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Evaluation and improvement proposals of uninterruptible power supply of the electronic system, within the battery system, for X2000 trains at EuroMaint AB

Master of Science Thesis in Electric Power Engineering

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Abstract

The Swedish high speed train X2000 was constructed by ABB between 1989 and 1998. The X2000 has in recent years been suffering of various problems regarding the electronics in the railcar. Different properties of the electronic system makes the reliability less satisfying. The need for refurbishment is therefore substantial.

The purpose with this report is to evaluate and give improvement proposals of the electronic system, within the battery system for the X2000 railcars. The electronic system that is in use today were studied and described to understand what possible improvements that could be made. Research was done to investigate what power units the market hold for rolling stock and what solutions that was possible to realize. Two improvement proposals were developed and presented.

The first proposal imply a total modernization of the electronic system. The second proposal is a less extensive solution which increases the lifetime of the original electronic system. With the proposals described in the report, the system reliability is improved and voltage interferences are suppressed. New converters are introduced with higher efficiency and power density compared with those used today. This minimizes the losses and enables more free space for future installations in the railcar.

Keywords: X2000 , electronic system, battery system, improvement proposals, rolling stock, EuroMaint Rail AB, railway, auxiliary system

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Dictionary

English

Auxiliary compressor
Auxiliary system
Auxiliary converter
Battery inverter
Battery system
Disconnecter
Drivers cabin light
Electronic system
Exterior lights
Exterior lights transformer
External test input
Grounding switch
Grounding transformer
Head light
High beam
Low beam
Main transformer
Maneuver car
Maneuver converter
Pantograph
Power supply unit
Railcar
Return current device
Rotary selector switch
Selector switch
Surge diverter
Tail light
Test alteration switch
Train heat supply
Train heating transformer
Train switch selection
Vehicle computer
Wagon
Wagon supply contactor

Swedish

Hjälpkompressor
Hjälpkraftsystem
Hjälpkraftsomriktare
Batteriomriktare
Batterisystem
Frånskiljare
Förrarhyttsbelysning
Elektronikmatningsystem
Utvändiga strålkastare
Transformator strålkastare
Externt provintag
Jordningsdon
Återledningstransformator
Frontbelysning
Helljus
Halvljus
Huvudtransformator
Manövervagn
Manöverströmslikriktare
Strömavtagare
Matningsdon
Motorvagn
Återledningsdon
Vridströmställare
Strömställare
Ventilavledare
Slutsignal
Provomkopplare
Tågvärme
Tågvärmetransformator
Tågslagsselektering
Fordonsdator
Löpvagn, vagn
Vagnmatningskontaktor

Abbreviations

Abbreviation	Full name
ABB	Asea Brown Boveri
ATC	Automatic Train Control
GTO	Gate Turn Off (Thyristor)
IGBT	Insulated Gate Bipolar Transistor
LED	Light Emitting Diode
PWM	Pulse Width Modulation
SJ	Statens Järnvägar
THD	Total Harmonic Distortion

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1 Introduction

The electronic system, which this project comprehends, is a vital part of the battery system in the X2000 railcar. The battery system provides uninterruptible power to important equipments for the functionality and safety of the train. The battery system is complex and consists of many converters and units that delivers different voltage levels.

1.1 Background

The Swedish high speed train X2000 was constructed by ABB from 1989 to 1998 on commission by SJ . The train was developed and furnished with state of the art technology by that time and were constructed to go as fast as 210km/h. The traction system was equipped with GTO thyristors for current control and asynchronous motors were used for propulsion. The traction system is also able to perform regenerative braking and supply the power back to the line (ABB Traction, TK 11001-EG , 1991).

EUROMAINT AB provides maintenance and refurbishment for rolling stock in the rail transport industry and is contracted by SJ to maintain the X2000 trains. EUROMAINT AB has during recent years been working hard with improvements of the reliability of the X2000.

The X2000 has been suffering from various problems regarding the electronics in the railcar. The main problem is that the drive circuits of the traction GTOs indicate "control error" and also sometimes break down. Much effort has been involved in solving the problems with the GTOs and their driving. The vehicle computers, which are supplied from the electronic system within the battery system, controls the traction GTOs. It is of utmost importance that the voltage supplied to the computers are of good quality with no interferences to maintain a good reliability of the system.

The electronic system in the X2000 supplies vital loads with uninterruptible power. Such loads are the vehicle computers, the auxiliary compressor and the exterior lights. The system is advanced and contains many voltage levels and therefore many converters and transformers. Loads of different character, like the vehicle computers and the auxiliary compressor are supplied from the same converter which can lead to unwanted voltage interferences. Another important aspect is that the electronic system is not designed with total redundancy and moreover all units are not equipped with error indication. Electromechanical contactors are used in the electronic system to control the functionality, which contributes to a more complex system.

The electronic system that is used in X2000 is more than 20 years old. Spare parts can be hard to find and some units are very expensive because of their unique properties. These system properties described above makes the reliability of the electronic system less satisfying.

1.2 Purpose

The purpose of the project is to specify and understand the existing electronic system. Thereafter to study the feasibility to renew the existing system. The main goal is to develop and document improvement proposals of the electronic system in such a way that the total reliability of the system increases.

1.3 Delimitation

The master thesis main focus is on the electronic system within the battery system. Electric circuits, and units outside the electronic system will only briefly be described and considered.

Focus is put on the system functionality and that the improvement solutions are possible to realize. New units that are mentioned in the report are not technically described in detail.

1.4 Method

The electronic system within the battery system has been studied in order to understand what improvements that can be done. Thereafter different improvement solutions were analyzed. Research was done to understand what power units the market hold for rolling stock and what solutions that was possible to realize.

Two improvement proposals were developed and described. The first proposal implies a total modernization of the electronic system. The second proposal is a less extensive solution but with many benefits.

2 Brief electrical overview of the X2000

The railway system in Sweden consist of a one phase overhead line of 15kV at 16 and 2/3Hz (16.67Hz). This voltage is then taken to the train through the pantograph, see figure 1. The pantograph is driven with air compression and is pushed up towards the overhead line with constant pressure. The main transformer is then supplied through the pantograph and from the transformer the entire system is powered, see figure 1 (ABB Traction, TK 11001-EG , 1991).

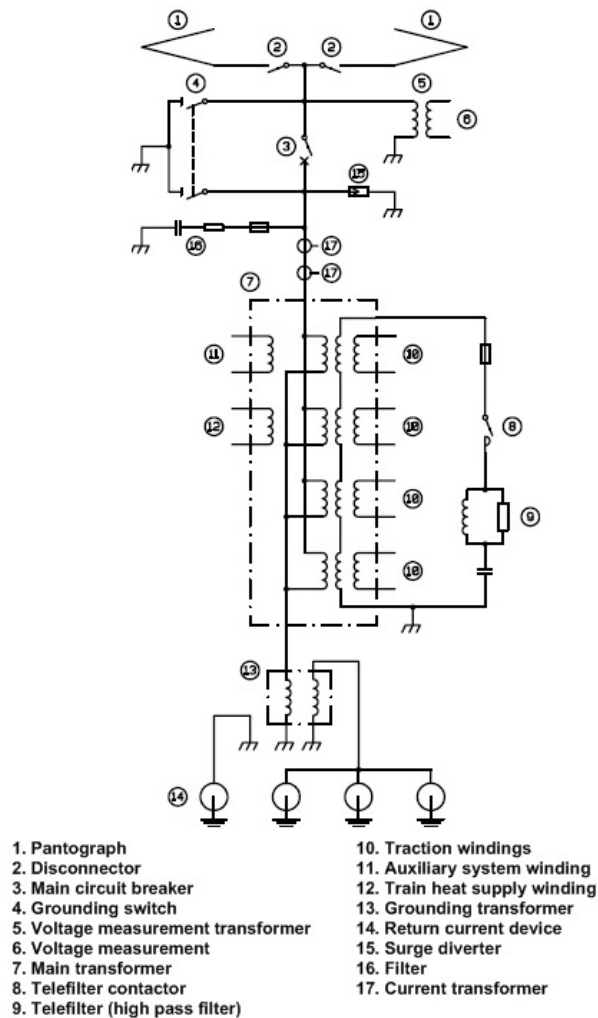


Figure 1: Electrical overview of the high voltage system

2.1 Main transformer

The main transformer supplies the traction and auxiliary systems in the train. The 15kV 16 and 2/3Hz are transformed into three voltage levels. These voltage levels have different functions in the train. As seen in figure 1 the main transformer has six secondary windings, four of them is used to power the traction system. The remaining two are used for the auxiliary system and for the train heat supply system (ABB Traction, TK 11001-EG , 1991).

2.1.1 Traction system

The traction system consists of two traction converters that supplies two asynchronous motors each, see figure 2. Four windings from the main transformer supplies the traction converters that consists of a rectifier, a DC-link and a three phase inverter.

The converters in the traction system consists of GTO thyristors. The traction system enables dynamic braking, which means that the asynchronous motors work as generators during electrical braking (ABB Traction, TK 11001-EG , 1991).

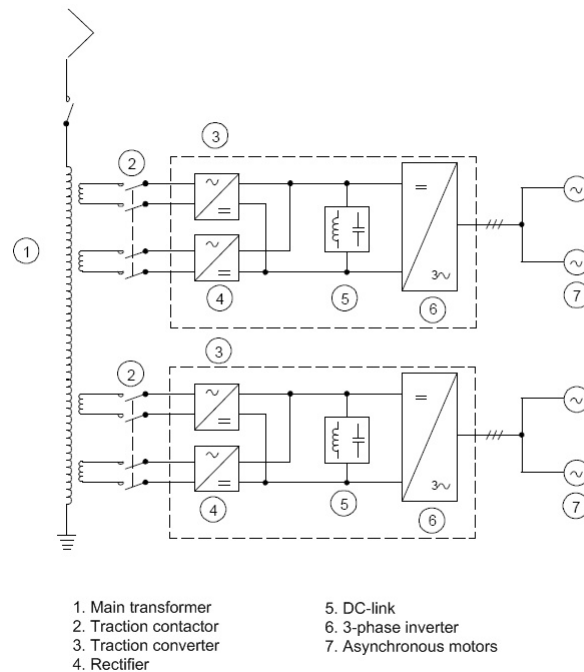


Figure 2: Electrical overview of the traction system

2.1.2 Auxiliary system

The auxiliary system uses the main transformer to transform the voltage level to 866V 16 and 2/3 Hz. This is then rectified and inverted into 3×380VAC 50Hz. The 3×380VAC is used for appliances such as the main compressor, the air conditioning systems and the tilting system. The auxiliary system supplies both the railcar and the wagons with a maximum power output at 360kW, see figure 3 (ABB Traction, TK 11001-CA , 1991).

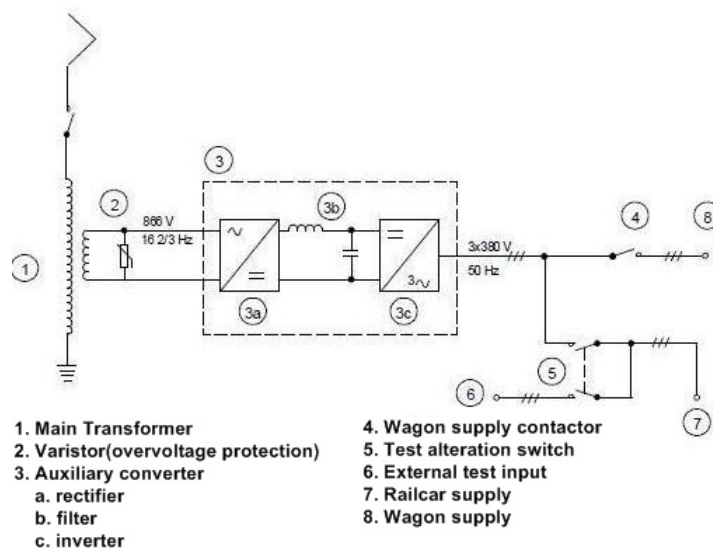


Figure 3: Electrical overview of the auxiliary system

2.1.3 Train heat supply system

The function of the train heat supply system is to supply the railcar and the wagons with 1000V 16 and 2/3Hz. This voltage is used to power heaters in the train and to charge the batteries. In the train heat supply system a transformer is connected with two secondary windings, as seen in figure 4. One of the windings is used to supply the battery charger. The other winding supplies heaters in the railcar. The train heat supply can also be connected externally if the pantograph is down and maintenance is done (ABB Traction, TK 11001-B , 1991).

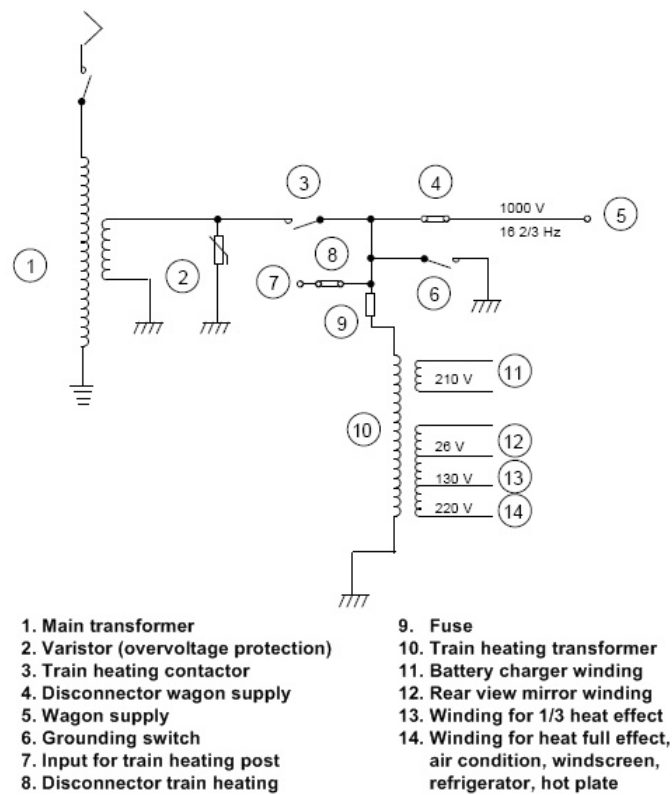


Figure 4: Electrical overview of the train heat supply system

2.1.4 Battery system

The battery system supplies the railcar with uninterruptible power, see figure 5. The battery system can be divided into three sections, battery and battery charger, maneuver converter and the electronic system (ABB Traction, TK 11001-D , 1991).

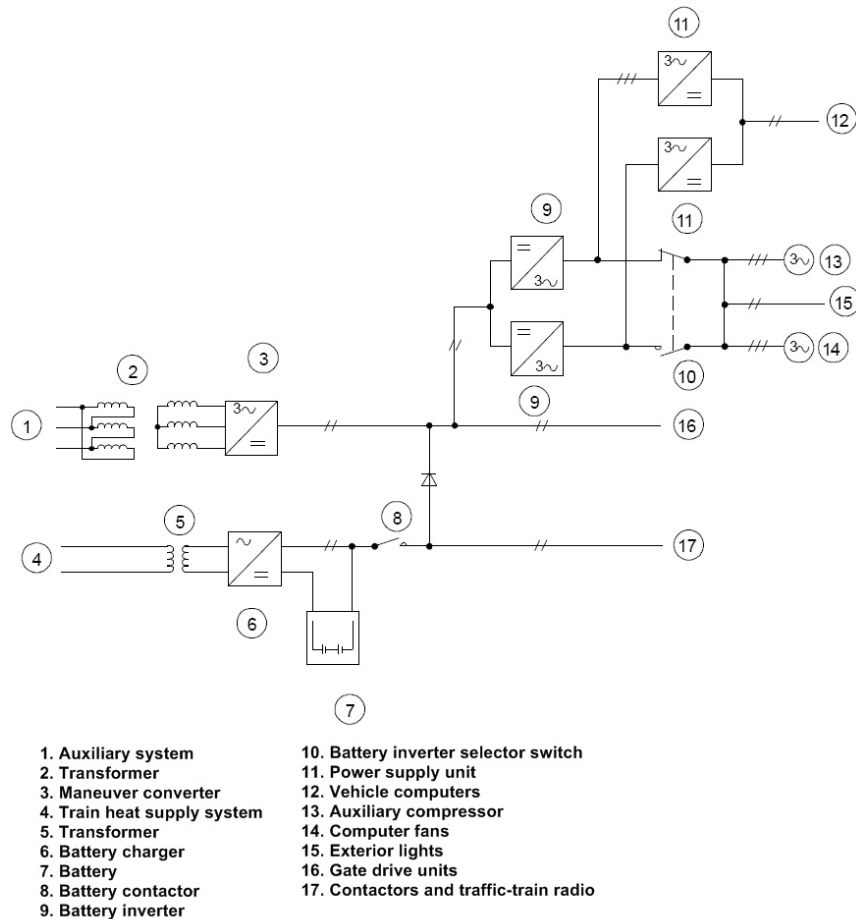


Figure 5: Electrical overview of the battery system

2.1.4.1 Battery and battery charger

The battery supplies the battery system with power when the pantograph is down or the connection with the line is lost. The battery charger supplies 110VDC to contactors and traffic train radio in normal operation. The battery charger is powered from the train heat supply system. This means that the battery system can be externally powered when the pantograph is down.

