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Multi-axis Servo and System Drives Comparison

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Abstract

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The goal of this study is to evaluate and follow the development of the multi-axis servo and drive systems. Systems were compared from several manufacturers for this study regarding their technical properties and solutions focusing on power electronics. Selected multi-axis servo systems were ordered and dissembled for closer observation. The power electronics components were listed and compared between each other. The datasheets of the components were obtained from the manufacturer websites.

In the beginning of the study the basic operation and principles of multi-axis servo drives are introduced. The benefits of multi-axis drive systems and common applications are presented. Next different system implementations are introduced and the different functions of the different modules are explained. After the theory, this study focuses on the results from the disassembled modules and processes the discovered information.

The conclusions focus on defining the limiting rules of designing multi-axis servo systems to guide and support future product planning. Such instructions concern dimensioning of the IGBT modules, distribution of common DC bus capacitance and addiotionally control electronics performance. The collected data has been added as an appendix of this study along with the reverse engineered power electronics schematics from the selected manufacturers that were ordered for closer inspection.

Keywords: motion control, system drive, servo controller, frequency inverter, robotics

Abstract in Finnish

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Tämän tutkimuksen tavoitteena on arvioida ja seurata moniakselisten servo ja systeemikäyttöjen kehitystä. Järjestelmiä on vertailtu eri valmistajien väliltä. Tarkempaan tutkimukseen valittiin näiden käyttöjen tekniset ominaisuudet ja ratkaisut, jotka keskittyvät tehoelektroniikkaan. Valitut moniakseliset servojärjestelmät tilattiin ja purettiin tarkempaa tarkastelua varten. Tehoelektroniikan komponentit oli listattiin ja niiden ominaisuuksia verrattiin keskenään, jota varten datalehdet osien kerättiin valmistajien verkkosivustoilla.

Tutkimuksen alussa käydään läpi tavanomaisen sähkökäytön perusteet ja periaatteet moniakselisista servokäytöistä. Edut moniakselisiin servojärjestelmiin ja yhteiset ominaisuudet esitellään. Seuraavaksi moniakselisten järjestelmien erilaisia toteutustapoja tarkastellaan ja kunkin eri moduulityypin tarkoitus selitetään. Teorian jälkeen keskitytään puretuista laitteista saatoihin tuloksiin eri komponenttien ja tehoelektroniikkaratkaisuiden osalta.

Päätelmissä keskitytään määrittelemään ääriviivoja tehoelektoniikkasuunnitteluun moniakselisissa servomoottorikäytöissä ja antaa tukea tulevaisuuden tuotesuunnitteluun. Tällaisiä kohteita ovat IGBT-moduulin mitoitus, yhteisen DC-kiskoston kapasitanssin jakautuminen mahdollisesti eri akseleille tai yhteiselle kondensaattorimoduulille. Lisäksi myös ohjauselektroniikan suorituskykyä on verrattu keskenään. Listat saaduista tiedoista on lisätty tämän tutkimuksen liitteisiin ja puretut tehoeletroniikan kaaviot tilattujen moduulien osalta.

Avainsanat: liikkeenohjaus, moniakselinen systeemikäyttö, servo-ohjain, taajuusmuuttaja, robotiikka

CONTENTS

Appendices

Appendix 1	Power electronics schematic of Lenze 9400 15 kW regenerative power supply E94ACLS0174-000P
Appendix 2	Power electronics schematic of Lenze 9400 5 kW passive power supply E94ACLP0104-000P1B
Appendix 3	Power electronics schematic of Lenze 9400 1,5 kW axis unit E94ACLM0044-000P
Appendix 4	Power electronics schematic of Lenze 9400 5,5 kW axis unit E94ACLM0174-000P
Appendix 5	Capacitor module schematic of Bosch-Rexroth HCL01.1C-02M4-A-007-NNNN
Appendix 6	Capacitor module schematic of SEW Moviaxis MXC80A-050-503-00
Appendix 7	Table of components
Appendix 8	Chart and table of delivery times of the multi-axis servo systems
Appendix 9	Under voltage test results of control electronics cards
Appendix 10	Table of dimensions and power ratings of all the modules included in this study

ABBREVIATIONS AND TERMS

AC	Alternative current
Axis	Part of machine or system that requires controlled motion
CAN	Controller Area Network
DC	Direct current
DC +	Higher voltage potential of intermediate circuit
DC -	Lower voltage potential of intermediate circuit
EMC	Electromagnetic Compability
EtherCAT	Ethernet for Control Automation Technology - is an open high performance Ethernet-based fieldbus system
FPGA	Field-programmable gate array
H-bridge	Electronic circuit which enables voltage over load to be switched in either direction.
HMI	Human Machine Interface
IGBT	Insulated Gate Bipolar Transistor
I/O	Input/Output
Micro class	Low cost <4 kW frequency inverter market area
PCB	Printed Circuit Board
PLC	Programmable Logic Controller
Powerlink	A real-time protocol standard for Ethernet introduced by B&R, automation company
Ppr	Pulses per revolution
PWM	Pulse Width Modulation

RFI	Radio frequency interference
SerCos	Serial Real-time Communication Standard
Servo Motor	Motor that together with its resolver or encoder is capable of being precisely controlled
SinCos	Encoder used in servo control

LIST OF SYMBOLS

C	Capacitance of a capacitor
E	Energy
R	Resistance
t	Time
U	Voltage

1 INTRODUCTION

In this section, the background for this thesis is explained and the goals are described. After this, the structure of the thesis is presented.

1.1 Background of the Study

As today's industrial machinery is becoming increasingly electrical, the mechanical transmission components that drive motion are being replaced by electric servo drives and motors. This technology provides not only better energy efficiency but also cost savings and fewer emissions as the energy demand all over the world increases. Among other advantages the precision of servo motor control can be highly increased by using servo drives to answer more and more demanding applications with multi-axis servo drives while the costs remain considerably low compared to the advantages.

Currently there are several new multi-axis servo systems under development for the market from various drive manufacturers and there was no complete system yet available for closer study. Such manufacturers included in this study are KEB, Bamüller and Beckhoff. Ready solutions were available from Lenze, B&R, SEW and Bosch Rexroth from which small 3-axis test systems were ordered with regenerative braking if available.

1.2 Goals of the Thesis

The main goal of this study is to examine the current trends of the multi-axis servo systems and try to define where the industry is heading. There are various ways to implement a multi-axis servo system and one aim is to examine the different solutions that different manufacturers have decided to make regarding the electrical components or modules.

The motion control industry is a considerably new and growing field which is developing in fast phase to more and more integrated systems.

This study concentrates on power transmission of multi-axis servo drive systems and considers the reasons why such solutions might have been made and what other ways would be possible to implement the same configuration. For closer inspection, Lenze

9400, SEW Moviaxs and Bosch Rexroth Indradrive M were chosen as an example of multi-axis servo systems and a certain type of multi-axis configuration from each manufacturer was ordered. The power electronic PCBs of the chosen disassembled modules were reverse engineered and studied. The different phases of disassembling were documented and photographed. The lists of the most important components and parts can be found in the Appendices of this study.

1.3 Structure

This thesis is divided into 4 sections. Section 1 presents the goals and backgrounds of this thesis. In section 2, example schematic and the basics of frequency inverters are introduced and the concept of servo drives is defined. Section 3 presents multi-axis servo systems and their benefits. Also the different modules of the system are introduced and their functions described. Section 4 of this thesis concentrates on the results of the selected disassembled models of multi-axis servo drive system configurations. Finally the conclusions and future trends are presented in section 5.

2 SERVO DRIVES

In this section, the basic components of a frequency inverter and a basic schematic are introduced along with definition of the servo drive leading to the introduction of multi-axis servo systems. A more detailed introduction of power electronic components is also made in this section.

2.1 Frequency inverters

A frequency converter is an electric device which can control the frequency of an alternating current electric motor by changing the motor's input frequency and voltage. A frequency converter consists of three parts: Typically a 3-phase rectifier part which converts 50 to 60 Hz alternating current to direct current for the intermediate circuit and back to alternating current by using a 3-phase inverter unit connected to the motor cables. The resistor parallel with a relay switch is used to protect the intermediate circuit capacitor from a dangerously high current loading spike from the network. The resistor's task is to reduce the charging current when the electric drive is turned on and the intermediate capacitor is considered empty of charge. After the capacitor has been charged to a reasonable voltage that won't anymore cause high currents to break the capacitor or diodes the relay can be switched on to bypass the resistor and allow the drive function without current limiting and unnecessary power dissipation in the intermediate circuit.

