Power Electronics for Public Transport Vehicles

LOCOMOTIVES

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MEDCOM is a manufacturer of single- and multisystem propulsion systems as well as high power auxiliary converters, which are used to supply on-board loads in electric locomotives.

MEDCOM developed modern propulsion inverters for new and modernized locomotives operated around Europe. Propulsion systems for locomotives provide output power of up to 5.6 MW. The auxiliary converters are manufactured with the power ranging from 80 kW to 500 kW and can operate separately or in redundancy systems. These devices have high overload capabilities, which allow large motors (compressors, engine fans and resistor fans) start up easily.

In the case of train systems, where vehiclees are powered only with low voltage, MEDCOM may also deliver auxiliary converters with the output power of up to 500 kW with three-phase output.

The devices for charging on-board batteries provide a high quality charging process for all types of batteries. The standard operation temperature range is –40°C ÷ +70°C.

The converters are equipped with a diagnostic-control system based on MVB, CAN 2.0 B, RS232, RS485 interfaces or the Ethernet.

FT-1600-3000

Propulsion inverters

The FT-1600-3000 propulsion inverter is a modern chopperless system of the direct three-phase inverter based on the HV IGBT 6.5 kV technology. The control of the converter is performed in the DSP (Digital Signal Processor) technology with the application of the FOC SVPWM (Field Oriented Space Vector Pulse Width Modulation). Within the range of high speeds, the system co-operates with a synchronized Bus Clamping Pulse Width Modulation, which causes reduction of losses and noise. The control system ensures acceleration with a constant torque and low power losses. The drive can operate with rheostatic or regenerative braking. The inverter system guarantees very good traction parameters and perfect stabilization of the driving torque. The applied braking resistors made of stainless steel guarantee a long service lifetime and low noise level. The applied system of busbars combined with a perfect IGBT driver guarantee a failure-free performance at short circuits. It also eliminates the possibility of secondary damages in case of the transistor's failure. The applied polypropylene capacitors ensure long service lifetime and resistance of the system to changes of voltage in the traction network. The inverter system is also protected with a thyristor crowbar. The inverter meets EN standards requirements with regard to safety and electromagnetic compatibility. The system has very low levels of low frequency interferencess conducted to the traction network. The inverter is equipped with a forced air-cooling system and operates within the temperature range of –25 °C ÷ +40 °C. Lack of the cooling liquid increases the reliability and lowers operating costs of the vehicle. The diagnostics and control of the inverter is possible through the CANbus interface.

Specification	
Input voltage	**3000 VDC, +30 ÷ –30%**
Auxiliary voltage	**24 VDC, +25 ÷ –30%**
Output rated current	**2 × 260 A**
Maximum output current	**2 × 300 A**
Rated power	**2 × 800 kW**
Cooling	**forced-air**
Weight (without output chokes)	**2530 kg**
Dimensions	**2800 × 850 × 2050 mm**

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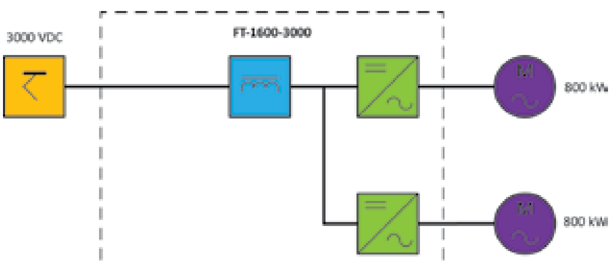

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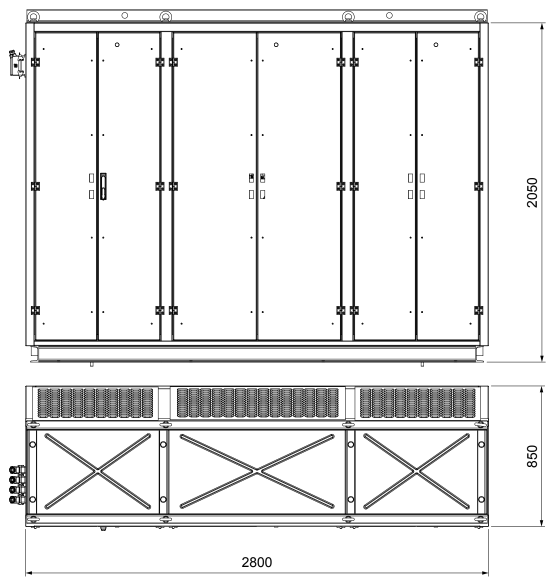

FT-1800-3000

Propulsion inverters

The container FT-1800-3000 is an integrated, mechanically optimized set of converters containing: two propulsion inverters 900 kW each, converter DC/DC to the brake resistor, auxilliary converter PSM-125 SiC made in SiC technology, rectifier ZT-1000 and battery charger ZB24DC400.

The propulsion inverters FT-1800-3000 are used to drive the axles of the wheels in the electric-diesel locomotives of the 111DE series. The use of two sets of inverters provides the drive of four driving axles of the locomotive. FT-1800-3000 traction converters are designed for installation inside the locomotive. The inverters are made using HV IGBT technology. Control of the converter is provided by DSP (Digital Signal Processor), which uses FOC SVPWM control (Field Orientation Control Space Vector Pulse Width Modulation).

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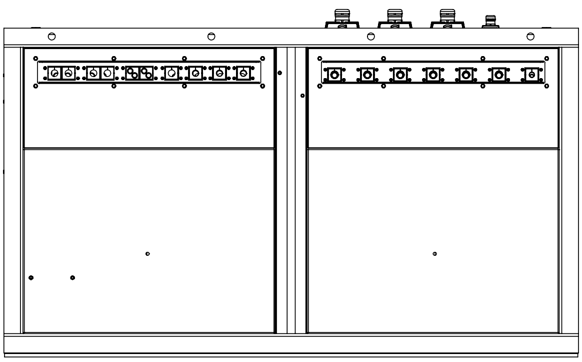
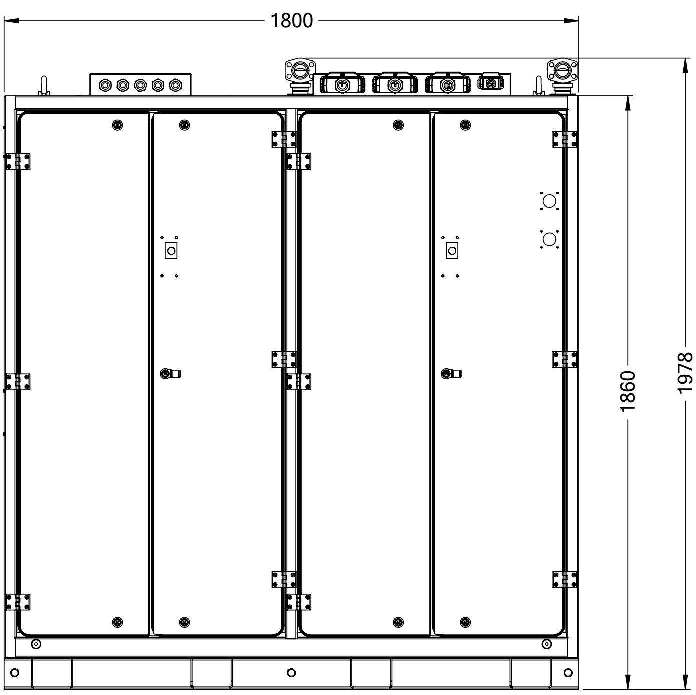
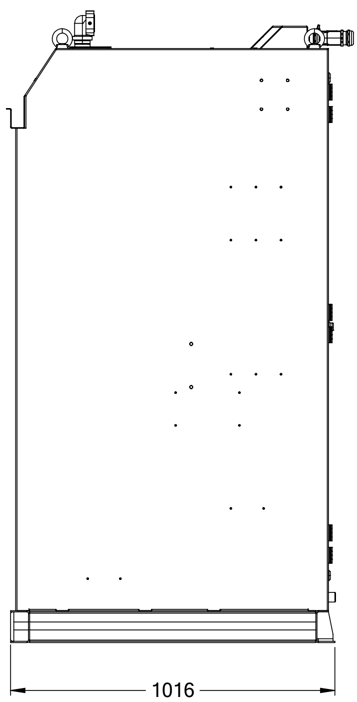


The auxilliary converter PSM-125 SiC, with the power 125 kVA, ensures the generation of 3x400 V voltage for three-phase loads. The ZB24DC400 series battery charger has been designed to charge batteries or supply DC loads of the rated voltage of 24 VDC – in co-operation with the battery. The use of two auxiliary converters and two battery chargers ensures full redundancy of 24 VDC and 3x400 VAC power.

The optimized mechanical structure of the converters, the use of SiC technology in auxilliary converters allowed to reduce the weight and volume, thanks to which it was possible to build a two-drive locomotive (electric and diesel) with the permissible axle loads.





NEW

FT-1800-3000

Propulsion inverters

Specification	
Input supply voltage from the overhead line	**3000 VDC**
Input supply voltage from rectifier output	**2098-3596 VDC**
Auxiliary voltage	**24 VDC +25% ÷ -30%**
FT-1800-3000	
Rated output current	**2 x 265 A**
Output power	**2 x 900 kW**
ZT-1000	
Output voltage	**0-3600 VDC**
Output current	**0-278 A**
Maximum power	**1000 kW**
PSM-125-SiC	
Input voltage - depot supply	**3x400 V 50 Hz**
	1x230 V 50 Hz
Depot supply socket	**63 A**
Output AC 1	**3x400 VAC, 50 Hz ±1 Hz / 125 kVA**
Output AC 2	**1x230 VAC, 50 Hz ±1 Hz / 10 kVA**

ZB24DC400	
DC input voltage	**600 VDC ±10%**
AC input voltage 1	**3x400 V ±15%, 50 Hz**
AC input voltage 2	**1x230 V ±15%, 50 Hz**
DC output	**24-30 VDC / 9.6 kW**
Housing	
Cooling	**Liquid**
Weight	**1550 kg**
Dimensions	**1800 x 1016 x 1978 mm**
Protection degree	**IP56**

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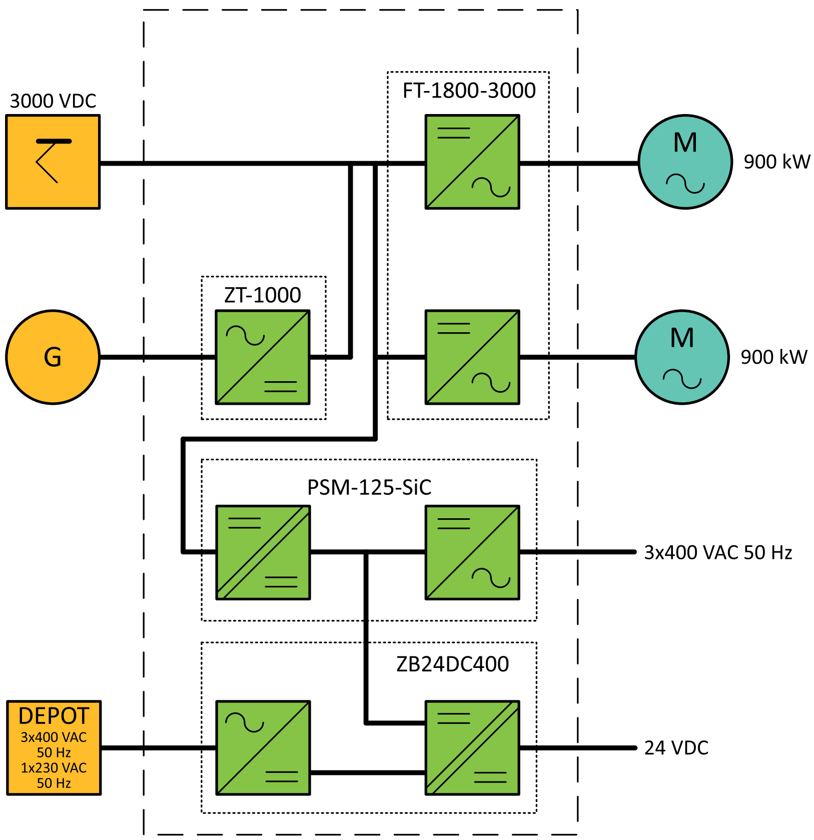

FT-2400-3000-MS

Propulsion inverters

Specification	
Input voltage DC	**3000 VDC**
Input voltage AC	**1880 V**
FT-2400-3000-MS	
Output current	**3 x 3x320 A**
Output power	**3 x 850 kW**
Auxiliary voltage	**24 VDC +25% ÷ -30%**
PSM-175-SiC	
DC input voltage	**3000 VDC**
Output power	**175 kVA / 150 kW**
Output voltage	**3x400 VAC, 50 Hz**
Auxiliary voltage	**24 VDC +25% ÷ -30%**
ZB24DC400	
DC input voltage	**600 VDC ±10%**
AC input voltage	**3x400 V ±15%, 50 Hz (depot power supply)**
AC input voltage	**230 V ±15%, 50 Hz (depot power)**
DC output	**24-30 VDC, 9.6 kW**
Housing	
Cooling	**Liquid**
Weight	**2500 kg**
Dimensions	**2678 x 926 x 1930 mm**
Protection degree	**IP56**

The container FT-2400-3000-MS is an integrated, mechanically optimized set of converters containing: three propulsion inverters 850 kW each, two controllable rectifiers AFE, converter DC/DC to the brake resistor, auxilliary converter PSM-175 SiC made in SiC technology and battery charger ZB24DC400.

The propulsion inverters FT-2400-3000-MS are used to drive the axles of the wheels in the dual-system electric locomotives of the E6MST series. The use of two sets of inverters provides the drive of six driving axles of the locomotive. FT-2400-3000-MS traction converters are designed for installation inside the locomotive. The inverters are made using HV IGBT technology. Control of the converter is provided by DSP (Digital Signal Processor), which uses FOC SVPWM control (Field Orientation Control Space Vector Pulse Width Modulation).

The auxilliary converter PSM-175 SiC, with the power 175 kVA, ensures the generation of 3x400 V voltage for three-phase loads. The ZB24DC400 series battery charger has been designed to charge batteries or supply DC loads of the rated voltage of 24 VDC – in cooperation with the battery. The use of two auxiliary converters and two battery chargers ensures full redundancy of 24 VDC and 3x400 VAC power.

The optimized mechanical structure of the converters, the use of SiC technology in auxilliary converters allowed to reduce the weight and volume.