2.1.4.2 Maneuver converter

The maneuver converter is supplied from the auxiliary system. In normal operation the maneuver converter supplies 126VDC to gate drive units for the GTOs and the electronic system. When the railcar is not connected to the line, the battery will supply these loads via a diode as seen in figure 5.

2.1.4.3 Electronic system

The electronic system supplies $3 \times 380\text{VAC}$ through battery inverters to equipment such as the exterior lights, auxiliary compressor and vehicle computers. In the next section the electronic system will be described in detail.

3 Electrical overview of the electronic system

The electronic system provides uninterruptible power to essential equipment such as the vehicle computers, the auxiliary compressor and the exterior lights. The electronic system includes a variety of converters, transformers, contactors and loads. The overview of the electronic system explains the different components and their function in the scheme shown in figure 6.

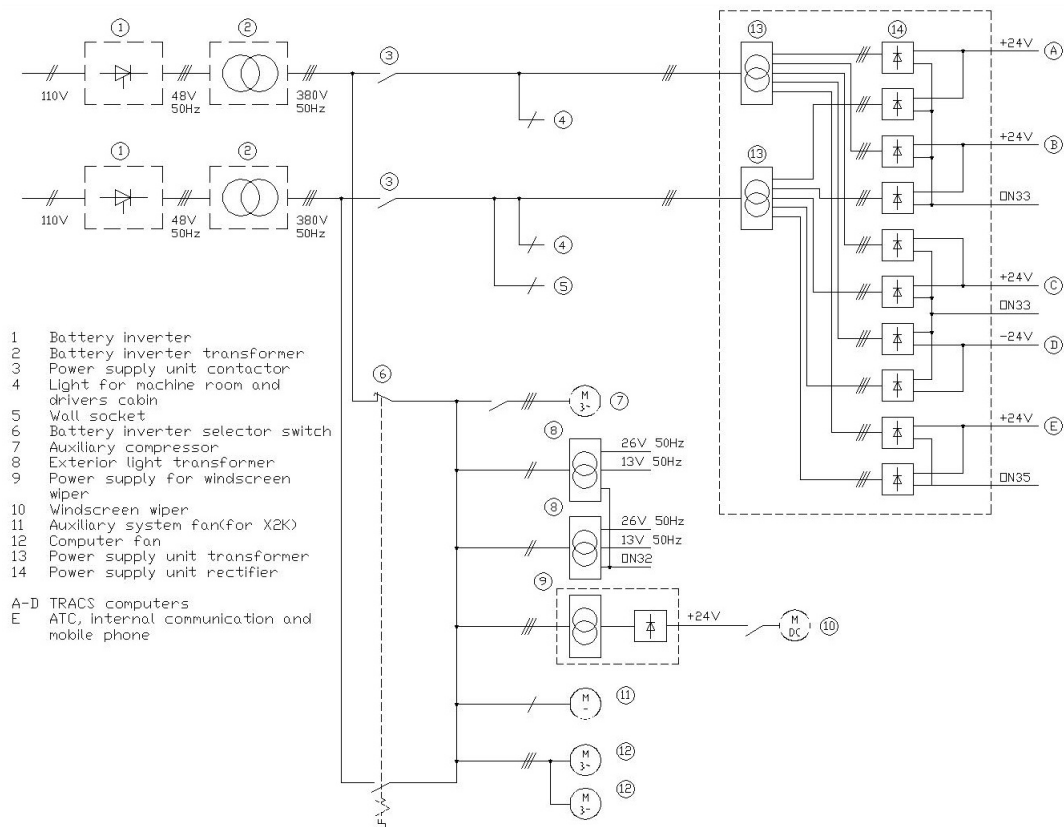


Figure 6: Electrical overview of the electronic system

3.1 Battery inverter (1)

The battery inverters are supplied with DC voltage from the battery (88-121VDC), or from the maneuver converter (121-131VDC) and inverts this voltage to tree phase AC voltage $3 \times 48\text{VAC}$ with 50Hz. There are two identical battery inverters to satisfy the redundancy requirements. They are connected in parallel and if one of them breaks down the other one can support the whole load.

The inverters are pulse width modulated with sinusoidal control voltages

and consists of IGBT technology, see table 1 for detailed information about the battery inverter. The battery inverters are automatically on as soon as the line in voltage is applied. There are no turn on/off switch for the inverters, instead they can be turned off with a turn off signal from the main computer (ABB Traction, TK 11001-ZA , 1991).

Table 1: Specifications of the battery inverter

Input voltage	75-140 VDC
	Ripple $\pm 5\%$
Output Voltage	3×48 VAC
	THD idle $< 5\%$
Frequency	50Hz $\pm 3\%$
Output power	1.8 kW with $\cos \theta = 1.0$
	1.5 kW with $\cos \theta = 0.8$
Efficiency	$> 75\%$
Weight	15 kg
Design	19" rack

3.2 Battery inverter transformer (2)

A three phase transformer is connected to each inverter in a delta/bye connection. The inverter output voltage 3×48 V is transformed to 3×380 V. The transformer has a rated power at 2200VA. On the secondary side of the battery inverter there is a feed-back winding which is connected to the battery inverter (ABB Traction, TK 11001-D , 1991).

3.3 Power supply unit contactors (3)

There are two contactors after each battery inverter transformer. The contactors are used to automatically disconnect one of the battery inverters from the power supply unit when starting the auxiliary compressor. In normal operation the power supply unit contactors are always set (ABB Traction, TK 11001-D , 1991).

3.4 Lights for machine room and drivers cabin (4)

In the machine room there are 14 light armatures with 9W lamps. Seven of these armatures are supplied from battery inverter 1 and the remaining seven are supplied from battery inverter 2. In this way there will always be light in the machine room even if one of the battery inverter breaks down. In the drivers cabin there are two light armatures with 25W lamps that are supplied from battery inverter 1. There is also a small express storage space

with one 9W lamp in the rear of the railcar. In total, these lights have a power consumption of 185W, see appendix A.

3.5 Wall sockets (5)

Two wall sockets are connected after the contactors, one is located in the machine room and the other one in the drivers cabin. They supply small applications with 220VAC 50Hz and are equipped with a fuse at 1A. The maximum power outtake from the wall sockets are therefore 220W (ABB Traction, 3EST 47-116 , 1999a).

3.6 Battery inverter selector switch (6)

With the selector switch one can manually select which of the battery inverter that will supply the loads connected after the selector switch. These loads are the auxiliary compressor, the exterior lights, the windscreen wipers and fans for ventilation. The battery inverter selector switch is only used when one of the battery inverters are broken. In normal operation, the selector switch is set so that the second battery inverter is connected to the loads. The selector switch is operated manually in the machine room (SJ, SJF 333.61 , 2008)

3.7 Auxiliary compressor (7)

The auxiliary compressor is used at startup of the train. Pneumatics is used for raising the pantograph against the overhead line and also to turn on the main circuit breaker. When the startup sequence is completed the train is connected to the main power grid and the regular compressor will be supplied through the auxiliary system. The auxiliary compressor will automatically stop when wanted air pressure is reached. The auxiliary compressor is driven by a three-phase AC induction motor supplied with $3 \times 380\text{VAC}$. The maximum flow rate and air pressure for the auxiliary compressor are 110 l/min and 8 bar respectively. The auxiliary compressor has a rated power at 1100W (ABB Traction, TK 11001-EG , 1991).

3.8 Exterior lights transformers (8)

There are two equal transformers for the exterior lights supply. One of the transformers supplies the beams on the left side and the timetable lights. The other transformer supplies the beams on the right side and the instrument panel lights. The primary winding of the exterior light transformers are supplied with 380VAC phase to phase. The winding on the secondary side delivers 13VAC and 26VAC. 13VAC is used for low beam and 26VAC is used for high beam. The timetable and the instrument panel are supplied

with 26VAC (ABB Traction, 3EST 47-116 , 1999a). The maximum power withdrawn from the exterior light transformers are 404W, see appendix A

3.8.1 Exterior lights

The exterior lights consists of eight beams. There are two upper and two lower head lights, two dim lights and two tail lights. The two tail lights are always lit and consumes 50W in total. The exterior lights control is set-up in such a way that only four of the the upper, lower and dim lights are supplied at a time. These beams have a rated power at 70W. The total power demand for the exterior lights is therefore 280W plus 50W for a total of 330W, see appendix A.

3.9 Power supply for windscreen wipers (9)

The power supply for windscreen wipers consists of one three phase transformer and one three phase diode rectifier. The transformer transforms the $3\times 380\text{VAC}$ to $3\times 19\text{VAC}$. The three phase diode bridge then rectifies the $3\times 19\text{VAC}$ to 24VDC (ABB Traction, 3EST 47-116 , 1999a).

3.10 Windscreen wipers (10)

The windscreen wipers electric motors and electric pumps for windscreen wiper fluid are powered with 24VDC. There are two sets of these motors and pumps, one for the left and one for the right windscreen. In total this equipment consume 190W, see appendix A.

3.11 Auxiliary system fan (only in X2K) (11)

Some of the X2000 trains are modified to run in Denmark, these trains are called X2K. The X2K trains have a new auxiliary system and a new cooling fan connected to it. The fan that is mounted under the auxiliary system converter is powered from the electronic system with one phase at 220VAC (ABB Traction, 3EST 47-116 , 1999a).

3.12 Computer fans (12)

There are two fans for cooling the computers and the electric converters. The fans are supplied with tree phase 380VAC and 50Hz. The total power consumption of the fans are 128W. The fans have a normal operation speed at 2800 rpm, see appendix A.

3.13 Power supply unit transformer (13)

The collective word for the transformers and rectifiers that converts $3\times 380\text{VAC}$ into 24VDC to the vehicle computers is the power supply unit. There are two

identical sets of power supply units to satisfy the redundancy requirements. One power supply unit consists of one transformer and five diode rectifiers.

The power supply unit transformer, converts $3 \times 380\text{VAC}$ to $3 \times 19\text{VAC}$. Each transformer consists of one primary winding and five identical secondary windings. The secondary windings are connected to diode rectifiers. In table 2 detailed information about the power supply unit transformer is presented (ABB Traction, TK 11001-GFN , 1993).

Table 2: Specifications of the power supply unit transformer

Rated Power	1430VA
Primary winding	$3 \times 380\text{VAC}$
	D-connected
Five secondary windings	$3 \times 19\text{VAC}$
	Y-connected
Frequency	50Hz
Isolation class	F
Winding material	Copper
Weight	30 kg
Measurements	$300 \times 312 \times 132\text{mm}$

3.14 Power supply unit rectifier (14)

The secondary windings of the power supply unit transformers are connected to three phase diode rectifiers. There are two identical sets of power supply unit rectifiers, each consists of five three phase diode rectifiers connected in parallel so that if one brakes down the other one can support the load.

All rectifiers have a rated output voltage at 24VDC, except the rectifier connected to output D that has a rated output at -24VDC. Output A, B, C and D supplies the vehicle computers, output E supplies the ATC (Automatic Train Control), the internal communication and the mobile phone, see figure 6.

Each power supply unit rectifier, with five diode rectifiers, has a continuous output power of 1400W in total. Rectifiers connected to output A and E have a rated output power at 400W, the remaining three rectifiers have a rated output power at 200W. See table 3 for detailed information about the power supply unit rectifier (ABB Traction, TK 11001-ZC , 1991).

Table 3: Specifications of the power supply unit rectifier

Input voltage	3×380VAC, 50Hz
Output voltage	Nominal 24VDC Min 21VDC Max 28VDC Ripple, max 0.5VDC Output power, per rectifier: Rectifier A,E: 400W Rectifier B,C,D: 200W
Weight	11 kg
Design	19" rack

3.15 Loads supplied from the power supply unit

The power supply unit supplies 24VDC to vital equipments for the functionality and safety of the train. This vital equipment consists mainly of four different computers and one safety system called the ATC system.

3.15.1 TRACS computers (*A – D*)

There are four computers in the railcar, which are called the TRACS computers. Their main task is to maneuver, monitor and control different kinds of systems in the train (ABB Traction, DR89513X2 , 1993).

3.15.1.1 Railcar computer

The railcar computer is the master computer and maneuvers the other computers. This computer controls most of the steering and logic for the communication, maneuvering, brakes and tilting of the train.

3.15.1.2 Traction computer

The traction computers main function is to control and regulate the traction GTOs. The railcar computer and the traction computer consists of extension cards that are placed in a cubicle.

3.15.1.3 Drivers cabin computer

This computer is a single board computer placed in the drivers cabin, it works as an interface between the control unit in the drivers's cabin and the other computers.

3.15.1.4 Pneumatic computer

The pneumatic computer is a single board computer that controls and maneuvers the pneumatics.

3.15.2 Automatic Train Control (ATC) (*E*)

The railcar is equipped with an automatic system that monitors the driving of the train, this system is called the automatic train control. Information about speed limits and other traffic signals are sent from balises located along the track to the ATC system. The ATC system then calculates a reference speed that the driver must follow. If the driver miss a stop signal or the train is going to fast, the ATC system will override the driver and slow down the train.

The ATC system is powered from output E from the power supply unit rectifier, see figure 6.

3.15.3 Internal communication and mobile phone (*E*)

With the internal communication the driver of the train can talk to other crew onboard and make announcements to the passengers. The mobile phone enables the driver to communicate with the guidance head office. This devices are feeded from the same rectifiers as the ATC system (ABB Traction, TK 11001-EG , 1991).

3.16 Functionality of the electronic system

The electronic system is static in normal operation, this means that no contactors in the system are switched. During startup of the auxiliary compressor contactors are switched. When one of the battery inverters are broken the battery inverter selector switch might need to be switched. The auxiliary compressor startup and the emergency startup sequences are described below.

3.16.1 Auxiliary compressor startup

When the auxiliary compressor is started a turn off signal is sent to the battery inverter that is connected to the auxiliary compressor through the battery inverter selector switch. The battery inverter then restarts, and voltage and frequency are ramped up to rated values with a ramp up sequence. The purpose of a ramp up sequence is to limit the high starting currents that the auxiliary compressor would require at direct start. To prevent this ramped up voltage and frequency to interfere with the power supply unit,

the battery inverter, that is used to start the auxiliary compressor is disconnected from the power supply unit with one of the power supply unit contactors. The power supply unit is therefore only powered from one of the battery inverters during the startup of the auxiliary compressor. When a wanted air pressure is reached the auxiliary compressor will automatically turn off and the power supply unit contactor is switched on again (ABB Traction, 3EST 47-116 , 1999a).

3.16.2 Emergency startup

If one of the battery inverters is broken, it is necessary to start the help compressor with a manual procedure. This operation is called emergency startup of the auxiliary compressor and is done by the operator in the engine room. The selector switch is set so the battery inverter that works is connected to the auxiliary compressor. The auxiliary compressor is then started with the same sequence as described above in 3.16.1. When one of the battery inverters are broken the computers will be powerless during the time the auxiliary compressor is started. When a wanted air pressure is reached the compressor stops and the power supply unit contactor is switched on again (SJ, SJF 333.61 , 2008).

3.17 Placement of units in the electronic system

All units in the electronic system are located in the railcar. The units are placed either in a cubicle or a rack. The auxiliary compressor is placed in the rear of the railcar, see figure 7.