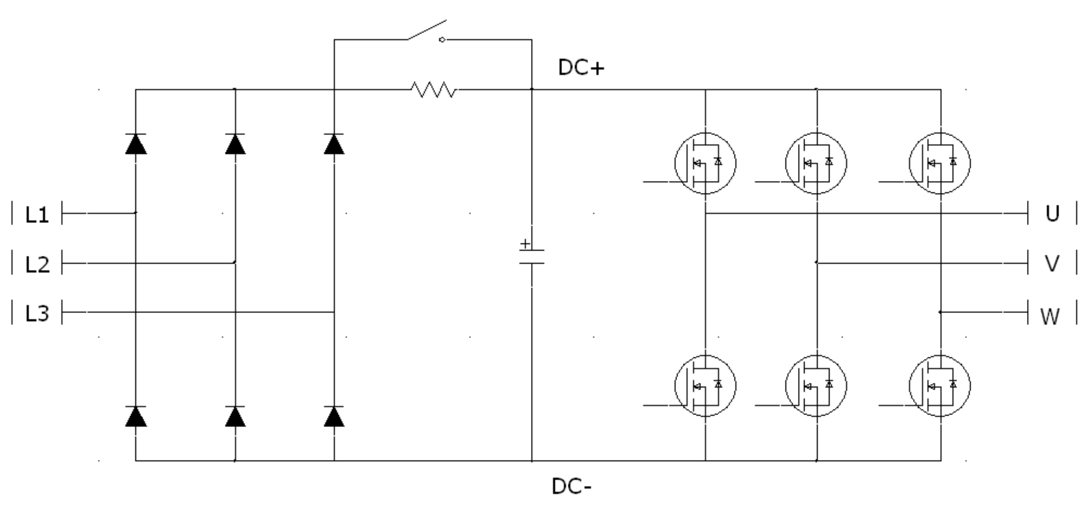

Figure 1: Circuit schematic of basic frequency inverter power electronics

Energy stored in the intermediate circuit is converted back to AC voltage by switching IGBT H-bridges in the desired frequency. The output frequency can be modified during the operation of the motor and makes it possible to operate the AC motor at different speeds and adjust the acceleration and deceleration times. [1, 20]

2.1.1 Rectifiers

A rectifier consists of diode or thyristor bridges and in the case of thyristors, control electronics is required to operate the thyristor bridge in a desired way. A diode-bridge-rectifier provides full-wave rectification from AC power supply network and it is also known as the *Graetz circuit*. The essential feature of a diode bridge is that the polarity of the output is the same regardless of the polarity at the input.

When a frequency converter is switched on the supply network, the voltage of the dc capacitor is considered zero. The Voltage of the capacitor has to be charged to its nominal voltage, before the inverter can be switched on to drive the motor. Usually the capacitor is charged through a charging resistor which limits the current flow until the capacitor has reached its nominal voltage. This kind of method is used in lower powered frequency inverters but with high powered inverters this starts to become an issue. Due to great power losses in the resistor and also the impractical size of a big resistor the capacitor can also be charged up by using a controlled thrysistor-bridge. After the charging the thyristors diodes are used as rectifier-bridge. [1, 20]

2.1.2 Charging circuit

A charging circuit is also needed between a common DC bus and inverter axis module's own capacitor banks to limit the capacitor charging current to protect the capacitors and to make it possible to separate the axis from a common DC bus feed if necessary. A charging circuit can be described as a typical RC circuit with a time constant.

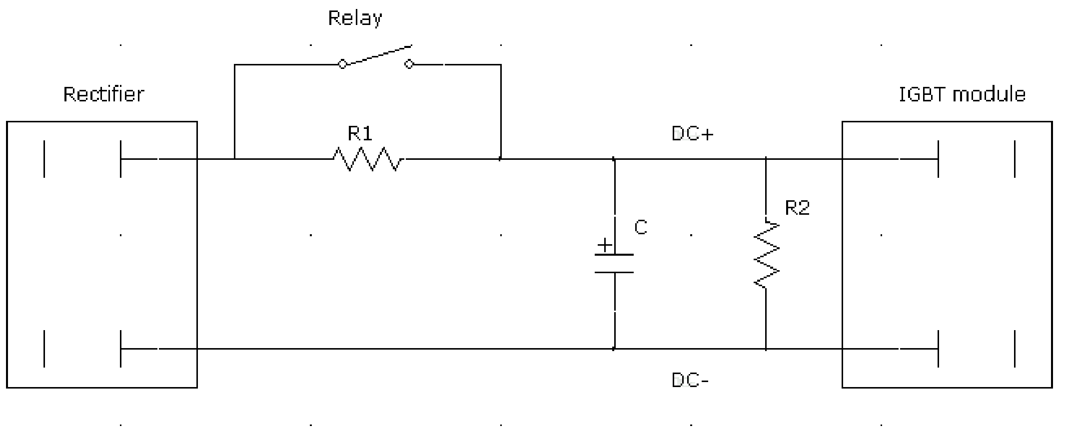

Figure 2: Typical loading circuit schematic

When the switch which is usually a relay, is closed the capacitor will charge up through the resistor until it reaches a common DC bus voltage. The time when the voltage across the capacitor is charged to 63% of the overall voltage over RC circuit is known as the Time Constant (T).

$$T = RC$$

Equation 1

$$E = \frac{1}{2}CU^2$$

Equation 2

Since the loading of the intermediate circuit capacitors is desired to execute fast the RC circuit resistor must be able to handle fast high current cycles through it and be able to tolerate the heat dissipated. [1]

2.1.3 IGBT modules

The IGBT (Insulated Gate Bipolar Transistor) H-bridge is a type of transistor which is used to switch current on and off for the AC motor. The IGB transistor consists from gate, emitter and collector. An equivalent circuit is formed from one npn, pnp and MOSFET transistors and resistors (fig. 3). MOSFETs typically have the ability to conduct a high current through a collector with small power consumption.

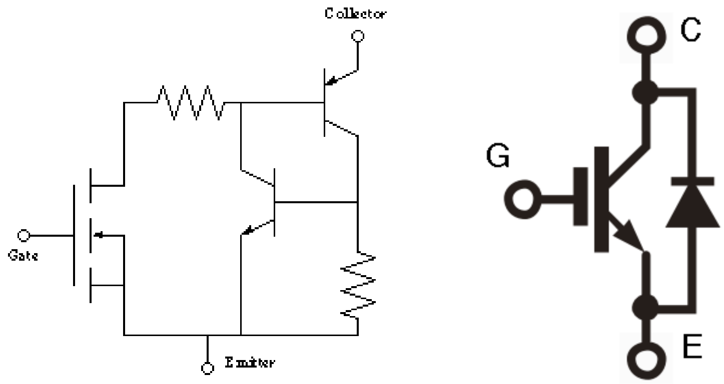

Figure 3: Equivalent circuit of IGB transistor

IGB transistors are widely used in medium and high power applications. In drive applications IGBTs are usually packed inside one component to ease the heat dissipation from many components to one and to save space on the circuit board. The anti-parallel diode parallel with the IGBT is needed to handle current forced by inductive loads at the turn off time of the IGB transistor. [1]

2.2 Servo Drives

The function of servo drives is similar to frequency inverters but servo drives are more specialized on accurate motor control and higher over load torques. Such drives are mainly used in CNC machining, factory automation and robotics solutions where accurate motion control is needed. The difference between a servo drive and a conventional drive is defined by precision and performance demands. These qualities are significantly higher in servo drives and most of the applications are more focused on the 1,5 – 50 kW power range.

Servo drives are generally used in applications that require high precision and performance where position feedback of the motor shaft can be used. A common function of a servo drive is based on the feedback loop from the servo motor. A servo drive receives a command signal from a motion controller, amplifies the signal and transmits electric current to a servo motor. The command signal can adjust the desired velocity, motor position or torque. The servo drive compares the desired quantity to the measured quantity from the feedback loop and controls the voltage frequency to correct any error between the quantities.

In typical low cost frequency inverters the desired qualities focus more on energy savings and in such motor control where precision and maximum performance are more modest but there are still possibilities to affect motor control.

In numerical values the servo drive manufacturer Yaskawa has specified that their Sigma Series servos can handle up to 200-300 % torque for short periods of time comparing to a typical frequency converter value of 150%. These overload values are also compatible with other servo drives. Such values in torque provide faster acceleration rates for the applications. Also the position controller's torque reference rate differs from 1 ms on normal vector control based frequency inverters to scan times of 125 µs with servo drives.

The encoder resolution of servo drives is an essential factor that defines servo drives as high precision components compared to the conventional frequency inverter with motor feedback. It is possible to have resolutions such as 8192 (typical!) ppr with an encoder frequency of 500 kHz.

IGBTs in servo drives are more oversized when comparing to conventional frequency inverters due to the nature of high overload currents which are handled through IGB-transistors and their maximum collector currents must be sized for these requirements. [1, 3, 5]

2.3 Multi-axis Servo Drives

Multi-axis servo drives are often needed in most demanding and complex applications of the motion control industry. The term multi-axis in this concept means that the servo drive is capable of feeding power to several servo motors. The advantage of multi-axis servo systems is to run many different motors driven by one motion controller which supervises the movement of every axis and commands them to keep the process as fast and accurate as possible although the torque loops are still driven by the axis controller themselves.