FT-2400-3000-MS

Propulsion inverters

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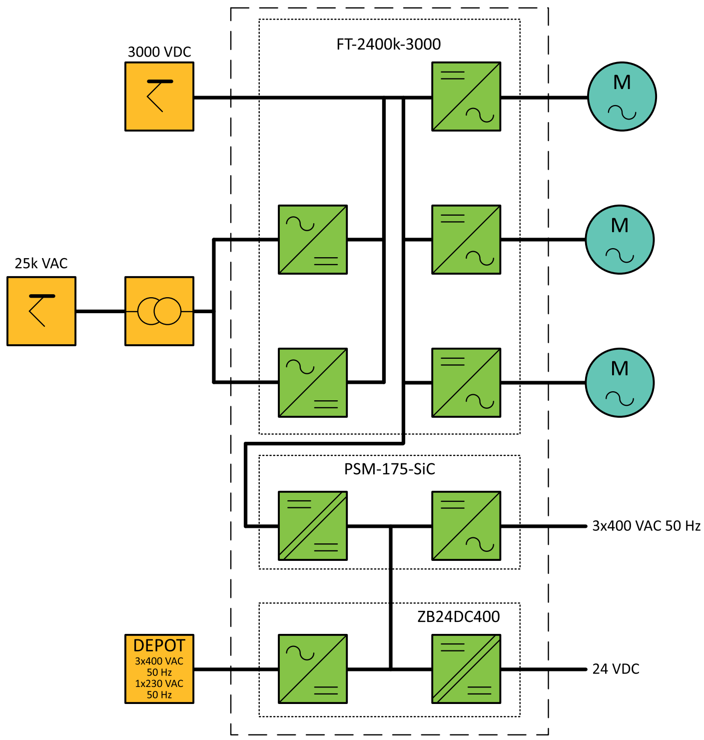

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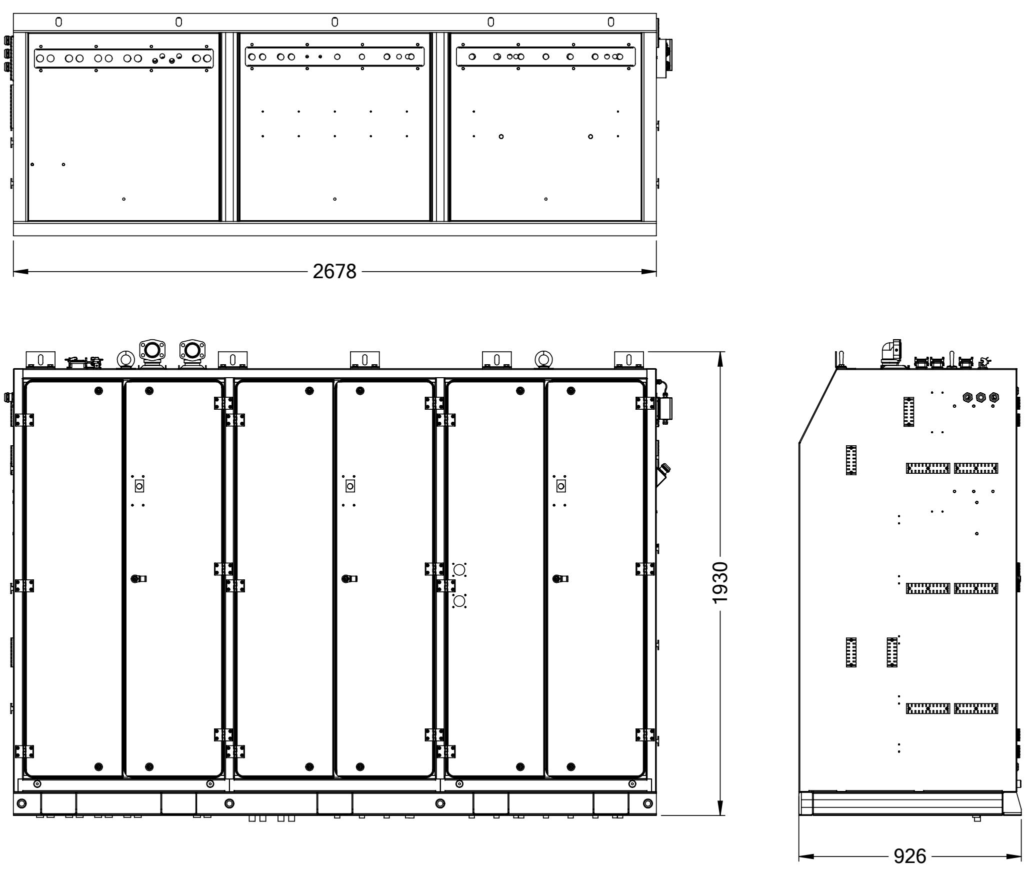

FT-2800-MS

Propulsion inverter for Asynchronous Drives

The FT-2800-MS propulsion inverter is a modern chopperless system, designed to drive wheel axles in E4MSU series multi-system electric locomotives. The inverter is based on the HV IGBT technology. The control of the converter is performed in the DSP (Digital Signal Processor) technology with the application of the FOC SVPWM (Field Oriented Space Vector Pulse Width Modulation). With the range of high speeds, the system co-operates with a synchronized Bus Clamping Pulse Width Modulation, which causes reduction of losses and noise. The control system ensures acceleration with a constant torque and low power losses.

Specification	
Input rated voltage DC1	**3000 VDC**
Input voltage AC1	**15000 V, 16 $^2/_3$ Hz (–20 ÷ +15%)**
Input voltage AC2	**25000 V, 50 Hz (–25 ÷ +10%)**
Output rated current	**2×400 A**
Maximum output current	**2×500 A**
Rated power	**2×1400 kW**
Output voltage	**2×2340 VAC**
Auxiliary voltage	**24 VDC (–30 ÷ +25%)**
Frequency	**0–50 Hz**
Insulation strength	**10.2 kV**
Protection degree	**IP56**
Total efficiency	**98%**
Ambient temperature	**–30°C ÷ +40°C**
Cooling	**liquid**
Weight	**2100 kg**
Dimensions	**2599 × 922 × 1921 mm**

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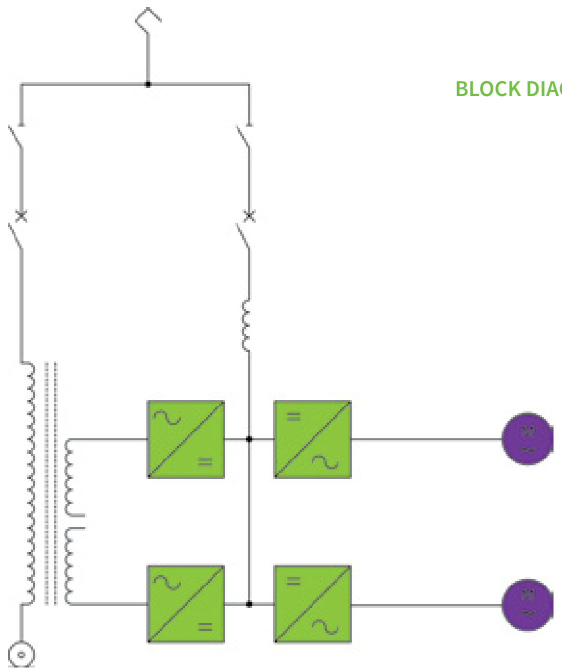

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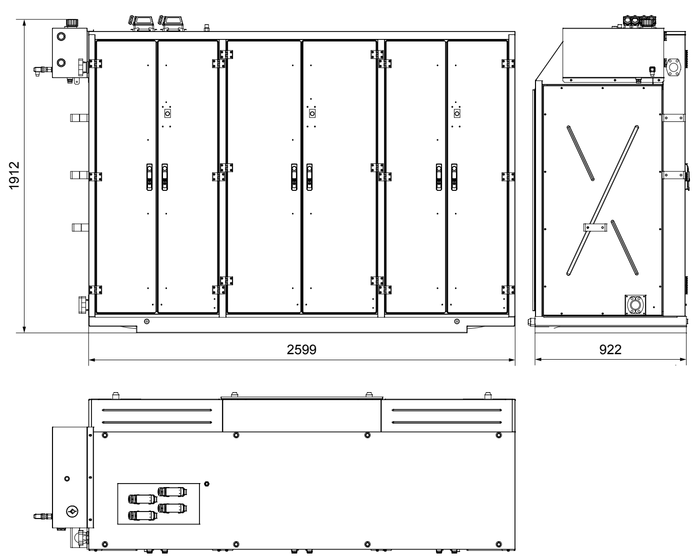

PSM–19U

Auxiliary converter

The PSM-19U auxiliary converter is a device designed to convert 3000 VDC traction voltage into and 50 VDC and 24 VDC as well as 230 VAC used in low voltage system of an electric locomotive.

Specification	
Input voltage	**3000 VDC (operating range 2200÷4000 V)**
Output voltage	
230 V 50 Hz	**P = 16.1 kW; voltage stability ≤ ±10%; frequency stability ≤ ±1.0%; In = 70 A**
50 VDC	**P = 3 kW; voltage stability ±2%; In = 60 A**
24 VDC	**P = 0.6 kW; voltage stability ±5%; In = 25 A**
Total power	**19.7 kW**
Efficiency	**> 83%**
Ambient temperature	**–40 ÷ +40°C**
Protection degree	**IP56**
Weight	**300 kg**
Dimensions	**1000 × 529 × 1602 mm**

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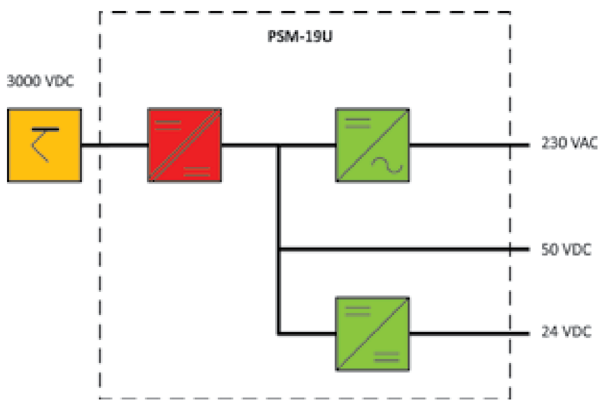

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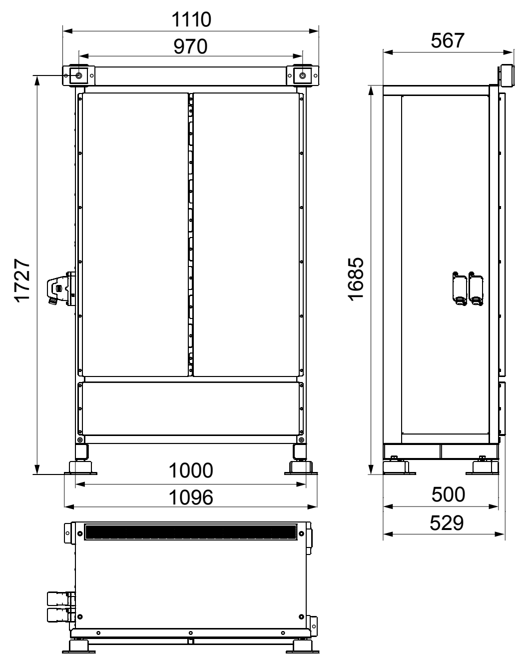
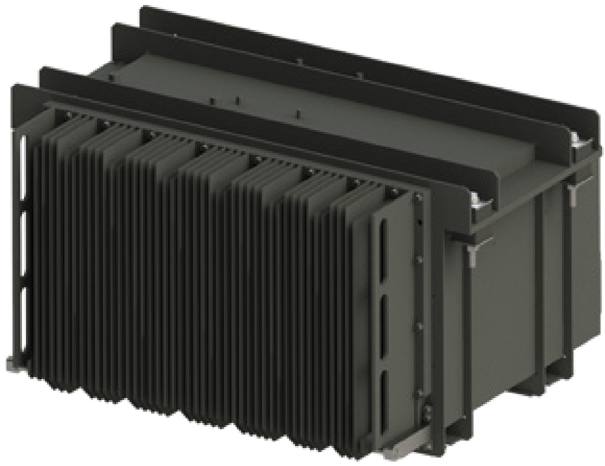


PSM-35

Auxiliary converter



The PSM-35 auxiliary converter has been designed to convert 3000 VDC voltage used in the railway traction networks into 3×400 VAC, used in the low voltage installation of the electric locomotive. The control system of the converter is powered from an external voltage of 110 VDC. Converter PSM-35 is a fully automated and allows continuous supply of low-voltage circuits, independently of the actual input voltage.

Specification	
Input voltage	**3000 VDC** (operating range 2000÷4000 V)
Output voltage	**3×400 VAC (50 Hz)**
S = 35 kVA In = 36 A; Overload capability 80 kVA/5 s; oltage stability ≤ ±5%; Frequency stability ≤ ±0.5 Hz; THD(u) ≤ 5%; Electronic short circuit and overload protection	
Rated power	**35 kW**
Total efficiency	**≥ 90%**
Ambient temperature	**–30 ÷ +50°C**
Protection degree	**IP56**
Weight	**300 kg**
Dimensions	**1090 × 600 × 926 mm**

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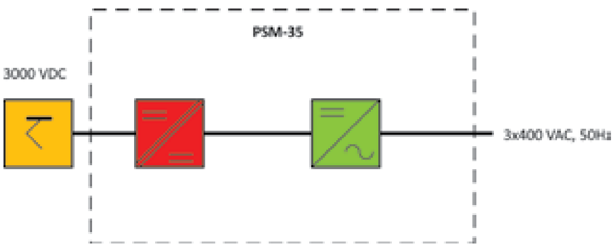

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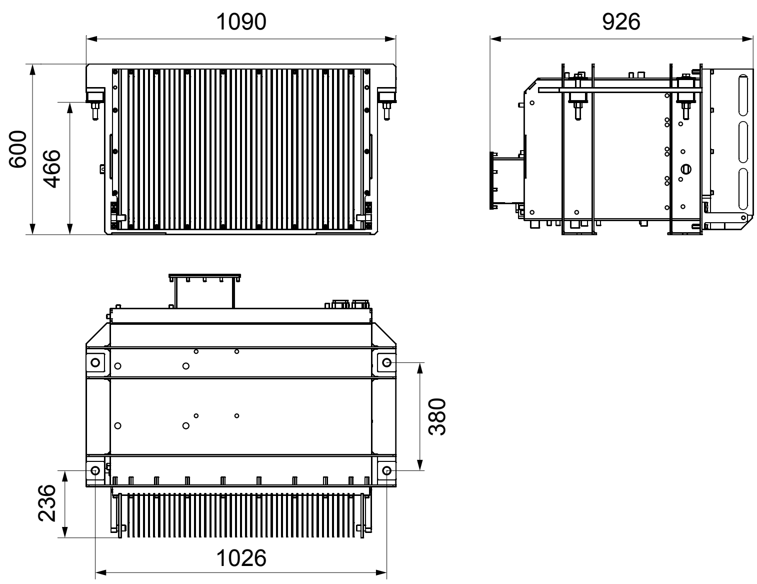

PSM-130D

Auxiliary converter

The auxiliary converter PSM-130D type consists of two 130 kVA converters in one cabinet with the operation redundancy. Both converters have been designed to supply the circuits of electric locomotive with 3×440 V/60 Hz and 24 VDC voltages. Input power supply for this converter is 3000 VDC or 25 kVAC, depending on operation mode of the locomotive. In both modes of locomotive operation the converters are supplied from DC link circuits, each auxiliary converter from its corresponding FT-2800-MS propulsion inverter system. It is possible to use 3×400 V 50 Hz depot power supply. The control units of the PSM-130D are supplied from a 24 VDC source.

