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High Speed Train Propulsion & TCMS Design Production Project

Active Front End Module Design

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Figure 1. shows the main block diagram of propulsion system. The propulsion and auxiliary systems consist of three types of converter boxes, namely Auxiliary Converter and Battery Charger Box (AB box), Propulsion Converter and Auxiliary Converter box (PA box), Propulsion and High voltage box (PH box), and Active Front End Module (AFEM).

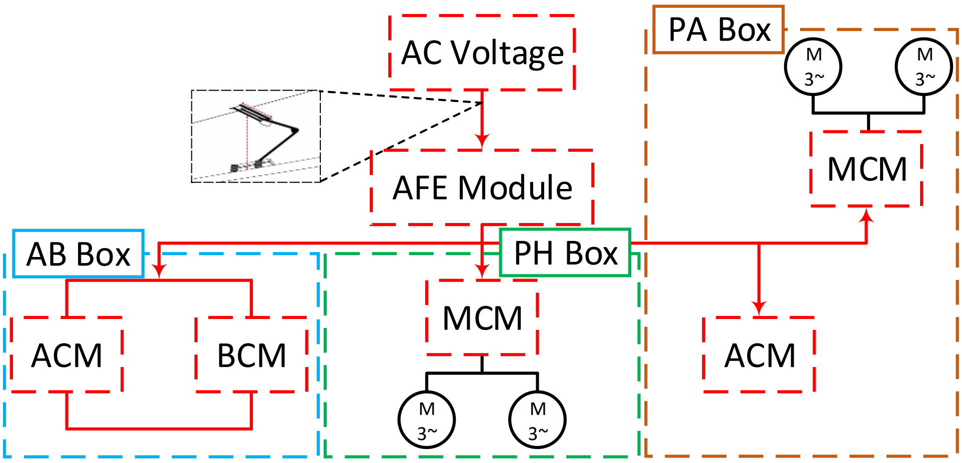


Figure 1. The main block diagram of propulsion system.

1.1. Purpose of this document

The purpose of this document is to give a brief description about Active Front End Module (AFEM). The document contains general information about the product and its components and both the function and the design of the product are described.

The document is intended to be read as an introduction to the product, by both management and maintenance personnel.

1.2. Acronyms and abbreviations

The acronyms and abbreviations used in this document are listed in the below table.

Table 1. List of abbreviations and acronyms

AB	Auxiliary converter and Battery charger box
PA	Propulsion / Auxiliary box
PH	Propulsion / high voltage box
MCM	Motor converter module
BCM	Battery charger module
AFEM	Active Front End Module
ACM	Auxiliary Converter Module
CCU	Communication controller unit
DCU	Drive control unit
DSP	Digital signal processor
FPGA	Field programmable gate array
GDU	Gate drive unit
IGBT	Insulated gate bipolar transistor
I/O	Input/ Output unit LED
LED	Light emitting diode
MCU	Micro controller unit
MVB	Multifunctional vehicle bus
OVP	Overvoltage protection
PSU	Power supply unit
VCU	Vehicle control unit
PWM	Pulse width modulation
SVM	Space vector

2. AFEM box Overview

The single diagram of AFEM is shown in Figure 2. AFEM converts AC voltage into DC voltage in order to fed the propulsion and auxiliary systems. The input voltage of AFEM is 850 V AC, which should be converted to 1500 V DC with less than ± 2.5 %.

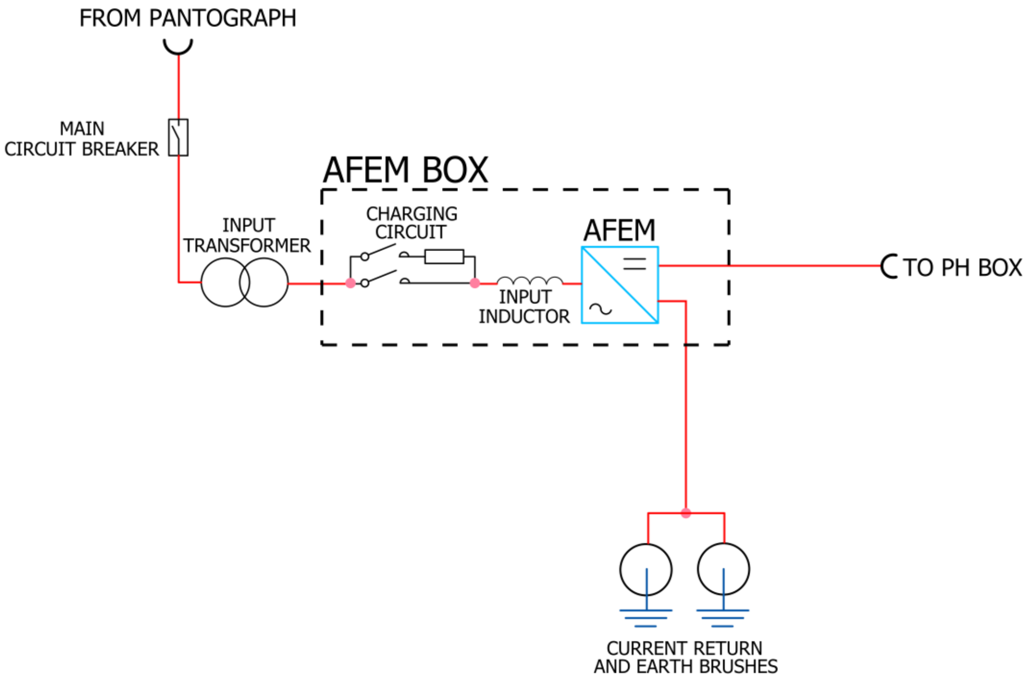


Figure 2. Single diagram of AFEM.

3. Active Front End Module (AFEM)

3.1. General product description

3.1.1. Product introduction

The main function of AFEM is to convert AC link voltage to DC voltage, which supplies other box in the propulsion and auxiliary systems.

Electrically, the system consists of the following main subsystems:

- DC link capacitor. Stabilizes the input DC voltage.
- One-phase converter. Converts the input AC voltage into controlled DC voltage.