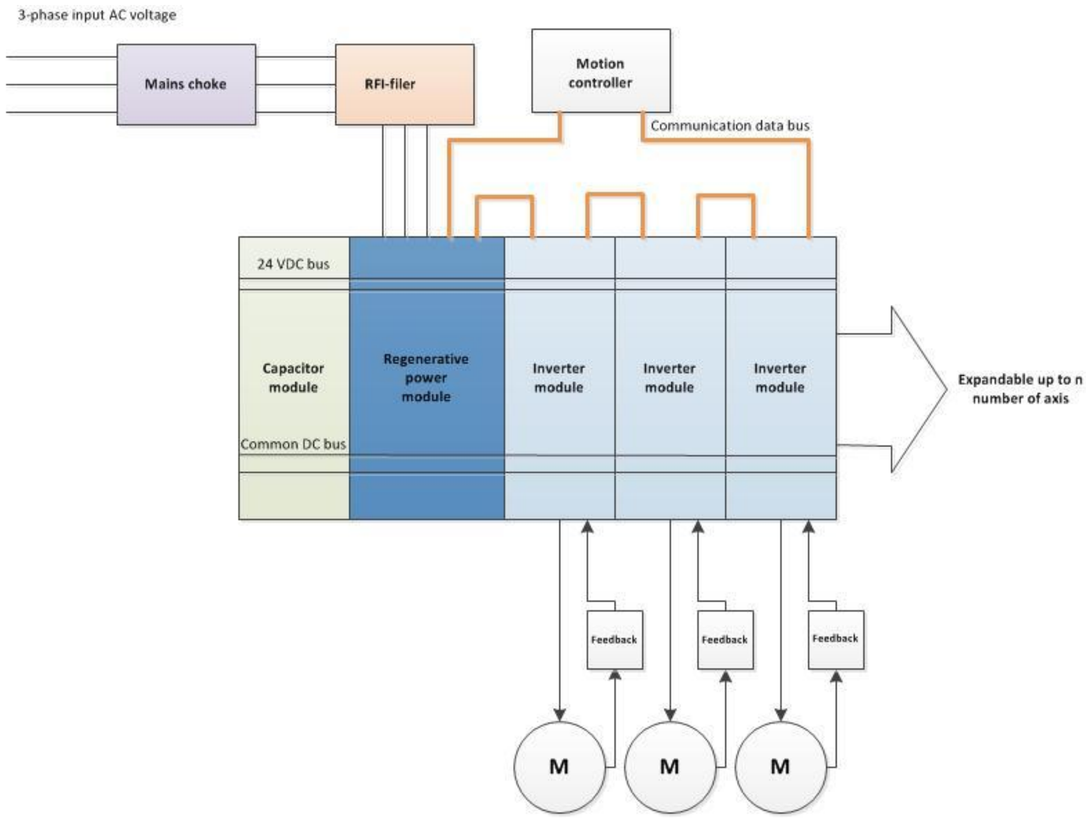

Figure 4: Example of typical multi-axis configuration.

The number of inverter axis modules varies depending on the application widely and there is no theoretical limit although a high number of axis will reduce the control loops of the communication bus significantly when all the commands have to travel through every axis to the motion controller and deliver the message from the controller back to the axis if a token ring type of communication bus is being used.

2.4 Benefits of Multi-axis Servo Drives

In operation common DC bus drive systems are more efficient than single servo drives because the power is shared in the DC bus and in braking situations the regenerated power can be loaded back to the DC bus and delivered to the use of the other axes that are currently accelerating or maintaining their speed. In this way the power doesn't need to be transformed as heat in the braking resistor or regenerated back to the 3-phase supply network with greater power dissipation. Multi-axis servo systems also require less wiring since only one set of rectifiers is needed for the whole system if only one power supply module is used. This will also make savings in the number of needed components and create a possibility for more compact modules.

One advantage is that multi-axis servo drive system modules can be mounted as side-by-side mounting without any clearances between the module units which also simplifies the wiring of the common DC bus and +24 VDC control supply voltage when the modules are stacked besides each other. As a downside the cooling has to be handled more efficiently if conventional air cooling with a fan is used instead of cold plate or liquid cooling.

A further benefit is that the control of the system can be optimized more easily with only one motion controller which monitors all of the axes and controls them to keep the process in order. [3, 5, 10]

3 MULTI-AXIS SERVO AND SYSTEM DRIVES COMPARISON

3.1 Range of Modules

The range of different modules from different manufacturers is wide. All the manufacturers had passive and regenerative power modules available except one. Different inverter units were also available and also as double-axis versions. Regenerative chokes and RFI filters were available throughout the power range. The differences were in the DC-bus capacitor modules and there were different solutions for implementing the capacitor banks and in some solutions they were not offered as an extension module for the multi-axis system since the capacitances can also be added straight to the axes.

Manufacturer	ABB	Siemens	B&R Automation	Lenze	SEW	Baumuller	KEB	Beckhoff	Schneider	Bosch-Rexroth
Model name	ACSM1	S120	ACOPOSmulti	9400Servo	Moviaxis	Bmaxx5000	Combivert H6	AX5000	Lexium LXM 62	IndraDrive M
Infeed unit	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Single-axis inverter	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Double-axis inventer	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes
Regenerative braking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Line filter	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Line choke	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes
Control unit	No	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes
Capacitor modules	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes
24VDC supply module	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Buffer module	No	No	No	No	Yes	No	No	No	No	No
DC-link discharge module	No	No	No	No	Yes	No	No	No	No	No

Table 1: Comparison of offered modules and functions

As can be seen from table 1, the variety of modules offered varies between manufacturers since there are many ways to implement a multi-axis servo drive system. The widest range of modules was provided by SEW Moviaxis which only lacks double-axis modules from its catalog. Wide ranges were also available from Lenze 9400, KEB Combivert H6, Siemens S120 and Bosch-Rexroth Indradrive M. These types of systems were closely scoped in this thesis. [2,3,4,6,11]

3.1.1 Power supply modules

The purpose of the power supply module is to rectify AC to DC. Input AC can be supplied from either 1-phase or 3-phase network but in this study it was decided to focus on 3-phase 400V systems since they are the most commonly used. Most of the multi-axis servo system manufacturers provide also regenerative power supply modules that can also regenerate DC back to AC and feed it to the supply network. The capability to regenerate current back to the network can in some cases be lower than the infeed capacity due to energy losses in the system and the kinetic energy that is transformed to electric current. In the Bosch-Rexroth’s Indradrive M there is exceptionally no specific power supply unit available for the system. All the inverter axis units get their supply from the common AC bus but also share a common DC bus which makes regenerative braking possible.

The regenerative modules do not necessarily have to be connected to the motion controller or higher level PLC which controls the multi-axis system. The operation of regenerative power supply is based on the continuous measuring of common DC bus voltage which has to be in a given voltage range. When servo drives start to brake they generate a voltage rise in the common DC bus which is detected by the regenerative power supply and feeding energy back to the supply network starts. In a reverse case when servo drives are using energy and the voltage in the common DC bus starts to drop the regenerative power supply starts to feed more energy to the common DC bus to keep the voltage at the desired values.

The rectifier can be either uncontrolled typical diode bridge or consist from H-bridged IGBTs and diodes. The latter configuration allows regenerative braking back to the supply network along with the power input to a common DC bus, although it is possible to use a separate rectifier and regenerative power module to achieve lower costs of the system. In this study it was found that the Lenze’s 9400 multi-axis servo series has different rectifier and regenerative modules and the schematic of their 15 kW power supply module is added to the appendices of this study.

It should be noted that single power supply module can alone be responsible of feeding the current to the system. It is essential that it can be able to provide inrush current to the total common DC bus capacitance and worst case operational current draws of the system. [2,3,4,11,14]

3.1.2 Capacitor modules

The capacitor modules are used to store the energy, which is fed into the common DC bus. In braking situations the excess energy is not dissipated via a braking resistor until the capacitor bank is loaded. The energy is withdrawn from the capacitor bank and is reused in the system when an acceleration process is started. Intermediate storage and reuse of energy is particularly useful for multi-axis systems.

In this way, most applications in the medium power range can be implemented in an energy efficient manner without excessive use of braking resistors or regeneration.

When the power modules are not recharging a DC voltage drop in the common DC link circuits will occur. To prevent this, the time intervals when the 3-phase infeed voltage is not recharging the common DC bus could be decreased by the sufficient option would be increase the capacitance of the intermediate circuit. There are manufacturers such as B&R, SEW, Siemens, Beckhoff and Bosch-Rexroth who provide such additional modules to increase the capacitance of the DC intermediate circuit to prevent serious voltage drops.

The capacitor or buffer modules are usually sized 1000 µF to 4920 µF and some manufacturers like SEW use these units to also as storage banks for braking energy. Such a solution will create a chance to re-use energy back to the inverter units and there decrease the overall energy consumption and remove the need of the braking chopper and resistor if the excessive energy is not meant to be regenerated back to the supply network.

Large capacitances increase inrush current of the system on power up situations when the capacitors are initially charged. Inrush currents can be reduced by using a loading resistor which is bypassed with a relay. Otherwise the current limitation must be made in the power supply module with a controlled rectifier bridge and current monitoring. The peak inrush current must be in the limits of the capacity of the power supply module. [14.15]

3.1.3 24V DC power supply modules

Modern electronics also need several lower voltage levels such as 1,2 VDC or 3,3 VDC for the logics and processor, 5 VDC for input and output operation, +15 VDC for IGBT gate driver and 24 VDC for fans. These voltages are usually converted from the intermediate circuit 600 VDC voltage level by using *flyback switching xxx* topology. These units are usually rebranded from another manufacturer because they don't have direct influence to the precision or performance of the motor control and there are already many optimized units in the market for a low price.