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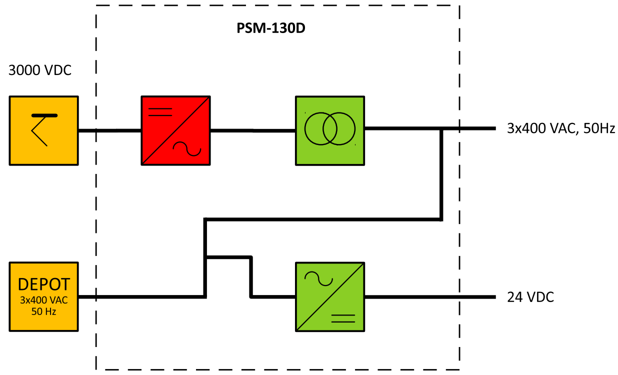

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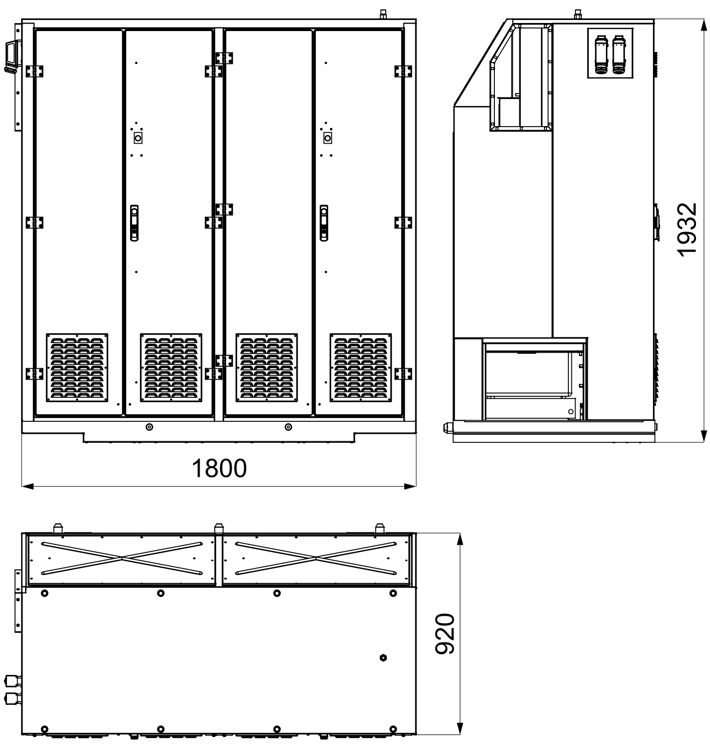

PSM-130D

Auxiliary converter

Specification	
Input voltage HVDC	**3000 VDC** direct from FT-2800-MS (operating range 2000÷4000 VDC)
Overvoltage protection	**MOV**
Input -output galvanic isolation	**yes**
Input voltage AC Depot	**3×400 VAC/50 Hz** (the same voltage on the output)
Input power	**44 kVA**
3-wire input	**L1, L2, L3**
Output voltage AC	**3×440 VAC/60 Hz**
Output power	**130 kVA**
3-wire output	**L1, L2, L3 grounded neutral**
Power factor	**≥ 0.85**
Voltage stability	**≤ 5%**
Frequency stability	**≤ 1%**
Overload /short circuit capacity	**3×In/3 s (300%/3 s)**
THD(u)	**≤ 5%, typical 3%**
Electronic overload and short circuit protection	**yes**
Output voltage DC	**24 VDC (range 16.8÷30 V)**
Output power	**8 kW**
Output current	**300 A**
Voltage stability	**≤ 1%**
Voltage ripples	**≤ 2%**
Battery current limit	**0.1–1 In**
Electronic overload and short circuit protection	**yes**
Output voltage thermal compensation	**option**
General	
Total output power	**130 kVA/122 kW**
Efficiency	**≥ 90%**
Dielectric Strength Test HV/LV	**9.5 kV, 50 Hz, 1 min**
Dielectric Strength Test LVAC/LVDC	**2.5 kV, 50 Hz, 1 min**
Monitoring	**CANopen**
Ambient temperature	**–30 ÷ +40°C**
Cooling	**forced-air**
Assembling	**inside locomotive**
Protection level	**IP22**
Weight of set	**1950 kg**
Dimensions of set	**1800 × 920 × 1932 mm**

PSM-175 SiC

Auxiliary converter

The PSM-175 SiC auxiliary converter is designed to generate the operating voltage of 3×400 V, 50 Hz required to power auxiliary circuits in the locomotive. PSM-175 SiC is used to convert the DC input voltage of 3 kV to an AC sinusoidal voltage of 3×400 V. The converter is equipped with efficient transformers providing galvanic isolation of the overhead line circuit from the circuits of the receivers. The locomotive is equipped with two fully redundant converters, each with a capacity of 175 kVA. At any given time, only one auxiliary converter is operating. In case of damage to the inverter or inverter container (which supplies the inverter), the master control system activates the second operational converter, ensuring the continuity of supply to the receivers.
The traction converters operate reliably at a supply voltage compatible with the requirements of theEMC standards. The auxiliary converter withstands short circuits in the output circuit.

The set of 2×PSM-175 SiC is made using the SiC technology. Control of the converter is implemented using a DSP (Digital Signal Processor). The power modules made of silicon carbide increase the switching frequency and significantly reduce the power loss in SiC modules, transformers and chokes.
The converter meets UN and EN standards for safety and electromagnetic compatibility. Diagnostics and converter control is provided via the CANBus interface.
The converter has a single-phase voltage output of 230 V.
For optimal use of the cooling liquid system and the space available in containers, the DC/DC blocks of two converters are mounted in two driving system containers. Two inverter blocks of two inverters are mounted in a separate container, which uses forced air cooling provided by a fan.

PSM-175 SiC		
Input voltage	**3000 VDC (from catenary)**	
Rated power	**2×175 kVA**	
AC Output 1	**3×400 V / 50 Hz / 175 kVA**	
AC Output 2	**230 V / 50 Hz / 3.5 kVA**	
Housing		
Cooling	**Air and liquid cooling**	
Weight	**470 kg**	
Dimensions	**950 × 1051 × 1950 mm**	
Protection degree	**Clean section**	**IP56**

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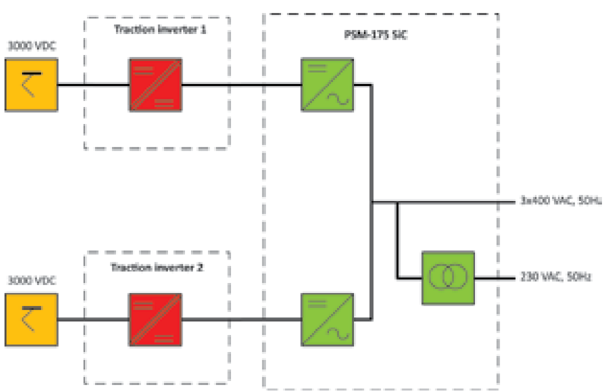

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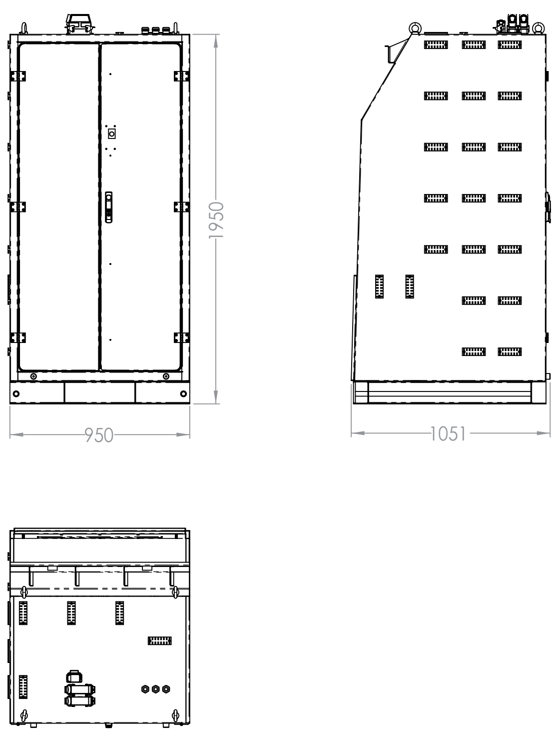

SWG-01

Excitation System
for Diesel-Electric Locomotive

The SWG-01 system is designed to control synchronous generators by controlling the excitation current. It is used to power supply voltage inverters for compressors and fans for cooling DC motors. The system consists of an input rectifier and an excitation supply for the auxiliary generator.

Specification	
Input voltage	**3×400 VAC (±20%)**
Auxiliary input voltage	**24 VDC (+25 ÷ –30%)**
Main excitation current range	**0÷60 A**
Main excitation voltage range	**0÷100 V**
Auxiliary excitation current range	**0÷10 A**
Auxiliary excitation voltage range	**0÷24 V**
Output voltage	**540 VDC (±25%)**
Maximum output current	**100 A**
Interface	**CANbus (CAN 2.0 B)**
Cooling	**forced-air**
Ambient temperature	**–25 ÷ +50°C**
Weight	**70 kg**
Dimensions	**600 × 586 × 261 mm**

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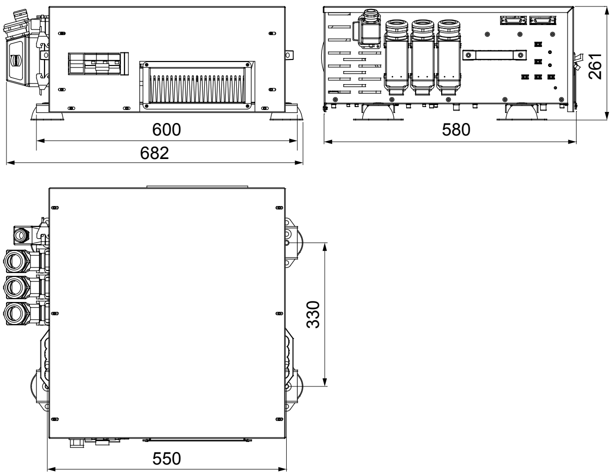
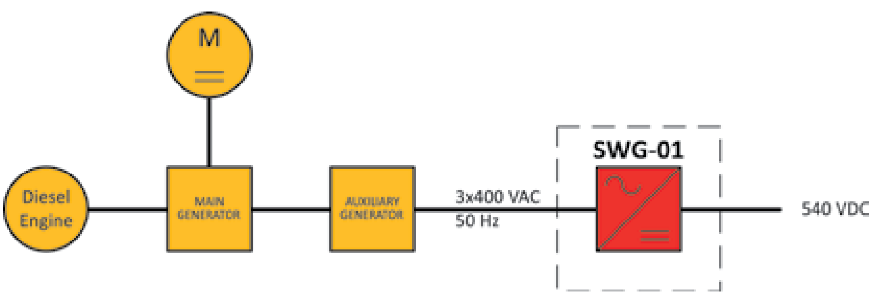


BLOK DIAGRAM OF THE SWG-01 EXCITATION SYSTEM FOR DIESEL LOCOMOTIVE



FN25+5/540

Auxiliary Circuit Inverter

FN25+5/540 auxiliary circuit inverters are designed to supply power for compressor in 6Dg/B locomotives (25 kVA inverter) and traction motors fans (5 kVA inverter). Inverters allow to start the motor of the locomotive with the characteristics U/f = const. Application ramp reduces the inrush current of the motor.
The DSP microcontroller controls inverters and delivers information via CANopen and to digital isolated outputs. FN25+5/540 inverters are equipped with several electronic protection system like overload, short circuit, overheating, loss of communication and overvoltage protection.
Output sine wave filter eliminates problems of motor/cable insulation failures, heating, and audible noise. Sine Wave Filters also reduce electromagnetic interferencess (EMI).

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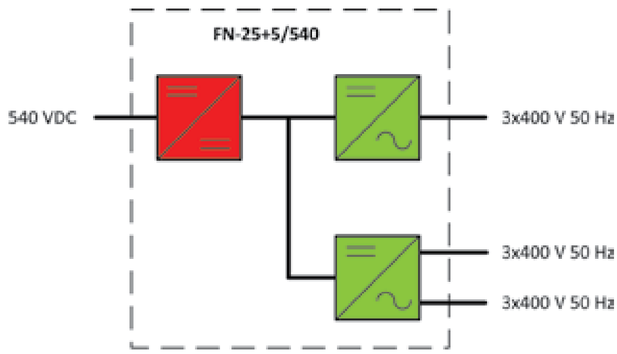

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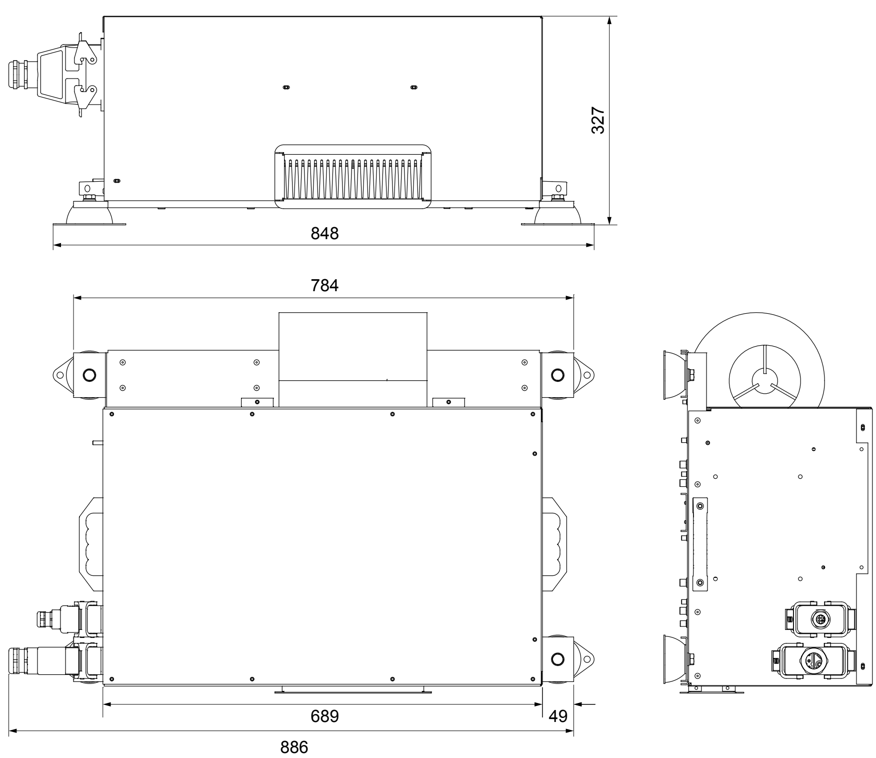


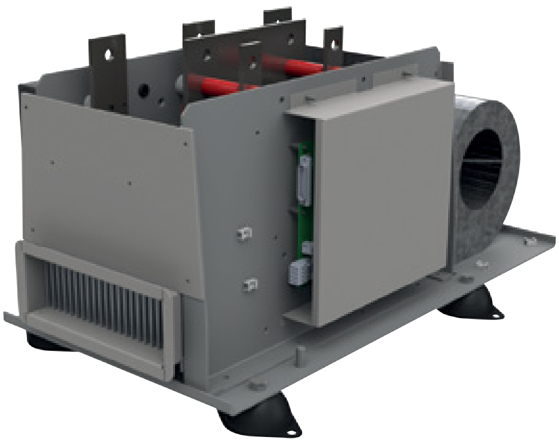
FN25+5/540

Auxiliary Circuit Inverter

Specification	
Input rated voltage	**540 VDC**
Input voltage range	**400÷750 VDC**
Inverter I	
Output rated voltage	**3×400 VAC**
Rated power	**5 kVA**
Rated frequency	**50 Hz**
Frequency output range	**5÷67 Hz**
Output voltage shape	**sinusoidal**
Voltage drop on the output sinusoidal filter	**≤ 8% (with nominal load)**
Current overload	**2 In/10 s**
Short circuit protection	**32 A**
Inverter II	
Output rated voltage	**3×400 VAC**
Rated power	**25 kVA**
Rated frequency	**50 Hz**
Frequency output range	**5÷67 Hz**
Output voltage shape	**sinusoidal**
Voltage drop on the output sinusoidal filter	**≤ 8% (with nominal load)**
Current overload	**2 In/10 s**
Short circuit protection	**155 A**
Power supply for electronic circuits	
Input rated voltage	**24 VDC**
Input voltage range	**16÷28 VDC**
Current consumption	**≤ 7 A**
Digital input	**START/STOP**
Input rated voltage	**24 VDC**
Current consumption	**10 mA**
Electric insulation of Input	**2.5 kV**
Digital output	
Output contacts	**1NO, 1NC**
Electric insulation of output	**2.5 kV**
Communication	
Transmission interface	**CANopen**
Electric insulation of transmission interface	**2.5 kV**
Dimensions	**327 × 848 × 596 mm**
Weight	**80 kg**

ZT–900

Traction Rectifier



The ZT-900 is a diode rectifier which supplies two DC traction motors in the 6Dg/B (SM42) diesel locomotive. The ZT-900 allows for measurement of the DC current and DC voltage of each motor and is equipped with overvoltage protection and fan speed control.