- Overvoltage chopper. Protects the converter module from voltage transients. All systems are supervised and controlled by an internal computer.

Mechanically, the system consists of following parts:

- power section and electronic unit.
- control section with the computers and power supplies.
- capacitor section.

3.1.2. Software function

This document also describes how the following functions are handled in the DCU software:

- Line trip
- Neutral sections
- Fault handling

3.1.3. Illustration

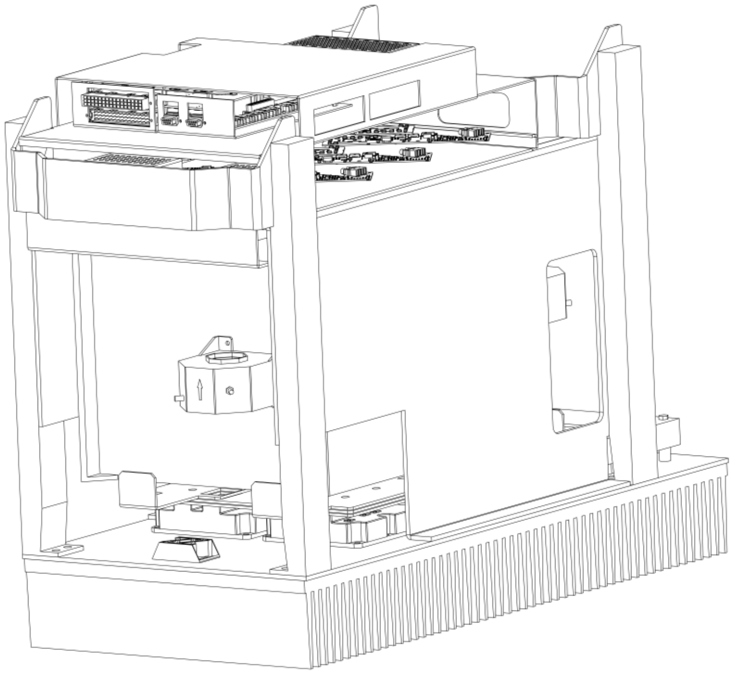


Figure 3. Active Front End Module (AFEM)

3.2. Functional description

3.2.1. Main circuit

The figure below shows an overview of the main circuit and components in the converter module.

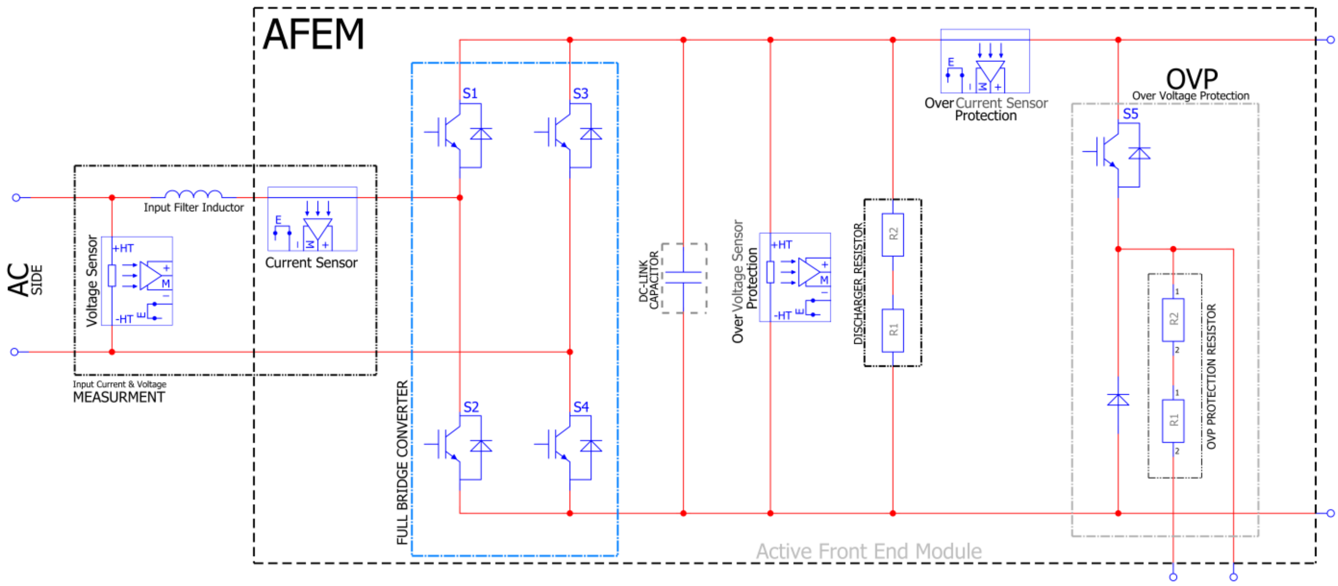


Figure 4. Block diagram of Active Front End Module (AFEM)

The Active Front End Module (AFEM) is based on IGBT technology and employs one phase. The IGBTs and freewheeling diodes located in each phase convert input AC voltage into the controlled DC link voltage by switching on and off. The produced DC voltage feeds the propulsion and auxiliary systems, namely Auxiliary Converter and Battery Charger Box (AB box), Propulsion Converter and Auxiliary Converter box (PA box), and Propulsion and High voltage box (PH box).

Gate drive units (GDUs) control the switching of the IGBTs and communicate with the Drive control unit (DCU).

The DCU monitors signals from sensors for temperature, current and voltage to control the converter module. It also switches the Overvoltage protection (OVP) chopper if the DC link voltage exceeds the defined maximum value.

The DCU, GDUs and the sensors are powered by a low voltage power supply unit.

3.2.2. DC link filter

- **DC link capacitor**

The DC link capacitor is an energy buffer. The capacitor filters and stabilizes the DC link voltage and is sized with sufficient capacitance to keep the voltage ripple in the DC link within permitted limits and enable accurate converter control.

- **Discharge resistor**

There is a discharge resistor connected in parallel with the DC link capacitor.