In situations of network failure it would be possible to keep the common 24V DC bus live by using a backup battery to feed the bus. Some manufacturers have drawn such backup batteries in their system overview schematics but such batteries are not being directly provided by the manufacturers. In such cases all the processors and control electronics would keep their position knowledge and they would be able to brake the movement of the axis safely. [3,11,14,15]

3.1.4 DC link discharge modules

SEW is the only manufacturer that offers a DC link discharge module in their catalog. The idea of such a module is to quickly discharge the DC intermediate voltage and the kinetic energy of the motor. The supply units must be disconnected from the system. A motor connected to the DC link generates braking torque that is dependent on the speed and the uncontrolled inverter unit can be decelerated electronically without inverter function. The duration of this quick discharge is meant to be equal or less than one second. The discharged energy itself is consumed in a special braking resistor and the maximum braking energy per discharge is limited to 5000 Joules with the only available module type MXZ80A-050-503-00 that SEW is offering. These sorts of discharge operations need to have at least 60 second of recovery time to prevent the braking resistor from overheating.

Other manufacturers offer same the sort of function with a separate braking chopper and brake resistor range. These solutions are meant to decelerate the motor’s kinetic energy in to heat but such devices won’t be to able discharge the common DC bus so SEW MXZ80A-050-503-00 could also be considered to increase the safety of the system. [19]

3.1.5 Single-axis inverters

The inverter axes form the backbone of the multi-axis servo systems and single-axis inverters typically have a wider power range than double-axis inverters. As table 2 shows the powers of the axis start from 0,37 to 5,5 kW and end up at the values of 15 to 160 kW which shows that some manufacturers have focused on different fields of applications and the wideness of the industry. [3,11,14,15]

Manufacturer	ABB	Siemens	B&R Automation	Lenze	SEW	Baumuller	KEB	Beckhoff	Schneider	Bosch-Rexroth
Model name	ACSM1	S120	ACOPOSmulti	9400Servo	Moviaxis	Bmaxx5000	Combivert H6	AX5000	Lexium LXM 62	IndraDrive M
[kW]	0,75	1,6	1,5	0,37	1,4	1,6	0,75	1,2	1,4	5,5
[kW]	1,1	2,7	3,0	0,75	2,8	3,2	2,2	2,5	3,5	11
[kW]	1,5	4,8	6,1	1,5	5,5	6,5	4	5	6,3	18,5
[kW]	2,2	9,7	12,1	3	8,5	10,8	5,5	10	15	22
[kW]	3	16	17,6	4	11	16,2	7,5	15		37
[kW]	4	24	26,4	5,5	17	21,6	11	20,8		55
[kW]	5,5	32	35,2	7,5	22	32,4	15	33		75
[kW]	7,5	46	70,4	11	33		22	42		125
[kW]	11	71		15	44		37	50		
[kW]	15	107			69		45	62		
[kW]	18,5						55	76		
[kW]	22						75	99		
[kW]	30						90	118		
[kW]	37						110			
[kW]	45									
[kW]	55									
[kW]	75									
[kW]	90									
[kW]	110									
[kW]	160									

Table 2: Single-axis inverters and ABB ACSM1 servo drive as single drive comparison.

3.1.6 Double-axis inverters

In the early phase of the study it was found out that many manufacturers provide also double-axis modules along with more traditional single-axis inverters. Such arrangement makes it possible to use fewer modules when compiling large servo systems. Double-axis modules are intended for smaller axis, which are rated at 16 kW power per axis at most as table 3 shows. [3, 4, 6, 15, 23, 24]

Manufacturer	Siemens	KEB	Beckhoff	Schneider	Bosch- Rexroth	B&R Automation
Model name	S120	Combivert H6	AX5000	Lexium LXM 62	IndraDrive M	ACOPOSmulti
[kW]	1,6	0,75	2,5	1,4	2,2	1,4
[kW]	2,7	2,2	5	3,5	3,7	2,8
[kW]	4,8	4	10	6,3	5,5	5,5
[kW]	9,7	-	-	-	-	11
[kW]	-	-	-	-	-	16

Table 3: Double-axis modules

3.1.7 Line filters

Line filters are used to keep electromagnetic compatibility of the multi-axis servo system in the desired limits for emissions and tolerances. The product standard EN 61800-3 divides the power drive systems into four categories according to the intended use. The purpose of the external filters is to achieve desired classes to make it possible to use power drive systems such as multi-axis servo drives in the desired environment. Conductive emissions can be limited by following ways:

- Using LCL or CLC filter in the case of regenerative drives
- RFI filtering for high frequency disturbances
- Using mains chokes against harmonics
- Using ferrite rings in power connections
- Using du/dt filter

-

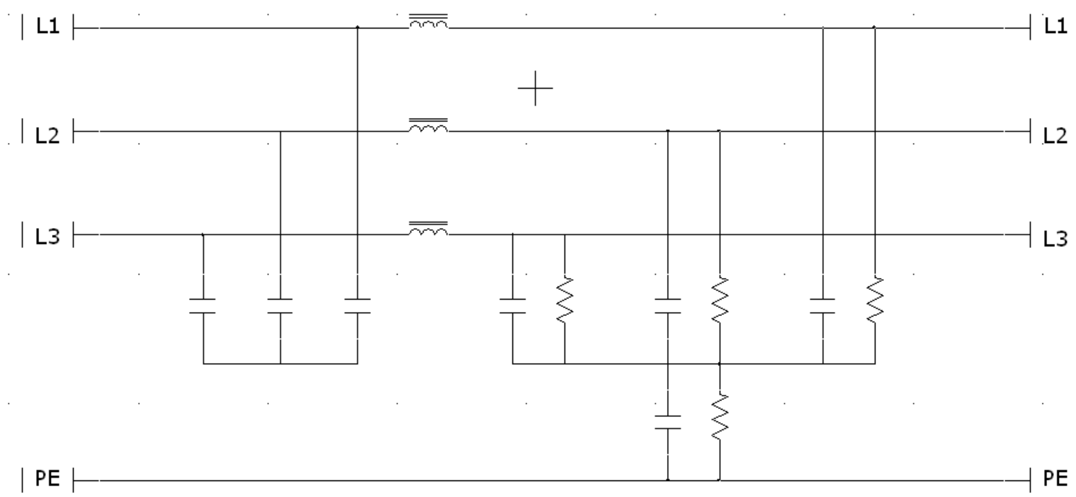

Figure 5: Typical electrical schematic of RFI filter

A varistor is an electronic component which is usually used to protect power supply units from excessive transient voltages from the supply network. Non-linear diode-type of current-voltage characteristics trigger varistors to conduct electricity through the component when the voltage in the power supply network increases to a dangerously high level. [1]

3.1.8 Mains chokes

Mains chokes are required for regenerative braking power back to the supply network. The purpose of the choke is to soften the voltage curve from the switching IGB transistors that cut the voltage back to the supply network. Another purpose is to reduce the AC input peak current level and meet the requirements for harmonic distortion. Mains choke can also be used in applications without regenerative braking to reduce the current ripples that strain the common DC bus capacitors and generate harmonic distortions in the power supply grid. The machine life time and reliability will be increased when charging current peaks are decreased. Chokes can also be used in output leads of the servo motor to reduce the harmonics.

3.1.9 Motion controllers

The motion controller’s main purpose is to control the inverter units. A motion controller calculates for example the position of the axis and uses that information and then commands axis to slow down or increase speed depending on the situation. The connection to inverter units is handled via a control bus, typically etherCAT based. The logic in each inverter unit (axis) determines the torque need

The control loop cycles of the system define for example how often position information of the servo can be delivered to the motion controller. These times are usually defined to be around 100 µs. These times are usually dependant on the number of the used axis in the system.

Typical motion controller in multi-axis servo systems is built with 32 bit 100 to 700 MHz embedded processor (for example ARM) with various amounts of RAM and programming memory. [7]

3.2 Input voltage

All the selected systems for this study used 3-phase voltage input from the supply network. There were, however differences in input voltage range as shown in the chart 1 below.