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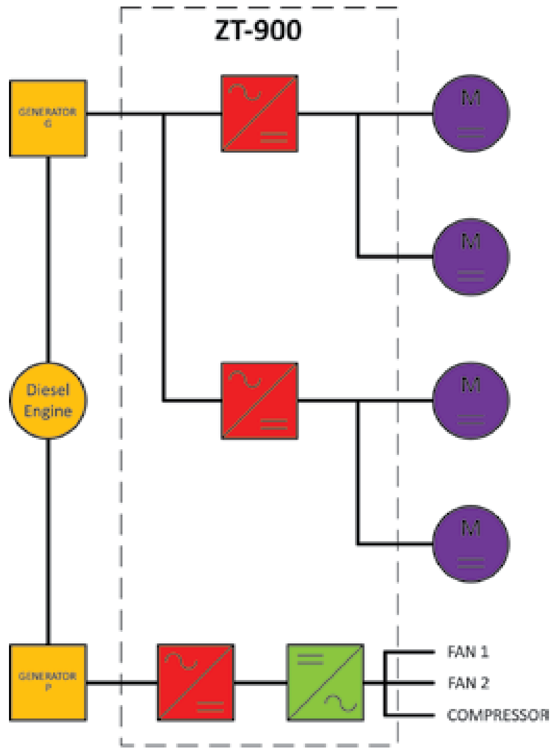

Specification	
Input voltage	**3×0–600 VAC, 20–60 Hz**
Output voltage	**0–900 VDC**
Auxiliary voltage	**24 VDC, +25 ÷ –30%**
Output current	**0–1000 ADC**
Maximum power	**350 kW**
Efficiency	**99.4%**
Ambient temperature	**+25 ÷ +50°C**
Cooling	**forced-air**
Weight	**59 kg**
Dimensions	**700 × 374 × 434 mm**

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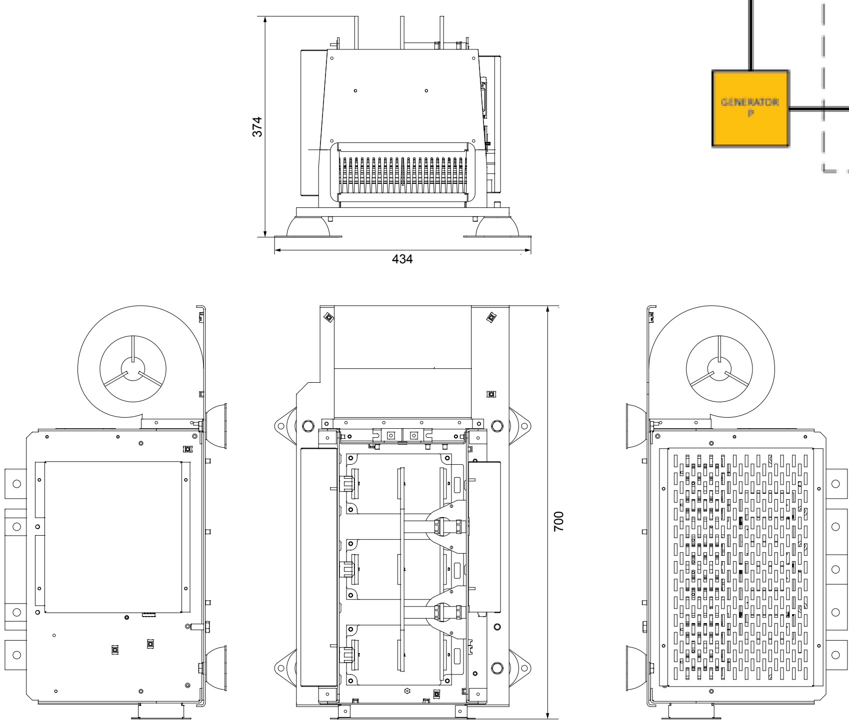


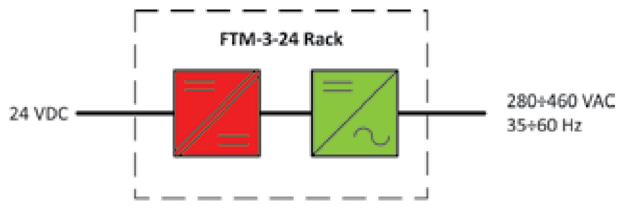
FTM-3-24 Rack

3-Phase Emergency Inverter

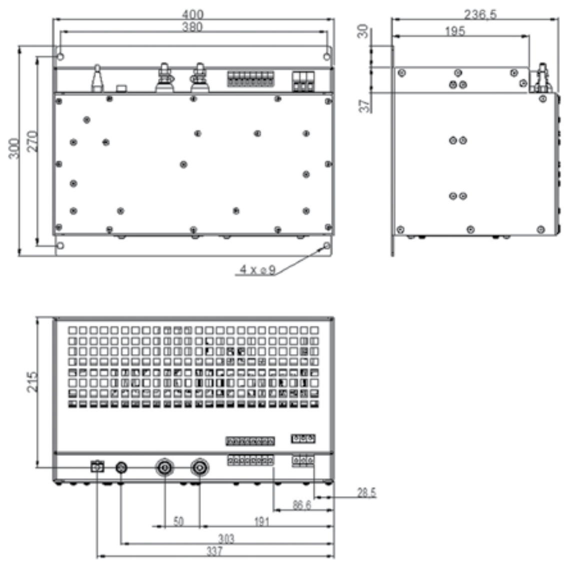
The converter FTM-3-24 (DC/AC converter) is designed to convert input voltage 24 VDC into 3×280 ÷ 460 VAC (35 ÷ 60 Hz), to supply fans and pumps in railway vehicles. Power dissipated in the inverter is blown out by fans which force cooling air flow.
The input voltage 24 VDC is feed by the filter to the DC / DC converter, which produces a stabilized voltage DC. The next element is the converter DC/DC with galvanic isolation. Inverter converts the voltage of VDC to three-phase AC voltage, which is applied to the output terminals. The control signal Ethernet bus driven phase allows you to adjust the output voltage of the range 280 ÷ 460 V (35 ÷ 60 Hz).

Specification	
DC input	
Nominal Input Voltage	**24 V**
Tolerance of input voltage	**(16.8 V) – 18–31,5 V**
Switch-on voltage	**18 V**
Switch-off voltage	**16.8 V**
Nominal input current at 24 V	**130 A**
AC output	
Output voltage range	**3 AC 280÷460 V; ±5%**
Frequency range (adjustable)	**35–60 Hz**
Oscillation mode	**sinusoidal (sinus filter)**
Output phase current	**4.33 A**
Output power (continuous)	**3.0 kVA, cosφ = 0.85**
Environments	
Relative humidity	**0–95%**
Ambient temperature	**–25 ÷ 40°C**
Noise level	**< 60 dB(A)**
Mechanical data	
Weight	**20 kg**
General	
Starting time	**< 10 s**
Discharging time	**< 5 min**
Dimensions	**400 x 300 x 240 mm**

BLOCK DIAGRAM

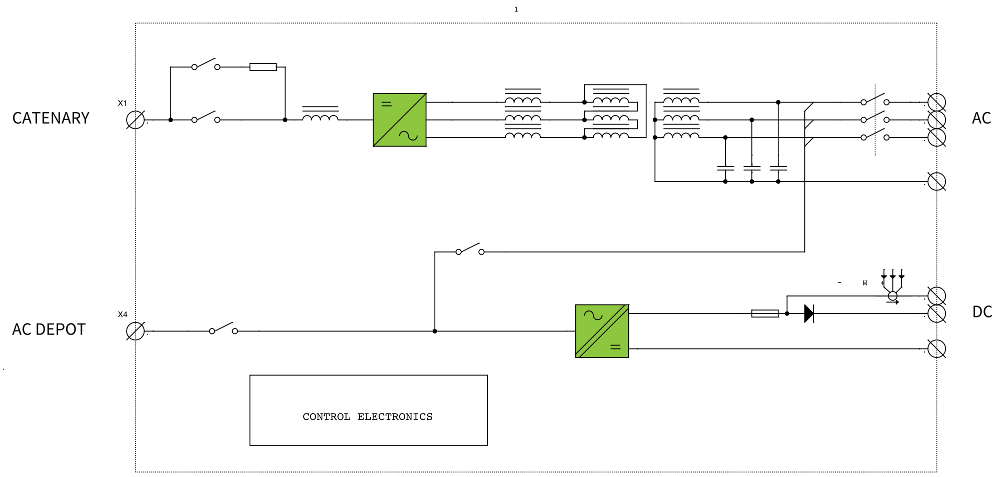


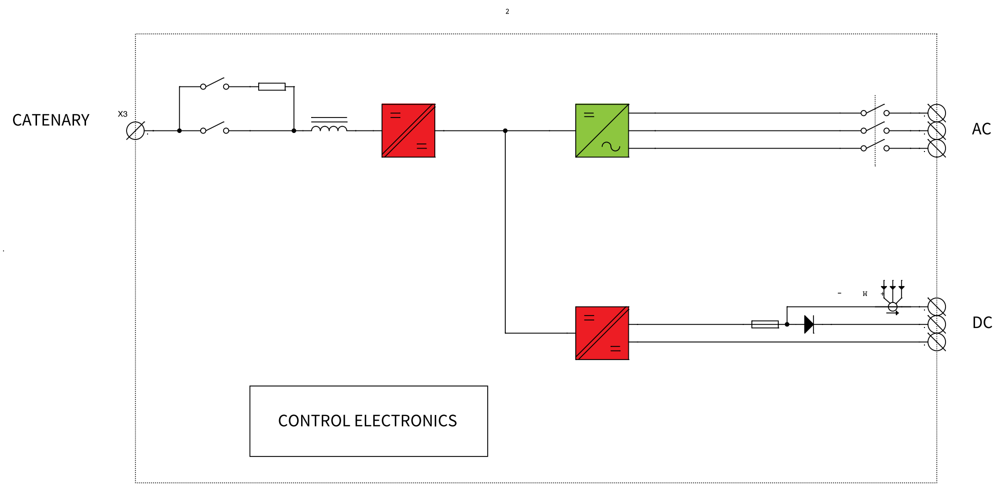
HOUSING



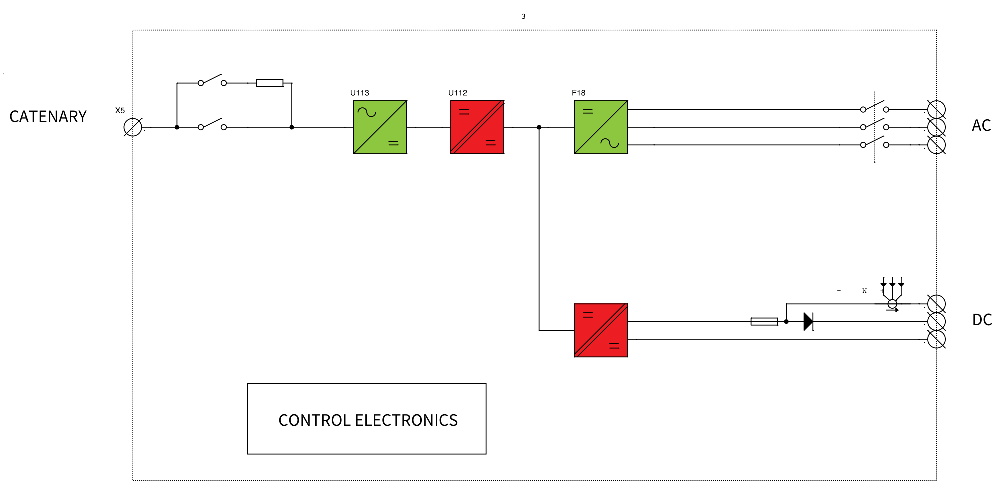
Structure of auxiliary converters

Single-system DC auxiliary converters



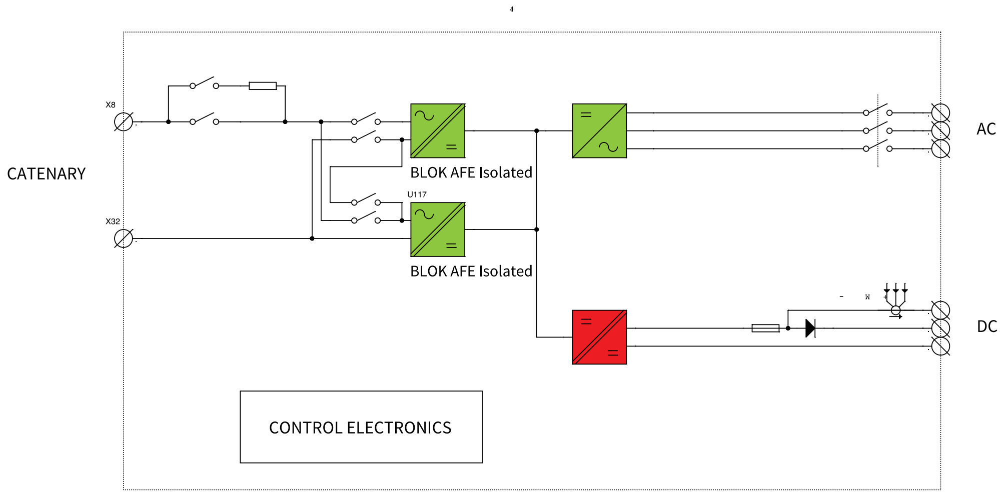


Single-system AC auxiliary converters

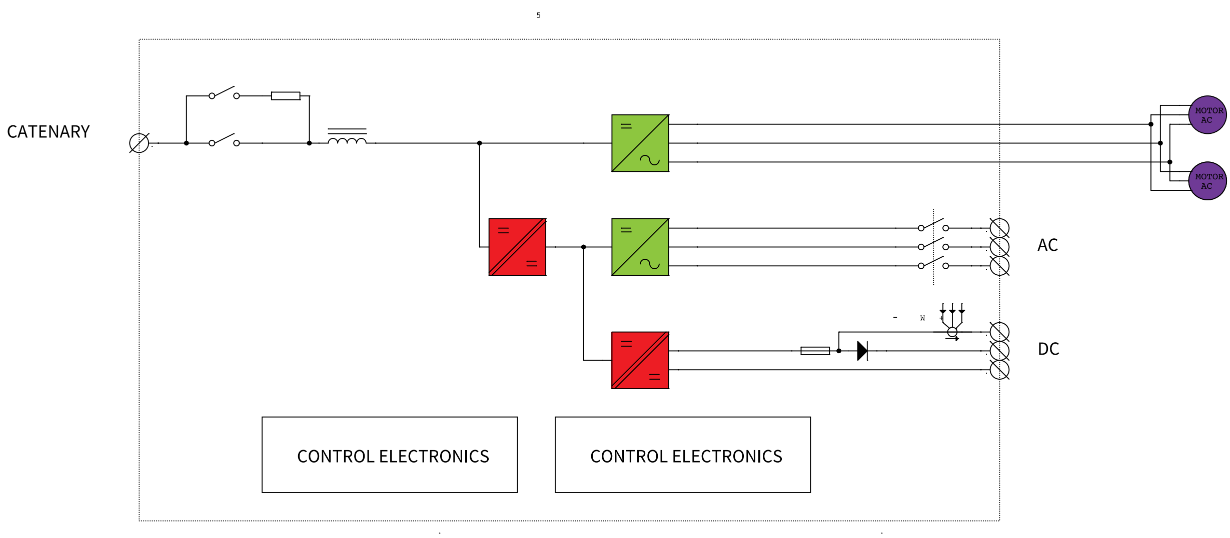


Structure of auxiliary converters

Multi-system auxiliary converters

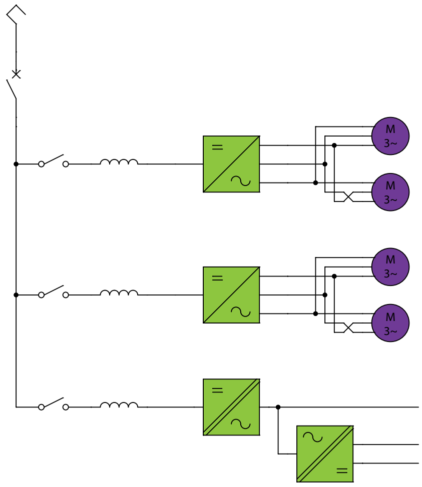


Auxiliary converters supplied from the inverters's intermediate circuit

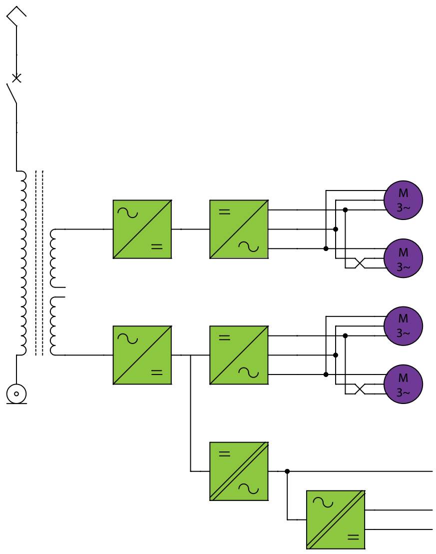


Propulsion systems structures

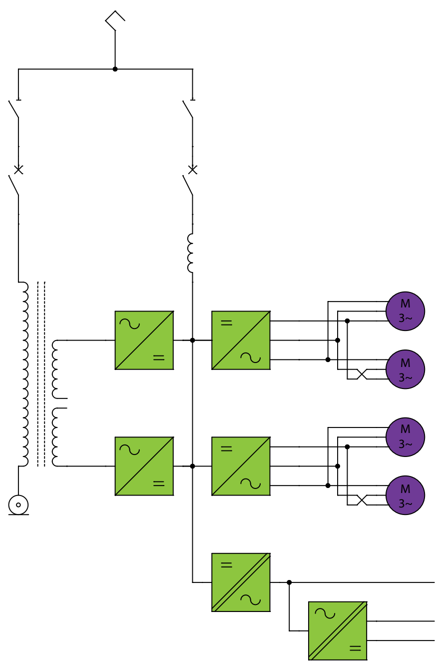
DC powered traction inverters



AC powered traction inverters



DC&AC Multi-system
traction inverters



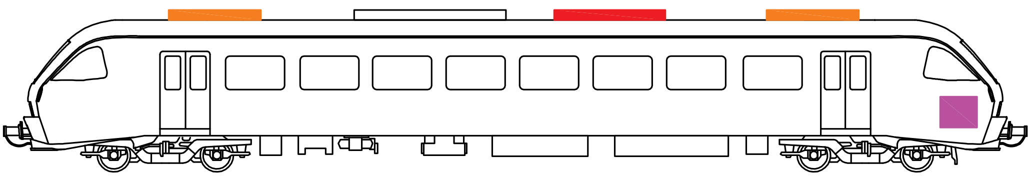
Public transport vehicles

Our scope of supply for public transport vehicles

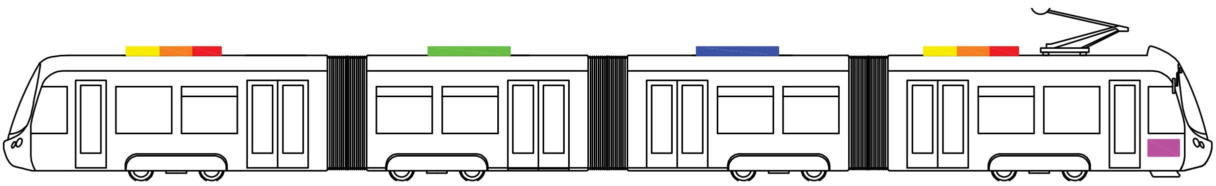
Legend:

- Auxiliary Converters
- Traction Inverters
- TCMS
- Battery Chargers
- Supercapacitors-based Energy Storage Systems
- Fuel Cell Converters

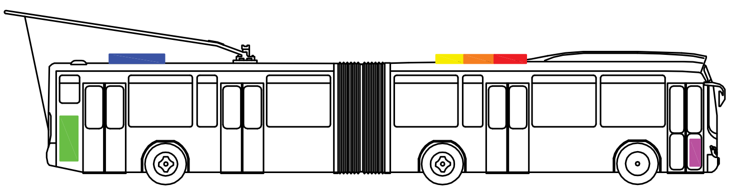
DMUs: Auxiliary Converters, Traction Inverters, TCMS



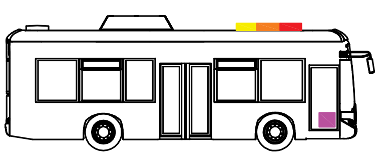
LRVs: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters



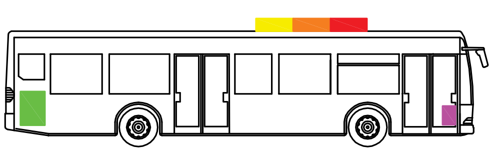
Trolleybuses: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters



Electric buses: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers

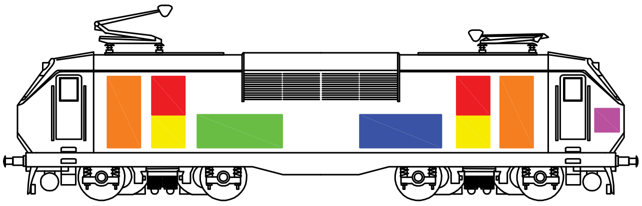


Fuel cell buses: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters

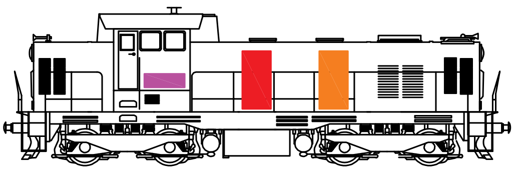


Public transport vehicles

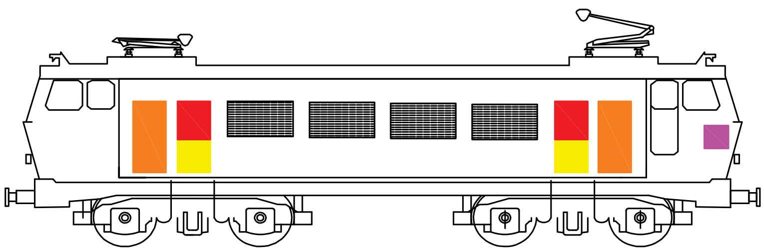
Hybrid electric locomotives: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters



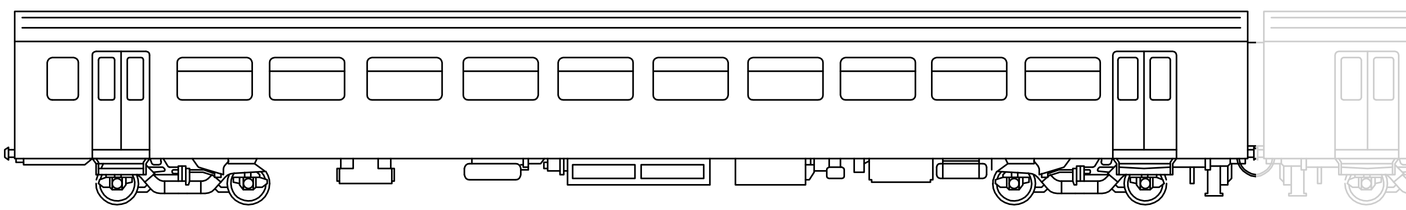
Diesel locomotives: Auxiliary Converters, Traction Inverters, TCMS



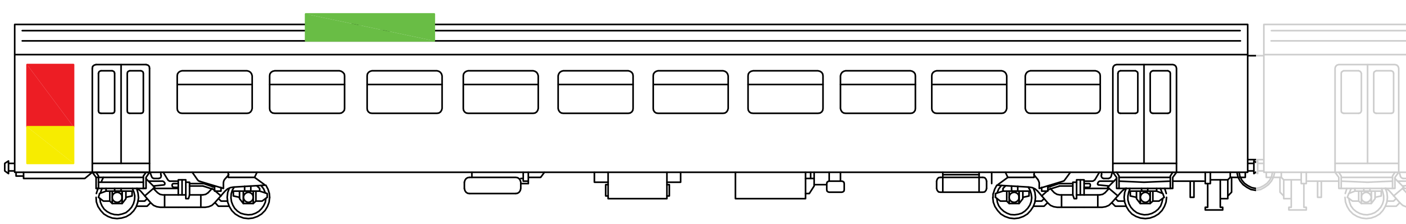
Electric locomotives: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems



EMUs Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters



EMUs Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems, Fuel Cell Converters

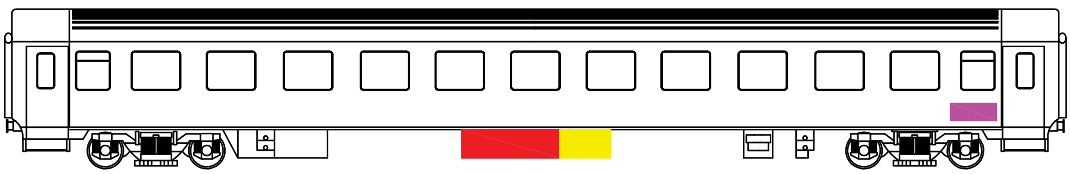


Public transport vehicles

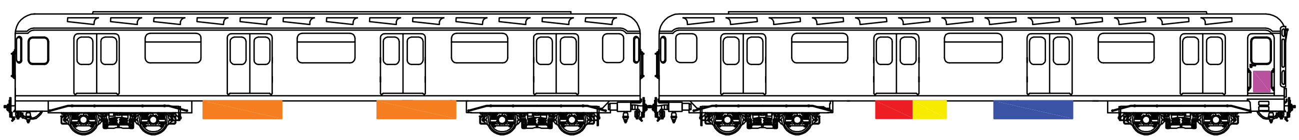
Legend:

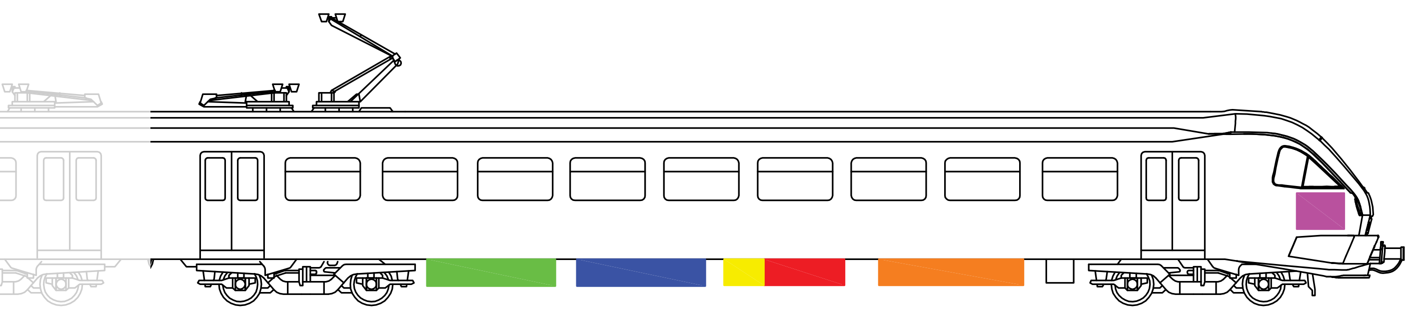
- Auxiliary Converters
- Traction Inverters
- TCMS
- Battery Chargers
- Supercapacitors-based Energy Storage Systems
- Fuel Cell Converters

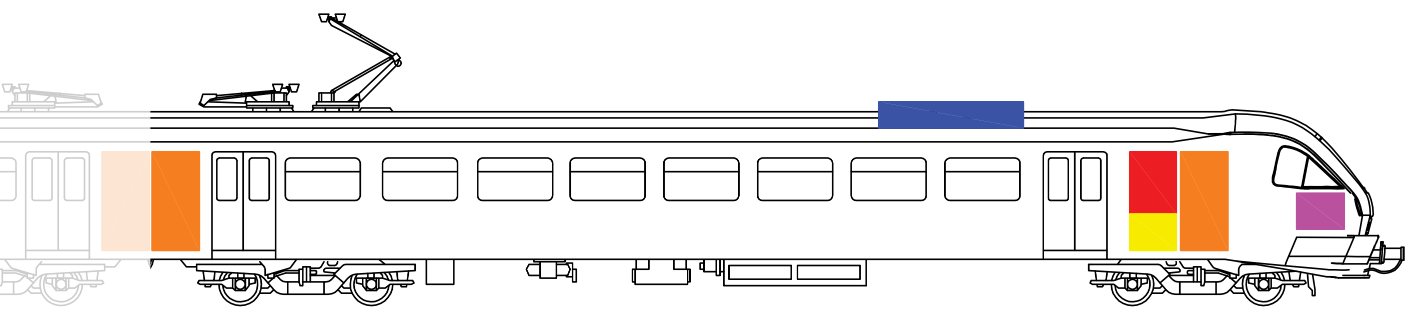
Passenger coaches: Auxiliary Converters, TCMS, Battery Chargers



Metro cars: Auxiliary Converters, Traction Inverters, TCMS, Battery Chargers, Supercapacitors-based Energy Storage Systems







TECHNICAL EXPERTISE

SiC TECHNOLOGY

In railway applications, where low weight, small size, and high efficiency are critical, the new SiC technology is changing the game.

Features of the new components include:
- far greater junction temperature limits
- very high switching speed
- low saturation voltage

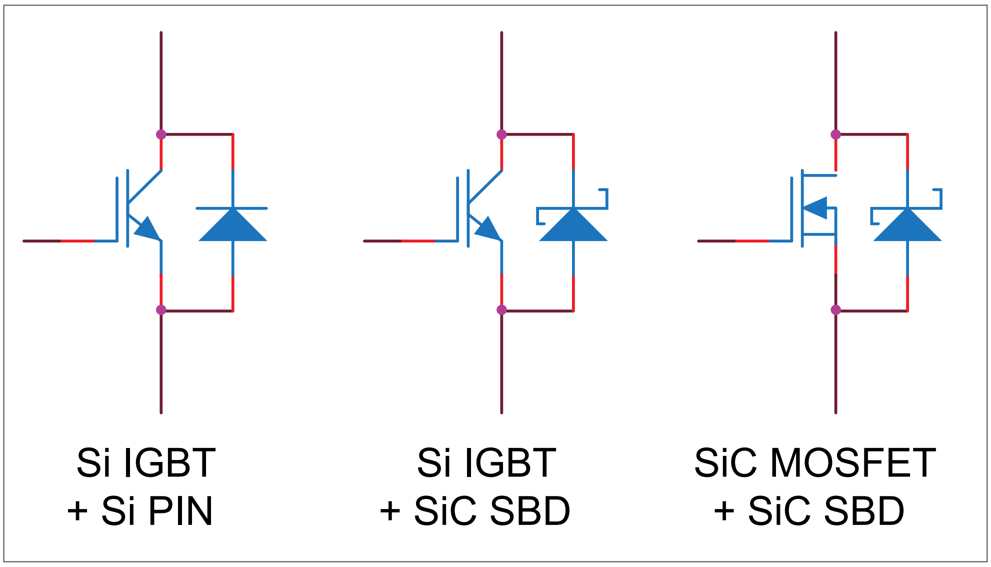
High energy efficiency and increasing the working frequency of the converter will make it possible to minimize the size of the cooling system and reduce energy consumption.

The use of the SiC technology in propulsion drives increases the efficiency of the converter by 1÷1.5%. Simultaneously, higher working frequency reduces losses in the traction motor, significantly lowering the cost of the energy consumed by the vehicle.

Auxiliary converters using the SiC technology are a new quality. The reduction of weight and size is very significant (50%). Higher switching frequency reduces the size of magnetic components (80%), and higher converter efficiency minimizes the size of the cooling system. The overall efficiency of the converter is extremely high (94÷96%).

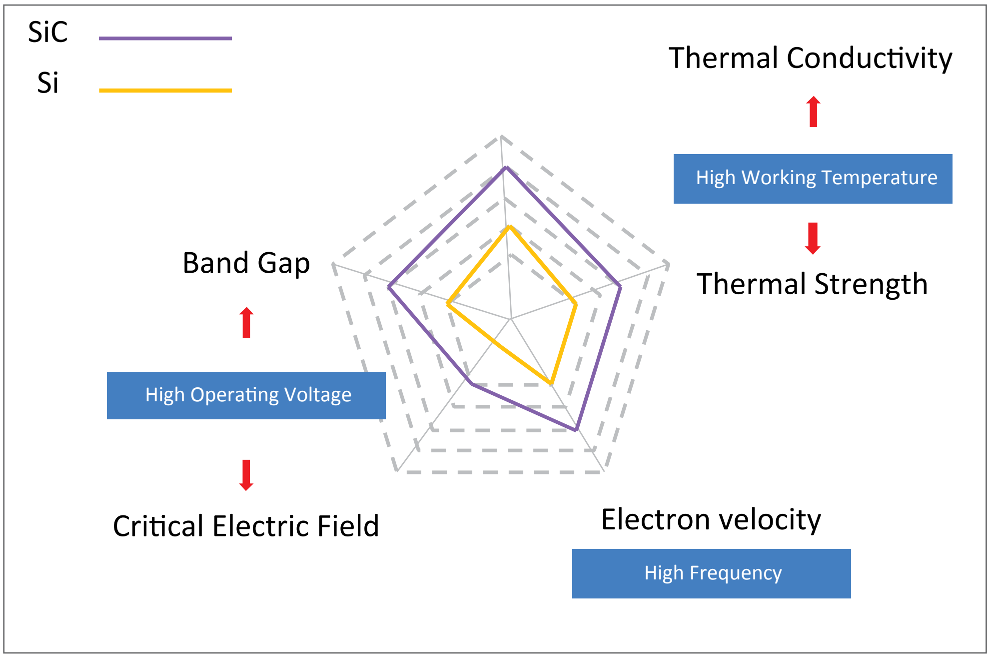
Currently, three types of SiC power components are available for use in traction converters:
- **Hybrid IGBT modules (Si IGBTs + SiC diode)**
- **MOSFET modules (SiC MOSFET + SiC diode)**
- **Schottky Diodes**

Currently (2016), commercially available SiC components make it possible to design and manufacture propulsion systems with the power of up to 500 kW (without parallel connection of modules) and static auxiliary converters with the output power of up to 200 kW.



