Lappeenranta University of Technology
School of Energy Systems
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BACHELOR'S THESIS

TRAIN AUXILIARY POWER SUPPLY SYSTEM'S SPECIFICATION

(Junan apusähkön syöttöjärjestelmän vaatimusmäärittely)

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Abstract

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Train auxiliary power supply system's specification

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This thesis presents the process to define specifications for an auxiliary power supply system used in trains. The main focus is to refine the requirements gathered from different sources into a specification to be used as the basis of designing the actual system. The process is separated into different engineering branches to categorize the requirements. These requirements build the basic form of the system. When the basic form has been reached, the definition of the specifications is separated into the suggested parts of the system. These specifications are then divided into separate engineering aspects of the parts. The parts are then forming into modules and the bigger picture of the system consists of these separately specified modules. The studied approach makes the specification process easier to approach and reduces the amount of time used in handling requirements that are not visible in the beginning of the process and helps to avoid possible conflicts in the cross engineering design.

Tiivistelmä

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Tämä työ esittelee junan apusähkön syöttöjärjestelmän spesifikaation määrittelyn. Pääaiheena on jalostaa eri lähteistä saadut vaatimukset spesifikaatioksi, jonka pohjalta varsinainen järjestelmä voidaan suunnitella. Esitelty prosessi on jaettu erillisiin teknisiin haaroihin – mekaniikka, elektroniikka ja ohjelmisto – vaatimusten luokittelemiseksi. Nämä vaatimukset luovat järjestelmälle perusmuodon. Kun perusmuoto on saavutettu, niin määrittely jaetaan järjestelmän olettuihin osiin. Tämä määrittely jaetaan vielä teknisiin haaroihin jokaiselle osalle erikseen. Nämä osat hahmottuvat itsenäisiksi moduleiksi ja varsinainen järjestelmä koostuu näistä erikseen määritellyistä moduleista. Tämä tutkittu lähestymistapa tekee määrittelyprosessista helpommin lähestyttävän ja vähentää prosessin alussa vielä tuntemattomien vaatimusten käsittelyyn käytettyä aikaa. Tämä lähestymistapa auttaa myös välttämään mahdollisia ongelmatilanteita suunnittelun eri teknisten haarojen yhteensovittamisessa.

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Abbreviations and symbols

AC – Alternating current

DC – Direct current

AC/DC – Power conversion from alternating current to direct current

DC/DC – Power conversion between direct current potentials

SCU – System Control Unit

DDU – DC-DC interconnect Unit

CAN – Controller Area Network

CANopen – a communication protocol and device profile specification for embedded systems used in automation

PDO – Process Data Object

1 Introduction

The outcome of this thesis is to define the technical specification of a passenger train auxiliary power supply system. It consists of battery management and charging and provides desired voltages and power for the vehicle environment. The system must also be able to communicate with the vehicle controller via CANopen -bus.

This specification will be used by Powernet Oy as basis of designing the power supply system for a European train manufacturer. This specification design will be divided into separate engineering branches (electrical, mechanical and software) to address the need and availability of specialized personnel in the actual design work done by Powernet Oy.

1.1 Scope of the thesis

This thesis will study the process of defining a specification for a power supply system. Powernet Oy has previously mainly designed only custom design power modules, which are integrated by the customers into larger systems. This thesis will look into the requirements caused by the more complex structure of the system design and how to recognize the previously unknown requirements. The requirements studied in this thesis will be the most critical ones for the systems operation to keep the scope of the work tight. The methods and tools to achieve the results will be co-operation with the colleagues at Powernet Oy and following the requirements exchange with the customer. This will be achieved by following and attending e-mail conversations and meetings.

1.2 Train power supply background

The modern passenger trains are usually fully electric or diesel electric. Fully electric trains draw their current from high voltage overhead wires or from a third rail. Diesel electric

trains use diesel generator to provide the electric current. This current is then used by the drive units to power motors to propel the train. In fully electric trains there is an auxiliary output from the high voltage drive units with lower voltage to power the train auxiliary power systems. In diesel electric trains there is also an auxiliary output from the diesel generator to supply auxiliary power systems. In the train systems covered in this thesis, the auxiliary output is 400 VAC three phased power. The auxiliary power is used to provide electricity for auxiliary – non-drive related – systems. These systems are doors, lights, air conditioning, control logics, on board systems communications, batteries etc. Although the auxiliary power is not related to propelling the train directly, the train will not move without it as the control systems require auxiliary power to function.