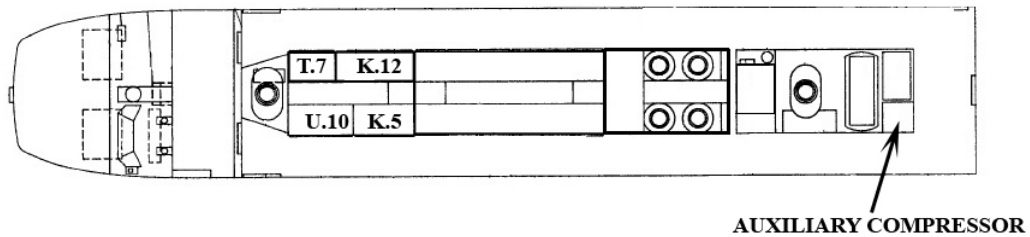


Figure 7: Placement of units in the electronic system

3.17.1 Cubicle K12

The battery inverters and the power supply unit rectifiers are placed in a cubicle called K12, see figure 7 and 8. The computer fans are mounted at the bottom of this cubicle.

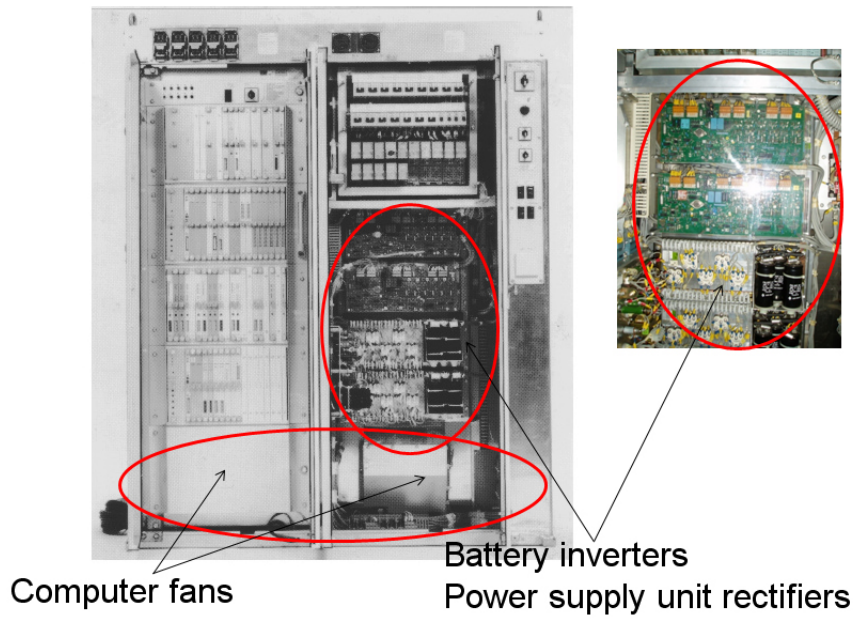


Figure 8: Overview of cubicle K12

3.17.2 Transformer rack T7

The transformers connected to the battery inverters and the power supply units are placed in a transformer rack called T7. The power supply for the windscreen wipers are also located in this rack, see figure 9.

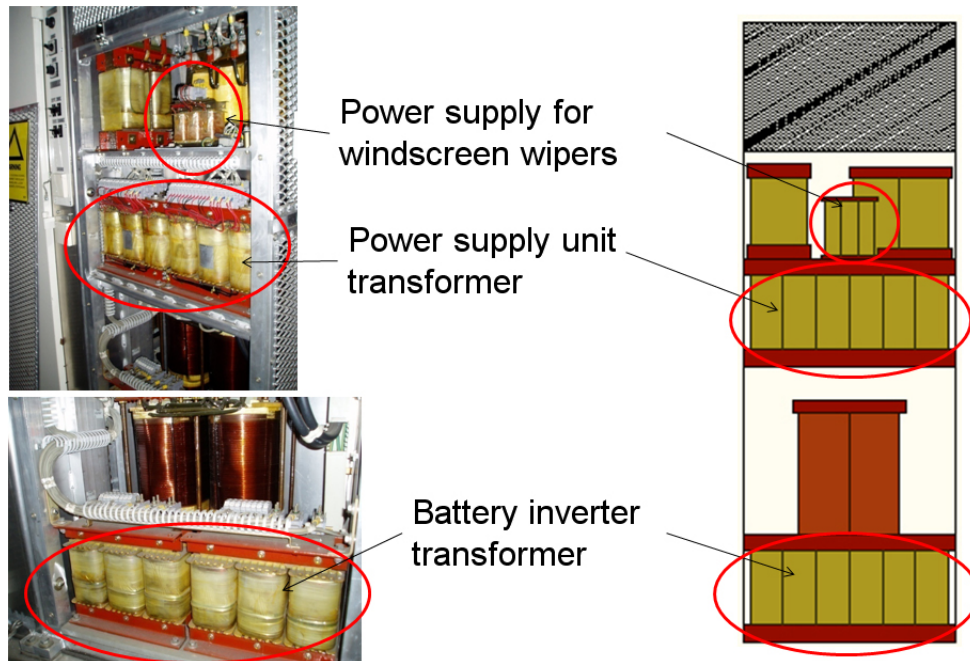


Figure 9: Overview of transformer rack T7

3.17.3 Cubicle K5

The exterior light transformers are located in cubicle K5, see figure 7. In this cubicle the power supply unit contactors and the battery inverter selector switch are placed.

3.17.4 Cubicle U10

The auxiliary system fan is placed in the bottom of cubicle U10, see figure 7.

4 Voltage levels and power consumption

When referring to the original setup, it is referred to the original connection setup that the X2000 has. The load calculations can be found in Appendix A. Here the loads are calculated based on the documentation made by SJ. These documents are found in different binders on EUROMAINT AB .

Below follows a description of what types of loads there are and their power consumption. By identifying the loads one can specify what level the new possible converter should be rated with. Furthermore it is also vital to determine how much of the load that needs redundancy.

4.1 380VAC phase to phase

The voltage is supplied by the battery inverter and are connected to important loads. The auxiliary compressor and the computer ventilation, see figure 6 in section 3.

4.2 220VAC phase to neutral

The voltage supplies light in the machine room and the drivers cabin, see figure 6 in section 3.

4.3 26VAC and 13VAC phase to ground

The voltage is transformed from 380VAC by the exterior light transformer, see figure 6. This voltage supplies the exterior lights of the train and lights for the instrument panel. The 26VAC supplies the exterior lights when high beam is required and 13VAC when low beam is needed, see section 3.8. The voltage is galvanic isolated from 380VAC and is grounded on the secondary side.

4.4 24VDC line to ground

The voltage is supplied from all three phases from the battery inverter and is transformed through the power supply unit transformer in a delta-why connection, see figure 6. It is then rectified to a 24VDC level that supplies important loads such as the TRACS computers and the ATC. The 24VDC is galvanic isolated from the AC supply.

4.5 Summary of voltage levels and maximum power consumption

In table 4 the power consumption for 380VAC contains three power levels. The first two cases describes the maximum power withdrawn, during the

startup sequence, when the auxiliary compressor is running. The difference of these two is that the middle column describes the case when the drivers instruction manual is followed, which it is normally done (see (SJ, SJF 333.61 , 2008)). The last column describes the maximum power withdrawn during normal run of the X2000 . The train is then connected to the main line through the pantograph. The last two rows in table 4 describes how the power is divided through the two battery inverters during the three cases. See appendix A for more details on the load calculations.

It should also be noted that the exterior lights can only be operated in such a way that maximum power is withdrawn when both upper and lower lights, at both sides, are at full beam. Some of the X2000 trains (X2K) are equipped with an auxiliary system fan and some trains have wall sockets. Due to these cases the calculations are done in such a way that it is said that all trains are equipped with these modifications. Hence the maximum power withdrawn for a X2000 train is constant and no special case due to modifications is done. For more information see appendix A.

Table 4: Summary of voltage levels & maximum power consumption from appendix A

Type	Max pow. startup	With drivers instr. manual	Max pow. normal run
380VAC	1228W	1228W	128W
220VAC	469W	249W	469W
26/13VAC	404W	124W	404W
24VDC	1590W	1400W	1590W
All	3691W	3001W	2591W
Bat. inverter 1	1513W	1513W	1513W
Bat. inverter 2	2178W	1486W	1078W

5 System and Euromaint AB requirements for modernization of the electronic system

The electronic system and EUROMAINT AB have requirements that need to be fulfilled. The research done of the electronic system has given the benefit in how the work process should be prioritized and on what. These requirements can be divided into different groups, in such a way to structure the problem and how to process the work. When referring to the system it should be clarified that it is referred to the electronic system. An overview of the priorities can be seen in fig 10 below.

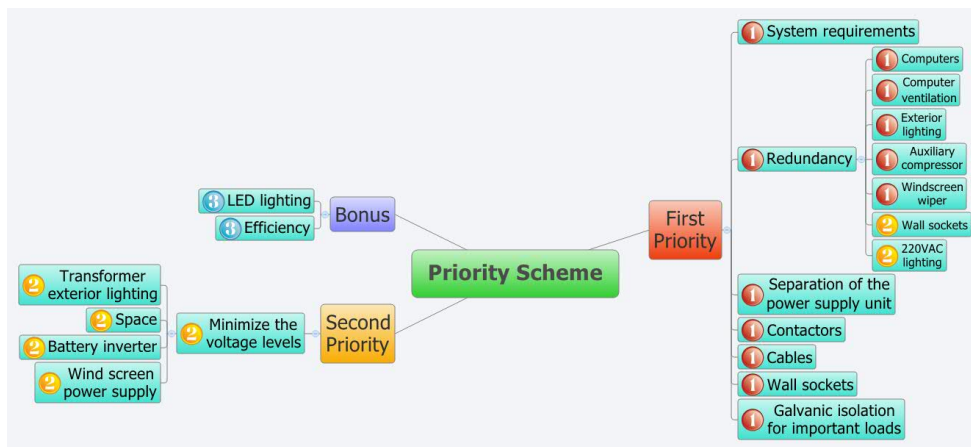


Figure 10: Priority overview for the electronic system

5.1 First priority

These are the most important aspects regarding the electronic system.

5.1.1 System requirements

As seen in figure 6 in section 3 the electronic system main voltage is 110VDC. But in fact this voltage is never 110VDC. It is just a mean definition where the actual voltage varies between 88-132VDC (ABB Traction, TK 11001-ZA, 1991). Therefore if any new converter or inverter is to be introduced, it must be able to operate in this voltage interval.

5.1.2 System redundancy

Redundancy in the X2000 means that certain loads that supplies the functionality of the train are of such importance that these loads require backup, when referring to the converter or transformer that supplies the load. For example if a 110/24 DC-DC converter supplies a vital load and this vital

load needs redundancy. It is then the best solution to add another 110/24 DC-DC converter in order to compensate the loss of one converter. That is, if one converter breaks down the other one would be able to supply the vital load. The load then has N+1 redundancy. When discussing proposals it would be good to keep higher prioritized redundancy loads separated from the lower ones. If they were to be mixed, the loads with the higher redundancy requirement would set the standard of the redundancy.

The redundancy can be categorized in two different categories after its priority. The first category is the most important one and contains vital component which the X2000 needs to function properly. The second category contains non-vital components which the X2000 can function without.

5.1.2.1 System redundancy priority one

The system contains vital components such as the TRACS computers and the ATC. Without these computers the train can not function properly, or not at all. Therefore the 24VDC that supplies the computers needs backup and redundancy, see figure 6.

The system also contains an auxiliary compressor. If the train pantograph is down due to repairs or security aspects and the pressure level is low, it is the auxiliary compressor (which most often run on the batteries) that makes sure that it is possible to push the pantograph up and put the train online. Therefore the auxiliary compressor is another vital part of the train and thus needs redundancy. The auxiliary compressor is currently running on 380VAC, see figure 6

The computer ventilation also needs redundancy. If the ventilation is not working the computers may be overheated and break down. The fans that drive the ventilation are currently running on 380VAC, see figure 6.

Without the exterior lights, the X2000 have navigation problems but would still be operational. However if the exterior lights are down the risk of an accident increases, therefore the exterior lighting redundancy is of priority one. The exterior lights are currently supplied with 26/13VAC.

5.1.2.2 System redundancy priority two

Other lights such as the ones in the drivers cabin and machine room are also important. But the train can still be functional without these and are therefore of second priority. These are currently supplied with 220VAC. There is also one 220VAC wall socket in the drivers cabin and one in the machine room. These are not vital for the functionality of the train and are

therefore of lower priority.

5.1.3 Separation of the power supply unit

The power supply unit supplies TRACS computers, ATC and other vital loads. These loads are of larger magnitude and it would be of great benefit to separate this load from the rest of the system to reduce the workload of the battery inverter. According to the startup sequence in section 3.16 the amount of contactors will be reduced by separating the power supply unit from the rest of the system.

The power supply unit is connected together with electrical motors such as the computer ventilation and windscreen wiper. By separating the power supply unit, the possible amount of interference done by electrical motors will be eliminated. The power supply unit has low pass filtering for EMC interference and also ripple filtering. However, it can not be determined if these filters are enough to eliminate any interference without measurements (ABB Traction, 3EST 47-116 , 1999a).

5.1.4 Contactors

For the original connection the power supply unit contactors switch on and off in different cases, see section 3.16. By eliminating these the system will be more stable and the maintenance cost will be lower. In emergency cases the driver will have to go to the machine room and adjust the battery inverter selector switch, see section 3.16. By removing the selector switch, the emergency actions are eliminated and hence the system will be more stable.

5.1.5 Cables

The original connection setup uses a lot of cables. Some of these cables are quite roughly mounted and it could require a lot of work to mount a new cable. Therefore if the cables can be reused it would save the workload. If the new system would use a lower voltage level for the cables, one must make current calculations to make sure that the cables can carry a higher amount of current.

5.1.6 Wall sockets

The wall sockets are of standard voltage level 220VAC. However the power intention of the wall sockets are not of high power and is therefore only fused with 1A ((ABB Traction, 3EST 47-116 , 1999a)). The purpose of the wall socket is to connect measuring tools of low power when needed, according to

Mats Palmberg¹. This occurs in cases such as when the train has electrical problems.

5.1.7 Galvanic isolation

The electronic system have different grounds, depending on the voltage system. It is important and a requirement from EUROMAINT AB to keep the galvanic separated loads, separated. Therefore one must take this into consideration when new system applications are to be introduced. The loads which are directly supplied with AC are separated from DC. The DC loads share common ground and are therefore not galvanic separated, see figure 6 in section 3.

5.1.8 Load isolation and configuration

According Mats Palmberg² the configuration of the loads in the power supply unit should be maintained, see figure 6. This is done for simplicity reasons. It should also be done due to the fact that the voltage level of -24VDC is needed to create a potential difference of 48VDC that certain electronic devices need, see (ABB Traction, 3EST 47-116 , 1999b).

5.2 Second priority

These are important aspects regarding the electronic system, but not vital.

5.2.1 Minimizing the number of voltage levels

By minimizing the number of voltage levels through removing converters and transformers a lot is gained. The system will be less complicated to apprehend and maintenance will thus be simplified. More voltage levels gives more converter units and thus more cost, space and higher requirements.

5.2.1.1 Exterior light transformer

All the lights connected to the exterior light transformer are rated mostly with 24VDC. They are however not fed with 24VDC, but with 26VAC for full beam and 13VAC for half beam. This is probably done due to the fact that it was easy to obtain both 13VAC and 26VAC from a transformer. If one wishes to change the electronic system it would be good to keep in mind that the current solution is a bit unusual.

One very interesting point is that the maneuver car is using 24VDC to power

¹Mats Palmberg, Head of the X2000 Railcars: Conversation 11 Mars 2009

²Mats Palmberg, Head of the X2000 Railcars: Conversation 24 April 2009

the exterior lights. The maneuver car is supplied from a 24VDC battery voltage. It uses 24VDC for full beam and a resistor is connected in series with the lights when half beam and 12VDC is needed. In an electrical-engineering point of view this is a waste of energy. It would therefore be a better solution to connect the lights in either parallel or series depending on what type of beam that is needed. But it is good to see that a 24VDC solution for the exterior lights are already in use for the X2000 . Hence, to change the operating voltage from 26/13VAC to 24/12VDC for the railcar will not be a problem (ABB Traction, 3EST 47-117 , 1999).

5.2.1.2 System space

If the voltage levels are to be minimized, one can remove or replace old equipment such as inverters, rectifiers and transformers. By eliminating these more space is gained for further installations. According to Christer³ a new ATC system will be installed in a near future and all new space are welcome.