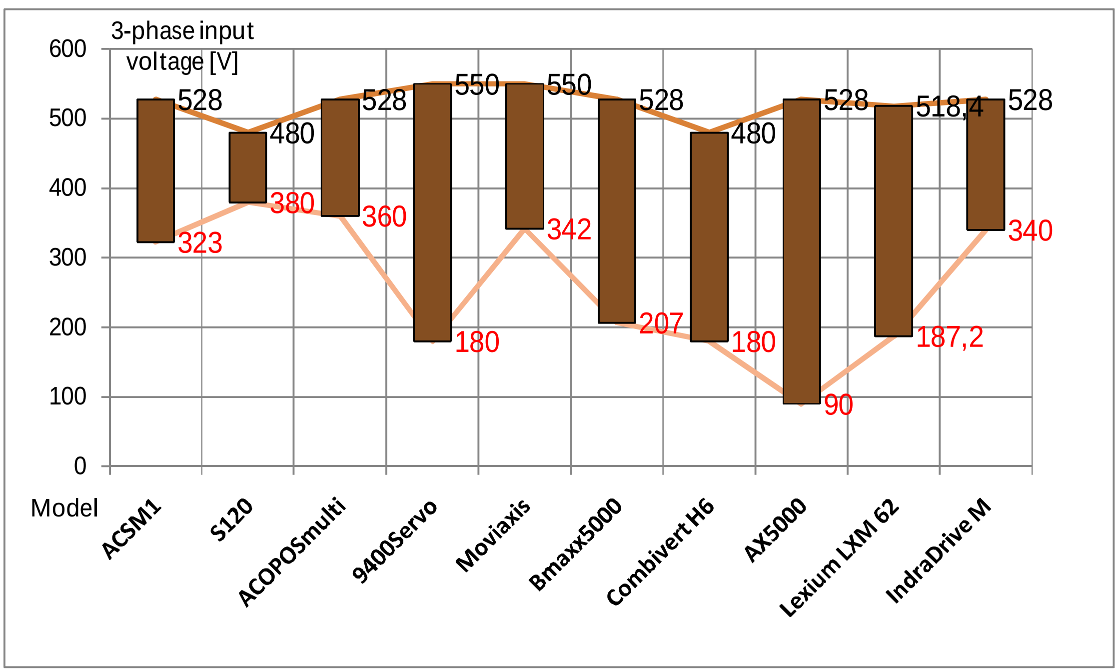

Chart 1: Comparison of input voltage of different models

Minimum and maximum voltages were calculated from the given margins to the 3-phase input voltage values. Most of the manufacturers that were chosen for this study were European in which means that the 3-phase voltage of 380 – 415 is covered by all manufacturers with ±10 % marginal.

A wide supply voltage of the system affects dramatically the common DC bus voltage and lowers the cost efficiency of the system because the common DC bus voltage is calculated according to the following formula:

$$U_{DCmax} = U_{L-L}\sqrt{3}$$

Equation 3

, where the Common DC bus maximum voltage is the same as the maximum voltage difference between two phases of supply network voltage excluding the voltage drop of rectifier diodes. When electrolytic capacitors are chosen to increase the capacitance of a common DC bus their maximum voltage must exceed the maximum voltage of common DC bus capacitance. An increase of the maximum working voltage makes the capacitor physically larger and cost more than the same value capacitor of a smaller maximum operating voltage. Also the voltage feed to the servo motors is directly dependent on the maximum voltage U_{L-L} difference of the supply network.

3.3 Common DC-bus

A common power supply module, which is equipped with only one rectifier can supply the power to the DC bus for all DC-AC inverter axes that are connected to the system. Having just one large rectifier unit instead of many smaller ones saves space, components, costs and provides many advantages and flexibility for multi-axis systems. A common DC bus can be implemented using different topologies but mostly used seems to be to build common DC bus behind the drives in to rails that go thru the whole system. Beckhoff AX5000 uses DC bus rails that are connected to the units on front of the modules. It is also possible to use normal wire connection between modules when using stand alone servo drives to bypass the rectifier bridges. A rectifier works also with DC voltage but efficiency will suffer.

In the common DC bus there will be need for fuses for every inverter axis unit and other modules. It is also possible to increase the common DC bus capacitance with capacitor modules and the extra capacitance will be there for all the modules to use and possibly even brake to in some cases.

Multi-axis systems can generally use either a DC bus choke or a three-phase AC line choke that smoothes the current draw to the capacitor modules and other common DC bus capacitances. In case of DC chokes the connection can be made either positive or negative side of the rail.

The modules that are directly fed by the common DC bus should be able to be isolated in case of over voltages or currents flowing in the system. Such malfunction states can cause severe damage and break multiple modules of the system. Fusing of the system is being discussed later in this study but another way to solve the problem is to use relays and have current monitoring between common DC bus and intermediate capacitors of the modules. Also the voltage level of the intermediate capacitors must be monitored to ensure power distribution to the servo motors and prevent capacitors from over voltages. [3, 10]

3.4 Fuses

In case of malfunction in the axis the common DC bus could be protected by multiple fuses in the series of each axis. If one of the drives gets short circuited it will drain current from common DC bus and empty its capacitor banks. With fuse between the module and DC common bus is switched off when such action might happen. Fast discharging of capacitor modules could cause breakdown of many modules such as capacitor banks, axis and power supply module if there is no current control or fusing to limit current push from the supply network.

3.5 Mounting and Installation

There are generally three different mounting methods available, and these choices must be considered when planning the sizing of the system. They are wall mounting, feed-through mounting which is also known as flange mounting, and cold plate mounting. KEB also provides liquid cooling option for Combivert H6 multi-axis drives but they also have defined their inverter unit’s power range for over 100 kW. Although frequency inverters are designed to have the highest efficiency rating possible they will always dissipate a slight amount of energy in to heat.

3.5.1 Wall mounting

The least efficient of the three mounting methods is the wall mounting when cooling is considered but it is usually the most simplest to install. In wall mounting design the cooling air must flow in the back side of the module units. Air flow can either be done with natural or by a cooling fans usually placed on the bottom of the inverter units to force air to flow in more through cooling plates where the IGBT bridges are thermally connected. [1, 3]

3.5.2 Feed-through mounting

In feed-through mounting multi-axis drives are installed in a cabinet which requires a hole to be cut in to the back of the cabinet. Modules are mounted through that hole in the way that the heat sinks are outside of the cabinet. These heat sinks can now be cooled more efficiently when they have large amount of air space around them.

3.5.3 Cabinet mounting

Multi-axis systems are usually mounted in a separate cabinet in the eventual install location that is usually an industrial environment where sometimes an upgrade of enclosure class with cabinet can be useful. The cooling is usually handled by installing the modules through the cabinets back wall to maximize the airflow on the heat sinks.

3.5.4 Cold plate mounting

Cooling can also be implemented by using a common passive heat sink or other cooling element to jointly handle the heat that is generated in the amp units of the inverter modules and other components that may require heat dissipation.

3.6 Axis module width comparison

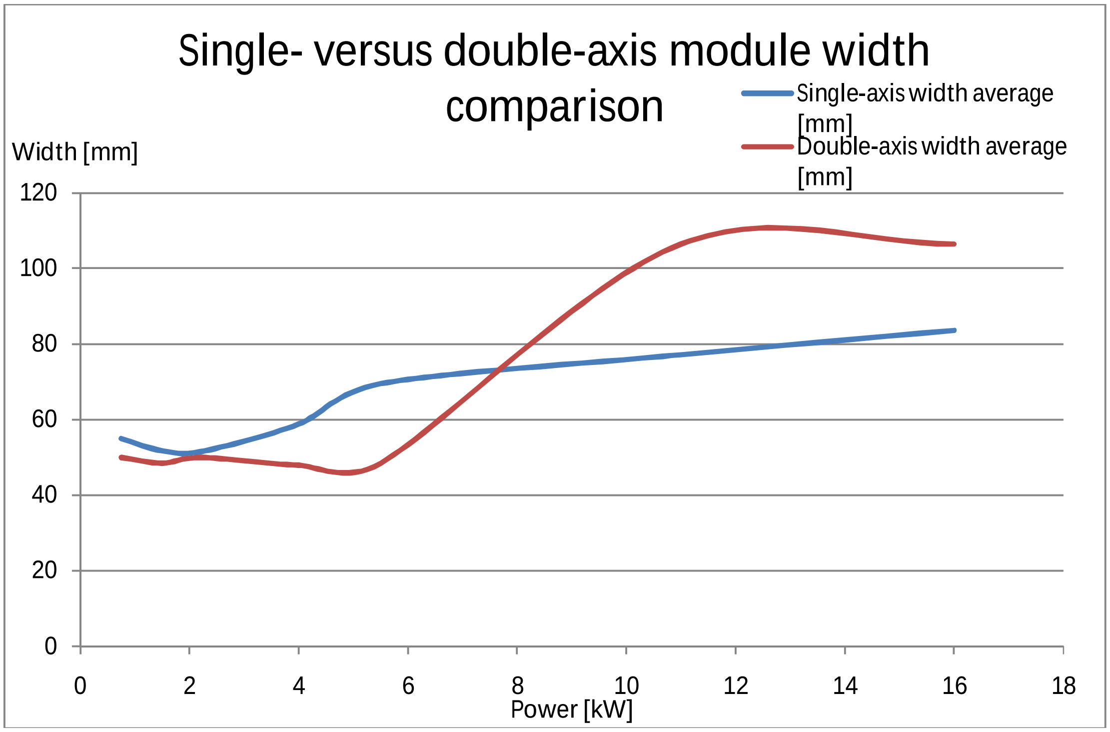

Chart 2: Single- and double-axis width comparison up to 16 kW. It should be noted that the single-axis modules are needed twice as many to achieve same number of axis but the size of the system is then being more than doubled in worst cases.

The module width of the axis greatly affect the size of the whole multi-axis drive system since the number of axis can vary as much as 255 or more. In this study it was found out that the double-axis modules have significantly smaller width values when width per axis is scoped out. The compactness of the double-axis modules comes from shared components like heat sink, cooling fan, power circuit board which has 2 IGBT modules instead of one and their control electronics although as it will be later discussed in this study two axis can be controlled with using just one processor.