Previously the auxiliary power has been handled by large monolithic power supplies with little or no feedback to the vehicle controller system. There might have been dry contact relay alarm of power supply failure, but no early warnings or diagnostics of what has failed. Also battery management had to be done by the vehicle controller. This approach required the train controller to have lots of measuring devices to monitor the status of the auxiliary power.

1.3 Contents of this thesis

The specification will be done for the system used to replace the old auxiliary power supplies. The system will consist of the modular power supplies, controller, required interconnections and mechanics to fit the system into the space requirements given by the customer. The specification will be limited to the most critical parts of the system and the individual modules.

The system in this thesis will be using switch mode power supplies to convert the 400 VAC power to the DC voltage level of the batteries and the auxiliary systems. Switch mode power supplies first rectify the input AC to DC with a diode rectifying bridge. This DC voltage is then converted through a transformer bridge to generate 50-100 kHz AC for the

transformer primary side. High frequency switching reduces the size and losses in the transformer [1]. The transformer secondary side has the second rectification stage and filtering capacitors to keep the output steady. By varying the primary side transformer bridge duty cycle, the energy transferred through the transformer can be affected and furthermore the output voltage can be controlled.

This thesis will address the process of turning the requirements in to specification and the quality of the process will be assessed in the summary chapter. This quality of the process is evaluated through the following research topics:

1) Identifying design requirements, known and unknown.
    - Known requirements come from the customer and from the existing knowledge of previous systems
    - Unknown requirements are those that arise during the process of defining specifications to known requirements and can furthermore be defined by knowing the requirements what the system should not do.
    - This will be assessed in the summary as confidence in the dis-ambiguity of the requirements.
2) Translating the requirements into specifications.
    - This is defining the specifications to fulfil the requirements.
    - This will be assessed by the margins of the specification exceeding the requirements.
3) Dividing the specifications to different engineering branches and identifying the needs for cross-branch co-design.
    - This will be assessed by the cross-branch design conflicts avoided.
4) How much design certainty can be accumulated by using pre-designed modules as building blocks in a modular power supply system?
    - This will be assessed by the reduction of unknown requirements in the power module design specification.

This thesis will use qualitative analysis method to assess the questions in the research topics.

2 General considerations

This specification has three major branches – mechanical, electrical and software. The branches are affecting each other and are causing constraints on solutions.

2.1 Mechanical considerations

Mechanical constraints arise from limited space on a passenger train. Also replacing failed units must be addressed in mechanical and electrical solutions. Mechanical solution must also be able to withstand the vibrations of the train environment [2]. This is particularly important for heavy magnetic components, cables and connectors. Also the heat dissipation from the system modules has to be dealt with the mechanical solution.

2.2 Electrical considerations

The electrical solution is closely related to the mechanical solution. As the total power requirement is 12.8 kW, a modular approach is selected to be able to use the previous designs. Modular approach also gives better flexibility for replacing failed units as the whole system needs not to be replaced, but only the failed module. In addition this improves the overall system availability by adding significant redundancy to the system, which is often required especially in SIL2 (Safety Integrity Level 2) rated applications [3]. Without modularity adding redundancy would need the whole system to be doubled. With modularity the required level of redundancy can be reached by adding enough extra power modules.

2.3 Software considerations

Software solution is also needed and in a way, is one of the most critical aspects of the design. Main challenges addressed by the software solution are:

- Controlling multiple high-power AC/DC converters operating in parallel
- Following parametrized non-trivial battery charging curves
- Extending the operational life of the converters through switching of the number of needed units on and off
- CANopen interface requirement

The customer wants to address the system as one device. In modular design the preferred way of achieving this is through a local centralized controller that is seen as one device on the train CANopen network. The controller must be able to communicate with the actual power modules to get the information needed by the train controller and to pass working parameters to the power modules. This means the actual power modules need to have software solution implemented in them as well.