5.2.1.3 Battery inverter

The battery inverter uses IGBT technology to switch from 110VDC to 48VAC at 50Hz before it is transformed up to 380VAC at 50Hz. This is rather modern technology and there is therefore from an electro-technical point of view no need for replacement. But according to Christer⁴ and by studying image 9 and 8 in section 3, one can see that the battery inverter takes some space. Hence by removing the battery inverter with smaller and more modern installations more space is gained for future installations.

³Christer Martinsson: Conversation 10 February 2009

⁴Christer Martensson: Conversation 10 February 2009

6 System solution proposals

By using the guidelines given in the previous section process-scheme were developed. The scheme describes the work-method or work-principle in how to break down and evaluate the problems regarding the upgrade of the electronic system, see figure 11. The power supply units are replaced with a

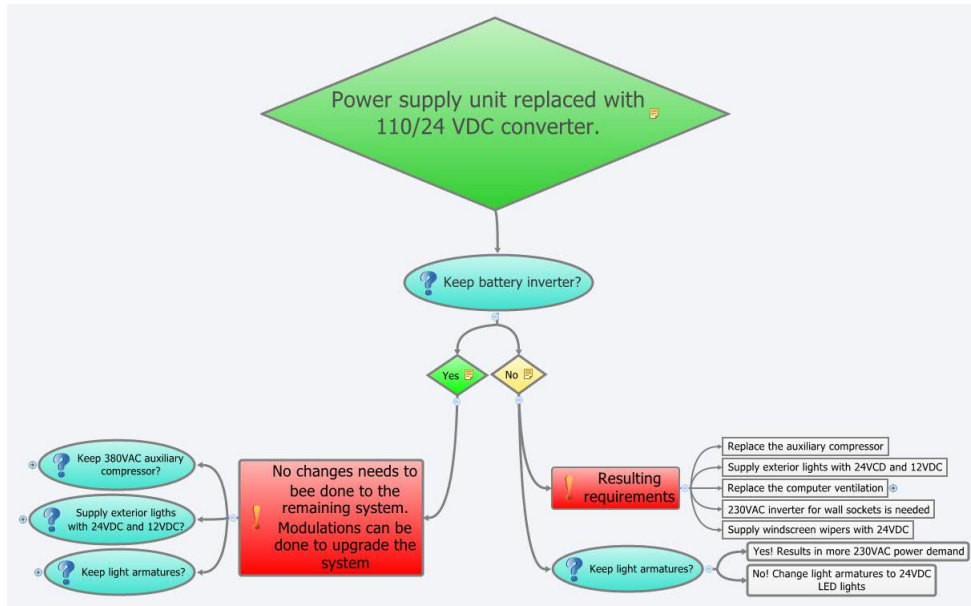


Figure 11: Process-scheme based on the priority list from section 5.2.1.3

110/24VDC converter in order to minimize the interference described in previous sections. Depending on if the battery inverter is removed two proposals for the electronic system is developed. The overview of the electronic system in section 3 reveals that there are many loads that are supplied with 24VDC or that could be supplied with 24VDC. Therefore the most natural selection would be to convert 110VDC down to 24VDC to supply most of the loads.

Another important aspect is that if the vital loads (TRACS computers, ATC etc.) are moved and removed from the battery inverter, one battery inverter would then be enough to supply the rest of the loads. Even during the startup sequence when the auxiliary compressor is running.

6.1 Proposal overview

Most of the loads in the original connection setup are either rated or are supplied with 24VDC. It is the most natural selection to convert 110VDC directly to 24VDC instead of inverting it to 380VAC and then rectify it down

to 24VDC. It is energy consuming and an unnecessary conversion that makes the power demand of the battery inverter higher.

6.2 Proposal 1

In this proposal, all the loads that are either rated or supplied with 24VDC. The converter needed for this operation is therefore a 110/24 DC-DC converter. The proposal also suggests that the battery inverter are to be removed and that a 110/230 DC-AC inverter is to be introduced. An overview of proposal 1 can be seen in figure 12 below. For more details regarding load

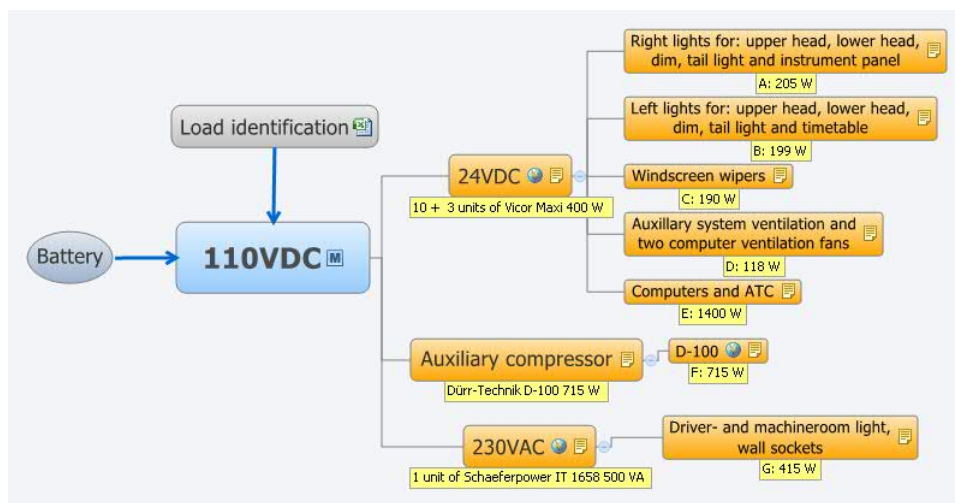


Figure 12: Overview of proposal 1

calculations, see appendix B. Depending on what voltage level the loads demand, it can be divided into different voltage level groups.

6.2.1 Loads connected to 110VDC

Since the voltage level 110VDC varies, the loads connected to it must be able to withstand its fluctuations. The only load connected directly to the 110VDC, in this proposal, is the auxiliary compressor.

6.2.1.1 Auxiliary compressor selection

According to section 3.7 the auxiliary compressor has the data seen in table 5. It would be a great benefit if the new compressor would have the same standards as the original compressor. If the standards were similar the installation would be a lot easier.

The new auxiliary compressor found was the D-100 from Dürr-Technik.

Table 5: Original auxiliary compressor data from section 3.7

Power rating	380 VAC
Power consumption	1100 W
Maximum pressure	8 bar
Maximum flow rate	110 l/min

Dürr-Technik is a German company who has its head office in Bietigheim-Bissingen near Stuttgart. According to Berndt Svensson⁵ the model D-061, which is a predecessor to the D-100, is in use of the more modern Regina trains. These trains are designed by Bombardier who are one of the world leading train manufacturer. Dürr-Technik have great experience in manufacturing rolling stock applications. Therefore the reliability of the new compressor is good. The data found on the new auxiliary compressor can be found in table 6. According to Berndt Svensson, despite the fact that

Table 6: The new auxiliary compressor data from appendix G

Power rating	110 VDC
Power consumption	715 W
Maximum pressure	8 bar
Maximum flow rate	100 l/min

the new compressor has lower maximum flow rate, than the original compressor, there should be no problems during the operation. Berndt Svensson explained that there should be no problem during the installation. For more details about the D-100 se appendix G.

6.2.1.2 Redundancy and galvanic isolation requirements

Since the new auxiliary compressor operates directly from the battery voltage the redundancy and galvanic isolation requirements are eliminated.

6.2.2 Loads connected to 24VDC

The power demand from the 24VDC loads can be found in appendix B. The total power demand from 24VDC are 2222W. By studying the redundancy priority in figure 10 and the redundancy section 5.1.2 with the galvanic isolation requirement from EUROMAINT AB (section 5.1.7), it is obvious that

⁵Berndt Svensson, Salesman for Dürr-Technik in Sweden, Nässjö: Conversation 14 Mars 2009

the TRACS computers and ATC loads should be separated from the other 24VDC loads that contain electric motors. It is a possibility that the electric motors may disturb the sensitive TRACS computer and ATC loads. From figure 10 it can be seen that there are totally five computer and ATC power outputs.

It has also been noticed that one of the outputs from the power supply unit has a voltage rating of -24VDC, see figure 6. This is done due to the fact that some electronic devices need 48VDC to operate.

6.2.2.1 Power supply unit loads

These loads are the TRACS computers and ATC that are vital for the function of the X2000 as discussed in section 3. The total load of the power supply unit is 1400W.

6.2.2.2 Other loads or the second power supply unit

These loads are exterior lights, windscreen wipers and different fans for ventilation, see figure 12 or study appendix B. The exterior lights need 12VDC to operate in half beam mode. The connection could therefore be setup in such a way as in the manoeuver wagon, see section 5.2.1.1. Otherwise the lights can be connected in parallel or in series depending on if full or half beam is wanted, see appendix K. The total load of the second power supply unit is 629W. The computer ventilation fans are now replaced with fans with similar properties. The new installed fans are of type BLDC and they are rated in such a way that the EMC-standards are fulfilled. The properties of the new fans are of equal magnitude compared with the original fans. See appendix I and H for further information.

6.2.2.3 Converter selection

The original power supply unit has five different outputs (see figure 6) where the outputs are rated 2x400W and 3x200W for a total of 1400W. According to Mats Palmberg⁶ due to logistical reasons it would be easier to have the same type of converter if a converter were to be replaced. Therefore the highest rated power output (400W) from the original rectifier will set the new power rated standard of the converter. The new power rated standard will therefore be 400W. The most important loads on the 24VDC are the TRACS computers and ATC. It is this load which will set the power rated standard for all 24VDC loads, due to logistical reasons.

⁶Mats Palmberg, Head of the X2000 Railcars: Conversation 11 Mars 2009

The Vicor Maxi Module á 400W is the perfect choice of operation. Vicor is an American cooperation who has its headquarters in Andover, Massachusetts. They operate worldwide and their components are used in a wide range of areas. Vicor provides a lot of detailed data sheets and are heavily tested for the railway industry (Vicor, 2009). The Vicor Maxi modules uses high frequency modulation to invert the voltage input. The voltage is then transformed through a transformer and then rectified to get the desired output. Since the Vicor Maxi module uses high frequency, the demand of the size of the transformer is lesser. With this transformer, the module provides galvanic isolation between the in- and output voltage. For more details on the functionality of the Vicor Maxi module study appendix E.

6.2.2.4 Redundancy requirement

For N+1 redundancy reasons each one of the TRACS computers and ATC loads are equipped with two Vicor Maxi á 400W modules. Since there are five power outputs, see figure 6 and every output needs N+1 redundancy the total amount of Vicor Maxi á 400W modules will be ten.

6.2.2.5 Galvanic isolation

In the original connection setup of the electronic system, the only loads that are purely galvanic separated are the AC and the DC loads. The question remains if the small electric motors will disturb the voltages to loads such as computers. It would therefore be the best solution to keep the ground of the TRACS computers, ATC and the second power supply loads separated, in such a way that each of these loads (TRACS computers, ATC and second power supply) has its own ground. That is, by not connecting these loads together through the chassis ground, the electrical interference will be minimized, see figure 14.

6.2.2.6 Load isolation and configuration

The TRACS computer loads will have common ground but the ATC ground will be separated from the TRACS computers, see figure 14. Other 24VDC loads such as the exterior lights will also have separated ground.

The Vicor modules are set up in such a way that the current through the modules are evenly shared among them, see figure 13. This means that the power demand from the loads are evenly spread through the modules connected to it. More power through a module means more heat dissipation, which means more losses and decreases the lifetime of the module. By sharing the current each module shares the power and thus less heat per module is required, hence longer lifetime per module. If current sharing is

not applied and two or more converter shares the load. The converter with the highest potential will provide the load with its demanded power. If the converter with the highest potential will fail, the other converter will start from zero to full conduction, resulting in a possible voltage dip. With current sharing the converter only have to go from half to full power in a scenario when having two converters and one fails. This results in a smoother power supply and thus a lower voltage dip. (Vicor, 2009, page 21)

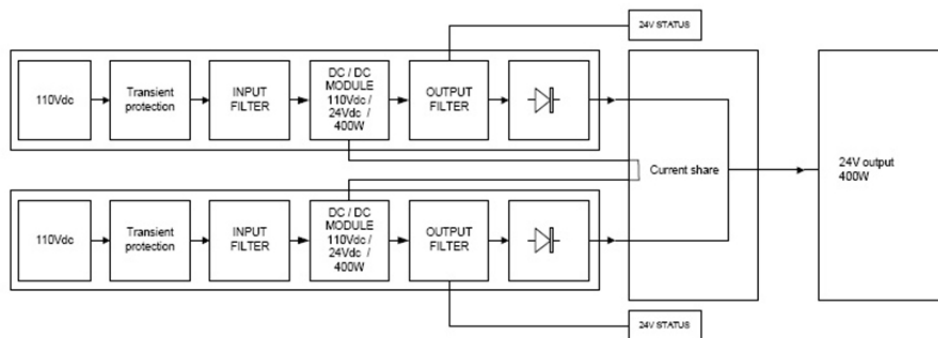


Figure 13: Current sharing by two Vicor Maxi modules á 400W

6.2.3 Loads connected to 230VAC

The loads connected to the inverter are drivers and machine room light plus two wall sockets. The total load of the inverter is 415W.

6.2.3.1 Inverter selection

The maximum power demand for 230VAC loads is 415W and the 230VAC wall socket is fused with 1 Ampere. Therefore the maximum power drawn is 415W or 415VA with no reactive power.

The Schaeferpower IT 1658 has a power rating of 500VA and is perfect for the wanted operation. Schaferpower is a German manufacturer who has its headquarters in Achern. Their main area of operation is within the railway industry and has been developing power electronic components since 1969. They have great documentation and their products are heavily tested for the railway industry, see appendix F. The IT 1658 uses PWM-technology to invert the the DC voltage into a pure sinusoidal output voltage. The voltage is then transformed through a transformer to the wanted 230VAC level and therefore provides galvanic isolation.

6.2.3.2 Redundancy requirement

There are no loads connected to 230VAC that are of high redundancy priority and the redundancy requirement for 230VAC loads are therefore eliminated, see section 5.1.2.

6.2.3.3 Galvanic isolation requirement

The neutral of the 230VAC system is isolated from the other grounds. Hence the 230VAC loads are galvanic separated from other voltage systems.

6.2.3.4 Load isolation and configuration

The 230VAC loads are totally isolated from other loads and the neutral will operate as the ground reference.

6.2.4 Electrical overview of proposal 1

As it can be seen in figure 14 the TRACS computers and ATC loads (A-E in the figure) are supplied with 10 vicor Maxi modules á 400W each. Other loads (F-J in the figure) such as computer ventilation, exterior lighting etc. are now supplied with three Vicor Maxi modules for 2/3 redundancy. If N+1 redundancy is wanted another module can be installed. The auxiliary compressor (K in the figure) is connected directly to the battery voltage and is running at 110VDC. As suggested, in section 6.2.2.5, the TRACS computers (A-D in figure 14) have ground ON33, the ATC (F) have ground ON35 and loads for the second power supply have ground ON32. These are all separated from one and other and are therefore galvanic separated from each other.