TECHNICAL EXPERTISE

Comparison of semiconductor materials



New possibilities of SiC technology comparing to silicon devices

	Si	vs.	SiC
Band gap	1.1 eV		3.3 eV
Critical Electric Field	300 kVcm^{-1}		2 000 kVcm^{-1}
Electron Velocity	Low		High
Thermal Conductivity	150 W/mK		490 W/mK

High Speed of Switching
High Working Temperature
High Voltage

Advantages of SiC technology → **Change of designs** → **New possibilities**

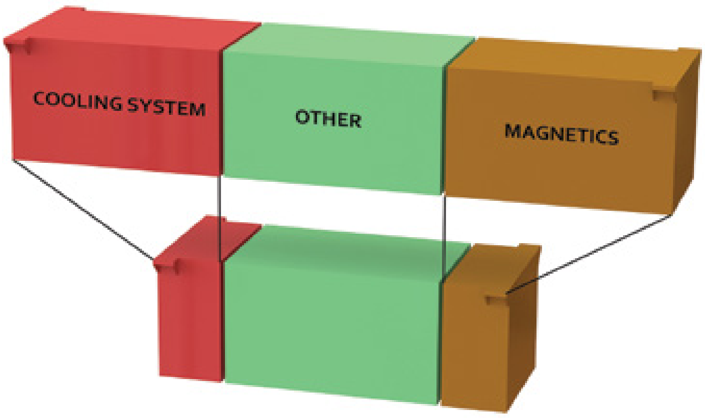
Advantages of SiC technology:
- Higher operating temperatures
- Lower swithing loss
- Higher swithing frequency

Change of designs:
- Smaller heatsinks
- Smaller magnetic components
- Smaller cooling system

New possibilities:
- Reduction of size
- Reduction of weight
- High efficiency and power density

TECHNICAL EXPERTISE

SiC auxiliary converter



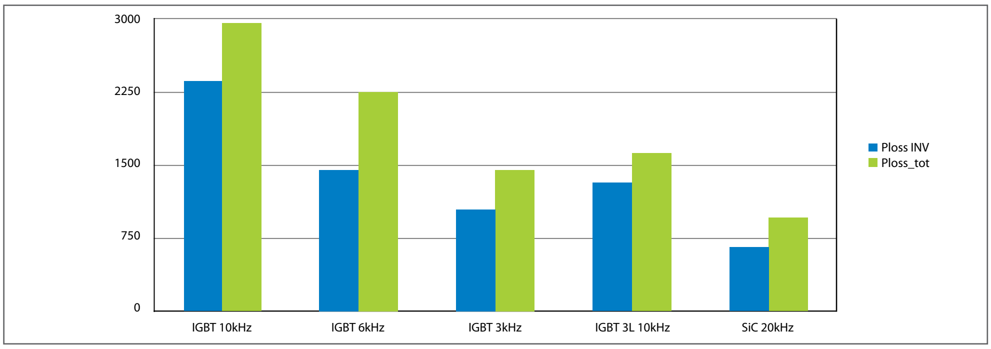
Weight reduction (45%)
Higher switching frequency decreases the size of the magnetic components, reduces losses,simplifies the cooling system and decreases the size of the heatsink and fan.

Energy consumption reduction (5%)
Higher efficiency of the converter and a smaller cooling system.

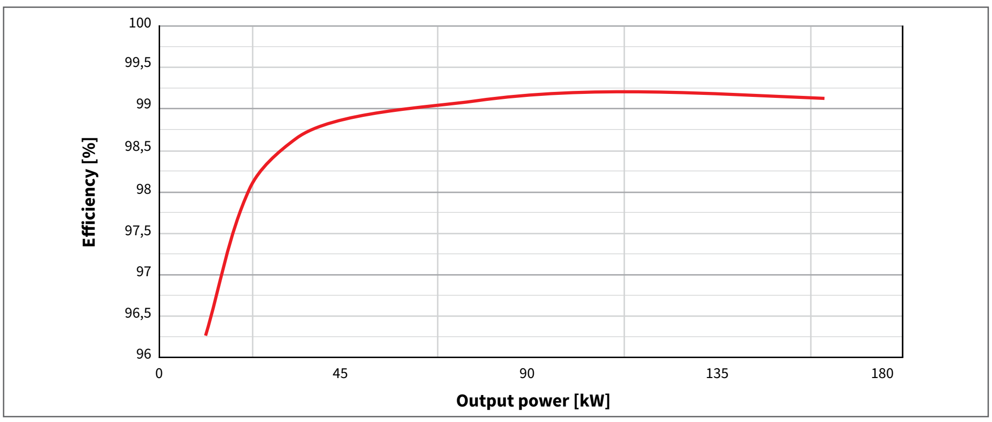
Noise reduction
Converter working with a frequency higher than 20kHz which is outside hearing range, a smaller cooling system additionally reduces noise.

Dimension reduction
Smaller heatsink and smaller magnetics.

120 kVA Inverter losses including sinusoidal filter

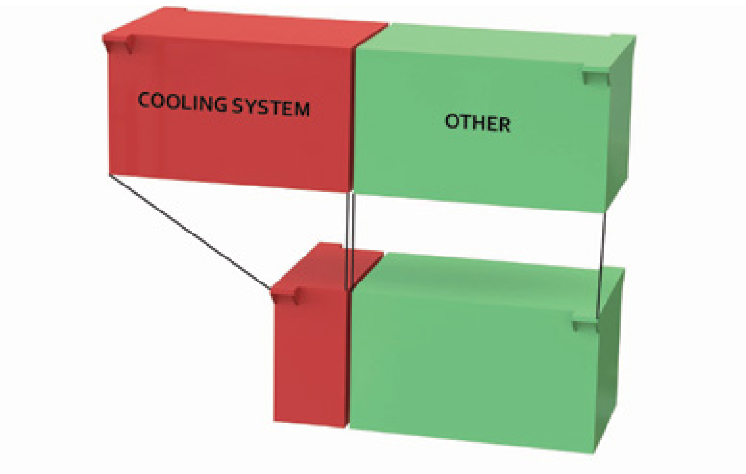


Efficiency of a 175 kVA propulsion inverter with a sinusoidal filter



TECHNICAL EXPERTISE

SiC propulsion inverter



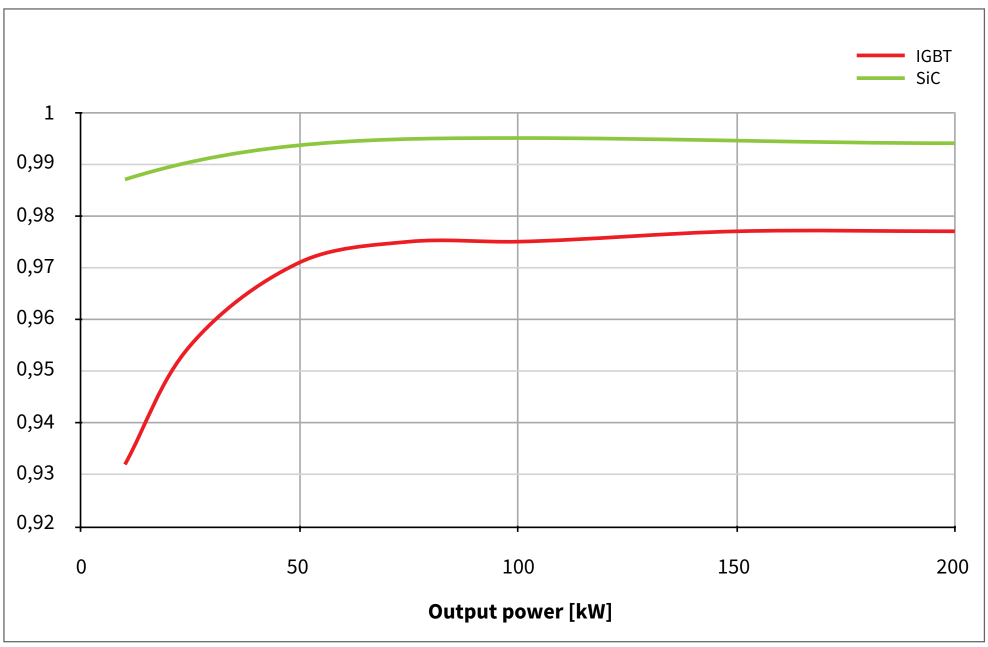
Energy consumption reduction (10%)
Efficiency of the converter and higher PWM frequency decrease energy losses in the inverter and motor. Energy regeneration is also higher. In battery powered vehicles, range is significantly increased.

Weight reduction (30%)
Smaller cooling system significantly decreases the weight.

Noise reduction
Smaller cooling system and smaller ripple in the motor current decrease noise.

Dimension reduction
Smaller cooling system significantly decreases the size.

Efficiency of the propulsion inverter for eBuses



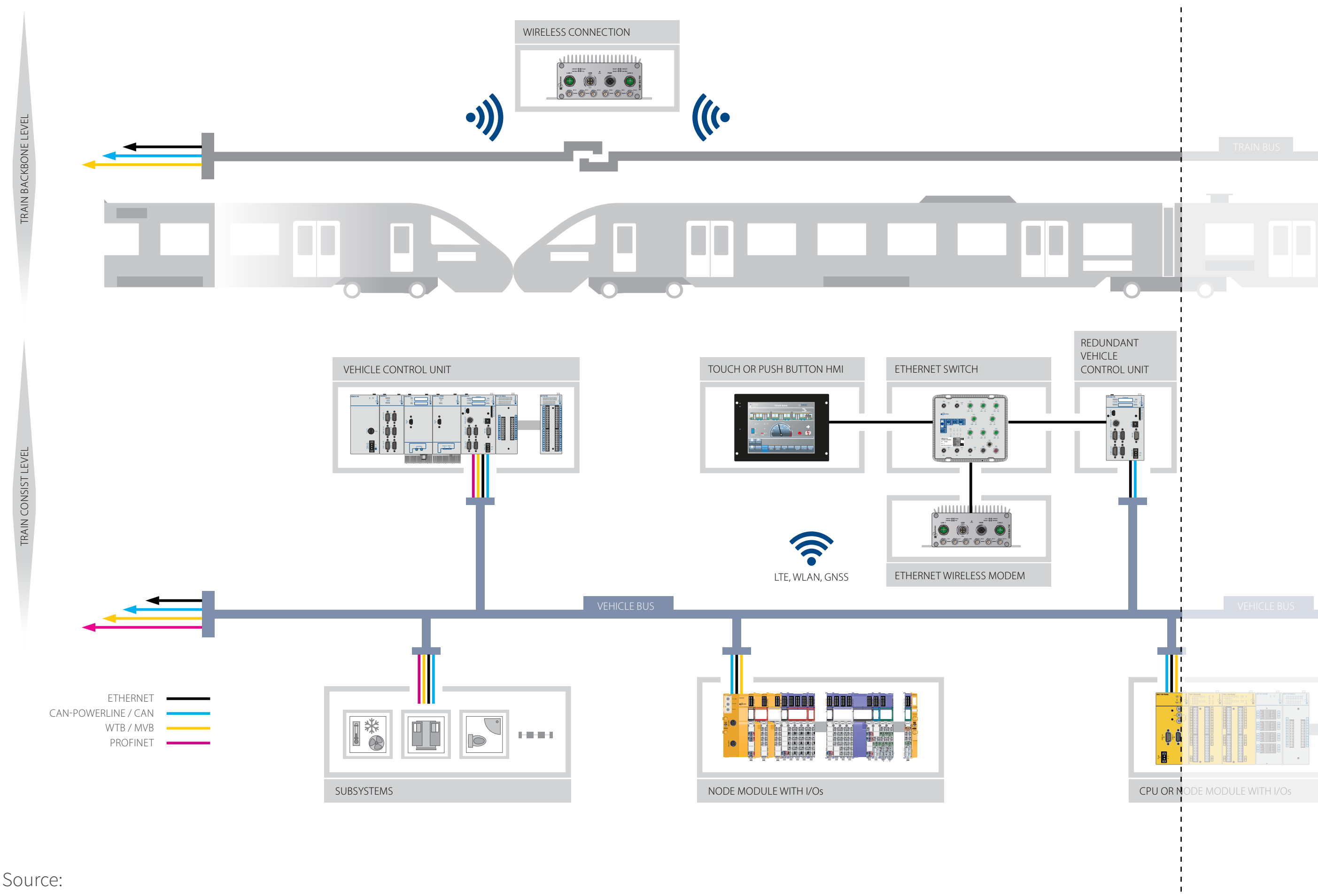
TECHNICAL EXPERTISE

TCMS SYSTEMS

TCMS - Train Control and Monitoring System – this system is used in rail vehicles to integrate the most important and most critical vehicle systems to reduce costs, increase system performance and provide redundancy. TCMS designed and delivered by MEDCOM is fully compatible with the baSiC safety (e.g. EN 50128) and environmental (EN 50155) standards, covering four main functions: communication management, traction and propulsion system, other systems, diagnostics and fault management. TCMS is used for a range of Rail Vehicles:

- **EMUs - Electric Multiple Units**
- **DMUs - Diesel Multiple Units;**
- **Locomotives;**
- **Passenger vehiclees;**
- **Metros;**
- **Trams/LRVs.**

Internal and external communication of the TCMS is the most critical issue. MEDCOM is developing a communication standard compliant e.g. with IEC 61375 standards.
Internal communication ensures safety, easy maintenance and reduced costs. In order to achieve the above objectives, we use CAN bus, MVB and Ethernet. In addition, MEDCOM implements projects that meet the requirements of SIL-2 (Safety Integration Level).