Battery management and charging requires both electrical and software solution to measure required variables to make decisions of the current battery state. The batteries and their placement is handled by the customer and are not included in the system design in this specification. Thus mechanical solution for battery management includes only cables and connectors.

2.4 Electrical solution

The input voltage for the system is 3×400 VAC at 50 Hz from the trains drive circuitry. The required output voltages are 110 VDC battery charging voltage, 110 VDC vehicle bus voltage and 24 VDC vehicle bus voltage.

The required power output is ranging from 6.4 kW to 12.8 kW on the 110 VDC vehicle bus output and 3.2 kW for the 24 VDC vehicle bus.

The modular solution on the electrical side can be seen in Fig 1. Up to four AC/DC converters convert the 3×400 VAC into 110 VDC for the internal bus and also for both 110 VDC outputs. The converters are based on previous models of Powernet's 3 kW platform that can provide 3.2 kW per unit.

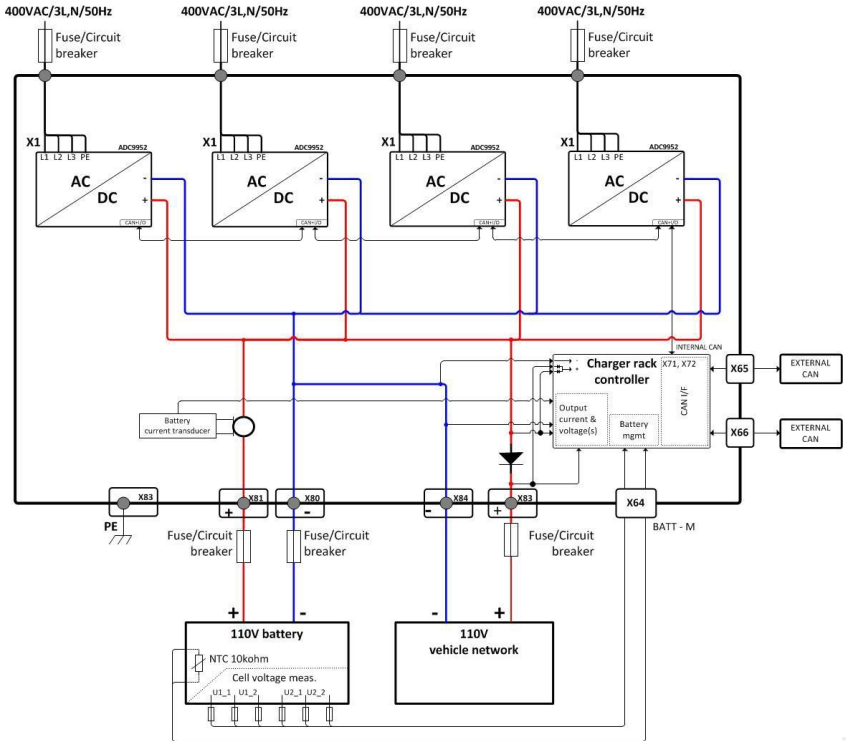

Fig 1. Functional block diagram of the system. Internal components and connections can be seen inside the frame and external connections can be seen outside the frame.

The converters internal control systems are connected to the centralized controller via CAN bus. The controller is powered by the internal 110 VDC bus and by the 110 VDC vehicle bus. The controller measures 110 VDC output voltage and current, the battery temperature, cell block voltages and total charging and discharging current.

There is a high-power diode situated inside the system to protect the battery if the 110 VDC vehicle bus voltage rises too high The diode can be seen in Fig 1. above the fuse of

the 110 VDC bus. The diode also prevents excessive loading on the 110 VDC vehicle bus, as well as excessive charging current to the battery in the situations when the battery is not fully charged but the voltage on the 110 VDC bus is raised by other sub-systems.

The 24 VDC output isn't shown in Fig 1. as the converters supplying 24 VDC are situated closer to their loads. They are powered through the 110 VDC vehicle bus and are connected to the same controller as the AC/DC converters.

Modular approach with the added controller means that the controller itself is a possible single point of failure, so enough robustness is required in the design as well as possibility of at least limited operational capability of the system in case of controller failure – so called “limp home operation”.

2.5 Mechanical solution

The train manufacturer has specified the limits for the size of the system. The space allocated for the system is within a 19” rack inside ventilated electrical cabinet. The system in the 19” sub rack can be seen in Fig 2.