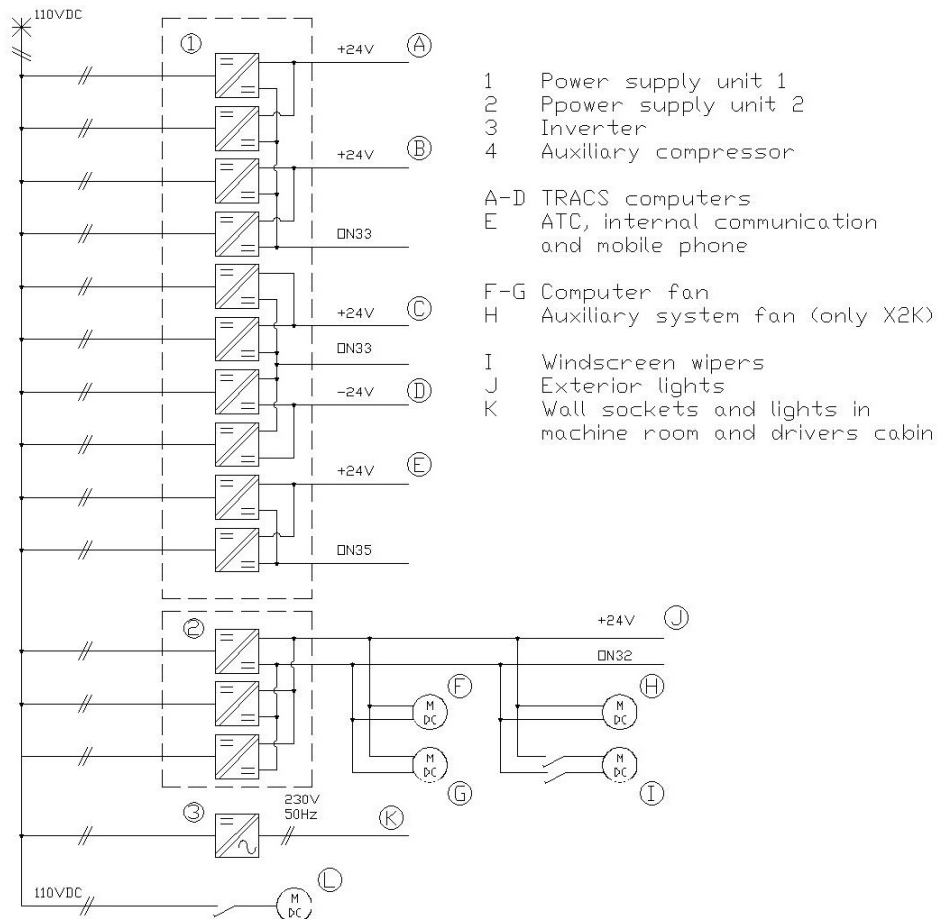


Figure 14: Electrical overview of proposal 1 for the electronic system

6.2.5 System contactor discussion

The selector switch that was used for battery inverter selection is removed. The contactors used for disconnection of the computers during the startup sequence is also removed. By eliminating these, the electronic system is now fully automatic and the maintenance cost for contactor replacement is removed. Safety breakers are obviously not removed.

6.2.6 Space discussion

The battery inverter and the old power supply unit are replaced with the new power supply unit with 13 Vicor Maxi modules that are mounted on a 19" rack. With old equipment removed and the new equipment installed a lot of space is gained in cubicle K12, see figure 15.

The transformer rack T7 contains transformers for the battery inverter, power supply unit and windscreen wiper. Since the new Vicor Maxi modules have integrated transformers all mentioned transformers above are removed, see figure 16.

6.2.7 Cable discussion

Cables on the secondary side for the power supply units, windscreen wipers and exterior lights can be reused. The cables for wall sockets and lights in machine and drivers room can also be reused. Cables that need to be modified are those that supply the new ventilation fans. Cables that need to be removed are all 380VAC cables. The new auxiliary compressor needs new cables for the 110VDC power supply. There will also be a need for new cables to the input of the power supply units.



Figure 15: Overview of cubicle K12 for Proposal 1

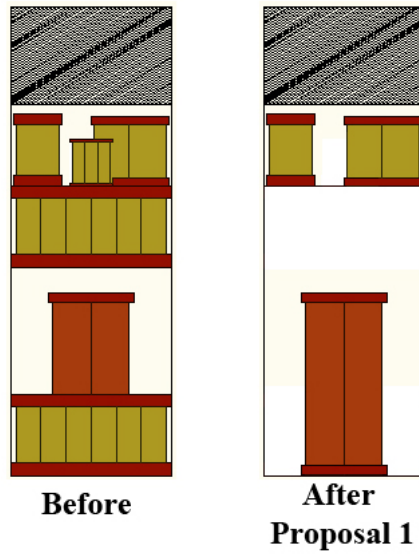


Figure 16: Overview of transformer rack T7 for Proposal 1

6.3 Proposal 2

The power supply unit is replaced with a 110/24 DC-DC converter. The rest of the system is still intact apart from the power supply unit contactors, which are removed. An overview of proposal 2 can be seen in figure 17 below. For details regarding load calculations, see appendix C. The loads can be

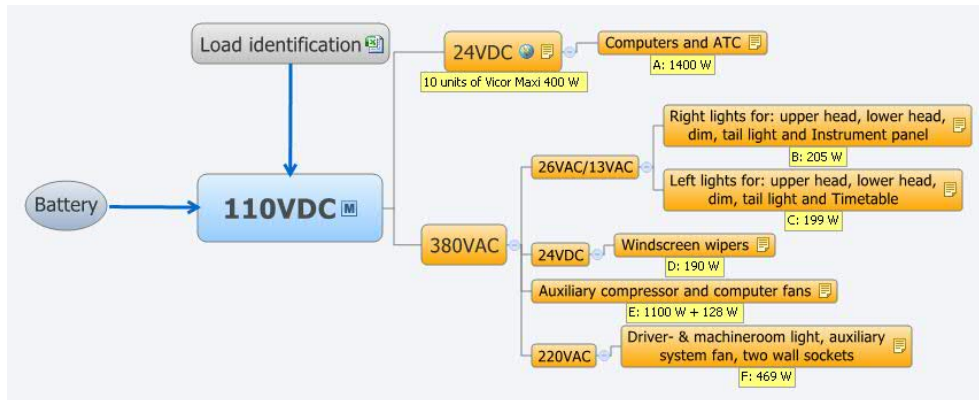


Figure 17: Overview of proposal 2

divided into different voltage level groups for which they are being used.

6.3.1 Loads connected to the battery inverter

The modification done from the original electronic system is that the power supply unit contactors are removed. The selector switch is not removed. There are no new or replaced loads.

6.3.1.1 380VAC phase to phase

There are no change done from the original electronic system. The loads supplied by 380VAC are still the auxiliary compressor and computer fans, see figure 17. The total power taken depends on if the train is in the startup sequence or in normal run mode. The total power taken during startup is 1228W due to the auxiliary compressor. The total power taken during normal run is 128W.

6.3.1.2 220VAC phase to neutral

There are also no change in the loads supplied by 220VAC. The loads supplied by 220VAC are lights in the machine room, lights in the drivers room, two wall sockets and one fan for the ventilation in the auxiliary system, see figure 17. According to the drivers instructions manual before startup there should be no equipment connected to the wall sockets (SJ, SJF 333.61 , 2008).

Therefore the maximum power taken during startup is 249W, see appendix C. However, when the train is connected to the power line and running normal, equipment may be connected to the wall sockets. Therefore the maximum power taken during normal run is 469W.

6.3.1.3 26VAC and 13VAC phase to ground

Compared with the original electronic system there are no changes done here. The loads are the exterior lights which are supplied with 26VAC or 13VAC depending on the type of wanted beam, see figure 17. All exterior lights connected to 26/13VAC should be turned off during startup, see (SJ, SJF 333.61 , 2008). The power taken during startup is therefore depended on the remaining loads connected. The remaining loads are panel lights, timetable lights and tail lights, see appendix C. Therefore the power taken during startup is total 124W. On the other hand, when the train is running normal the maximum power taken is 404W, see section 3.16 where the exterior lights modes are discussed. The voltage is galvanic isolated from 380VAC and is grounded on the secondary side.

6.3.1.4 24VDC

The supplied loads are the windscreen wipers. The windscreen wipers are turned off during startup, hence the power taken then is zero (SJ, SJF 333.61 , 2008). The windscreen wipers can however be turned on during normal run. The power taken has then a maximum of 190W, see appendix C.

6.3.1.5 Summarization of the power demand for the battery inverter

The maximum power demand for the battery inverter depends on if the X2000 is in a startup mode or running normal. Therefore a summarizing table can be done, see table 7. By following the drivers instruction manual

Table 7: Summarization of the power taken depending on which mode the X2000 is in

Voltage level	Power in startup	Power in normal
380VAC	1228W	128W
220VAC	249W	469W
26/13VAC	124W	404W
24VDC	0W	190W
ALL	1601W	1191W

before startup, the power demand is lesser than the rated power, 1800VA, for one battery inverter. The maximum power output during startup from one battery inverter is similar to the original maximum power output during startup at 1513W for one inverter. According to Mats Palmberg⁷, the battery inverter should have no problem to deliver this power at startup. During normal run the total power demand is lesser than during startup. Therefore one battery inverter is enough to supply the loads both during startup and at normal run, see appendix C for more information.

6.3.1.6 Redundancy requirement

As discussed in the previous section one battery inverter is enough to supply the loads during both startup and at normal run. This means that the battery inverters can be connected in such a way that automatic N+1 redundancy is set up for all loads connected to the battery inverter.

6.3.1.7 Galvanic isolation

All AC loads connected through the battery inverter are galvanic isolated from the rest of the system, including loads connected through the exterior light transformer. The 24VDC loads such as the windscreen wipers are also galvanic separated from the AC loads and from the power supply unit loads.

6.3.1.8 Load isolation and configuration

AC loads will have their own floating ground through the neutral and will be a system of its own. The 24VDC loads will also have a separated ground from the rest of the system.

6.3.2 Loads connected to 24VDC

The power unit connected directly to the battery voltage of 110VDC is the new power supply unit. The power supply unit consists of multiple 110/24 DC-DC converters.

6.3.2.1 Power supply unit loads

The loads connected to the new power supply unit are the TRACS computers and ATC, see figure 17. The supplied loads remains the same, compared with the original original electronic system. The power taken may differ depending on if the train is in startup mode or the running normal mode, but is neglected. The maximum taken power is 1400W.

⁷Mats Palmberg, Head of the X2000 Railcars: Conversation 27 April 2009

6.3.2.2 Converter selection

As discussed in section 6.2.2.3, the original power supply unit has five power outputs. Due to logistical reasons the new rated power standard will be 400W, per output. The Vicor Maxi Module á 400W is also used here for choice of operation and provides galvanic isolation from input versus output. For more functionality details read section 6.2.2.3 or study appendix E.

6.3.2.3 Redundancy requirement

As discussed for the redundancy requirements for Proposal 1, see 6.2.2.4 each one of the TRACS computers and ATC loads are equipped with two Vicor Maxi á 400W modules. There are totally five power outputs, see figure 6. Every output needs N+1 redundancy, thus the total amount of Vicor Maxi á 400W modules will be ten.

6.3.2.4 Galvanic isolation

The modules provide input to output galvanic isolation. The power supply unit loads have a separated ground from the rest of the electronic system, to minimize interference and the presence of ground currents.

6.3.2.5 Load isolation and configuration

The TRACS computers will have common ground but the ATC-ground will be separated from the computers, see figure 18. For configuration of the Vicor modules and current sharing see section 6.2.2.6 (or see Vicor, 2009, page 21).

6.3.3 Electrical overview of proposal 2

The TRACS computers and ATC loads (A-E in the figure) are supplied with 10 Vicor Maxi modules á 400W each, see figure 18. All other loads are connected through the battery inverter. With outputs A-E in the figure secured with double modules and the remaining loads provided with two battery inverters, all loads will have automatic N+1 redundancy. The selector switch is replaced with an automatic switch which only will be in use if the battery inverter in use will fail. The AC loads have a neutral and are galvanically separated from the rest of the system. The 24VDC loads are separated from one and other to eliminate possible disturbances. They will therefore be galvanic separated from one and other through ground ON33, ON35 and ON32 see figure 18.

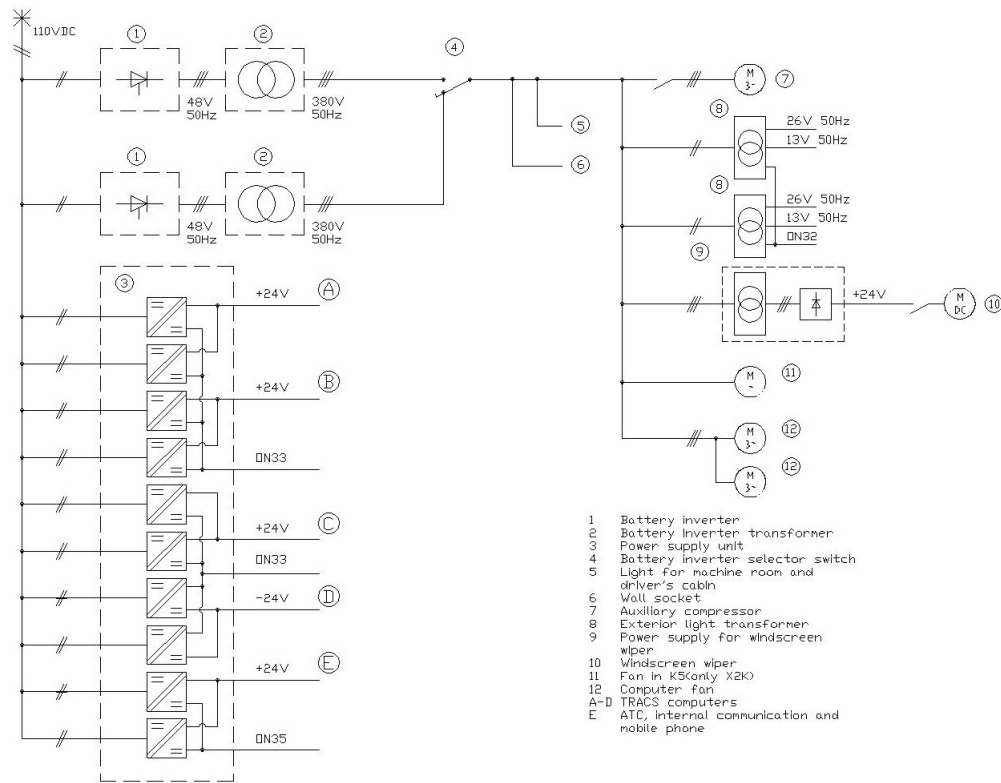


Figure 18: Electrical overview of proposal 2 for the electronic system

6.3.4 System contactor discussion

As in Proposal 1, the power supply unit contactors are removed. The selector switch is replaced with a automatic switch and thus certifying that Proposal 2 is fully automatic. Safety breakers are not removed.

6.3.5 Space discussion

The battery inverters are still intact, but the power supply unit is replaced with a new one. With the power supply unit replaced some space is gained in K12, see figure 19. Transformer rack T7 contains transformers for the old

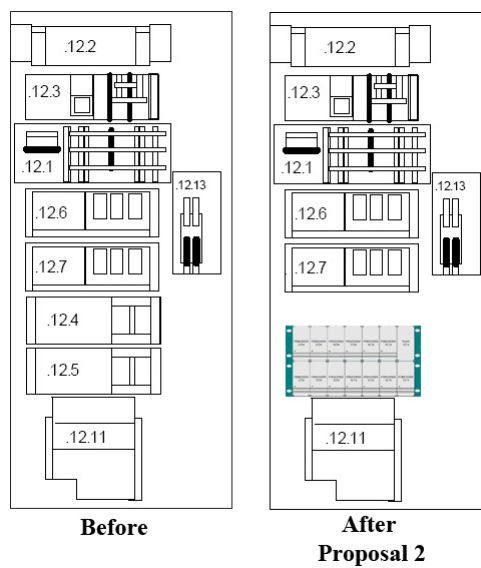


Figure 19: Overview of cubicle K12 for Proposal 2

power supply unit. The new power supply with Vicor Maxi modules have integrated transformers therefore the old power supply units transformer are removed, see figure 20.

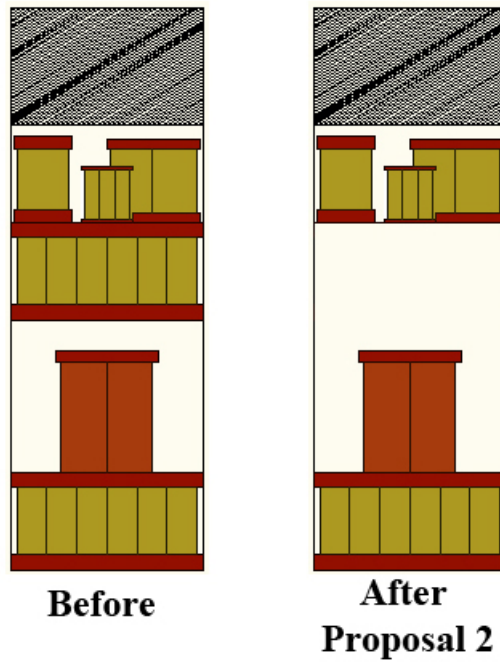


Figure 20: Overview of transformer rack T7 for Proposal 2

6.3.6 Cable discussion

The power supply unit output cables can be reused. The 380VAC input cables for the power supply unit are replaced with 110VDC cables. All other cables will be intact.

6.4 Other proposal discussion and possible improvements

Other proposals were discussed but most of them failed when comparing one and other. The option of simply replacing the battery inverter with a new one at 380VAC was discussed but the saved space was not of satisfaction. Most of the discussed inverters were of equal magnitude in volume and was therefore quickly dismissed. When discussing different proposals it was obvious that the auxiliary compressor load was of such a magnitude in power that the best proposal was to connect it directly to 110VDC. It was also realized that most of the taken power from the battery inverter was intended for 24VDC, hence the best solution was to convert 110VDC to 24VDC, see appendix A.