- **Neutral section**

By using the kinetic energy of the vehicle, it is possible to maintain the voltage across the DC link capacitor during neutral sections.

When a neutral section is detected, the torque reference is momentarily replaced by gentle braking. In braking mode, the one-phase converter has a reversed power flow and power is fed back from the motors to the AC grid. As soon as the supply voltage returns, the original torque is applied.

In this way the converter module does not have to be reactivated after each neutral section.

3.2.3. Converter function

- **Function overview**

The main task of the AFEM is to supply the propulsion and auxiliary system of the vehicle with DC voltage. This is done by converting AC voltage into the controlled DC voltage with high power factor (approximately PF=1), low current harmonic, and low voltage ripple (less than $\pm$2.5%). Since it is possible to control DC voltage with AFEM, the AFEM could boost DC voltage to desired value.

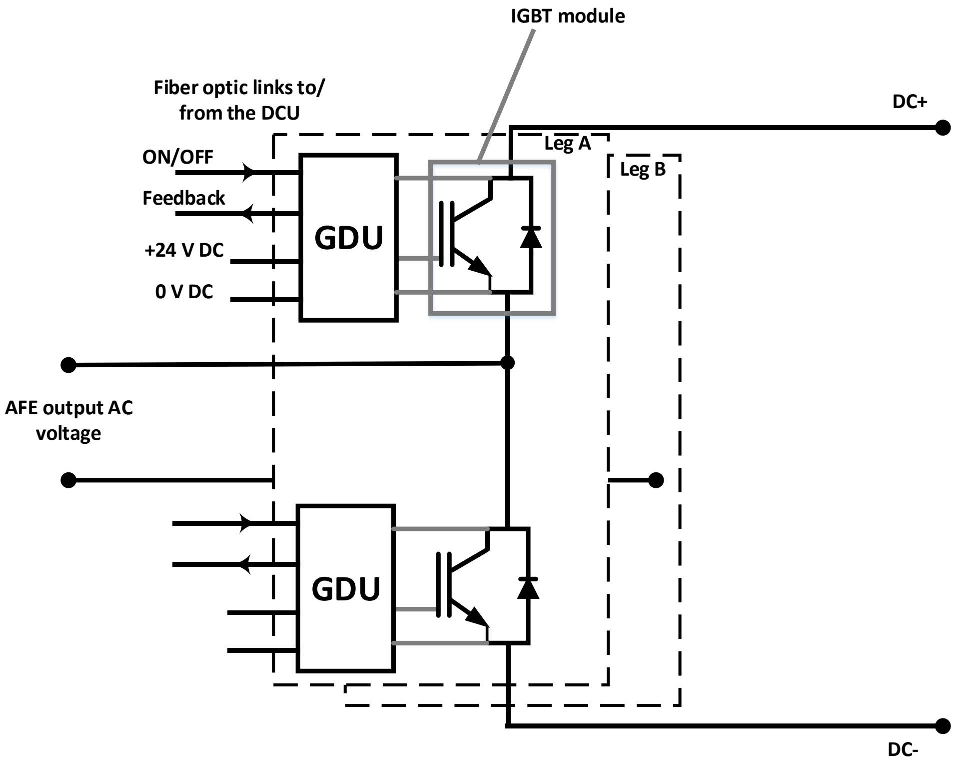


Figure 5. Two identical legs in the Active Front End Module (AFEM)

□ IGBT module

Each phase leg in a converter has two IGBT modules. Each module consists of one IGBT and one anti-parallel freewheeling diode. The IGBT is switched on and off by the GDUs feeding a voltage signal to the gate terminal.

In AFEM, the phase and the amplitude of converter output voltage can be controlled by switching of the IGBTs. So the transmitted active power and reactive power can be controlled between AC side and converter.

□ Gate drive unit

There are two GDUs per phase leg, one for each IGBT. The GDU switches the IGBT on and off, based on orders from the DCU. The GDU can also detect phase leg short circuits and send this information, via optical cables, back to the DCU.

The GDUs are powered with +24V from the low voltage power supply. If the GDU detects a loss of the +24 V power, the converter is immediately blocked.

The switching orders from the DCU are transmitted via optical cables which galvanically separate the high voltage system from the control system.

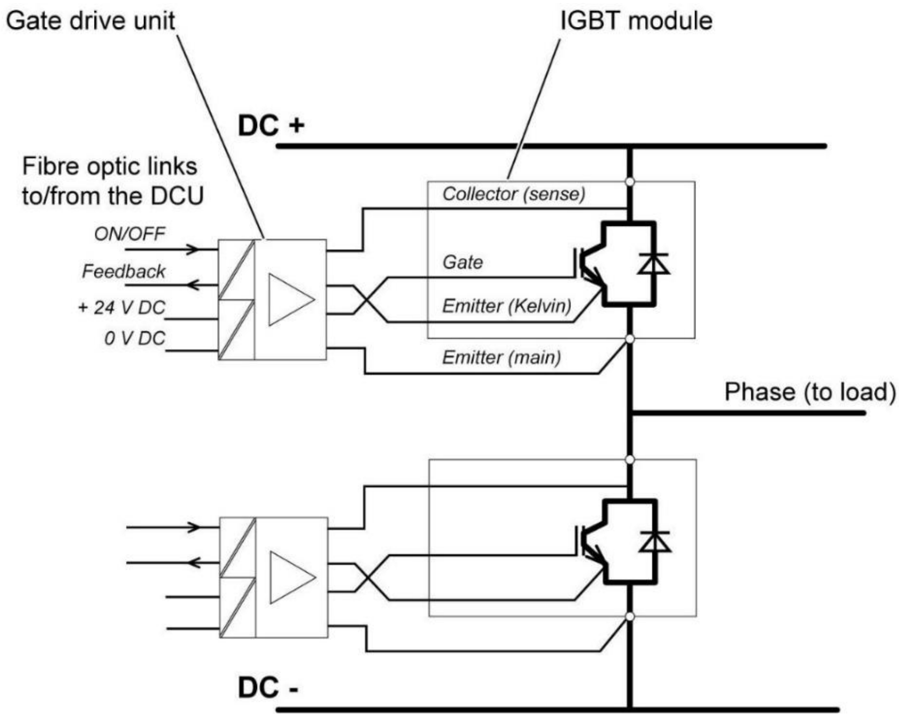


Figure 6. Gate drive unit

3.2.4. Overvoltage protection

- **General**

The overvoltage protection (OVP) unit is connected across the DC link and consists of an overvoltage resistor in series with an IGBT, as shown in the following figure.