Fig 2. Rendering of the mechanical 19” rack enclosure (without 24 VDC supplies)

The system consists of three shelves. On top and bottom shelves there is space for up to four AC/DC converters. The middle shelf contains the system controller (henceforth referred as the SCU module) located on the right side with connectors for the internal and the vehicle CANopen networks and signal, power and measurement connectors. On the left side there is the interconnection module (referred as DDU module henceforth) that includes the connectors for the battery, the 110 VDC vehicle bus (leftmost) and the connectors for the individual AC/DC converter outputs. The DDU module also includes the power diode, the battery current transducer as well as vehicle 110 VDC and battery terminal measurement circuits.

The mechanical solution focuses mostly on the module enclosures, connectors and cabling. Requirements addressed by mechanical solution include heat dissipation, vibration and current carrying capabilities.

2.6 Software solution

The system must be able to function independently from the vehicle controller so that it requires only minimal amount of external control. The system must also monitor battery status and charging. If the communication to the vehicle controller fails, the system must be able to deliver power for the train and manage the battery operation in stand alone mode.

To achieve the required functional status, every module in the system must be equipped with microcontrollers. The main controller must be able to communicate with the vehicle controller through CANopen. The module interconnection can also be done with CANopen to reduce the need for different communication protocols.

All of the configuring from the vehicle controller will be implemented through software. Maximum voltage settings, current limits and main operational parameters must be adjustable with the software.

If the firmwares in the system stop running, a watchdog functionality must be implemented. A watchdog in a microcontroller is a dedicated timer, which needs to be reset on certain intervals. If the firmware fails to reset the watchdog, then it will reset the microcontroller.

2.7 Benefits of the proposed solution

The whole system consists of small easily replaceable modules and is still seen as one device from the vehicle controller point of view. The system provides good power density due to the use of switch mode power supplies. The system provides an all in one solution for the train auxiliary power needs with battery monitoring and charging included. The customer does not need to communicate with each device separately, but they can communicate only with one device with one protocol while getting all the needed

information through that node. The inbuilt logic inside the system controller allows the customer to remove the battery management monitoring and calculations from the vehicle control system entirely.

3 Specifying the solution

Since the system is consisting of many separate modules, the specification is done for each module separately. Fig 3. illustrates the proposed positioning of the modules in the system. As the DC/DC (DDC9870) modules are located separately of the main enclosure, they are pictured here only for specification purposes.

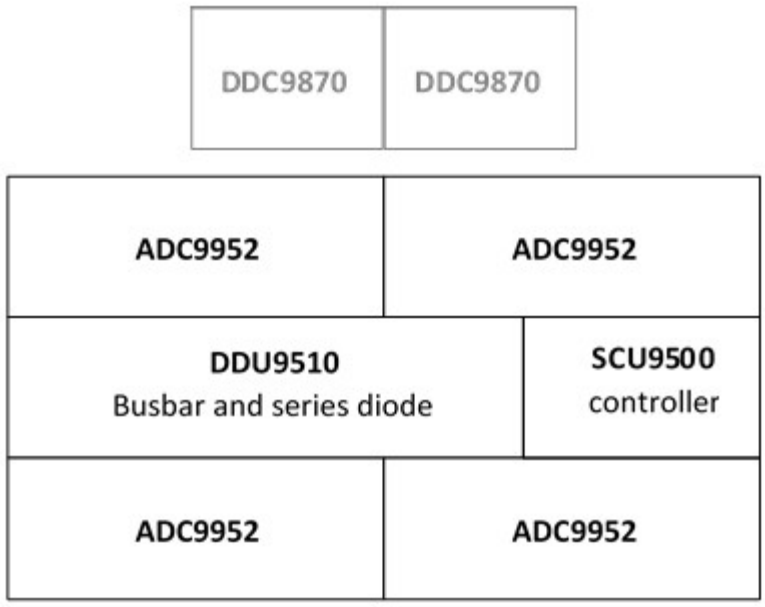

Fig 3. Top-level diagram of system modules (optional 24 VDC units greyed out)

3.1 System controller

The system control unit (SCU) is the system main controller and handles the system communications interconnections and also the connection to the vehicle communication network. It also handles system level measurements and controls the functionality of the separate AC/DC and DC/DC modules.