Other improvements for proposal 1 that could be done is the usage of light emitting diodes (LED) instead of the electric fittings that are used today in the machine and drivers room. This is a more modern installment and the LED has very low power consumption. Due to low power consumption it would not be a problem at all to connect it to the second power supply, see figure 14. However the market for smaller inverter than the one for proposal 1 barely exists (500VA). Therefore the installment seems unnecessary since the inverter would have no problem to deliver power to the two wall sockets and the lights in the machine and drivers cabin room.

6.5 Proposal comparison and discussion

Volume measurements were made and a comparison was done between the different proposals regarding power and volume for the original case and the proposals, see appendix D. The most interesting conclusion is that for both proposals the volume is decreased and at the same time the power output is increased. For proposal 1 the output power per volume is increased by 500%! For proposal 2 the gain is not as much but still an increase by 120%.

To apprehend and make the differences between the original setup of the electronic system and the proposals more subjectified a summarizing table was made, see appendix D. Here the differences are made very clear.

The lifetime of the battery inverter in the original electronic system was said to be at least 20-25 years⁸. Since that time has almost past the time left is somewhat uncertain. The mean time before failure (MTBF) for the new inverter in proposal 1 is 120000h and the MTBF for the new power supply unit is 330000h. It is practical to calculate the MTBF for electrical equipment based on the hours of use in a X2000. According to Mats Palm-

⁸Mats Palmberg, Head of the X2000 Railcars: Conversation 11 Mars 2009

berg⁹ it is a rule of thumb to estimate the daily use of an X2000 for 12 hours. This would correspond to a MTBF of 27 years for the inverter and 75 years for the new power supply. The purpose of proposal 2 is to double the lifetime of the battery inverter by only running one of the two available, until the one in use fails.

According to Mats¹⁰ there where no attention taken to electromagnetic capability when the X2000 was constructed. Therefore there are no tests that satisfies the EMC standards. The new introduced equipment in proposal 1 will fulfill the EMC standards (Vicor, 2009, page 19-20) and be well tested for train applications (Vicor, 2009).

The table from appendix D shows that proposal 1 is by far the best solution for X2000, while proposal 2 is more of a light version of proposal 1 where focus has been on reducing the interference.

⁹Mats Palmberg, Head of the X2000 Railcars: Conversation 14 April 2009

¹⁰Mats Palmberg, Head of the X2000 Railcars: Conversation 21 April 2009

7 Conclusions

The variety of desired voltage levels contributes to a very complicated electrical system in the railcar with many different power systems. The electronic system is an relatively old system which probably has been expanded when the need for a new voltage level existed. It is unnecessary complex and the design lacks the wish for thoughtfulness. Connecting sensitive loads with electrical engines might contribute to the problems that the X2000 has today. There are also no error indication for the power supply unit today and no total redundancy in the system.

By separating the vital TRACS computers from the rest of the system and with new BLDC technology, for motor drives, the amount of interference could be minimized in such a way that the desired voltage stability are fulfilled. The given proposals deliver a new electronic system with total redundancy and error indication. With the advancement of transistors the power units can be more integrated and therefore be of less volume. By installing the new power supply unit one can remove much of the old units and hence space is gain for further installations. The EMC standards of the electronic system today, do not exist. The new units will be classified with EMC standards given for rolling stock applications. Proposal one will, without a doubt, contribute to an uncomplicated system that is by far much more easier to troubleshoot with better maintenance properties.

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8 Appendix

A Load calculations and specifications for the original setup

Load identification and description.						
Article	Voltage (V)	AC/DC	Frequency (Hz)	Description	Power rating (W)	Power efficiency
Instrument panel lights	26	AC	50	A	40	0.75
Upper head light right	26	AC	50	A	70	0.75
Lower head light right	26	AC	50	A	70	0.75
Dim light right	26	AC	50	A	70	0.75
Dim light left	26	AC	50	A	70	0.75
Turnable light driver	26	AC	50	B	12	0.75
Turnable light assistant	26	AC	50	B	12	0.75
Turnable light box	26	AC	50	B	5	0.75
Turnable light box	26	AC	50	B	5	0.75
Upper head light left	26	AC	50	B	70	0.75
Dim light left	26	AC	50	B	70	0.75
Tail light left	26	AC	50	B	25	0.75
Windscreen wiper 1	24	DC		C	50	0.7125
Windscreen wiper 2	24	DC		C	45	0.7125
Windscreen wiper 3	24	DC		C	45	0.7125
Power Supply Unit output A	24	DC		D	400	0.7125
Power Supply Unit output B	24	DC		D	200	0.7125
Power Supply Unit output C	24	DC		D	200	0.7125
Power Supply Unit output D	24	DC		D	400	0.7125
Power Supply Unit output E	24	DC		D	400	0.7125
Computer fan	380	AC	50	E	64	0.75
Computer fan	380	AC	50	E	64	0.75
Auxiliary compressor	380	AC	50	E	1100	0.75
Auxiliary system fan	220	AC	50	F	64	0.75
Drivers cabin lights	220	AC	50	F	50	0.75
Two wall socket machine, driver	220	AC	50	F	220	0.75
Group Explanation						
Group A	Right lights: headlight (high & low beam), dim and tail light and instrument & panel light					
Group B	Left lights: headlight (high & low beam), dim and tail light and instrument & panel light					
Group C	Windscreen wiper					
Group D	Computers and A/C					
Group E	Auxiliary compressor and computer fans					
Group F	Machine room lights, drivers cabin lighting, expresspackage lighting, two wall sockets, auxiliary system fan					
Maximum power distribution						
Group	Maximum power at start up (W)	Percentage of total at start up (%)	Maximum power during normal run (W)	Percentage of total during normal run (%)		
A+B (2x13 VAC) *	404	10.35	404	15.59		
C (24 VDC)	190	5.15	190	7.33		
D (380 VAC)	1668	43.21	1668	64.61		
E (220 VAC)	1228	31.21	1228	47.81		
F (220 VAC)	469	12.71	469	18.10		
Total	3691	100.00	2591	100.00		
* All head lights can not be ON at once						
Maximum power consumption with redundancy						
Group	Maximum power during start up (operating instructions)	Maximum power during normal run				
Battery Inverter 1	1492.5	1492.5				
Battery Inverter 2	1508.5	1508.5				
Total	3001	2991				
Maximum power input due to losses during normal run						
Group	Total input power (W)	Percentage of total				
A+B (2x13 VAC) *	538.67	15.10				
C (24 VDC)	266.67	7.48				
D (380 VAC)	1964.91	55.10				
E (220 VAC)	1626.33	45.92				
F (220 VAC)	626.33	17.53				
Total	3566.25	100.00				
* All head lights can not be ON at once						
System properties						
	Total volume* (dm ³)	178.23				
	Maximum power output* (W)	3600				
	Total weight** (kg)	106				
** The barometers are estimated through data and dimensions.						
*** The barometers are estimated through data and dimensions.						
**** Weight is estimated through data on the equipment.						

Figure 21: Load calculations for the original setup

C Load calculations and specifications for Proposal 2

Load identification and descriptions.									
Article	Voltage (V)	AC/DC	Frequency (Hz)	Description	Power rating (W)	Lowest efficiency	Available	Note	
Power Supply Unit output A	24	DC	400	A	1400	0.82	G1	Power rating on the feeding gear (continuant)	
Power Supply Unit output B	24	DC	400	B	1400	0.82	G1	Power rating on the feeding gear (continuant)	
Power Supply Unit output C	24	DC	400	A	1400	0.82	G1	Power rating on the feeding gear (continuant)	
Power Supply Unit output D	24	DC	400	A	1400	0.82	G1	Power rating on the feeding gear (continuant)	
Power Supply Unit output E	24	DC	400	A	1400	0.82	G1	Power rating on the feeding gear (continuant)	
Instrumentation lights	24	AC	50	B	48	0.75	SA 1.1	Rated voltage 24V DC. Item on 13V at half light.	
Upper head light right	26	AC	50	B	70	0.75	SA 1.1	Rated voltage 24V DC. Item on 13V at half light.	
Lower head light right	26	AC	50	B	70	0.75	SA 1.1	Rated voltage 24V DC. Item on 13V at half light.	
Upper head light left	26	AC	50	B	70	0.75	SA 1.1	Rated voltage 24V DC. Item on 13V at half light.	
Lower head light left	26	AC	50	B	70	0.75	SA 1.1	Rated voltage 24V DC. Item on 13V at half light.	
Tail light right	26	AC	50	B	25	0.75	SA 1.1	Rated voltage 24V DC	
Tail light left	26	AC	50	B	12	0.75	SA 1.1	Rated voltage 24V DC	
Immuable light driver	26	AC	50	C	5	0.75	SA 1.1	Rated voltage 24V DC	
Immuable light driver (continuant)	26	AC	50	C	5	0.75	SA 1.1	Rated voltage 24V DC	
Immuable light box	26	AC	50	C	5	0.75	SA 1.1	Rated voltage 24V DC	
Upper head light bulb	26	AC	50	C	70	0.75	SA 1.1	Rated voltage 24V DC. Supplied with 13V at half light.	
Lower head light bulb	26	AC	50	C	70	0.75	SA 1.1	Rated voltage 24V DC. Supplied with 13V at half light.	
Dim light left	26	AC	50	C	70	0.75	SA 1.1	Rated voltage 24V DC	
Dim light right	26	AC	50	C	70	0.75	SA 1.1	Rated voltage 24V DC	
Tail light left	26	AC	50	C	25	0.75	SA 1.1	Rated voltage 24V DC	
Tail light right	26	AC	50	C	25	0.75	SA 1.1	Rated voltage 24V DC	
Windscreen wiper 1	24	DC	45	D	45	0.125	SA 1.1	24VDC	
Windscreen wiper 2	24	DC	45	D	45	0.125	SA 1.1	24VDC	
Computer fan	500	AC	50	E	64	0.75	SA 1.1	24VDC	
Support compressor	380	AC	50	E	64	0.75	SA 1.1	24VDC	
Support compressor (continuant)	380	AC	50	E	64	0.75	SA 1.1	24VDC	
Drivers room lights	220	AC	50	F	50	0.75	C.3.1	15 tubes at 9W	
Two wall socket	220	AC	50	F	50	0.75	C.3.1	2 tubes at 25W	
Insulating system fan	220	AC	50	F	14	0.75	SA 1.1	1A fans for both	
								Power rating estimated	
Group Explanation									
Group A	Compressor, VIC, dim and other								
Group B	Right lights, headlight high & low beam, dim and tail light and instrument & posalight								
Group C	Left lights, headlight high & low beam, dim and tail light and immuable lights								
Group D	Windscreen wiper and computer fan								
Group E	Light for Machine room, drivers cabin, expresspackage, Auxiliary system fan and wall sockets.								
Group F	Light for Machine room, drivers cabin, expresspackage, Auxiliary system fan and wall sockets.								
Maximum power identification									
Group	Maximum power at startup (W)	Percentage at startup (%)	Maximum power at startup (drivers instruction manual) (W)	Percentage at startup (drivers inst. Man.) (%)	Maximum power during normal run (W)	Percentage of total during normal run (%)			
A (EA VAC)	1400	37.53	1400	46.55	1400	54.03			
B (AO VAC)	48	1.25	48	1.47	48	1.73			
C (AO VAC)	194	5.15	194	6.06	194	7.23			
D (AO VAC)	1228	33.27	1228	40.52	1228	44.94			
E (BB VAC)	489	13.71	489	15.30	489	17.50			
F (BB VAC)	3891	10.68	3891	12.56	3891	13.99			
* All head lights can not be ON at once									
Maximum power limit vs losses during normal run									
Group	Maximum power (W)	Percentage of total							
A (EA VAC)	1707.32	51.68							
B (AO VAC)	538.67	16.28							
C (AO VAC)	210.87	6.34							
D (BB VAC)	170.87	5.16							
E (BB VAC)	625.33	18.90							
F (BB VAC)	3086.65	93.65							
* All head lights can not be ON at once									
Maximum power consumption and unit determination with redundancy									
Group	Maximum power during start up (W)	Maximum power during start up (drivers instruction manual) (W)	Maximum power during normal run (W)	No. of devices	Unit type				
A (AO VAC)	1400	1400	1400	1400	Vicor Max				
B (AO VAC)	48	48	48	1191	As before				
C (AO VAC)	194	194	194	1191	As before				
* All head lights can not be ON at once									
Vicor 119W Input Max I Family									
Name	Power rating (W)	Max. input power (W)	Max. input power (W)	Max. input power (W)	Max. input power (W)				
Power rating (W)	119	119	119	119	119				
Max. input power (W)	119	119	119	119	119				
No. of units	10	10	10	10	10				
No. group A	0	0	0	0	0				
No. group B	0	0	0	0	0				
No. group C	0	0	0	0	0				
No. group D	0	0	0	0	0				
No. group E	0	0	0	0	0				
No. group F	0	0	0	0	0				
Data sheet									
Total power Group A	4000								
Total power Group B	0								
Total power Group C	0								
Total power Group D	0								
Total power Group E	0								
Total power Group F	0								
Total power (W)	4000								
* Unit is 4.75 x 1.18 x 1.65 mm 117 x 56 x 13.7									
*** http://www.vicorpower.com/documents/datasheet/tdp_119w-max-family.pdf									

Figure 23: Load calculations for proposal 2

D Original and proposal comparison

Power and volume comparison: Original vs Proposal 1				
	Original	Proposal 1	Increase/Decrease	Increase/Decrease in percentage
Maximum power input (normal run) (W)	3566	3088	-478	-13%
Total rated power (W)	3600	5700	2100	58%
Volume (dm ³)	178	47	-131	-74%
Total rated power per volume W/dm ³	20	121	101	500%
Power and volume comparison: Original vs Proposal 2				
	Original	Proposal 2	Increase/Decrease	Increase/Decrease in percentage
Maximum power input (normal run) (W)	3566	3309	-258	-7%
Total rated power (W)	3600	5800	2200	61%
Volume (dm ³)	178	130	-48	-27%
Total rated power per volume W/dm ³	20	44	24	120%
Power and volume comparison: Proposal 2 vs Proposal 1				
	Proposal 2	Proposal 1	Increase/Decrease	Increase/Decrease in percentage
Maximum power input (normal run) (W)	3309	3088	-221	-7%
Total rated power (W)	5800	5700	-100	-2%
Volume (dm ³)	130	47	-83	-64%
Total rated power per volume W/dm ³	44	121	77	173%
Comparison of original and proposals				
	Original	Proposal 1	Proposal 2	
Automatical redundancy	No	Yes	Yes	
Error indication for power supply unit	No	Yes	Yes	
Error indication for power inverter unit	Yes	Yes	Yes	
Number of voltage levels (110VDC excluded)	5	2	5	
Electromechanical contactors	Yes	No	Yes	
Fulfill EMC standards	No	Yes	No	
Volume	178 dm ³	47 dm ³	130 dm ³	
Maximum power output	3600	5700	5800	
W/dm ³	20	121	44	
Weight	~106 kg	<35 kg	<85 kg	
Computer & other loads separation	No	Yes	Yes	
MTBF for power supply unit	N/A	330000 h	330000 h	
MTBF for power inverter unit	N/A	120000 h	N/A	

Figure 24: Original and proposal comparison

E Vicor Maxi Module

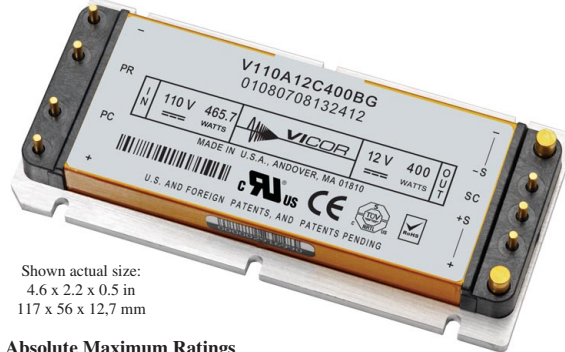


Data Sheet 110V Input Maxi Family DC-DC Converter Module



Features

- DC input range: 66 – 154 V (continuous)
- Encapsulated circuitry for shock and vibration resistance
- Extended temperature range (-55 to +100°C)
- Input surge withstand: 250 V for 100 ms
- DC output: 3.3 – 48 V
- Programmable output: 10 to 110%
- Regulation: ±0.2% no load to full load
- Efficiency: Up to 90%
- Maximum operating temp: 100°C, full load
- Power density: up to 80 W per cubic inch
- Height above board: 0.43 in. (10.9 mm)
- Parallelable, with N+M fault tolerance
- Low noise ZCS/ZVS architecture
- RoHS Compliant (with F or G pin option)
- Agency approvals



Shown actual size:
4.6 x 2.2 x 0.5 in
117 x 56 x 12.7 mm

Product Overview

These DC-DC converter modules use advanced power processing, control and packaging technologies to provide the performance, flexibility, reliability and cost effectiveness of a mature power component. High frequency ZCS/ZVS switching provides high power density with low noise and high efficiency.