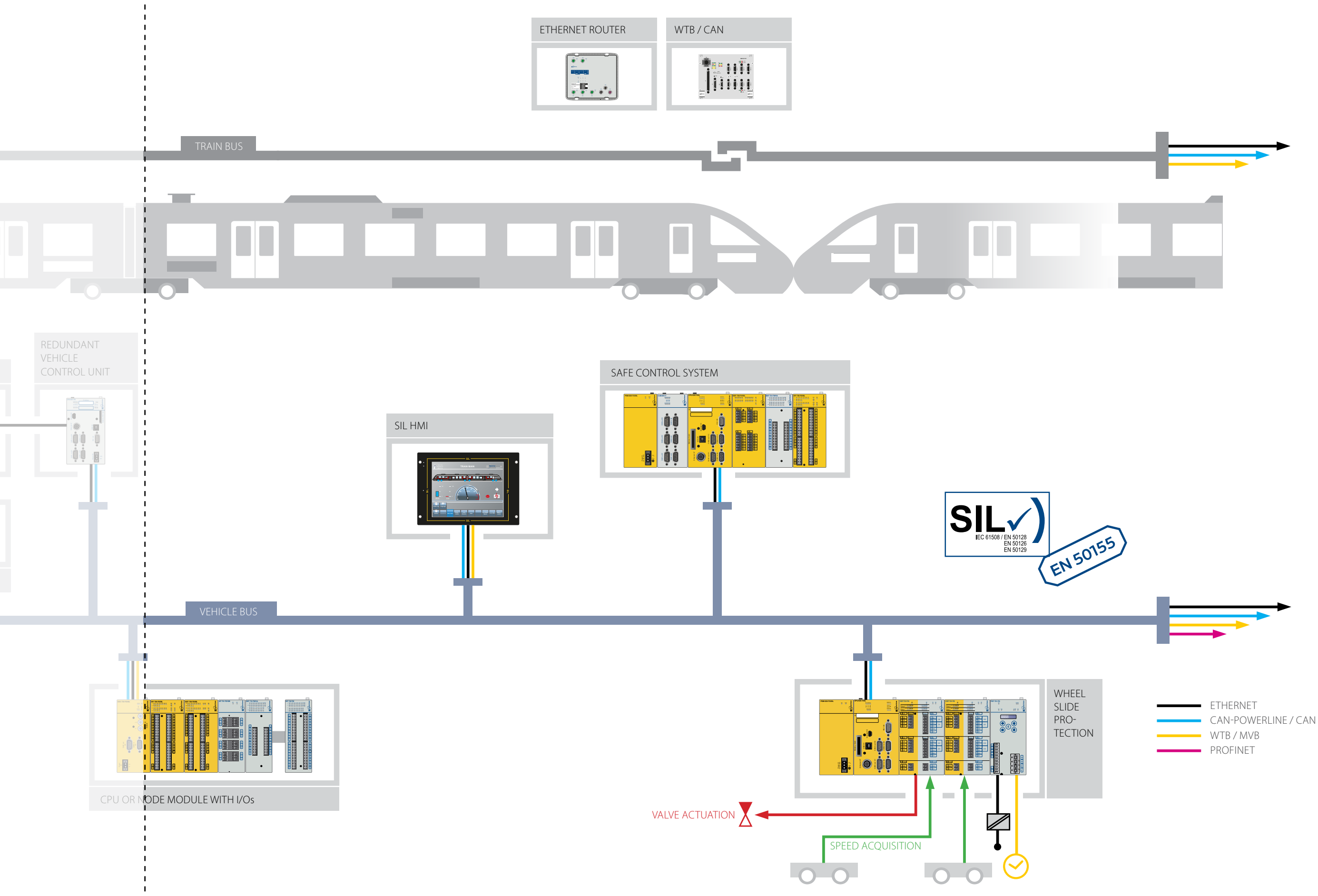


Source:

Knorr-Bremse Group Selectron

TECHNICAL EXPERTISE

CAN bus (Controller Area Network) has been very popular in the automotive industry for the last 15 years and it is currently used in rail vehicles. CANopen described in DS 301 standard has become a common data transmission protocol. It provides data transfer between the central computer, individual control panel drivers, propulsion system/braking systems, HVAC (Heating, Ventilation, Air Conditioning), indoor and outdoor lighting.



TECHNICAL EXPERTISE

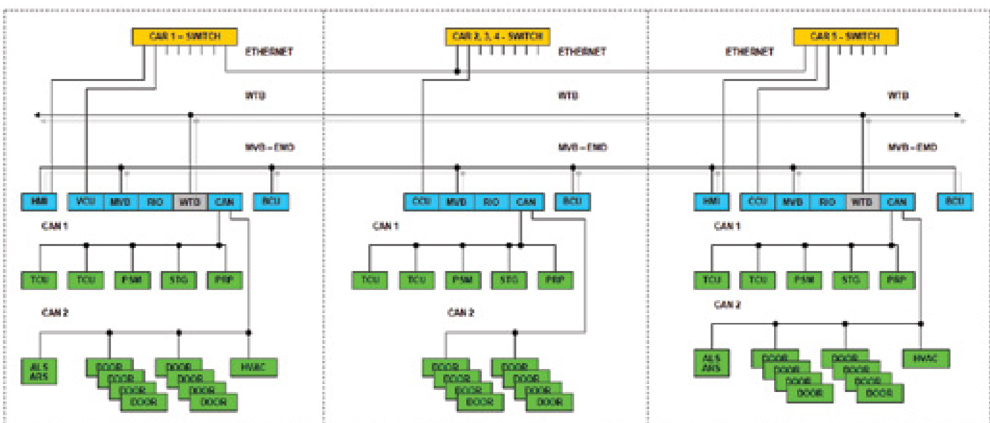
MVB (Multifunction Vehicle Bus) is a widely used communication standard for rail vehicles. There are three classes of media used: OGF based on fibre optics, EMD for line lengths up to 200 m and ESD for line lengths up to 20 m. The bus has a relatively large capacity, while the transmission speed is 1.5 Mbit/s. The base period of data transmission for MVB is 1 ms or 2 ms and their multiplicity. This bus has a unique feature of a built-in mechanism for data transmission redundancy.

Ethernet bus provides broadband Ethernet data transmission with rates up to rates of 100 Mbit/s, 1Gbit/s and it is used for the diagnostic operations that require processing a large amount of data. The bus may be used for control processes with the ETB (Train Ethernet Backbone).

The external communication is operated by the WTB (Wire Train Bus) and Ethernet. Another alternative may be CAN Powerline. Wire Train Bus (WTB) has been widely used for the last 20 years, allowing its users to connect multiple traction units and passenger vehiclees in an open layout. Its unique feature is the inauguration, which provides automatic identification and numbering compliant to the TCN (Train Communication Network) and UN 556 standard. In addition, the WTB has a built-in mechanism, which ensures data transmission redundancy. The maximum line length is 860 m, the number of nodes is 32, and the maximum number of vehicles is 22 with bus speed of 1 Mbit/s. The base period for data transmission of WTB is 25 ms and its multiplicity.

In the area of traction and propulsion systems, MEDCOM develops interfaces and algorithms for the following modules in accordance with generally accepted standards:

- Control and monitoring of all high-voltage modules, including pantographs, disconnectors, fast-acting circuit breakers, residual current detectors, harmonic current detectors, emergency disconnectors;
- Control and monitoring of the propulsion system, inverters with regard to driving directions and slIP& slide features;
- Braking system with blending feature - i.e. combining electro-pneumatic and electrodynamic brake, magnetic brake, automatic brake, parking brake and some functions of a safety loop;
- Sand blasting and cleaning functions for rolling wheels;
- Main and auxiliary air compressors, pressure monitoring in the main and supply line.



ETHERNET - Ethernet BUS
SWITCH - Ethernet Switch

WTB - Train BUS (for future development)
MVB-EMD - Vehicle BUS
VCU - Vehicle Control Unit
HMI - Human Machine Interface
CCU - Car Control Units
RIO - Remote I/O, Analog Inputs, Digital Inputs/Outputs
BCU - Brake Control Unit

CAN - Car BUS
TCU - Traction Control Units
PSM - Power Converter
STG - AntiSlid Controller
PRP - Differential Current Controller
ALS ARS - Automatic Train Control
DOOR - Door System
HVAC - Heating ventilation Air Condition
Control System

TCMS provides functional interfaces for other systems of rail vehicles, including:

- Propulsion Inverters Control and Monitoring
- PSM Auxiliary Power Auxiliary converters with battery charging and servicing systems, their connection to external power sources controlled by the TCMS, energy meters;

TECHNICAL EXPERTISE

- Control of the doors, including the green loop;
- Heating, ventilation and air conditioning (HVAC) - including the function of advanced integration level;
- Systems for indoor and outdoor lighting;
- Passenger Information System (PIS) features and many others.

HMI (Human Machine Interface) and desktop provide the driver and operator with the necessary control, information and diagnostic functions:

- Integration of the driver's desk according to EUDD (European Driver Desk) with an integrated propulsion controller and braking;
- Diagnostics and fault management, including the driver's panel with Technical and Diagnostic Display (TDD);
- Communication with a GSM module, including the preventive features and real-time data exchange with the operations centre;
- Integration with ETCS, including the driver's panel (Command Control Display);
- Advanced system of automatic speed control;
- Data Logger with GPS;
- Monitoring and diagnostics of fire-prevention system.

MEDCOM focuses in particular on compliance with the UN 612 standard.
TCMS is a key element of the architecture of rail vehicles and is often regarded as "the "brain of the train". It is crucial for achieving the required performance in terms of integration and maintenance costs, improving RAMS and reducing LCC factor.

Advantages of the offered system:

Scalability
The system allows the user to easily extend and modify it during the project implementation by adding and exchanging modules to meet additional criteria and requirements.

Efficient configuration and commissioning
System configuration and all works are implemented using high-level languages according to IEC 61131.

Modular design
The system allows the use of multiple modules and interfaces and easy modification during the project implementation.

Computing power
The system is based on microprocessors, which provide short time of computing cycle.

TECHNICAL EXPERTISE

MTBF of redundant systems

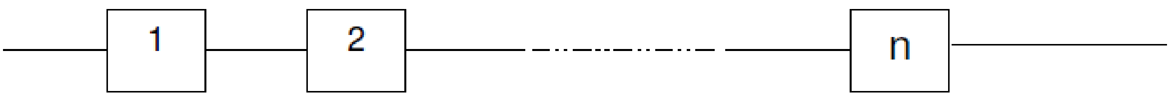
Reliability Characteristics for Repairable Subsystems in Series or Parallel or n Subsystems in m_out_of_n Arrangement

(based on: Lin Don. L. Reliability Characteristics for Two Subsystems in Series or Parallel or n Subsystems in m_out_of_n Arrangement. Tech Rep, Aurora Consulting Engineering LLC)

1 Introduction

Redundancy is a common approach to improve the reliability and availability of a system. Adding redundancy increases the cost and complexity of a system design and with the high reliability of modern electrical and mechanical components, many applications do not need redundancy in order to be successful. However, if the cost of failure is high enough, redundancy may be an attractive option. This information provides a basic background into the types of redundancy that can be built into a system and explains how to calculate the effect of redundancy on system reliability - for reliability of two subsystems in series or in parallel, the case of system consisting of n identical subsystems in parallel and system is declared as failed if m or more subsystems fail (the m_out_n case).

2 Connection in series - a system consists of two (non-identical) subsystems in series



2.1 System Failure Rate

For just one subsystem, the failure rate is λ_1. The probability of failure in dt is $\lambda_1$dt. For two subsystems in series, the probability of failure in dt is ($\lambda_1$dt + $\lambda_2$dt). The system failure rate is ($\lambda_1 + \lambda_2$).

$\lambda_{series} = \lambda_1 + \lambda_2$

The reliability function is $R(t)=\exp[-(\lambda_1 + \lambda_2)t]$.

2.2 System MTBF

From the exponential form of the reliability function, it is formula:

$$MTBF_{series}=1/(\lambda_1 + \lambda_2)=\frac{MTBF_1 \cdot MTBF_2}{MTBF_1 + MTBF_2}$$

2.3 System Availability and unavailability

For the system to be available, each subsystem should be available:

$$A_{series} = A_1 \cdot A_2$$

Conversely, the unavailability is:

$$UA_{series} = 1 - A_{series} = 1 - (1 - UA_1) \cdot (1 - UA_2) = UA_1 + UA_2 - UA_1 \cdot UA_2$$

2.4 System Mean Down Time for Repairable subsystems

For two repairable subsystems, one with mean down time MDT_1 and the other MDT_2, the system is in one of the 4 states:

- both subsystems functional,
- only subsystem #1 is non-functional,
- only subsystem #2 is non-functional,
- both subsystems are non-functional.

The last three cases are responsible for the system being non-functional. It is assumed that the 4th case has negligible probability. Given the system is down, the probability that it is because the subsystem #1 is non-functional is $\frac{\lambda_1}{\lambda_1 + \lambda_2}$. Since subsystem #1 needs MDT_1 to repair, the repair time associated with repairing subsystem #1 is then

$$\frac{\lambda_1}{\lambda_1 + \lambda_2} * MDT_1$$

A similar expression is true for subsystem #2. The final formula is:

$$MDT_{series} = \frac{MTBF_1 \cdot MDT_2 + MTBF_2 \cdot MDT_1}{MTBF_1 + MTBF_2}$$

3 Connection is Parallel two repairable subsystems with mean down times MDT_1 and MDT_2.

3.1 System Failure Rate

If the system just consists of subsystem #1, then the system failure rate is λ_1. The probability of failure in dt is $\lambda_1$dt. Adding subsystem #2 in parallel, the probability for system failure in dt is $\lambda_1$dt scaled down by the probability that the subsystem #2 is in the failure state. The probability to find the subsystem #2 in the failure state is given by $\frac{MDT_2}{MTBF_2 + MDT_2}$. Assuming $MDT_2 << MTBF_2$ and using $MTBF_2 = \frac{1}{\lambda_2}$, the scaled down failure rate for subsystem #1 is then given by $\lambda_1 \cdot \lambda_2 \cdot MDT_2$. Likewise, the scaled down failure rate for subsystem #2 is $\lambda_1 \cdot \lambda_2 \cdot MDT_1$. Consequently,

$$\lambda_{parallel} = \lambda_1 \cdot \lambda_2 \cdot (MDT_1 + MDT_2)$$

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3.2 System MTBF

Taking the approach that the inverse of the failure rate is MTBF (true for exponential distribution):

$$MTBF_{parallel}=1/\lambda_{parallel}=\frac{MTBF_1 \cdot MTBF_2}{MDT_1 + MDT_2}$$

Note: if the two subsystems are not repairable, then the MTBF for the parallel case is the sum of the individual MTBF's.

3.3 System Availability and unavailability

For the system to be available, either subsystem should be available.

$$A_{parallel} = A_1 + A_2 - A_1 \cdot A_2$$

The unavailability is:

$$UA_{parallel} = 1 - A_{parallel} = 1 - (A_1 + A_2 - A_1 \cdot A_2) = (1 - A_1) \cdot (1 - A_2) = UA_1 \cdot UA_2 \quad (1)$$

3.4 System Mean Down Time for Repairable subsystems

From the definition:

$$Unavailability = \frac{MDT}{MTBF + MDT} \approx \frac{MDT}{MTBF}$$

the MDT formula for the parallel case by using Eq. (1) above is:

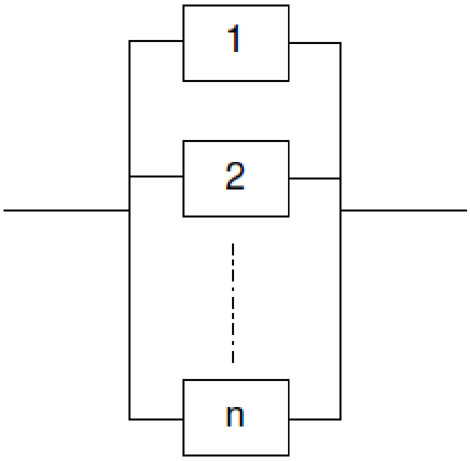
$$UA_{parallel} = \frac{MDT_{parallel}}{MTBF_{parallel}} = \frac{MDT_{parallel}}{\frac{MTBF_1 \cdot MTBF_2}{MDT_1 + MDT_2}}$$

$$UA_1 \cdot UA_2 = \frac{MDT_1}{MTBF_1} \cdot \frac{MDT_2}{MTBF_2}$$

Consequently,

$$MDT_{parallel} = \frac{MDT_1 \cdot MDT_2}{MDT_1 + MDT_2}$$

4 M out of N Parallel Subsystems - n parallel, identical subsystems



4.1 System Failure Rate

If the system just consists of subsystem #1, then the system failure rate is λ. The probability of failure in dt is λdt. To have a system failure, other (m-1) subsystems should be in the failure state. The chance that any one subsystems is in the failure state is given by MDT/(MTBF+MDT), or (MDT/MTBF), if it is assumed MDT<< MTBF.

To find (m-1) subsystems in the failure state, the probability is $(\frac{MDT}{MTBF})^{m-1}$. There are ${}_{n-1}C_{m-1}$ ways to group (m-1) subsystems out of (n-1) subsystems. Any subsystem can be indicated to be the #1 subsystem in the analysis. Taking this into account:

$$\lambda_{m\_out\_of\_n} = \lambda \cdot (\frac{MDT}{MTBF})^{m-1} {}_{n-1}C_{m-1} \cdot n = \frac{n!}{(n-m)!(m-1)!} \lambda^m \cdot MDT^{m-1} \quad (2)$$

This is the failure rate for exactly m subsystem failures. The failure rate for more than m subsystem failures is going to be smaller by a factor of $(\lambda \cdot MDT)$.

For a consistency check, it could be considered n=m=2. This is a system consisting of two parallel, identical subsystems. When m=2 subsystems fail, the system fails. This was Paragraph 2. And Eq.(2) for this case is $\lambda_{system} = \lambda^2 \cdot (2 \cdot MDT)$ which agrees with the formula in Paragraph 2.