3.1.1 Electrical specification

The SCU module is not handling any power conversions so the electrical design focuses on handling of the communication buses and measurement values from the DC-DC interconnect unit (DDU) and battery blocks. The CANopen buses must have galvanic isolation in each device to protect the vehicle control network from any problems that a catastrophic failure on the charger system could cause and also to protect the internal CANopen network from a failing module.

The SCU module requires external 12 VDC power supply. The biggest loads on the SCU module are the microcontroller [4] and the CAN communication transceivers [5], so they are defining the power needs for the module. Combined maximum current for the two transceivers and the microcontroller is 200 mA and with 12 VDC supply the power requirement for these is 2.4 W. It is safe to assume, that the total power consumption of the module is less than 10 W.

3.1.2 Mechanical specification

SCU module's mechanical size is the most flexible mechanical parameter of the whole system. The circuit board contains measurement circuits, CAN transceivers, microcontroller and connectors. The face plate of the module has to be large enough to contain the connectors to the battery block measurements, DDU module and the CAN connectors for the internal CANopen bus and the vehicle CANopen bus. For the CANopen connections both male and female D9 connectors should be provided for ease of system assembly. Also, the chosen position next to the DDU module restricts the size. Thus, the SCU module can take the remaining space from the 19” rack shelf left over by the DDU module.

3.1.3 Firmware specification

SCU module is the central controller of the whole system and the firmware capability and reliability requirements are high. If this module fails, the remaining system falls into a fail safe mode with no communication with the vehicle controller. This reliability must be

addressed in design and also in the type testing of the system. For flexibility and ease of updates the firmware has been split in two somewhat independent parts. The two main parts of the SCU firmware are the bootloader and the application firmware. The application firmware must be upgradable on the train itself by service personnel and that will be handled by the bootloader. The bootloading process must be fail safe.

The SCU firmware must be compatible with CANopen [6] and the used communication stack must be extremely fail safe as it is connected to the main vehicle CAN bus. In no circumstances a failure in the SCU unit is allowed to interrupt the communications on the main vehicle CAN bus.

The main vehicle controller software communicates with the system through the CANopen on the SCU. The SCU firmware must provide measurements and status registers to the main vehicle controller. The SCU firmware must also be configurable by the main vehicle controller. Configurable entities include the CANopen process data objects (PDO), system output voltage and power limit [7].

The SCU firmware must also use the operational system platform designed by Powernet Oy. This platform handles task launching and scheduling with programmable delays.

3.1.4 Special requirements

The SCU must be able to regulate the loading of the separate AC/DC converters by measuring the output voltage and currents of the system and by reading the status information from the AC/DC converters' CANopen PDOs. The load regulation will be done by altering the output voltages of the AC/DC converters by small corrections. This method is droop current sharing [8] with the SCU module handling the control.

If output power is low, then the SCU must be able to switch off idle AC/DC converters to reduce power losses. This must be done in a such way, that all AC/DC converters will be loaded as equally as possible.

3.2 DC-DC interconnect unit

The DDU module handles the interconnection of the individual AC/DC module outputs, the connection to the vehicle 110 VDC bus and the connection to the 110 VDC battery. The DDU module also measures voltages and currents of the high power buses.

DDU module is the only module in the system that does not need a microcontroller of its own since it uses the computational capabilities of the SCU module.

3.2.1 Electrical specification

The internal cabling and bus bars of the DDU module must be able to handle currents up to 116 A continuously (4 x 29 A, appendix A, table 3 “Maximum output current”).

The connection to the vehicle 110 VDC bus must be protected with a series diode [9] to prevent reverse current from the vehicle bus. This diode must be able to withstand continuous 116 A current and 137 V voltage (appendix A, table 3, “Output voltage adjustment range”).

DDU module will have a current transducer measuring the charging and discharging currents of the battery. The required measurement range is +/-200 A. The ability to recognize current direction is mandatory to determine whether the batteries are being charged or discharged.

