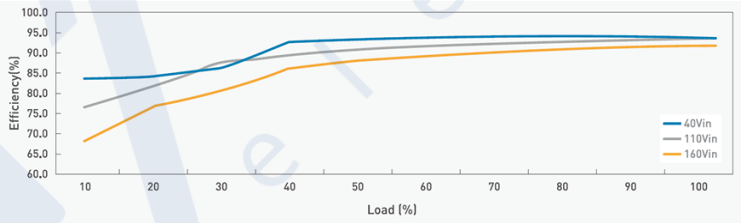


Figure 10: Efficiency vs. Load Curve

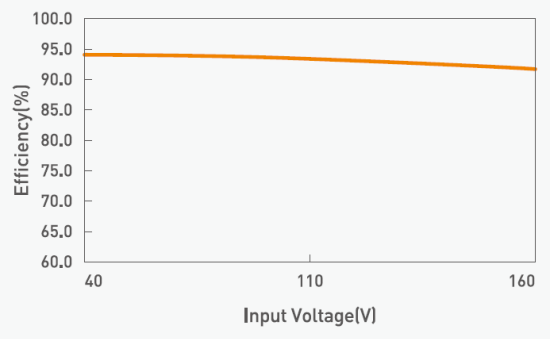


Figure 11: Efficiency vs. Input Voltage Curve

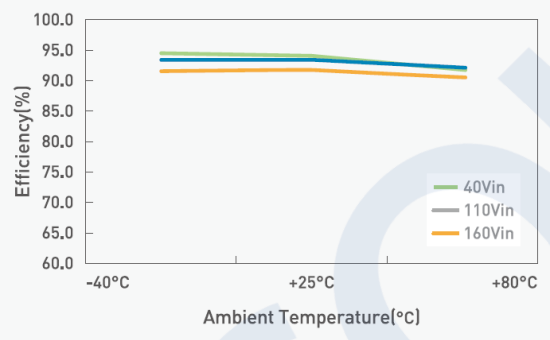


Figure 12: Efficiency vs. Operating Ambient Temperature Curve

ENERGY SAVINGS AND ADDRESSING THE ISSUE OF TEMPERATURE INCREASE

By utilizing MINMAX's latest green energy design, the products achieve lower idle power consumption, which significantly improves the issue of temperature increase, mitigates heat management problems, and ultimately leads to energy savings and an extended operational lifespan of train batteries.

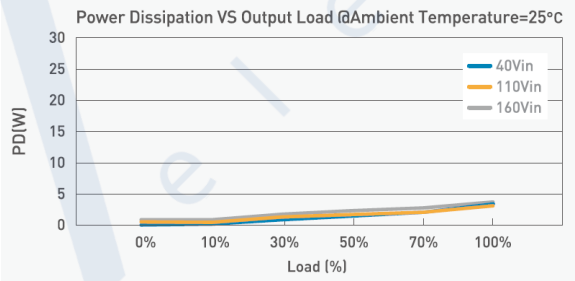
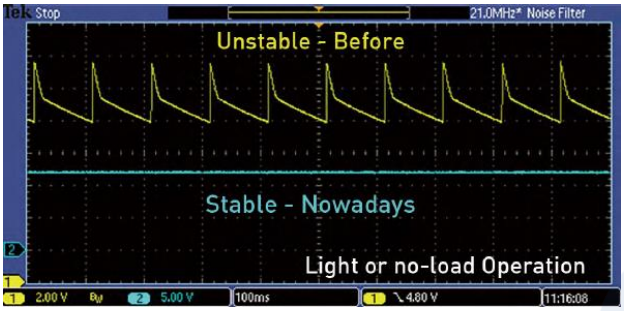


Figure 13: Power Consumption vs. Load Curve

NO MINIMUM OR DUMMY LOAD REQUIREMENT

MINMAX's railway-certified power supplies feature an internally designed negative feedback circuit with high stability. This design ensures that the output voltage remains stable and does not generate resonance or oscillation even

under conditions of no load or extremely light load. This contributes to the stability of the system during operation.



FASTER STARTUP TIME WITHOUT OVERVOLTAGE

MINMAX's railway-certified products have a faster startup time without generating overvoltage. This feature helps to prevent system failures during load conditions and ensures safety during prolonged operation.

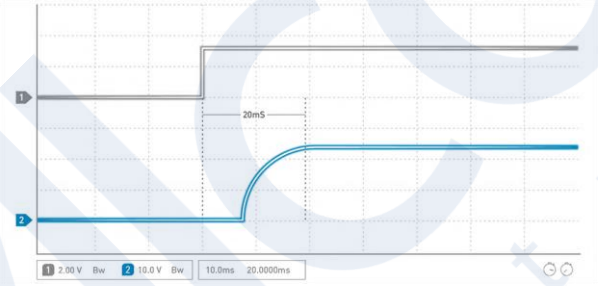


Figure 14: Rapid Startup Completed in just 20ms

ENHANCED LOAD DRIVING CAPABILITY

MINMAX's MRZI150 series offers excellent system load driving capability even under extremely low or zero output voltage, ensuring successful startup without failures to meet the needs of onsite operation.