As can be seen from chart 10 the size of the double-axis modules starts to increase faster than the single-axis modules after 7,5 kW but becomes steadier after 11 kW mark. Chart 10 has been created from average width values of single- and double-axis inverters from all multi-axis servo systems scoped in this study. The list of dimensions can be found from the appendices of this study.

3.7 Speed and Position Feedback

In systems where precise control of position or speed is important, a position or speed sensor is required. Also there are various sensorless control techniques available which can estimate position or speed by measuring the motor currents. Motor feedback is an important feature of servo drives because it improves the performance and precision of the servo motor making it as good choice for demanding motion control applications. The purpose of feedback is to give

- Speed feedback to speed controller
- Position control to motion controller
- Shaft position to the drive
- Absolute information after black out

3.8 Electromagnetic Compatibility (EMC)

Electromagnetic compatibility is the ability of an electrical or electronic device to operate properly during in an electromagnetic environment. It also has the ability not to disturb or interfere with other electrical equipment or system within its radius. This is legally required for all equipment taken into service within European Economic Area (EEA).

Multi-axis servo drives have to be able to tolerate different interference frequencies. Most common low frequency interferences are harmonics and asymmetry phases. High frequency interferences are also known as RFI (Radio Frequency Interference) are for example electrostatic discharges, transients and electromagnetic fields. Servo drives cause high frequency interferences because of the semiconductor switching frequencies and they also cause harmonics to the supply network.

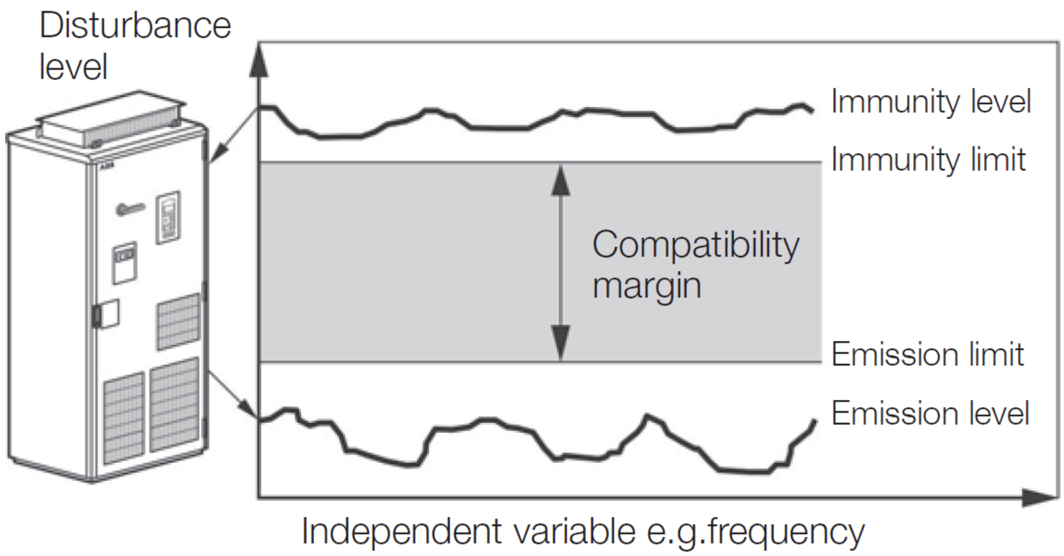

Figure 8: Electric device must tolerate interferences from other devices and from power supply network and not to interfere their operation. ABB Technical guide nr 3 page 8

3.8.1 EN 61800-3 EMC standard

EN 61800 is a standard for power drive systems (PDS) has defined limit values for emissions and immunities.

		EN61800-3 (2004)				Without options	With options
		Cat. C1, 1st env.	Cat. C2, 1st env.	Cat. C3, 2nd env.	Cat. C4, 2nd env.	Cable length max [m]	Cable length max [m]
Manufacturer	Model	Unrestricted	Restricted	Unrestricted	Restricted	shielded/unshielded	shielded/unshielded
KEB	Combivert H6	As external option	As external option	No	Standard	NA	300
B&R	ACOPOSmulti	No	No	As external option	Standard	25	NA
Lenze	9400servo	No	As external option	Standard	Standard	100	50
Beckhoff	AX5000	No	As external option	Standard	Standard	>25	NA
SEW	Moviaxis	No	No	No	Standard	25	25
Siemens	S120	No	As external option	As external option	Standard	300 / 450	350/560
Bosch-Rexroth	Indradrive M	No	No	No	Standard	NA	NA
Schneider	Lexium 62	No	No	No	Standard	NA	NA
Baumuller	Bmaxx	No	No	No	Standard	NA	NA
ABB	ACSM1	No	As external option	No	Standard	50/75	50

NOTE! Marked as No when there is no mention of applience of such category. To fullfil C4 no actual filter required

Table 4: Comparison of categories provided concerning EN 61800-3 EMC standard.

In table 4, the differences in the promised categories were found and oddly there was no information given from all the multi-axis servo drive manufacturers. However it can be assumed that category 4 can be fulfilled since it does not require actual filtering.

3.9 Regenerative Braking

In many applications the electrical drives need to be accelerated or decelerated quickly. The braking power can either be transformed as heat in the braking resistors or fed to use of other electrical drives which are currently consuming power from the common DC bus or if that is not possible, brake the power back to supply network. Regenerative power supplies are used for this purpose.

Regenerative energy is fed by the motor to the common DC link when the motor procedures negative torque and then brakes. In this mode the motor works as a generator and the power produced can be either stored in the capacitor banks if the braking energy is small enough and the rest of the power can either be transformed as heat or optionally fed back to the supply network as sinusoidal voltage via the same type of IGB transistor H-bridge as there is in the amp of the inverter units for the motor. As the IGB transistors can't conveniently transform DC voltage to sinusoidal voltage by cutting the DC in the wanted frequency extra components must be used. Such components are mains choke which is also known as regenerative choke in some applications and sometimes optional EMC filter that can either be integrated in to the power supply unit or to be located as separate module in the system.´

The maximum regenerative braking power varies highly depending on the application and it is possible that the regenerative braking time is so slow that the regenerative braking IGBTs can have smaller maximum current as is in the power supply modules. In multi-axis applications it can be also so that the regenerative power from the motor which is working as a generator can be directly fed for motors which are currently being fed with infeed power. If the regenerative power exceed the limit of the single regenerative power supplies ability to brake back to supply network it is possible to use several regenerative power supplies in parallel. [1]

3.10 Communication Bus

The communication between the modules is being handled by using a fast speed Ethernet-type communication field bus. Multi-axis servo systems can either use ring type of Ethernet topology or star network where all the axis and regenerative modules are connected directly to the motion controller.

3.10.1 EtherCAT

EtherCAT is a real-time Ethernet-based fieldbus developed by Beckhoff. Speed of EtherCAT is 100 Mbit/s and it uses standard Ethernet cables for data transfer. It is a widely used communication bus among multi-axis servo drive manufacturers. With 100 servo axes it is still possible to have cyclic update rates as low as 100 µs. [6,7,8]

3.10.2 SerCos III

Sercos III is the third generation of the SerCos communications technology, which is supported internationally by more than 50 manufacturers and more than 30 drive manufacturers. Speed of SERCOS III is 100 Mbit/s and it can provide cyclic updates at rates as low as 31.25 µs. From the selected manufacturers Schneider Lexium 62 and Bosch-Rexroth Indradrive M supported SerCos III as communication technology in data communication between modules. [4, 14]

3.10.3 PowerLink

Ethernet Powerlink is a real-time protocol for standard Ethnernet like EtherCAT. It was introduced by B&R in 2001. In the end of 2006 Ethernet Powerlink with Gigabit Ethernet came with 1000 Mbit/s support still the fastest cycles are being rated under 200 µs which are also possible with other communication bus topologies. [9]

3.11 Safety Features

Safety has become a more and more important issue in the frequency inverter markets where customers have started to demand devices that are safe to operate and maintain. The european safety standard EN 954-1 is considered today as the internationally applicable standard in the area of safety-related control systems. "Safety of machinery– Safety-related parts of control systems" is established as the international state of technology in the area of machine safety. It applies for all safety-related parts of control systems, regardless of the power type used, e.g. electric, hydraulic, pneumatic or mechanical. EN 954-1 defines categories for classifying different safety-related capacities (categories B, 1, 2, 3, 4).

3.11.1 Safe Torque Off (STO)

Safe Torque off is a functional safety feature which allows the drive output to be disabled so that the drive cannot generate torque in the motor. In the absence of a 24V enable input, the drive is disabled to a high degree of integrity where no sinlge cpmponent failure and only very unlikely combinations of three component failure, could result in it being enabled. [21]

3.11.2 Stop Category 0.

Immediate removal of power to the motor the motor will coast to stop. The time required to stop motion is dependent on the load internia and speed as well as the friction in the mechanical power transmission equipment used in the system.

3.11.3 Stop Category 1.

Controlled stop when removal of power to the motor. A ramp to stop will be used to control the mechanical power transmission to rest then power is removed from the motor. The time required to bring the mechanical system to rest is dependent upon load inertia and speed as well as the regenerative dissipation capacity of the drive.