Applications

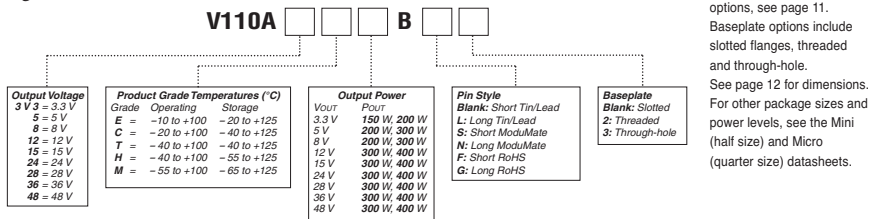
Railway/Transportation system applications including communications systems, information display, lighting, control systems, ticket machines, passenger entertainment, public address systems, door control, industrial power systems and power generation systems.

Absolute Maximum Ratings

Parameter	Rating	Unit	Notes
+In to -In voltage	-0.5 to +260	Vdc	
PC to -In voltage	-0.5 to +7.0	Vdc	
PR to -In voltage	-0.5 to +7.0	Vdc	
SC to -Out voltage	-0.5 to +1.5	Vdc	
-Sense to -Out voltage	1.0	Vdc	
Isolation voltage			
in to out	3000	Vrms	Test voltage
in to base	1500	Vrms	Test voltage
out to base	500	Vrms	Test voltage
Operating Temperature	-55 to +100	°C	M-Grade
Storage Temperature	-65 to +125	°C	M-Grade
Pin soldering temperature	500 (260)	°F (°C)	<5 sec; wave solder
	750 (390)	°F (°C)	<7 sec; hand solder
Mounting torque	5 (0.57)	in-lbs (N-m)	6 each

Part Numbering

e.g. V110A24C400BL



MODULE FAMILY ELECTRICAL CHARACTERISTICS

Electrical characteristics apply over the full operating range of input voltage, output load (resistive) and baseplate temperature, unless otherwise specified. All temperatures refer to the operating temperature at the center of the baseplate.

■ MODULE INPUT SPECIFICATIONS

Parameter	Min	Typ	Max	Unit	Notes
Operating input voltage	66	110	154	Vdc	EN50155
Input surge withstand			250	Vdc	<100 ms
Undervoltage turn-on		64	65.4	Vdc	
Undervoltage turn-off	54	56		Vdc	
Overvoltage turn-off/on	155.5	161.7	169.4	Vdc	
Disabled input current			1.3	mA	PC pin low

■ MODULE OUTPUT SPECIFICATIONS

Parameter	Min	Typ	Max	Unit	Notes
Output voltage setpoint			±1	% Vout nom.	Nominal input; full load; 25°C
Line regulation	±0.02		±0.20	%	Low line to high line; full load
Temperature regulation	±0.002		±0.005	% / °C	Over operating temperature range
Power sharing accuracy		±2	±5	%	10 to 100% of full load
Programming range	10		110	%	Of nominal output voltage. For trimming below 90% of nominal, a minimum load of 10% of maximum rated power may be required.
+Out to -Out, +Sense to -Out – Absolute Maximum Ratings					
3.3 V			-0.5 to 4.7	Vdc	Externally applied
5 V			-0.5 to 7.0	Vdc	Externally applied
8 V			-0.5 to 10.9	Vdc	Externally applied
12 V			-0.5 to 16.1	Vdc	Externally applied
15 V			-0.5 to 20.0	Vdc	Externally applied
24 V			-0.5 to 31.7	Vdc	Externally applied
28 V			-0.5 to 36.9	Vdc	Externally applied
36 V			-0.5 to 47.4	Vdc	Externally applied
48 V			-0.5 to 62.9	Vdc	Externally applied

Note: For important information relative to applications where the converter modules are subject to continuous dynamic loading, contact Vicor applications engineering at 800-927-9474.

■ THERMAL RESISTANCE AND CAPACITY

Parameter	Min	Typ	Max	Unit
Baseplate to sink; flat, greased surface		0.08		°C/Watt
Baseplate to sink; thermal pad (P/N 20265)		0.07		°C/Watt
Baseplate to ambient		4.9		°C/Watt
Baseplate to ambient; 1000 LFM		1.1		°C/Watt
Thermal capacity		165		Watt-sec/°C

MODULE FAMILY ELECTRICAL CHARACTERISTICS (CONT.)

■ **MODULE CONTROL SPECIFICATIONS**

Parameter	Min	Typ	Max	Unit	Notes
PRIMARY SIDE (PC = Primary Control; PR = Parallel)					
PC bias voltage	5.50	5.75	6.00	Vdc	PC current = 1.0 mA PC voltage = 5.5 V
current limit	1.5	2.1	3.0	mA	
PC module disable	2.3	2.6	2.9	Vdc	Must be able to sink ≥4 mA. See Fig. 1
PC module enable delay		4	7	ms	
PC module alarm			0.5	Vavg	UV, OT, module fault. See Figs. 2 and 4
PC resistance	0.9	1.0	1.1	MΩ	See Fig. 2
PR emitter amplitude	5.7	5.9	6.1	Volts	PR load >30 Ω, <30 pF
PR emitter current	150			mA	
PR receiver impedance	375	500	625	Ω	25°C
PR receiver threshold	2.4	2.5	2.6	Volts	Minimum pulse width: 20 ns
PR drive capability			12	modules	Without PR buffer amplifier
SECONDARY SIDE (SC = Secondary Control)					
SC bandgap voltage	1.21	1.23	1.25	Vdc	Referenced to –Sense
SC resistance	990	1000	1010	Ω	
SC capacitance		0.033		μF	
SC module alarm		0		Vdc	With open trim; referenced to –Sense. See Fig. 6

■ **MODULE GENERAL SPECIFICATIONS**

Parameter	Min	Typ	Max	Unit	Notes
Remote sense (total drop)			0.5	Vdc	0.25 V per leg (senses must be closed)
Isolation test voltage					
in to out	3000			Vrms	Complies with reinforced insulation requirements
in to base	1500			Vrms	Complies with basic insulation requirements
out to base	500			Vrms	Complies with operational insulation requirements
Isolation resistance (in to out)		10		MΩ	
Weight	7.4 (209.3)	8.2 (232.5)	9.0 (255.7)	ounces (grams)	
Temperature limiting	100	115		°C	See Figs. 2 and 4
Agency approvals		cURus, TÜV, CE			UL60950-1, EN60950-1, CSA60950-1, IEC60950-1. With appropriate fuse in series with the +Input

Note:
Specifications are subject to change without notice.

■ MODULE SPECIFIC OPERATING SPECIFICATIONS

24 Vout, 400 W (e.g. V110A24C400BL)

Parameter	Min	Typ	Max	Unit	Notes
Efficiency	85.6	86.6		%	Nominal input; full load; 25°C
Ripple and noise		140	175	mV	p-p; Nominal input; full load; 20 MHz bandwidth
Output OVP setpoint	27.1	28.1	29.1	Volts	25°C; recycle input voltage to restart (>100 ms off)
Dissipation, standby		14.6	15.4	Watts	No load
Load regulation		±0.02	±0.2	%	No load to full load; nominal input
Load current	0		16.67	Amps	
Current limit	17	19.2	22.6	Amps	Output voltage 95% of nominal
Short circuit current	11.6	19.2	22.6	Amps	Output voltage <250 mV

24 Vout, 300 W (e.g. V110A24C300BL)

Parameter	Min	Typ	Max	Unit	Notes
Efficiency	87.5	88.9		%	Nominal input; full load; 25°C
Ripple and noise		195	244	mV	p-p; Nominal input; full load; 20 MHz bandwidth
Output OVP setpoint	27.1	28.1	29.1	Volts	25°C; recycle input voltage to restart (>100 ms off)
Dissipation, standby		7.9	10.3	Watts	No load
Load regulation		±0.02	±0.2	%	No load to full load; nominal input
Load current	0		12.5	Amps	
Current limit	12.7	14.4	16.9	Amps	Output voltage 95% of nominal
Short circuit current	8.75	14.4	16.9	Amps	Output voltage <250 mV

28 Vout, 400 W (e.g. V110A28C400BL)

Parameter	Min	Typ	Max	Unit	Notes
Efficiency	87	87.7		%	Nominal input; full load; 25°C
Ripple and noise		160	200	mV	p-p; Nominal input; full load; 20 MHz bandwidth
Output OVP setpoint	31.5	32.7	33.9	Volts	25°C; recycle input voltage to restart (>100 ms off)
Dissipation, standby		14.4	15.4	Watts	No load
Load regulation		±0.02	±0.2	%	No load to full load; nominal input
Load current	0		14.28	Amps	
Current limit	14.5	16.4	20	Amps	Output voltage 95% of nominal
Short circuit current	10	16.4	20	Amps	Output voltage <250 mV

28 Vout, 300 W (e.g. V110A28C300BL)

Parameter	Min	Typ	Max	Unit	Notes
Efficiency	86.7	87.7		%	Nominal input; full load; 25°C
Ripple and noise		225	282	mV	p-p; Nominal input; full load; 20 MHz bandwidth
Output OVP setpoint	31.5	32.7	33.9	Volts	25°C; recycle input voltage to restart (>100 ms off)
Dissipation, standby		10.9	11.8	Watts	No load
Load regulation		±0.02	±0.2	%	No load to full load; nominal input
Load current	0		10.71	Amps	
Current limit	10.9	12.3	14.5	Amps	Output voltage 95% of nominal
Short circuit current	7.49	12.3	14.5	Amps	Output voltage <250 mV

F Schaefer - IT 1658

IT 1658 - DC/AC inverter



Input	Nominal voltage	110 VDC
	Voltage range	(80 - 160) V DC
	no load input power	7 W
	input protection	with external fuse (rating 16A)
	input fuse	16 A
	bursts	acc. to EN 61000-4-4 (level 3)
	High energy pulses (surge)	acc. to EN 61000-4-5 (level 3)
Output	Nominal voltage	230 VAC
	max. current output 1	2,00 A
	Power	500,0 VA
	softstart	100 ms
	turn on rise time	1 ms typic
	response time	1 ms typic
	Efficiency	81 %
	control	IU characteristic
	line regulation ($\pm 10\%$)	2%
	load regulation (10-90%)	1% typ., 3% max
	waveform	true sinewave
	output frequency	50 / 60 / 400 Hz crystal stabilized Hz
	distortion	3% typical
	surge power	2 x Pnom for 1 sec. W
	crest factor	approx. 3
	output power factor	cos phi \geq 0.7 inductive/capacitive
	ripple	< 1,5%
short circuit protected	standard	
overload protection	current limited to 105 - 110% of full load	
remote sensing	optional	
General	temperature coefficient	0.02% / °C typical
	operating temperature	-20°C to +75°C (optional: -40°C to +75°C)
	load derating	2.5% / °C from +55°C
	storage temperature	-40°C to +85°C
	cooling	natural convection
	switching frequency	approx. 20 kHz
	isolation resistance	> 10M Ohm at 500 VDC
	isolation (input - ground)	3500,0 VDC
	isolation (output - ground)	3500,0 VDC
	isolation (input - output)	3500,0 VDC
	isolation voltage	acc. to EN 60950, class 1 (SELV ask factory)
	safety	acc. to EN 60950, class 1
	crepage distance	acc. to VDE 0110, \geq 4mm
	air distance	acc. to VDE 0110, \geq 3mm
	earth leakage	< 3.5mA at 230 VAC, acc. to EN 60950
	EMC emission	acc. to EN 55022 class A, optionally class B
	EMC immunity	acc. to EN 55022 class A, optionally class B
	dimensions	[H x W x D], 6U x 42 TE x 160mm, (6,3inch)
	weight	12 kg/ 26,5 lb
	CE marking	yes
	MTBF	approx. 120000h
	connector	H 15 / F24 + H7 (DIN 41612)



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Page 1/3

Reliability is our strength

Oil-free compressor solutions for
railway applications



Hightech for the Highest Demands

DÜRR TECHNIK is your specialist for oil and maintenance free piston compressors. Meeting the highest demands of reliability, precision and durability. Original equipment suppliers have been utilising our high-quality and compact product solutions for many years.

Oil-free auxiliary compressor applications for railway vehicles:

• **Raising the pantograph**



• **Sanding installations**



- **Wheel flange lubrication**
- **Support for the braking system**
- **Toilets**
- **Sand Filling Systems**

Innovative oil-free compressor technology with key advantages:

- **Oil and problem free**, ensures a perfect operation of all components. Maintenance is almost unnecessary.
- **Low LCC**, no oil changing, and the use of high-quality materials assures minimal wear and an above average lifetime.
- **Extremely reliable**, robust design of the components all tested under extreme conditions.
- **QS Management System** Certified according to DIN EN ISO 9001:2000.

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For raising the pantograph we manufacture auxiliary air supply packages. Consisting of an oil-free compressor, dryer, purge tank, magnetic valve and fittings completely mounted on a base plate.

Our specialists also design and build tailor-made system solutions to meet individual customer requirements.



COMPRESSORS WITH DC-MOTOR									
Type	Free air flow at 0 bar (l/min)	Nominal Pressure PN (bar)	Noise level dB (A)	Protection class (IP)	Motor input P ₁ (W)	Rating data Current consumption (A)	Voltage (V)	Weight (kg)	Dimensions LxWxH (mm)
D-040	40	7	61	20	192	17.5	12 DC	6.0	242x121x175
D-061	61	7	69	54	500	21	110 DC	7.3	245x133x190
D-100	100	8	68	54	715	6.5	110 DC	20.5	368x176x292
D-105	105	7	71	44	800	7.5	110 DC	12	350x255x225
DG-180	180	2	69	56	1100	46	24 DC	16	392x276x157

1 or 3 phase motors as well as alternative voltages with DC motors are available on request.