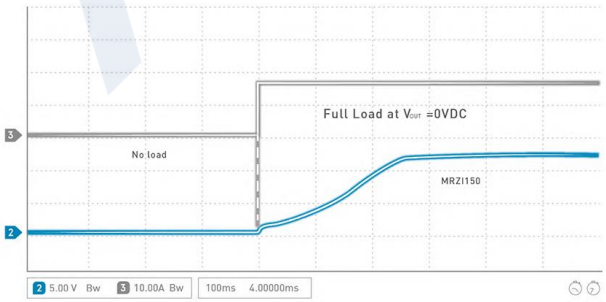
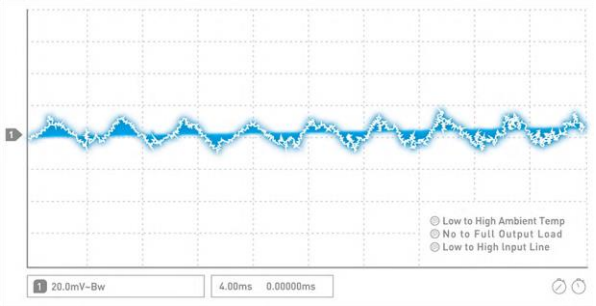


Figure 15: MRIZ150 series exhibits outstanding instantaneous load driving capability

RIPPLE AND NOISE SUPPRESSION CAPABILITY

With upgraded noise filtering technology, MINMAX's railway-certified products maintain low output ripple and noise across a wide range of input voltage, output current load, and operating ambient temperatures. This capability allows our customer's system to reduce the need for external components and minimizes noise interference.



COMPREHENSIVE FAULT PROTECTION AND EXTERNAL CONTROL FEATURES

MINMAX's railway-certified products come with comprehensive fault protection features, including input undervoltage protection, output overcurrent protection, output short circuit protection, output overvoltage protection, and over-temperature protection. Additionally, they are equipped with remote control switch functionality, output voltage fine-tuning capability, and sensing functionality. The fine-tuning feature allows adjusting the output voltage level, enhancing customer flexibility and freedom in system design.

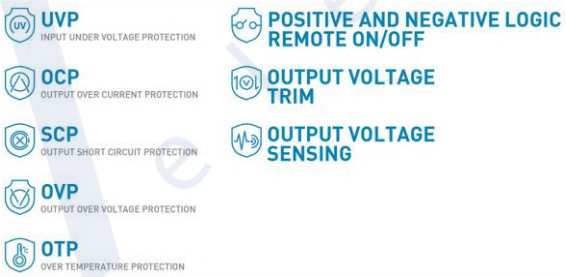


Figure 16: Comprehensive fault protection is an essential safety feature in railway-certified products

FULLY ENCAPSULATED VACUUM PACKAGING FOR PROTECTION FROM EXTERNAL INTERFERENCE

MINMAX's railway-certified products are all wrapped in fully encapsulated vacuum packaging, providing excellent protection and resistance against environmental electromagnetic interference (e.g., static electricity) as well as environmental physical stress interference (e.g., thermal shock, temperature cycling, vibration, shock, impact, dust, moisture, oil, and gas). This packaging ensures comprehensive protection and resilience against various external disturbances.

Figure 17: Fully encapsulated vacuum packaging effectively blocks external interference

PASSING FIRE PROTECTION TESTS TO ENSURE CUSTOMER SYSTEM SAFETY

All MINMAX railway-certified products undergo testing for four fire performance parameters: heat release rate, combustibility, smoke toxicity, and smoke opacity. These tests are conducted on the plastic casing, printed circuit board (PCB), and encapsulation materials of the products to ensure safety during railway operations.

CERTIFIED BY INTERNATIONAL ACCREDITATIONS

All MINMAX railway-certified products have undergone third-party certifications by international organizations or associations. These certifications not only demonstrate MINMAX's confidence in its products, but also provide customers with the assurance of using our products with peace of mind. By obtaining objective third-party certifications, we aim to eliminate any concerns regarding the safety or fairness of MINMAX's products.

- Railway Application : EN 50155 (IEC 60571)
- Fire protection on railway vehicles : EN 45542-2
- Vibration and shock testing: EN 61373
- Cooling, Drying, Damp Heat Reliability Test Standards
- Damp heat compliance testing : IEC/EN 60068-2-1, 2, 30
- Electromagnetic compatibility (EMC): EN 50121-3-2
- CE Label
- International standard for infotech equipment safety
- UL/cUL/IEC/EN 623681(60950-1)