The overvoltage protection is dimensioned to handle the appearance of an energy pulse. An example is when the AFEM is connected in parallel and is blocked at full load.

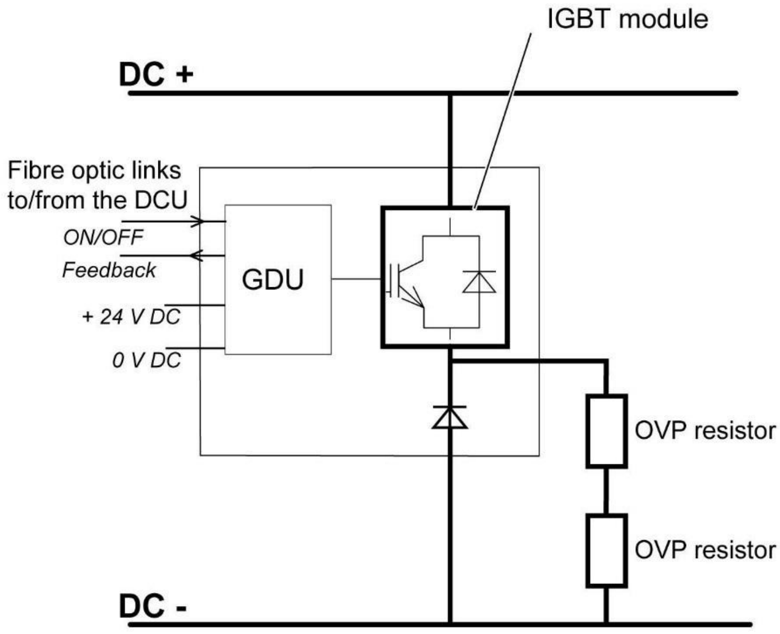


Figure 7. OVP unit block diagram

□ **IGBT module and freewheel diode**

The IGBT module includes an IGBT and two freewheel diodes, one for the IGBT and one for the resistor, which are necessary due to internal inductances.

The function of the IGBT is detailed further in section IGBT module.

□ **Overvoltage protection**

The OVP function is used for suppressing overvoltages and for active discharge of the DC link. If the DC link voltage rises above the OVP turn-on threshold, the OVP chopper is activated to reduce the voltage, in order to protect the converter modules and the other equipment connected to the DC link. The OVP chopper is turned off when the DC link voltage falls below the OVP turn-off threshold.

3.2.5. Computer

□ **Function**

The DCU is a local computer that supervises and controls most of the functions in the converter module. The DCU is both software and hardware. Most of the system controls are programmed in a Micro controller unit (MCU) and a Digital signal processor (DSP). Some important and time critical functions are implemented in the programmable hardware called Field programmable gate array (FPGA).

The DCU in the converter module is a part of the distributed control system in the vehicle. Hence, the converter module is almost independent of external controls and operates with a minimum of input and output signals for the propulsion control.

- **Communications with the vehicle computer**

The following is the most important information that is transmitted between the DCU of the converter module:

- Activation order (in)
- DC link voltage (out)
- AC link voltage (out)
- DC Line current (out)
- Status (out)
- Fault indications (in/out)

- **Optical cables, inputs and outputs**

There is a separate circuit board for the optical cables assembled on the DCU. The cables are used for communicating with the GDUs. The optical board converts voltage-based signals into optical signals (light pulses), transmits them through the cable and at the other end, the signals are converted back to voltage signals.

The optical cables galvanically separate the power circuit from the DCU, thus reducing the electrical interference.

3.2.6. Control and supervision

- **Control areas**

The DCU for the AFEM has the following functions:

- Charging and discharging of the DC link capacitor.
- Temperature measurement.
- Overcurrent protection.

- Earth fault indication.
- Cooling system supervision.
- Test functions.

□ **Charging and discharging of DC link capacitor**

The DCU has standard functions for the control and supervision of the separation and charging contactors. The train control system initiates the converter start-up by sending a command to the DCU. Provided the converter is in normal discharged state, with no active faults and is not blocked, the DCU will start the converter using the separation and charging circuit.

The charging circuit consist of a charging contactor and a charging resistor, connected in parallel with the separation contactor in the AC line.

During normal converter operation, the separation contactors are closed and the charging contactor is open.

During converter start-up the charging circuit is used to connect the AC line to the converter in a controlled manner, using the charging resistor to limit the inrush currents into the DC link. The actual component being charged is the DC link capacitor which is connected between the DC link poles.

When starting DC link charging in the first stage of starting-up, the charging contactor is closed. The separation contactor remains open. Now the DC link capacitor is slowly charged, with current limiting provided by the charging resistor. When the DC link voltage approaches the supply line voltage, the charging contactor is opened and the separation contactor is closed. Then, the second starting-up stage is started in order to increase the DC link voltage from maximum AC line voltage to desired DC voltage.

Normally, a fast DC link discharge is required, using the overvoltage protection chopper. The active discharge is supervised. As a back-up, if the active discharge would fail, the DC link will always be discharged automatically and passively through its discharge resistor.

Before performing any maintenance work inside the converter, the maintenance personnel must follow the proper instructions for checking and discharging the DC link voltage.

- **Overcurrent protection**

The DCU is equipped with a protection from over currents in DC link. DC link overcurrent may occur during DC fault. The protection is based on the current measurements in positive line of DC link and the protective function is implemented in the computer hardware for quick overcurrent responses.