3.11.4 Safety comparison

Table 5 below summarizes the safety functions that are provided from the selected servo drive manufacturers. It is important to get diagnostic information from the drive system. An estimated product release year has been added to the table to help to reflect on the increase of safety features over the years.

Manufacturer	ABB	Siemens	B&R	Lenze	SEW	KEB	Beckhoff	Schneider	Bosch Rexroth	Rockwell
Model name	ACSM1	S120	Acopos	9400Servo	Moviaxis	H6	AX5000	LXM 62	Indradrive M	Kinetix 6500
Safe stop 1 (SS1)	No	No	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes	Yes	Yes
Safe stop 2 (SS2)	No	No	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes	No
Safe stop emergency	No	No	No	No	No	No	No	No	No	No
Safe torque off (STO)	Yes	Yes	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes	Yes	Yes
Safely limited torque (SLT)	No	No	No	No	No	No	No	No	No	No
Safe torque range (STR)	No	No	No	No	No	No	No	No	No	No
Safe operating stop (SOS)	No	No	Yes, option	No	No	Yes, option	Yes, option	Yes, option	Yes	No
Safe maximum speed (SMS)	No	No	No	Yes, option	No	No	No	No	Yes	No
Safe limited speed (SLS)	No	No	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes, option	Yes	Yes
Safe speed range (SSR)	No	No	No	No	No	No	No	No	No	No
Safe brake control (SBC)	No	Yes	No	No	No	Yes, option	No	No	No	No
Safe speed monitor (SSM)	No	No	No	No	No	No	No	No	No	No
Safe direction (SDI)	No	No	No	Yes, option	No	Projected	Yes, option	No	Yes	No
Safe acceleration range (SAR)	No	No	No	No	No	No	No	No	No	No
Safely limited acceleration (SLA)	No	No	No	No	No	No	No	No	No	No
Safely limited position (SLP)	No	No	No	No	No	No	Yes, option	No	Yes	No
Safely limited increment (SLI)	No	No	No	No	No	No	No	No	Yes	No
Safe motor temperature (SMT)	No	No	No	No	No	No	No	No	No	No
Safe cam (SCA)	No	No	No	No	No	No	No	No	No	No
Safe stand still	No	Yes	No	No	No	No	No	No	No	No
Estimated year of product release	2008	2006	2007	2007	2006	2010	2005	2009	2009	

Table 5: Comparison of safety functions

None of the provided models complied with all of the safety functions although features like the Safe Torque Off have become industry standards since all the manufacturers provide such function. Safe stop 1 and Safe stop 2 were also widely provided along with the Safe limited speed. Most of the manufacturers want to provide increased safety as optional extra.

4 DISASSEMBLED MODULES

This section is focused on dissembled units that were chosen for this study to be reverse engineered. One of the models chosen for closer study was Lenze 9400 servo drive system and a certain type of module system was ordered for a closer look. The modules that were ordered were:

- 1pc E94ARNE0134A22ETNN-P036 15 kW power supply. 7,5 kW regeneration possible
- 1pc E94APNE0104 5kW power supply
- 2pcs E94AMHE0044E22ETNN-M024NA0021 1,5 kW single axis inverter module
- 1pc E94AMHE0134E22ETNN-M024NA0 5,5 kW single inverter module
- 1pc EZV1200-001 24 VDC power supply

The modules were ordered to be researched and reverse engineered for this study. Also Bosch Rexroth's Indradrive M was chosen for this study with a similar type of configuration of two 2,2 kW axis and one higher powered 5,5 kW axis with 18kW regenerative power supply unit and extra capacitor module to be studied. The ordered list was as follows:

- 1pc HMV01.1R-W0018-A-07-NNNN 18 kW regenerative power supply module
- 1pc HMD01.1N-W0012-A-07-NNNN Double-axis inverter module 2x 2,2
- 1pc HMS02.1N-W0028-A-07-NNNN Single-axis inverter module 6,9 kW (+0,14mF)
- 3pcs CSB01.1N-SE-ENS-NNN-L1-C-NN-FW Control unit with SerCos
- 1pc HNL01.1E-0600-N0032-A-500-NNNN Mains choke
- 1pc HLC01.1C-02M4-A-007-NNNN 2,4 mF capacitor module

From SEW the ordered Moviaxis modules followed the same type of configuration of 3-axis were one of the axis was power rated around 6 kW and two smaller axis to 1,5 kW power class. The following types of modules were ordered:

- 1pc MXA82A-012-503-00 6,7 kW axis
- 1pc MXS80A-060-503-00 24 VDC power supply
- 1pc 8299730 choke + filter MXR 50KW
- 1pc MXC80A-050-503-00 4920 µF Capacitor module
- 1pc MXZ80A-050-503-00 DC-link discharge module
- 1pc MXR80A-075-503-00 50 kW regenerative power supply

4.1 Power modules

Due to the nature of possible high overload currents of servo drives dimensioning power supply units are also needed to provide certain period of overloads for drive axis. This provides a possibility to have cost savings in semiconductor power electronics if the semiconductors are driven near to their maximum currents.

4.1.1 Regenerative power module

The Lenze's 9400 15 kW regenerative unit consisted from 3 different PCBs: Power electronics board, processor card board and connection board. It was found out that they used a PCI-style connection method that is more commonly known from the computer world. The advantage of using such a method must bring cost savings hence the connector type is already popularly used and it has been found out to be reliable and even supports high speeds of data transfer.

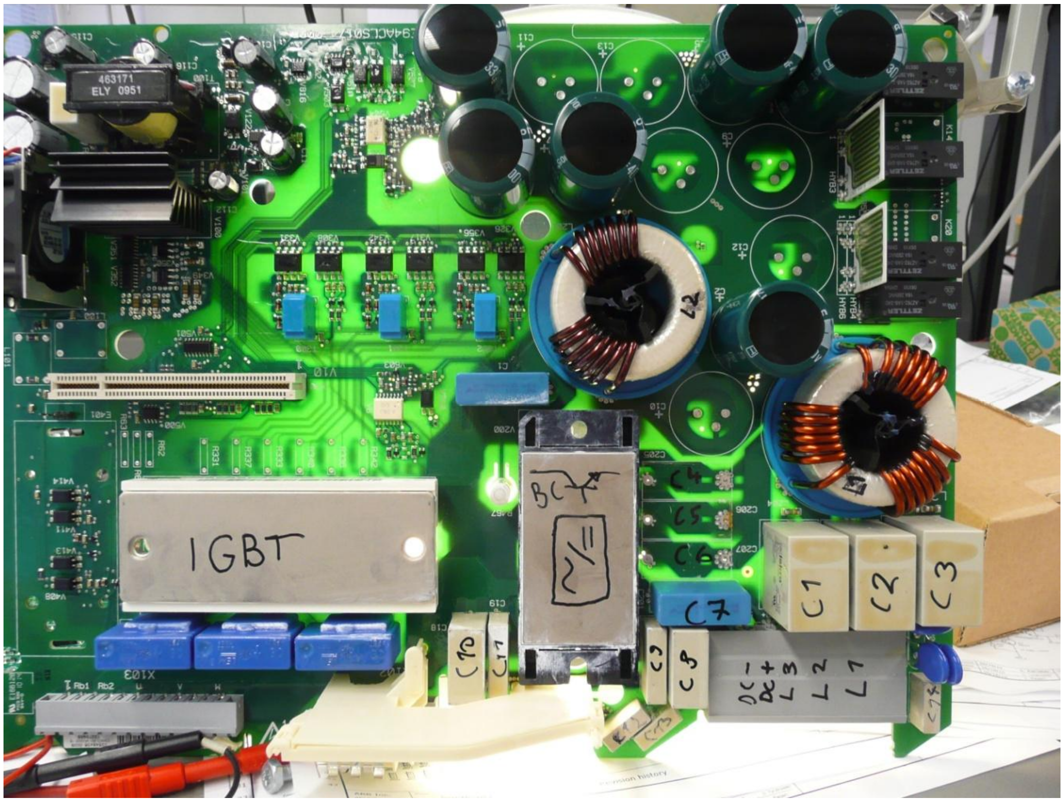

Figure 9: Power electronics PCB of Lenze 9400 15kW regenerative power supply unit

Power electronics card consisted of sections of supply network voltage power section and control section that can be seen on the left side of the figure 9 where the switched power supply generates separated lower voltage for the control circuits. The actual data procession is made in the processor card which was found out to be the exact same circuit board in every module that was ordered from Lenze. The schematic of the power electronics was reserve engineered by using Fluke 175 multimeter and with the help a of powerful lamp which allowed some of the routing to be seen in the power electronics card.

Lenze had clearly decided to implement regenerative braking with using a separate IGBT H-bridge module along with a more conventional rectifier diode module. In the circuit board there are different connectors for the infeed power and out coming regenerated power from the IGBT module which has to have a RFI-filter module connected to it.