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H ebmpapst - W1G200HH7752

QG030-198/14

DC tangential blower
forward curved



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Nominal data

Type	QG030-198/14	
Nominal voltage	[VDC]	24
Power input	[W]	8,0
Min. ambient temperature	[°C]	-20
Max. ambient temperature	[°C]	60
Air flow	[m³/h]	100
Sound pressure level	[dB(A)]	51

mi = max. load · ma = max. efficiency · ffa = running at free air · cs = customer specs · cu = customer unit
Subject to alterations

QG030-198/14

DC tangential blower

forward curved

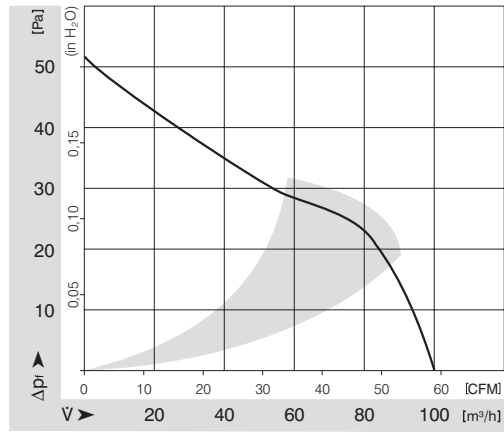
Technical features

General description	Cross flow fan with high air flow. Large outflow surface. Electronic commutation completely integrated.
Locked-rotor protection	Blocking and overload protection
Direction of protection	Right, looking at rotor
Note	Tangential fans are suitable for operation at high air flow and low counterpressure only.
Bearing	Motor with ball bearing system. Impeller bracket with sliding bearings.
Lifetime L10 at 40 °C	30000 h
Lifetime L10 at maximum temperature	10000 h
Mass	0.290 kg
Housing material	Aluminum, housing side parts of plastic.
Material of impeller	Aluminum
Motor protection	Protected against reverse polarity and locking.
Approval	VDE, CSA, UL, CE

QG030-198/14

DC tangential blower
forward curved

Charts: Air flow



I ebmpapst - QG030-198/14

W1G200-HH77-52

EC axial compact fan



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info1@de.ebmpapst.com

Nominal data

Type	W1G200-HH77-52	
Motor	M1G074-BF	
Nominal voltage	[VDC]	24
Nominal voltage range	[VDC]	16 .. 28
Type of data definition		rfa
Speed	[min ⁻¹]	2950
Power input	[W]	55
Current draw	[A]	2,6
Max. ambient temperature	[°C]	60
Air flow	[m ³ /h]	1090
Back pressure	[Pa]	0

nt = max. load · ne = max. efficiency · rfa = running at free air · cs = customer specs · cu = customer unit
Subject to alterations

W1G200-HH77-52

EC axial compact fan

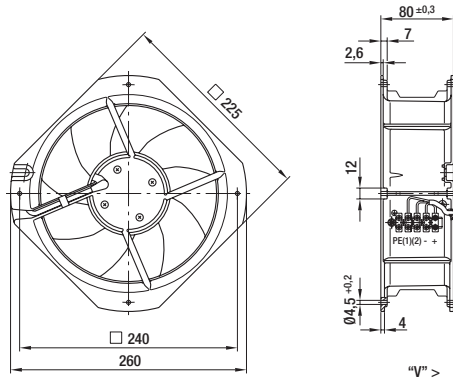
Technical features

Leakage current	<= 0,25 mA
Dimensions	200 mm
Size	200 mm
Operation mode	Continuous operation (S1)
Direction of rotation	"V"
Electrical leads	Via terminal strip
Insulation class	"B"
Bearing motor	Ball bearing
Mass	2.1 kg
Housing material	Die-cast aluminum
Material of impeller	Sheet steel, coated in black
Motor protection	Reverse polarity and locked-rotor protection
Type of protection	IP 42
Protection class	I
Technical features	Control input 0-10 VDC / PWM, tach output, polarity and locked rotor protection
Approval	CSA C22.2 Nr.77; UL 1004

W1G200-HH77-52

EC axial compact fan

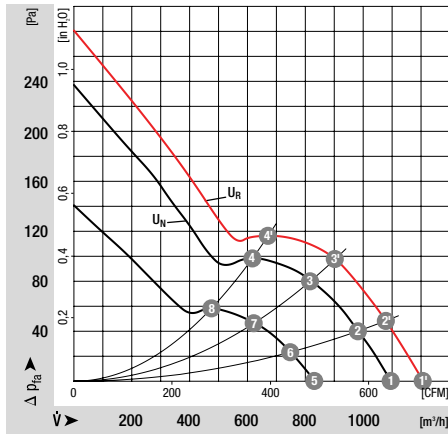
Product drawing



W1G200-HH77-52

EC axial compact fan

Charts: Air flow



Measured values

	n	P ₁	η_{TL}
	[min ⁻¹]	[W]	[%]
1'	2300	73	
2'	2970	77	67
3'	3100	80	64
4'	2970	80	54
1	2950	55	
2	2890	58	67
3	2800	61	64
4	2780	63	54
5	2270	27	
6	2230	28	67
7	2170	29	64
8	2130	30	54

J PowerBox - Custom made power supply

powerbox®

Specification PBNO0908

Specifications

for

custom made

power supply

PBNO0908

Power supply specification	Product	PBNO0908	Revision pre02
	Company	Signature	Date
Approved	For Customer		
Approved	For Powerbox	2009-05-05	Page 1 of 15

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Power supply specification		Product	PBNO0908	Revision pre02
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Approved	For Powerbox		2009-05-05	Page 2 of 15

1. REVISION HISTORY

Description	Written by	Motivation	Revision
1 st draft	Øyvind Leira	Basis for development and product cost	Preliminary 1
2 nd draft	Øyvind Leira	Basis for development and product cost	Preliminary 2

Power supply specification	Product	PBNO0908	Revision pre02
Company	Signature	Date	
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2. REFERENCE DOCUMENTS

DOC. ID.	DOC. NO.	Rev. no.	DOC. TITLE
[1]	EN 50155	2007	Railway applications. Electronic equipment used on rolling stock
[2]	EN 60950	2002	Information technology equipment- Safety
[3]	EN 50124-1	2001	Railway applications. Insulation coordination. Basic requirements. Clearances and creepage distances for all electrical and electronic equipment
[4]	EN 61373	1999	Railway Applications - Rolling Stock Equipment - Shock and Vibration Tests
[5]	EN 50121-3-2	2006	Railway applications. Electromagnetic compatibility. Rolling stock. Apparatus
[6]			
[7]			
[8]			
[9]			
[10]			

Power supply specification	Product	PBNO0908	Revision pre02
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3. SCOPE

This power supply is providing continuous power to the X2000 unit. The power supply is to be placed in a 19" rack. The rack has got a back plane that connects 2 power supplies to supply 24V and 400W with redundancy. The power supplies will have current sharing. The power supply does not have reverse polarity protection.

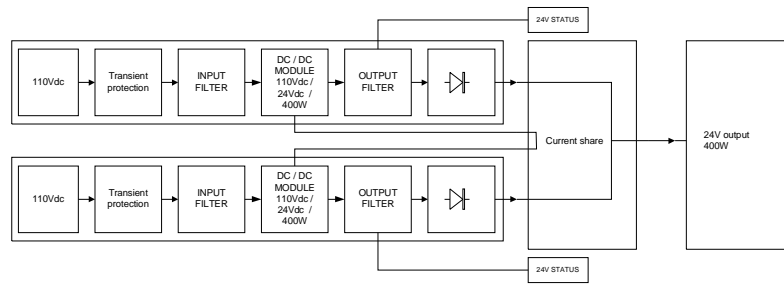


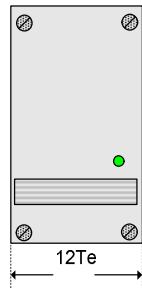
Figure 3.1 Block diagram for power supply

Power supply specification		Product	PBNO0908	Revision pre02
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4. DIMENSIONS

4.1. MECHANICAL SIZE

Size	Weight
3U x 12Te x 280mm	TBD



Power supply specification		Product	PBNO0908	Revision pre02
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5. TERMINATION

5.1. CONNECTORS

Description	Pin nr.	Signal
CN1: H15MAZ	4	TBD
	6	TBD
	8	TBD
	10	TBD
	12	TBD
	14	TBD
	16	TBD
	18	TBD
	20	TBD
	22	TBD
	24	TBD
	26	TBD
	28	TBD
	30	TBD
32	TBD	

Table 1 Connector CN1 pinning

Power supply specification		Product	PBNO0908	Revision pre02
	Company	Signature	Date	
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6. SPECIFICATION

6.1. OUTPUT

6.1.1. OUTPUT

Characteristic		Value	Unit	Tolerance	Condition
Output voltage 1	Vout ₁	24.0	V	±2.0%	At the connector
Output current 1	Iout ₁	16.7	A	Maximum	
Output power 1	Pout ₁	200.0	W	Nominal	
Output power 1	Pout ₁	400.0	W	Maximum	
Current limit 1	Iout ₁	19.2	A	-2.2 / +3.4	
Short circuit 1	Iout ₁	19.2	A	-7.6 / +3.4	Output short circuited
Ripple voltage 1	Vout ₁	±1.0	%	Maximum	Peak to peak < 20MHz At nominal load nominal input voltage
Load regulation 1		1%	%	Maximum	10% to full load
Line regulation 2		0.2%	%	Maximum	Low line to high line
Temperature coefficient		0.010	%/K	Maximum	
OVP set point		28.1	V	±1.0	
Current sharing		10%			

1 at nominal input voltage

2 at nominal load

6.1.2. OVERLOAD PROTECTION

TBD – is it necessary?

Power supply specification		Product	PBNO0908	Revision pre02
	Company	Signature	Date	
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6.2. RESPONSE TIME

Characteristic	Condition
Response time	TBD – is it necessary

The response time is defined as the time from the input voltage is applied to the output voltages are within the range shown in chapter 6.1.1 and 6.1.2.

6.3. INPUT VOLTAGE

Characteristic	Value	Min	Nom	Maximum
Input voltage range DC	[Vdc]	66	110	154
Input current	[A]			TBD
Fuse rating				TBD
Reverse polarity protection	No			

6.4. EFFICIENCY

Characteristic	Condition
Expected efficiency	≥82% typical at nominal input nominal load

6.5. SAFETY

Characteristic	Condition
Safety standard	EN 50124-1

Power supply specification		Product	PBNO0908	Revision pre02
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6.6. RELIABILITY

Characteristic	Value
MTBF	TBD
Expected lifetime	TBD

6.7. SUPERVISION

Characteristic	Condition		
+24V_OK		Closed circuit	OK
		Open circuit	NOT OK

The signals are isolated from the power supply and each other. The switches are able to sink 10mA of current and maximum permissible voltage is 30Vdc. The signal is provided from opto couplers of type SFH-617A3. The voltage drop of the switch loop shall not exceed 450mV@10mA.

Green LED placed on the front plate.

6.8. STORAGE

TBD.

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7. ENVIRONMENTAL CONDITIONS

7.1. CLIMATIC

Characteristic	Value	Description
Operating temperature DC input	-20°C to +85°C	On power supply heat sink
Storage temperature	-40°C to +85°C	
Humidity	TBD	
Storage altitude Pressure change	TBD	

* Forced air cooling required at high ambient temperatures.

7.2. MECHANICAL

7.2.1. SHOCK AND VIBRATION

Standard	Test specification	Severity levels
EN 61373	Functional random vibration test	1.0 m/s ²
	Simulated random vibration long life test	7.9 m/s ²
	Shock test, half sine pulses	50 m/s ² , 30ms

Table 7.3.1 Shock and vibration

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8. EMC

8.1. EMC EMISSION

Port	Frequency range	Limits	Basic standard
Enclosure*	30MHz – 230MHz	40dB(dBµV/m quasi peak) at 10m	EN55011
	230MHz – 1000MHz	47dB(dBµV/m quasi peak) at 10m	EN55011
DC mains	9kHz-150kHz	No limits	EN55011
	150kHz-500k Hz	99dB(dBµV quasi peak)	
	500kHz-30MHz	93dB(dBµV quasi peak)	

*Radiated emission is pending on cabinet

8.2. EMC IMMUNITY

8.2.1. ELECTRICAL FAST TRANSIENTS / BURST TEST

Description	Value	Value
Pulse	5/50ns, 15ms burst every 300ms	EN 61000-4-4, level 3
Amplitude	± 2kV	
Imposed on	± input	
Duration	2 minutes per polarity	
Repetition rate	5kHz	
Amplitude tolerance	±10%	
Performance criterion	A	

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8.2.2. ELECTRICAL SLOW TRANSIENTS / SURGE TEST

Description	Value	Reference standard
Pulse	5/50µs voltage surge	EN 50155
Amplitude	1.8kV	
Imposed on	± input	
Source impedance	100 Ohm	
Performance criterion	B	

8.2.3. ELECTROSTATIC DISCHARGE

Description	Value	Reference standard
Imposed voltage	Air 8kV Contact 6kV	EN 61000-4-2
Polarities	±	
Amplitude tolerance	±5%	
Performance criterion	B	

8.2.4. CONDUCTED RADIO FREQUENCY

Characteristic	Value	Reference standard
Frequency range	150kHz - 80MHz	EN 61000-4-6
Amplitude	3V _{rms}	
Imposed on	Input terminals	
Amplitude modulation	80% at 1kHz sinusoidal	
Maximum sweep rate	0.005 octave/s (1.5 x 10 ⁻³ decade /s)	
Amplitude tolerance	±10%	
Performance criterion	A	

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8.2.5. VARIATIONS AND INTERRUPTIONS OF POWER SUPPLY

According to EN 50155 [3]

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9. CHANGES

From preI01 to preI02

All pages	Footer changed to Revision preI02 2009/05/05
Page 2	Table of content updated
Page 3	Revision history updated
Page 4	EN61000-6-1 and EN61000-6-3 removed (redundant standards) EN added to 50124-1 EN50121-3-2 updated to 2006
Page 5	"The power supply does not have reverse polarity protection" added
Page 6	Mechanical size and drawing changed to 3U 12Te and 280mm
Page 7	Connector CN2 removed
Page 9	Reverse polarity protection = no added to input chapter EN60950 removed (not a valid requirement)
Page 11	Shock and vibration merged to one table.

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K Exterior lights - Full/Half beam proposal

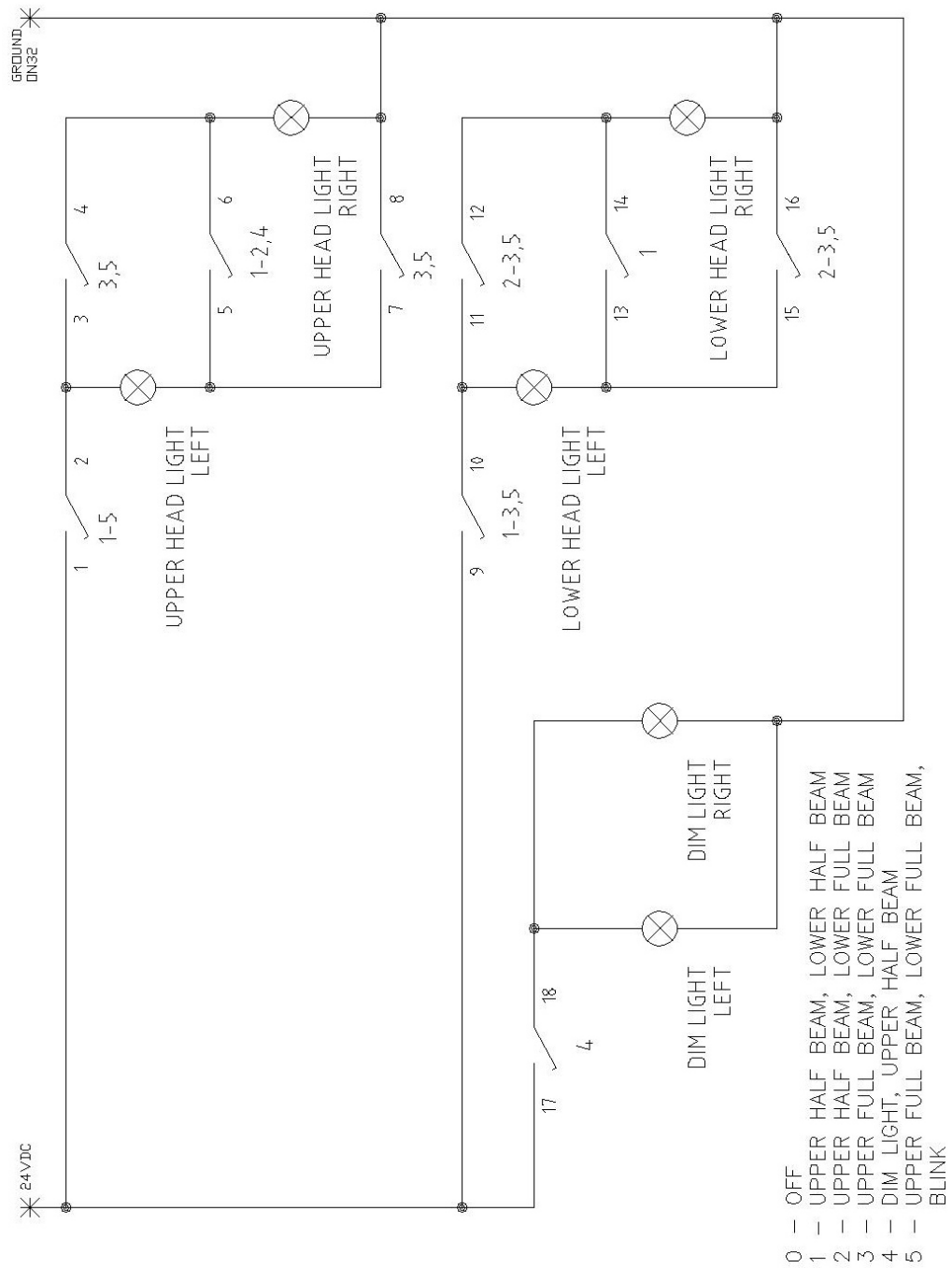


Figure 25: Full (24VDC) and half (12VDC) beam solution for proposal 1