There is also a short circuit detection and protection in the GDUs. The protection can handle both short circuits occurring before switching IGBT ON and short circuits occurring during the IGBT ON-state. This protection is extremely fast and is activated both at short circuits in the power circuit and short circuit to earth.

The short circuit is detected on the IGBT collector-emitter supervision. When the protection is activated, the IGBT is switched OFF.

- **Cooling principle**

The internal fan circulates the internal air inside the converter module, distributing the heat evenly. As a result, the internal cooling system is a closed loop system.

The internal fan starts as soon as the battery power supply is connected to the converter module.

The fan power can be disconnected manually during maintenance.

- **Diagnostics**

The DCU is equipped with extensive diagnostics and fault tracing system to minimize maintenance and down time.

The system has a self-test function of the DCU and fault tracing/diagnostics of the components that can be performed during operation. There are also semi-automatic test functions to be used during maintenance.

To prevent damage to the equipment, some faults will result in deactivation of the converter. Relevant information about the fault is being sent to the VCU.

By connecting a PC to the DCU, it is possible to download data from the internal transient recorder. The data from the recorder can be subject to extensive analysis by the maintenance crew.

3.2.7. Measuring sensors

- **Current sensors**

There are two current sensors in the AFEM in DC side and AC side.

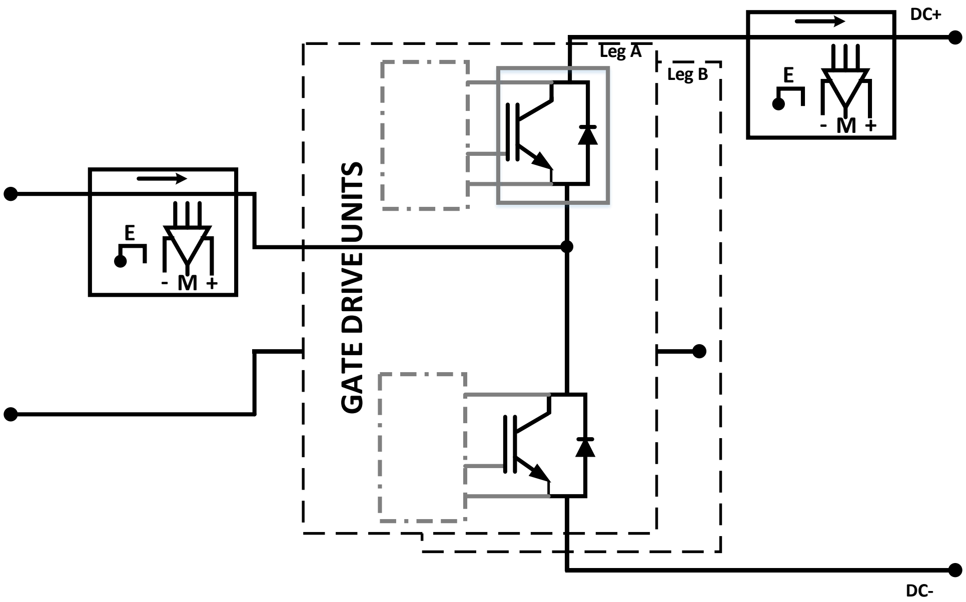


Figure 8. Phase current sensors in the AFEM

All current measuring devices are powered with ±24 V DC from the DCU. The current signals are connected to the analogue inputs on the computer.

High DC components in the phase currents will result in a deactivation of the converter box, in order to eliminate the torque ripple that will otherwise occur in the traction motors.

- **Voltage sensor**

The voltage sensors measure the voltage across the DC link capacitor and AC side. Information about the DC link and AC side voltages is continuously sent to the DCU. The information is used in the converter control algorithm, as well as for triggering protective actions.

□ **Temperature sensors**

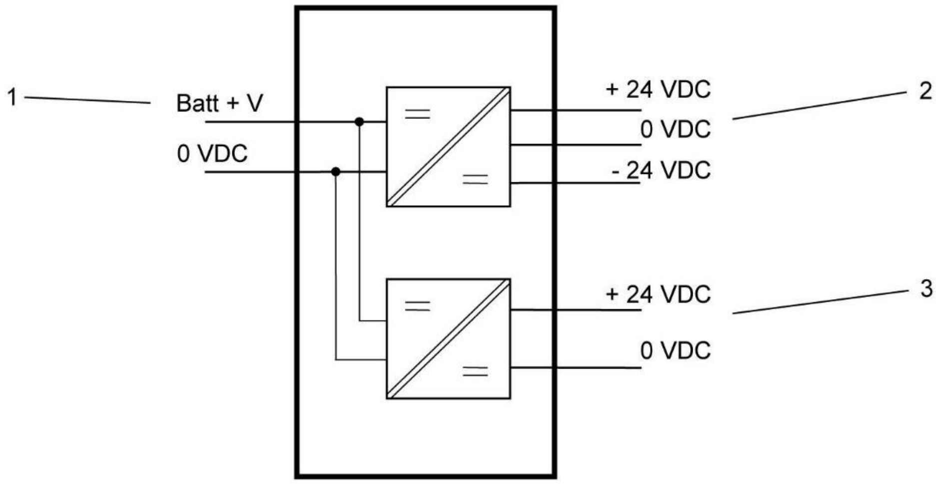
There are two temperature sensors in the converter module, placed in the heat sink area (measuring heat sink temperature) and inside the module (measuring air temperature). They measure the temperature and send a signal to the DCU when they reach a predefined value.

When a certain (higher than normal) temperature is reached, the output power of the converter is limited. If the temperature remains high for a predefined time, a fault is indicated and the converter is deactivated. It will be activated again when the temperature drops.

3.2.8. Low voltage power supply

The power supply has a power input from the vehicle battery voltage.

The input voltage is converted into the mentioned output voltages using a DC/DC converter (part of the PSU) with galvanically separated inputs and outputs. The battery voltage is also used to drive the external contactors.