DDU module will contain a measurement circuit board that has a connection for the SCU module. The measurement board pre-scales and redirects the measurements of 110 VDC bus voltage and the internal 110 VDC voltage before the diode to the SCU module. The measurement board also handles the scaling and transmission of the current transducers measured value to the SCU module.

A small auxiliary power supply of 12 VDC is situated in the DDU module to power the

measurements circuitry and the SCU module.

3.2.2 Mechanical specification

The mechanical size of the module is dictated by the required interconnections for handling the high power.

The 110 VDC bus series diode requires space for itself and for its cooling. There is a convection channel added to the side of the DDU module to cool down the heat sink of the bus series diode with a fan controlled by the SCU module. The convection channel construction allows the cooling of the diode without interaction and possible contamination by ambient air of the internal components of the module. The cooling requirement for the diode can be calculated by the power loss from the maximum continuous current of 116 A and the threshold voltage of 0.8 V [9]. The total power loss is thus 116 A x 0.8 V = 92.8 W.

All connectors used in the DDU module must be able to withstand the high-power requirements and the vibrations of the train environment. The vibration requirements can be found in the standard EN 61373. This standard covers the requirements for random vibrations and shock testing for the system to be fitted on to railway vehicles.

3.3 AC/DC and DC/DC modules

AC/DC and DC/DC modules used in this specification are based on development of previous models of the ADC9900 and DDC9900 family of AC/DC and DC/DC converters made by Powernet Oy. Most of the power electronics and topologies used in the converters are derived from the previous models as well [10]. Changes required for the modules to operate in the system are mostly related to their firmware behaviour. The earlier models already have CAN connectivity implemented in their hardware and need to be updated to comply with CANopen protocol requirements. This requirement leads to the selection of a more capable microcontroller for the converters to be able to support the CANopen stack

and to provide the functionality to control the power supply circuitry at the same time. The microcontroller must be able to measure input and output voltages, output current and internal temperature. It has to supply the power supply circuitry with target value for output voltage and limit for output current. It must also be able to control and monitor cooling fans of the unit.

3.3.1 Electrical specification

Electrical specifications for the units are derived from the previous ADC9900 and DDC9900 models designed by Powernet Oy [10]. These previous models have already been in use with the same customer in similar applications. Electrical specification example for the ADC9900 series devices can be found from appendix B, chapters 2 and 3.

Electrical changes to be implemented are related to changing the microcontrollers to more powerful versions.

3.3.2 Mechanical specification

The mechanics should follow the dimensions from the previous models to keep up compatibility with existing manufacturing capability. Mechanical specification example for the ADC9900 series devices can be found from appendix B, chapter 4.

3.3.3 Firmware specification

The firmware controls the AC/DC and DC/DC modules functionality and communications with the SCU module. Controllable variables include output voltage, current limit, LED and cooling fans. Communication with the SCU module is done through CANopen network and the AC/DC and DC/DC modules must be able to provide SCU module with measurement data and status flags. The AC/DC and DC/DC modules must also be controllable by SCU module through the CANopen network. SCU controllable variables include output voltage and current limit settings and they must be able to shut down their outputs if the SCU module commands them to do so.

For flexibility and ease of updates the firmware has been split in two somewhat independent parts as the SCU module firmware was. This was described in chapter 3.1.3.

4 Results

The proposed solutions will be compared against the specifications which can be found in appendix A and is done here for each module separately. Reasonable margins and the necessity for them will be described for the most critical parts.

4.1 SCU module

Proposed SCU module electrical and mechanical solutions are simple and fulfil their requirements. Software solution is in comparison the most complicated part of the proposed solution as are the requirements for it's functionality. The proposed solution also fulfils the software requirements.

4.2 DDU module

Proposed DDU module is large enough to accommodate cabling and bus bars with the specified current capabilities. Also the electronics and connectors satisfy the target specification. The series diode proposed (IXYS MDO500-12N1) has 444 A margin (560 A average from the diode specification against 116 A from the output parameters 4x29 A) for the current and satisfies the specification. The proposed cooling method for the diode also fulfils the temperature requirements**.**

4.3 AC/DC and DC/DC modules

These modules have been the basis of the proposed system and their known specifications have been used in co-operation with the customer to set the values in the requirements. These modules are proven to fulfil the requirements by acceptable margins already. The

previous modules have been type tested by accredited test laboratories for safety and electromagnetical compatibility. Also comprehensive type tests have been conducted by Powernet Oy.