4.2 System MTBF

Taking the approach that the inverse of the failure rate is MTBF (true for exponential distribution):

$$MTBF_{m\_out\_of\_n} = 1/\lambda_{m\_out\_of\_n} = \frac{MTBF^m}{\frac{n!}{(n-m)!(m-1)!} \cdot MDT^{m-1}}$$

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4.3 System Availability and unavailability

For the system to be available, at least (n-m+1) subsystems should be available:

$$A_{m\_out\_of\_n} = \sum_{i=n-m+1}^{n} \frac{n!}{(n-i)!\cdot i!} A^i (1-A)^{n-i}$$

Using the formula:

$$1 = [A + (1-A)]^n = \sum_{i=0}^{n} \frac{n!}{(n-i)!\cdot i!} A^i (1-A)^{n-i}$$

the availability could be presented:

$$A_{m\_out\_of\_n} = 1 - \sum_{i=0}^{n-m} \frac{n!}{(n-i)!\cdot i!} A^i (1-A)^{n-i} \approx 1 - \frac{n!}{m!\cdot(n-m)!}(1-A)^m$$

The unavailability is given (for MDT<<MTBF)as follows:

$$UA_{m\_out\_of\_n} = \frac{n!}{m!\cdot(n-m)!} UA^m$$

4.4 System Mean Down Time for Repairable subsystems

From the definition:

$$UA_{m\_out\_of\_n} = \frac{MDT_{m\_out\_of\_n}}{MTBF_{m\_out\_of\_n}}$$

the MDT for the m_out_of_n case by using in points 4.2 and 4.3 for $UA_{m\_out\_of\_n}$ and $MTBF_{m\_out\_of\_n}$:

$$MDT_{m\_out\_of\_n} = \frac{MDT}{m}$$

5 All Formulas in One Table

	Two subsystems In Series (λ is failure rate)	**Two subsystems In Parallel**	**n identical subsystems in parallel; system fails if m or more subsystems fail. (m_out_of_n)**
System Failure Rate	$\lambda_{series} = \lambda_1 + \lambda_2$	$\lambda_{parallel} = \lambda_1 \cdot \lambda_2 \cdot (MDT_1 + MDT_2)$	$\lambda_{m\_out\_of\_n} = \frac{n!}{(n-m)!(m-1)!} \lambda^m \cdot MDT^{m-1}$
System MTBF	$MTBF_{series} = \frac{MTBF_1 \cdot MTBF_2}{MTBF_1 + MTBF_2}$	$MTBF_{parallel} = \frac{MTBF_1 \cdot MTBF_2}{MDT_1 + MDT_2}$	$MTBF_{m\_out\_of\_n} = \frac{MTBF^m}{\frac{n!}{(n-m)! \cdot (m-1)!} \cdot MDT^{m-1}}$
System Availability (A)	$A_{series} = A_1 \cdot A_2$	$A_{parallel} = A_1 + A_2 - A_1 \cdot A_2$	$A_{m\_out\_of\_n} = 1 - \frac{n!}{m! \cdot (n-m)!}(1-A)^m$
System Unavailability (UA)	$UA_{series} = UA_1 + UA_2 - UA_1 \cdot UA_2$	$UA_{parallel} = UA_1 \cdot UA_2$	$UA_{m\_out\_of\_n} = \frac{n!}{m! \cdot (n-m)!} UA^m$
System Mean Down Time (MDT)	$MDT_{series} = \frac{MTBF_1 \cdot MDT_2 + MTBF_2 \cdot MDT_1}{MTBF_1 + MTBF_2}$	$MDT_{parallel} = \frac{MDT_1 \cdot MDT_2}{MDT_1 + MDT_2}$	$MDT_{m\_out\_of\_n} = \frac{MDT}{m}$

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Condition-based maintenance

Many complex systems, in different engineering application fields (e.g. aerospace, aeronautic, naval, railway, etc.), work in specific environmental conditions for which it is required to be compliant with specific requirements of usability, reliability, safety, and maintainability. In particular, regarding these requirements, the target of the maintainability is to maximize the lifetime of the systems produced with the minimum global cost (Life Cost Cycle). Based on this consideration, the maintenance of a system becomes a strategic element for the economic competitiveness of the infrastructure operators . Indeed, in order to have a system of high complexity that properly operates, without interruptions, it is necessary to sustain its usage by a constant maintenance activity. The “traditional” approach to the maintenance is typically intended as repair. However, it is possible to evolve this approach through actions such as the prevention and the continuous improvement of the maintenance process focused on the system lifecycle (Fig. 1) [1, 4].

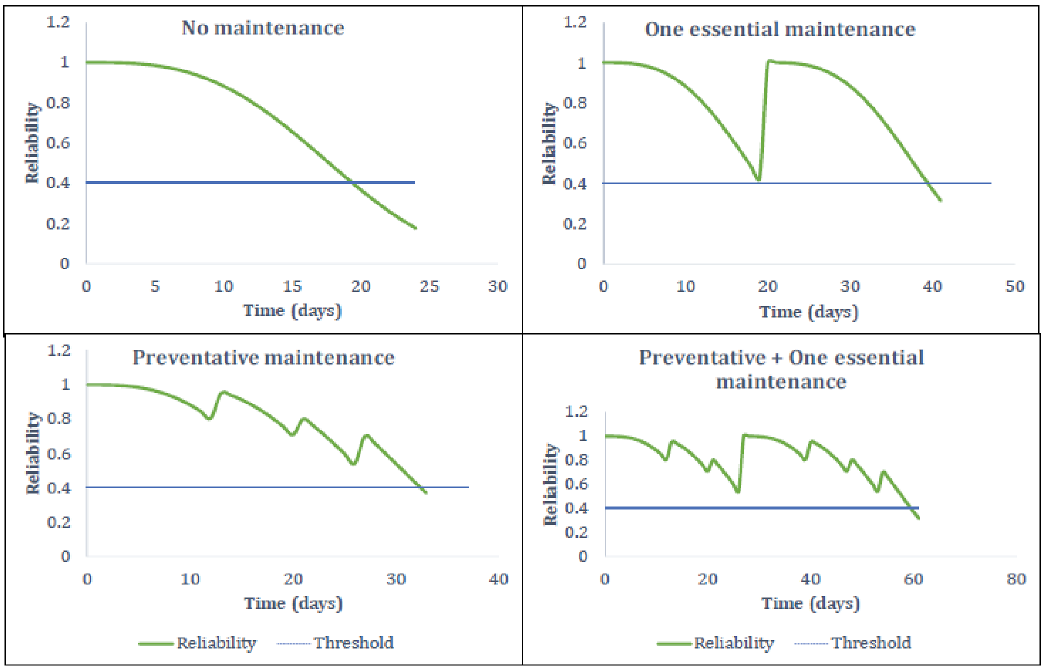

Fig. 1. Engineering Maintenance [4]

Predictive Maintenance - condition-based maintenance [1]

Another approach is represented by the condition-based maintenance as a method to reduce the uncertainty of maintenance activities. These activities will be performed according to the needs indicated by the results of system status monitoring (condition-monitoring). The predictive condition-based maintenance uses, therefore, the results of condition-monitoring and, according to these, plans the maintenance actions. The goal of condition-monitoring is to delete the failures and extend the preventive maintenance intervals. The condition-based maintenance assumes that the existence of indicative prognostic parameters can be identified and used to quantify potential system failures before they occur. The prognostic parameters provide an indication of potential problems and new issues that may cause the deviation of the system from its acceptable level of functioning. The condition-based fault diagnosis is triggered by the detection of an evaluated condition of the system, such as the deviation from the expected level, recognizes and analyzes symptomatic information, identifies the causes of the malfunction, obtains the development trend of the fault and predicts the remaining useful life of the system (Remaining Useful Life – RUL).

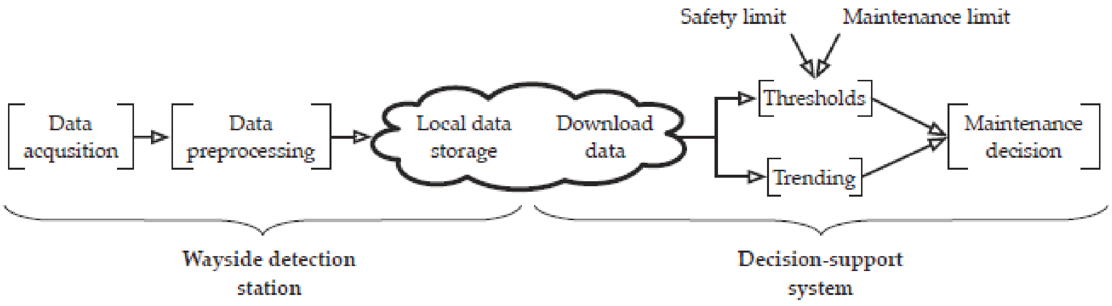

Figure 2: Illustration of condition monitoring data to decision [3]

In order to obtain a fully automated system for condition-monitoring, new analysis techniques need to be used, such as Artificial Intelligence, able to handle large amounts of data, Neural Networks, Motivation Case-Based and Fuzzy Logic. Equipped with this such predictive skill, the diagnostic system becomes more reliable. Once a component has been identified as the cause of a new failure, the function devoted to prediction of the development trend of the fault can be activated to compute the remaining life time. Furthermore, a scheduled action of corrective maintenance can be appropriately performed before a possible irreversible damage of the system occurs. A maintenance in advance can be performed in order to avoid an excessive supply of replacement parts. Therefore, the implementation of an automated condition-monitoring process provides a better and timely determination of the maintenance interventions, which will result in a decrease of the life cost of the system, thanks to an increment of its availability and to a reduction of operations and maintenance costs.

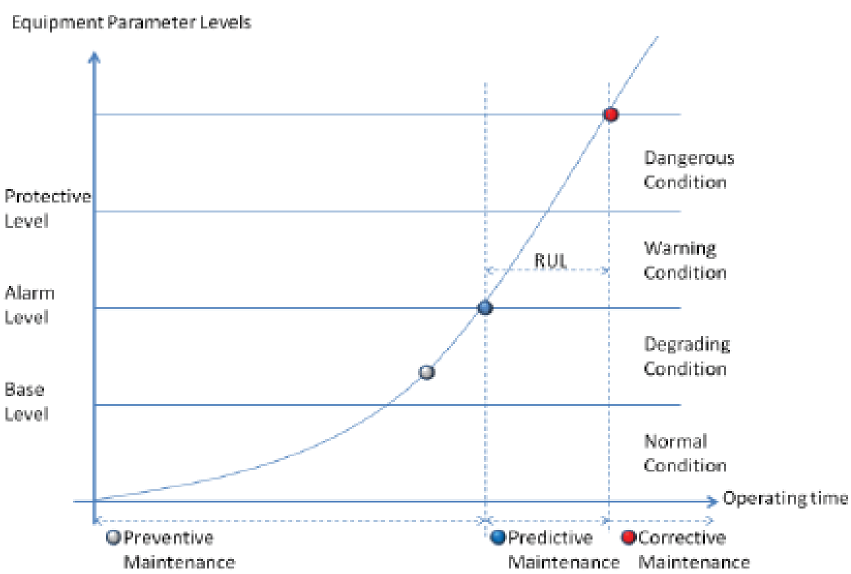

Fig. 3 Management of maintenance activities through a Predictive Decision Support System (RUL=Remaining Useful Life) [1]

The principal benefits of implementing CBM include [2]:

1. Expensive and labour-intensive routine maintenance activities arer educed and maintenance scheduling can be improved. This is due to a greater understanding of the operating characteristics of plant items through trending, and quicker assessment of equipment condition
2. CBM allows preventive measures to be taken before costly breakdowns occur, allowing a reduction in unscheduled downtime
3. CBM can increase reliability of systems through remote inspection and assessment

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4. Energy savings can be achieved through improved operating conditions of equipment
5. Equipment life can be extended by preventing degradation of internal components
6. Equipment sub-components can be tested before handover in the commissioning process.

The proposed/implemented solution divides the condition-based maintenance system in seven different levels, all interconnected (Fig. 4).

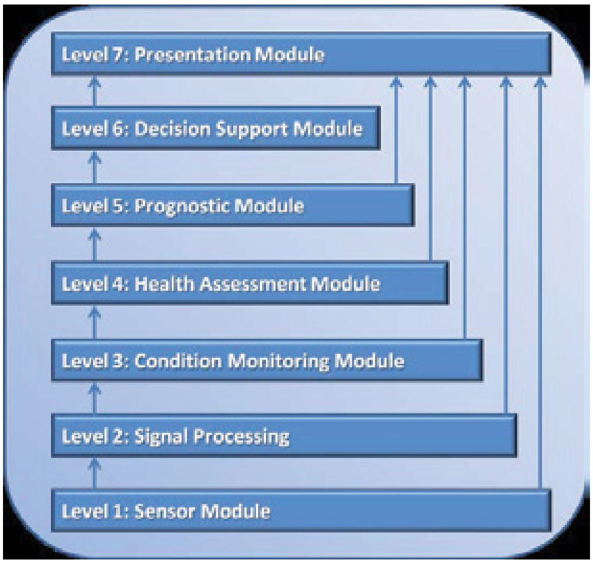

Fig. 4 CBM Architecture [1]

Level 1 Sensor Module. It provides sensors that return digitalized results or transducers that return data.

Level 2: Signal Processing. The module receives signals and data from the sensor module or other modules of signal processing. The output of signal processing module includes sensor-data digitally filtered, frequency spectrum, signals of virtual sensor and other features related to the condition-based maintenance.

Level 3 Condition Monitor. The condition-monitor level receives data from sensor modules, signal processing modules and other condition-monitor modules. The main goal of this level is to compare data with their expected values. The condition-monitor level shall be also able to generate alerts based on operational limits previously set. This latter can be a very useful function during development of rapid failures.

Level 4: Health Assessment. The module devoted to the assessment of the "status of health" receives data from different condition-monitor modules or other modules of assessment of the system conditions. The main goal of the condition assessment module is to determine if the condition of the monitored component/subsystem/system is degraded. The evaluation module shall be able to generate diagnostic recordings and propose failure estimation. The diagnosis shall be based on trends of the health status history, on operating status, workload and maintenance history.

Level 5: Prognostics. The prognostic module shall be able to take into account data from all the previous levels. The main goal of the prognostic module is to compute the future health status of an asset, taking into account its future profile of usage. The module will report the future health status at a specified time or, alternatively, the remaining useful lifetime.

Level 6: Decision Support. The decision support module receives data from the module of health status evaluation and the prognostic module. Its main goal is to generate the recommended actions and the alternatives ones. Actions may be of maintenance type but also related to how to run an asset until the current mission is completed without the occurrence of breakage.

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Level 7: Presentation. The presentation module must show the data coming from all the previous modules. The most important levels of which present the data are those related to Health Assessment, Prognostic and Decision Support, as well as the alarms generated by the condition-monitor modules. The presentation module can also have the opportunity to look further downwards and can be inserted also into a machine-interface.

CBM method evaluation [2]:

***	Highly effective method, can detect the severity, location and rate of degradation
**	Has a high detection ability, but may have a limited ability to evaluate severity and rate of degradation
*	Can detect fault, but can not evaluate severity and rate of degradation

	CBM method	Faults indicated	Effectiveness
	Electrical		
Circuit breakers	Power quality	High crest-factors	***
Cables	Power quality	Harmonic current	***
Electrical	Thermography	Faulty switchgear, undersized conductors	***
Transformers	Power quality	Harmonic current	***
	Wear & oil analysis	Fluid leakage	*
		Contamination	***
Variable speed drives	Power quality	High frequency noise	***
UPS	Power quality	Low-crest factor	***
Standby generators	Wear & oil analysis	Fluid leakage	*
Motors	Acoustic emissions	Bearing degradation	***
	Power quality	Harmonic voltage	***
	Vibration	Stator & armature damage	**
		Coupling damage	**
	Thermography	Bearing degradation	*

However, although each of these CBM techniques can identify that there is a problem within the equipment, the accuracy of predicting the severity and precise location of the problem varies from technique to technique. All the CBM techniques have the potential to improve the effectiveness of the maintenance regime, regardless of the type used. Understanding and using the strengths of each CBM method will allow an effective CBM strategy to be implemented with possible using a combination of techniques.

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