1 Input battery voltage	2 Power to the DCU and measuring devices
3 Power to the GDUs	

Figure 9. Low voltage power supply

3.3. Product design

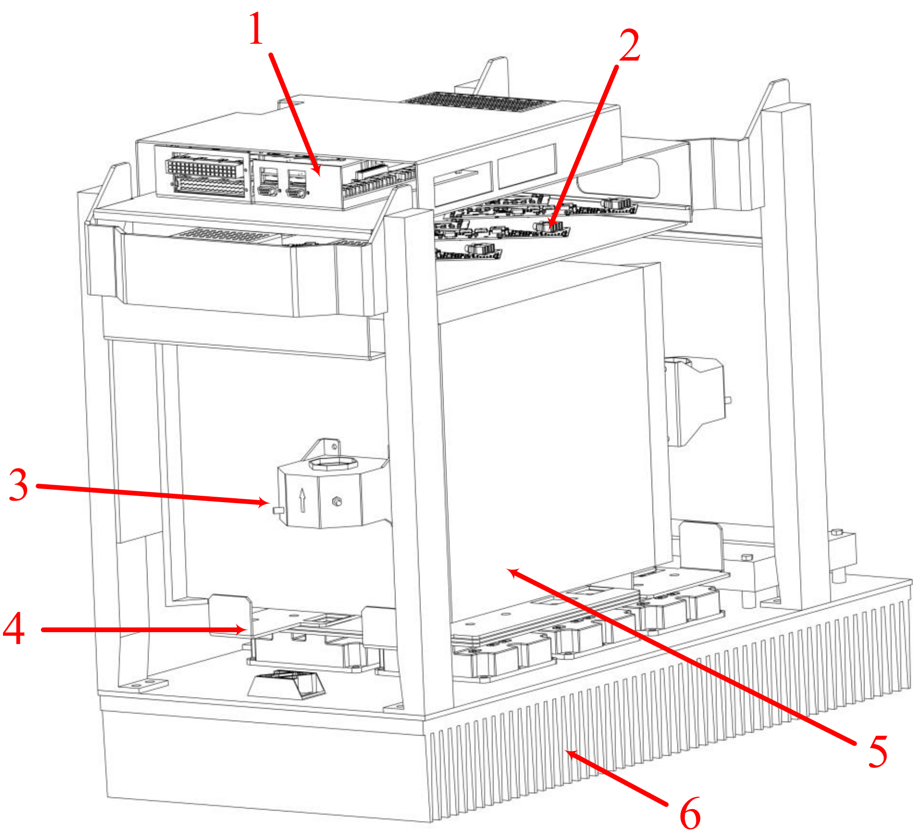
3.3.1. Converter module

The converter module is air cooled and based on IGBT technology. The module is assembled in a converter box, which is located in the undercarriage of the vehicle. The control signals are connected to the module with plug-in connectors. The drive control unit is assembled on top of the module.

The converter module contains the following sub-assemblies:

- DCU assembly
- GDU assembly
- DC terminal assembly
- DC link capacitor
- Power section
- AC terminal assembly

3.3.2. External view



1	DCU assembly	2	GDU assembly
3	Current sensors, AC terminal assembly	4	Power section
5	DC link capacitor	6	Heat sink

Figure 10. Active Front End

3.3.3. DCU assembly

- **Drive control unit (DCU) assembly**

The DCU assembly is located on top of the module and is partly screened to prevent electromagnetic interference between the power circuit and the DCU. The assembly has a non-enclosed design to facilitate cooling.

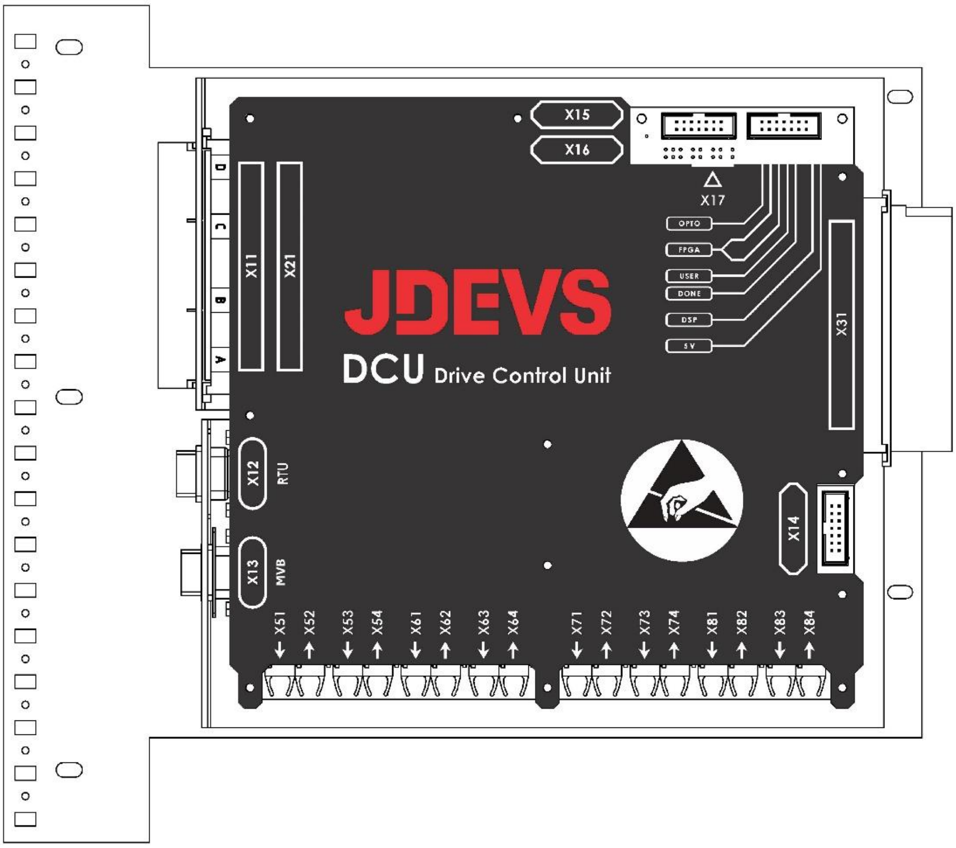


Figure 11. Drive control unit

- **Drive control unit (DCU)**

The DCU is a part of the DCU assembly. It is designed to slide into a connection box and is easily accessible, being fixed on the top of the converter module.