4.4 System level

Mechanically the proposed system fulfils the specified size constraints as the proposed system uses all the space allocated by the customer specification. The proposed solution also fulfils the electrical requirements for inputs and outputs. Software solution fulfils the required measurements and communications with the train vehicle controller.

5 Summary

Identifying the design requirements has been done in co-operation with the customer. These requirements are described in appendix A. The customer is mostly interested in the external parameters of the system, including size, input and output values and communications. They also know the environment for the system and thus can provide the specification with information about, for example, temperatures and vibrations. The requirements have been reviewed by both companies multiple times and through iterative process the known requirements have reached mutually accepted level. Thus all external requirements can be said to be known.

Powernet Oy's interest is to fulfil the known customer requirements. Using existing converter modules as basis for the power conversion modules of the system, the number of unknown requirements is reduced as the existing designs have been type tested with similar requirements and against same standards. The unknown requirements for the converters have been found and addressed as known requirements.

The proposed design is modular and based on the existing converters. This provides the specification with restraints as these modules have certain specified mechanical and electrical attributes. Dividing the specification to different engineering branches helped to see the proposed solution take form.

First the electrical design required the high currents to have adequate cabling and a way to measure required voltages and currents. This set size constraints for the minimum viable solution. Mechanical engineering added a box around the solution with all the electrical parts inside. This could be seen as a separate module in the system and was named the DDU.

The requirements call for a centralized controller for the communications, measurements and decision making. From the requirements a solid state controller with no power

conversion requirements can be proposed. It is electrically simple and can be designed to be reliable electrically as there are no high currents or voltages inside. Mechanical solution had a lot of freedom on this module that was named SCU in the solution. Mechanical design could take up rest of the space in the proposed solution. Software solution had a lot of measurement requirements and these requirements were fulfilled by the electrical solutions of the DDU and SCU modules.

The co-operation with colleagues and customer has produced viable specification to start designing the system. The scope of the thesis seemed to be changing a bit throughout the work. New ideas and problems to look into in the study formed mostly during the process.

Next topics to follow this study could be to specify more modularity in the system design, to study and create needed building blocks for different kinds of systems. This would reduce the time to market as the design time would be shorter due to picking the required modules from a ready made library to form systems.

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APPENDIX A

Requirement tables.

1 Environmental parameters

These parameters define the usage environment of the system. This sets limitations to materials and components that can be used.

Parameter	Value/Standard	Note
Operating temperature range	-40˚C … +55˚C	EN 50155 T2 (up to +70˚C for <10minutes)
Cold start-up	-50˚C	Maximum 50% load
Relative air humidity	EN 50155	Yearly average ≤75% RH 30 consecutive days 95% RH
Shock and vibration	EN 61373, category 1 class B	
Pollution degree (PD)	PD2	

2 Input parameters

These parameters define the capabilities of the electrical input supply for the system and also defines the systems limits to the loading of the electrical supply.

Parameter	Value/range	Note
Input voltage	*number of chargers* x 3x400 VAC rms (+15 % / -20 %)	According to DIN IEC 60038
Input current	7 A_{rms} x number of chargers	Nominal
Power factor	>0,8 (at load range 50…100 %)	3-phase input rectified with diode bridge, i.e. no active control against unbalanced input voltages and conducted harmonics.
Inrush current	12 A_{peak} x *number of chargers*	<15 A_{peak} during first 200µs *x number of chargers*
Input frequency	47…63 Hz	
Input characteristic	inductive	
Standby power consumption	20W x *number of chargers*	from 3-phase AC input
	<1 W	Rack controller standby power consumption. (From 110VDC battery circuit.)

3 System output parameters

These parameters define the customer power needs provided by the system. This also sets the limits for the quality of the system output power.