The software in the DCU consists of an operating system and application software. The DCU hardware consists of several printed circuit boards:

- A base board
- An analogue input board
- A power supply board

All optical transmitters and receivers are located on the base board. The DCU is assembled on a metallic base plate, providing both stability and multiple earthing points.

There are separate interfaces for the MVB and DCU test connections.

□ **Power supply unit (PSU)**

he PSU consists of a DC-DC converter.

3.3.4. GDU assembly

□ **Gate drive unit (GDU) assembly**

Figure 12. GDU assembly

□ **Gate drive unit (GDU)**

The gate drive units together with voltage transformer is assembled on a mounting plate, forming the GDU assembly.

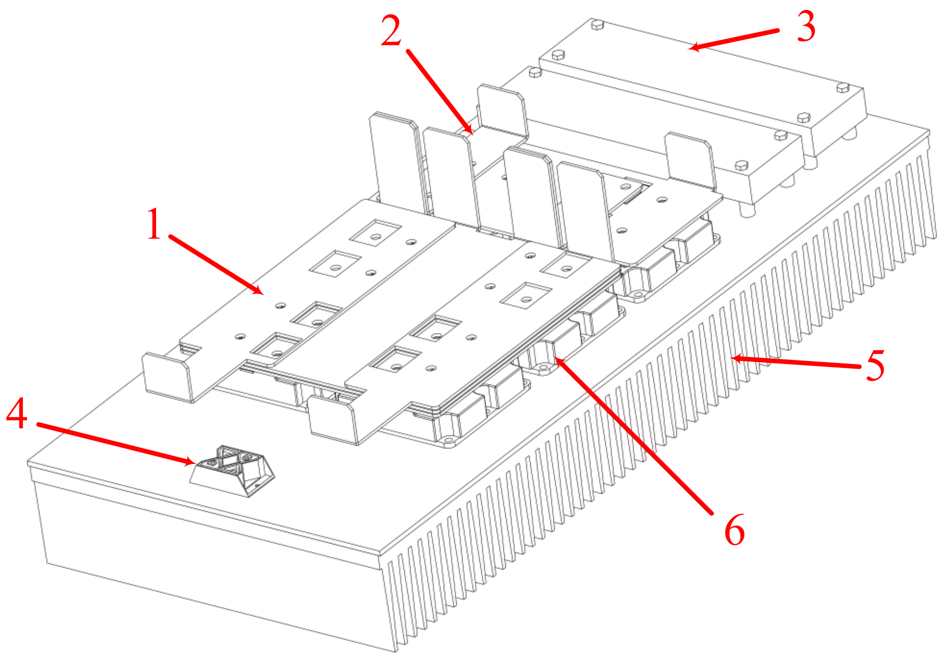
□ **Voltage sensors**

The voltage sensor is assembled in a shielding box on the apparatus plate. The sensor measures the DC link voltage on the DC-plus and DC-minus terminals and AC voltage between AC lines.

3.3.5. Power section

□ **Power section**

The figure below shows the power section.



1	AC laminated busbar	2	DC laminated busbar
3	OPV resistors	4	Discharge resistor
5	Heat sink	6	IGBT module (5 pcs)

Figure 13. Power section

□ **IGBT modules**

The IGBT modules are mounted with screws directly to the heat sink for optimal cooling. Cooling of the IGBTs is a very important factor for their performance.

The base surface of the IGBT is covered with a thermally conductive compound before mounting on the heat sink.

Figure 14. IGBT module

- **OVP resistors**

The two OVP resistors are mounted with screws on the heat sink.

- **Discharging resistor**

The discharging resistor is assembled with screws directly to the heat sink. The resistor is dimensioned to be able to discharge the DC link capacitor to less than 50V within 5 minutes, if the capacitor has not been discharged actively.

3.3.6. DC link capacitor

The DC link capacitor consists of two capacitors connected in parallel, housed in the same enclosure. The capacitor is of the self-healing type with segmented metallization using metallized polypropylene. The capacitor is dry (contains no electrolyte or oil) and is gas insulated (gas pressure 1 bar).

3.3.7. Sensors

- **Temperature sensor**

In the module there are two temperature sensors:

- One on the GDU assembly, measuring the internal air.
- One on the power section, measuring the heat sink temperature.

- **Current sensor**

The (differential) current sensors measure the difference between the incoming DC+ current and the outgoing DC+ current. The sensors are provided with a test coil that could be periodically energized to ensure the sensor is working properly.

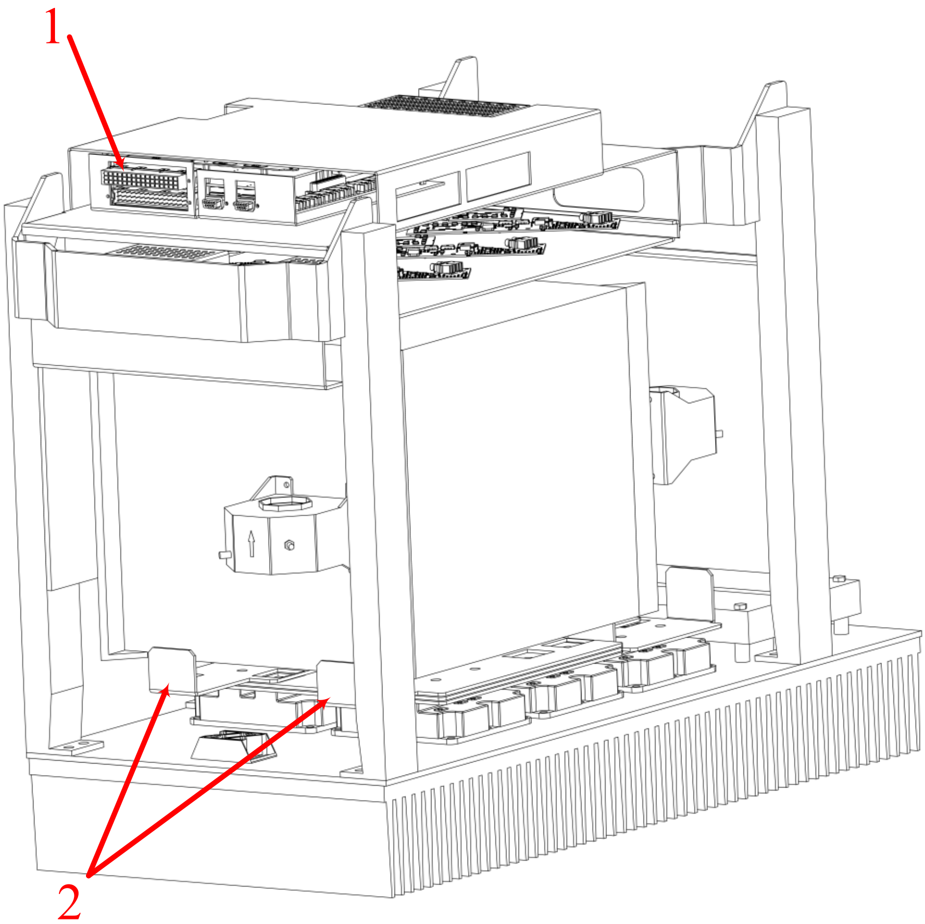
- **Phase current sensor**

The phase current sensor detects an electrical current on a busbar and generates a signal that is proportional to the current.

3.3.8. Signal interface

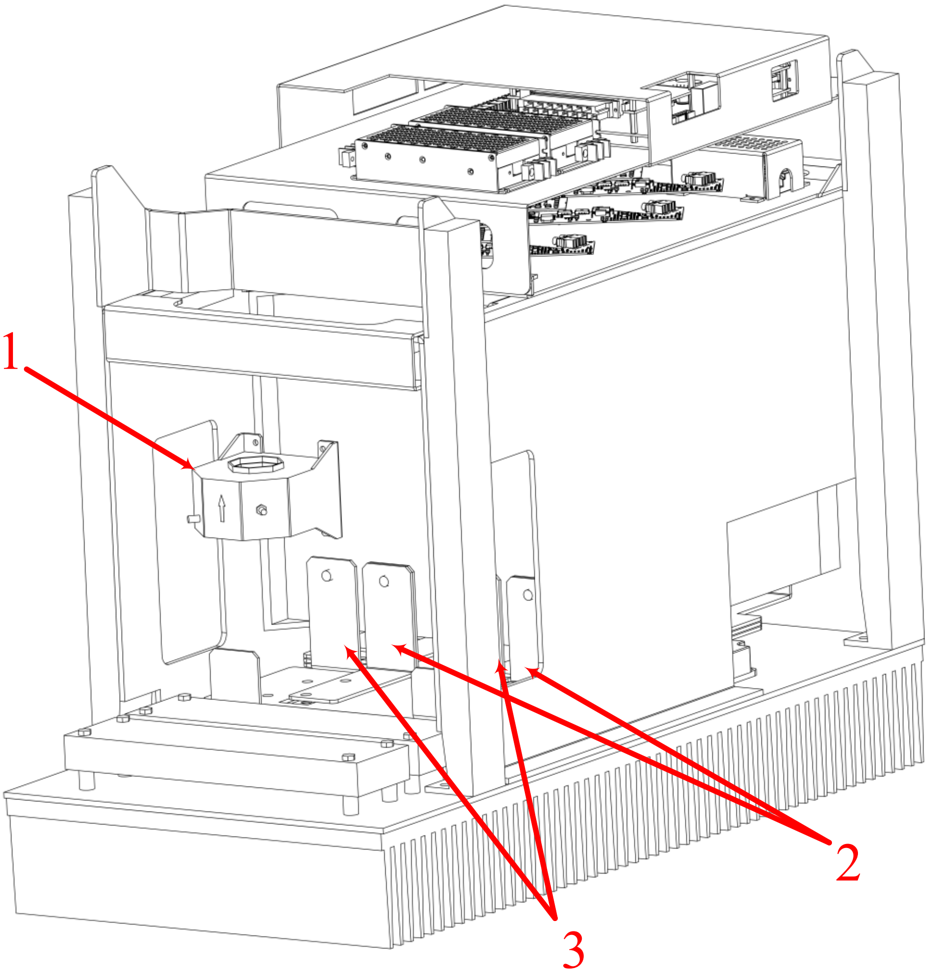
- **Internal connections and busbars**

All communications between the DCU and the GDUs are made using optical cables. The optical cables galvanically separate the circuit boards and isolate the battery voltage from the power circuit. Laminated, low inductive, busbars are used between the DC link capacitors and the converter phases (IGBT modules). This minimizes the inductance, which in turn minimizes the voltage overshoots and switching losses. Connections to equipment outside the converter module are made by copper busbars. These connections are the AC connections and the DC-plus and DC-minus connections.



1	control signals	2	Busbar, AC lines

Figure 15. Phase connections for AFEM.



1	Current sensor of DC side	2	DC +
3	DC -		

Figure 16. Power connections for AFEM.

3.4. Technical specification

3.4.1. Electrical data

Table 2. Electrical data of Active Front End Module

Converter module	Value
Input nominal voltage	1500 V DC
Input max. voltage continuous	2000 V DC
Input min. voltage continuous	1000 V DC
Three-phase output voltage	400 V AC
Output frequency	50 Hz
Output phase current, max. continuously, fundamental frequency	400 A RMS
Trip level	2000 V DC

3.4.2. Power supply unit, voltage range

The power supply units provide regulated supply voltage to the DCUs and GDUs. The units are specified for nominal 24V DC to account for the 110 V DC battery voltage available on the train.

3.4.3. IGBT module, phases

Table 3. Specification of IGBT module

Type of value	Value
V_{CEM}	Upper than 3300 V
I_{NOM}	400 A