Parameter	Value/range	Note
Output voltage	110 V_{DC}	Nominal
Output voltage adjustment range	100…137 V_{DC}	
Output overvoltage protection	145 VDC	
Maximum output current	23…29 ADC x number of chargers	
Maximum output power	3200W x number of chargers	MSR9830 system, up to four chargers = 12800W Output current is automatically reduced to maintain power limits.
Efficiency	90…93 %	at load range 35…100 %
Output voltage regulation	Voltage ±1 %	Accuracy of output voltage
Output current limitation	number of units X 29ADC ±5 %	
Output voltage adjustment	Via CAN bus	Remote output voltage adjust only
Battery temperature compensation	CPU controlled per programmed characteristic of customer requirements	in charging mode (charging curve per customer specification)
Battery temperature compensation	NTC, battery temperature sensor	10 kΩ (Murata NTSA0XV103FE1B0)
Output ripple voltage	150 mV_{RMS} (f = 20…300kHz, T_{amb} = 25°C)	
Load sharing	Via external CAN-bus	Load sharing between MSR9830 charger racks.

4 Mechanical parameters

These parameters define the size and weight limits and enclosure material for the system.

Parameter	Value/range	Note
Enclosure material	Sheet metal, aluminum	
Weight	36 kg	With three converters (ADC9952 appr. 7kg incl. cables) and external wire sets
Dimensions	483 X 355 X 405 mm	(W x H x D)

5 EMC parameters

These parameters define the electromagnetical compatibility standards that the system is required to comply to. These standards require testing at an accredited testing laboratory.

Parameter	Value/Standard	Note
Surge	EN 50121-3-2	
Fast transients	EN 50121-3-2	
Conducted disturbances	EN 50121-3-2	
Radiated disturbances	EN 50121-3-2	

6 Safety parameters

These parameters define the safety standards that the system is required to comply to. These standards require testing at an accredited testing laboratory.

Parameter	Value/Standard	Note
Fire safety	DIN5510-2 (CEN/TS 45545-5)	
Voltage withstand tests	EN 50124-1	
Insulation resistance	EN 50155	
Protection degree	IP20	

APPENDIX B

ADC9900 series device specifications.

1.1 Environmental conditions – general parameters

Parameter	Value	Comment
Class	T2	EN 50155
Ambient temperature	-40°C … +55°C	Up to +70°C with derated output power.
Extreme cold start-up capability	-50°C	10 consecutive start-ups at 50% load
Shock and vibration	EN50155 (EN61373)	
Humidity	EN50155	Yearly average ≤ 75 % RH 30 consecutive days 95 % RH

1.2 Applicable standards

Parameter	Value/range	Note
EN 50121-3-2	Railway – electromagnetic compatibility	
EN 50124	Railway – insulation coordination – part 1: basic requirements	
EN 50153	Railway – protective provisions relating to electric hazards	
EN 50155	Railway – electronic equipment used on rolling stock	

2 Input parameters

Parameter	Value/range	Note
Input voltage	3x400 VAC rms (+15 % / -20 %)	three wire connected, no neutral
Input current	6,5 A_{rms}	nominal at 400Vac with 3200W load
Power factor	>0,8 at load range 50…100 % (0,9 at 100% load)	3-phase input rectified with diode bridge, i.e. no active control against unbalanced input

		voltages and conducted harmonics.
Inrush current	12A peak/phase	15A peak/phase during first 200µs
Input frequency	47…63 Hz	
No load power consumption	20W	

3 Output parameters

Parameter	Value/range	Note
Nominal output voltage	110 V_{DC}	
Output voltage adjustment range	80…138 V_{DC}	
Overvoltage protection	145 V	
Maximum output current	23…29 A	depending on the output voltage level
Maximum output power	3200 W	Output current is automatically reduced to maintain power limits.
Efficiency	90…93 %	at load range 35...100 %
Regulation	Voltage ±1 % Current ±5 %	
Output ripple voltage	150 mV_{RMS} (f = 20…300kHz, T_{amb} = 25°C)	
Rev.-polarity-protection	Mechanical	by output connector

4 General parameters

Parameter	Value/range	Note
Safety	EN 50155	
EMC	EN 50121-3-2	
Isolation voltages	According to EN 50155	
Isolation coordination	According to EN 50124-1	
Cooling	Rear to front, CPU controlled fan	
Mechanical dimensions	W: 220 mm, H: 88 mm, D: 400 mm Front panel height 105 mm	

Enclosure	Painted aluminum enclosure	
Weight	6,5 kg	
IP class	IP20	
Output grounding	Floating	