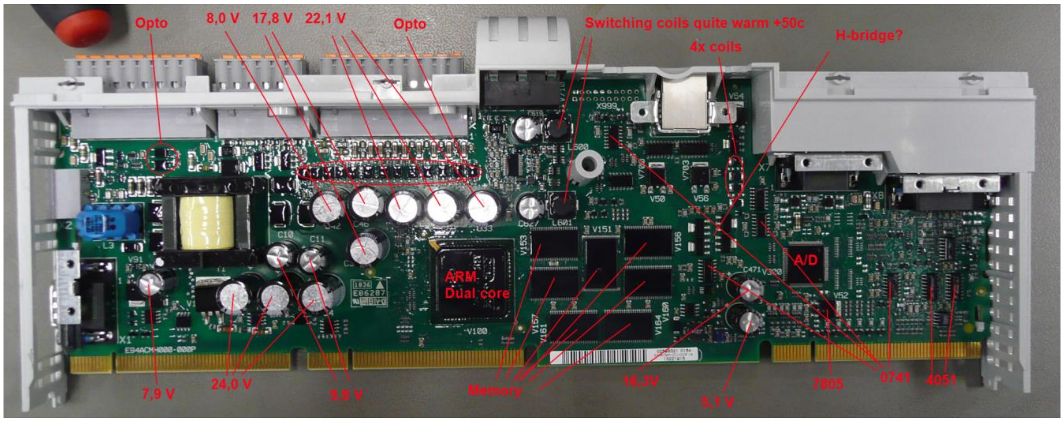

Figure 10: Processor card of Lenze 9400 modules

The regenerative power supply module (E94ARNE0134A22ETNN-P036) was also equipped with the same processor card as all the inverter axis units. Regenerative braking needs control electronics to handle the braking and make sure that the current that is regenerated is suitable for the network. The same type of IGBT H-bridge that is used in the servo axis to drive the motors is used to drive power back to network so the function of the regenerative control card remains very close to the servo drive axis. With minor technical changes in the software it would be possible to use the regenerative power supply module as a passive power supply module with a drive unit of 50% of infeed power.

4.1.2 Passive power supply

A passive 5 kW power supply unit consisted from power electronics card figure in 12 and from a smaller card that was attached to the front panel of the module and delivered the 24 VDC supply voltage for electronics in the power electronics card. Although the rectifier module cannot be controlled by any means closer look to the connections from the mains revealed a small *analogue* circuit that seems to be some kind of watching circuit to check that all the 3-phases of the supply network are fully operational and there is no significant phase shift.

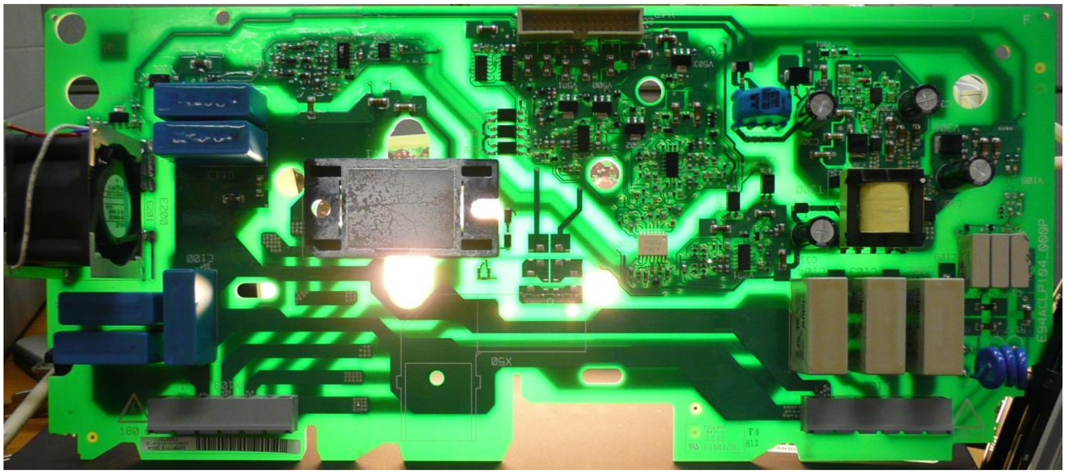

Figure 12: 5kW passive power supply power electronics PCB.

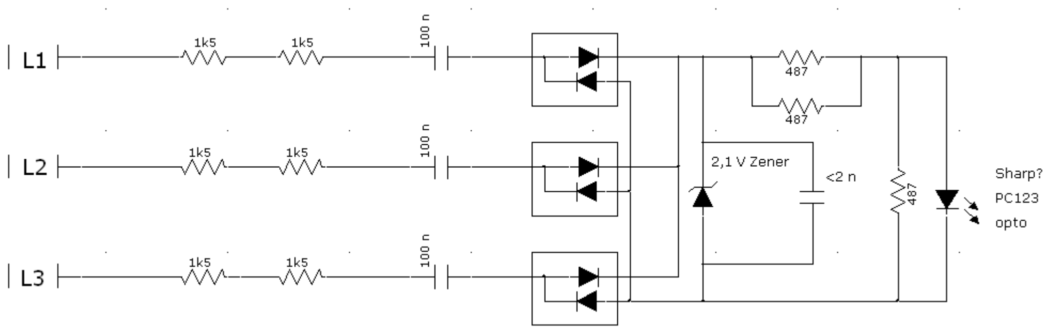

Figure 13: 3-phase guard circuit

The structure of the passive power supply was found out to be quite simple when comparing to the regenerative power supply. A basic uncontrolled rectifier with filtering capacitors and some supply network diagnostics electronics and a cooling fan combine the passive power supply. A switching regulated power supply can also be found from the circuit board which uses 24 VDC input voltage and distinguishes it to the different potential as a operating voltage for the electronics. The lack of electrolytic capacitors was found surprising to add capacitance to the common DC bus but apparently Lenze had decided to use only the axis as capacitor banks.

The phase checker circuit in both Lenze's 9400 power supplies became an object of interest since their function could not be identified directly. It was being suspected that it would either detect the supply voltage of the network or work as a detector for lost phase connection perhaps. Closer inspection was carried out by using National Instruments Multisim version 10 electronic schematic and simulation program. A corresponding schematic with 3-phase 400V 50 Hz supply voltage gave out the following types of voltage levels over the photodiode.

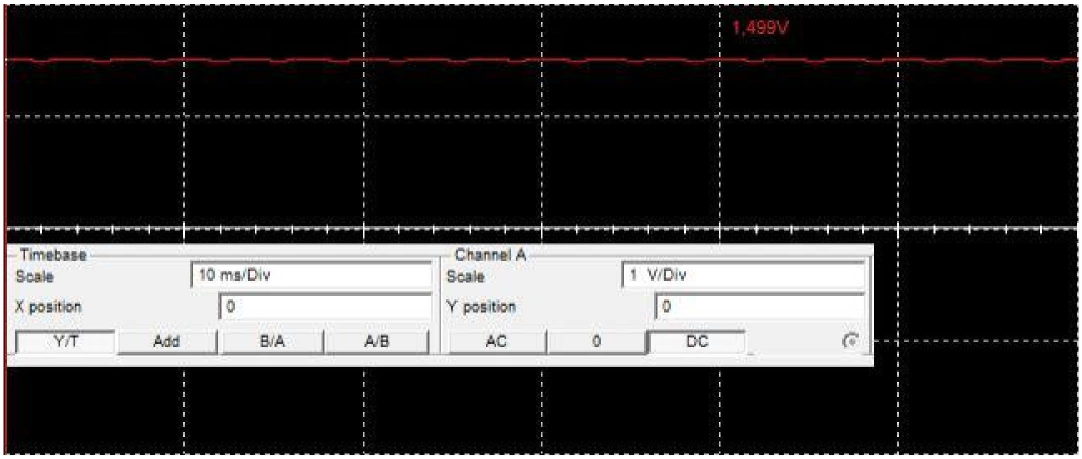

Figure 14: All phases up and running and the voltage over photodiode stays quite steady 1,5 V with some minor ± 10 mV_p ripple.

Figure 15: One phase disconnected from the schematic and the voltage over photodiode is being in pulse like form.

After the simulations the circuitry can be clearly defined as phase checker and will carry out the information from lost phase to the control electronics to possible shut down of the multi-axis drive system infeed or warn the user from a disconnected phase. The schematic was tested in range of Lenze 9400servo given input voltage values 180-550 3-phase AC at frequency of 50 Hz.

4.1.3 Rectifiers

Rectifiers in Lenze 9400 servo drive system are implemented by separate heatsinked rectifier module. In regenerative 15 kW module regenerative IGBT module and rectifier shared the same heatsink to make the cooling solution simple and efficient. In small power ratings simple diodes probably could be used as well since the power loss in them wouldn't raise the temperature of the casing to dangerous levels.

4.1.4 Intermediate circuit capacitance comparison

When examining the disassembled modules it was being found out that the regenerative power modules always have electrolytic capacitors to increase capacitance in the intermediate circuit and common DC bus capacitance. Lenze 9400 5 kW passive power module had no significant increase to the common DC bus capacitance and there is also no need for loading circuits in the passive power module or either on the common DC bus hence the axis are separated by a loading circuit resistors and relays.

4.2 Drive modules

4.2.1 IGBT comparison

The IGBT-modules of the disassembled inverter axis units were recognized by their part number code and datasheets were searched through the internet. It was expected that due to high possible overload torques, the current rating of IGBTs was not driven even near their maximum collector current values and this seemed to comply with the searched values.

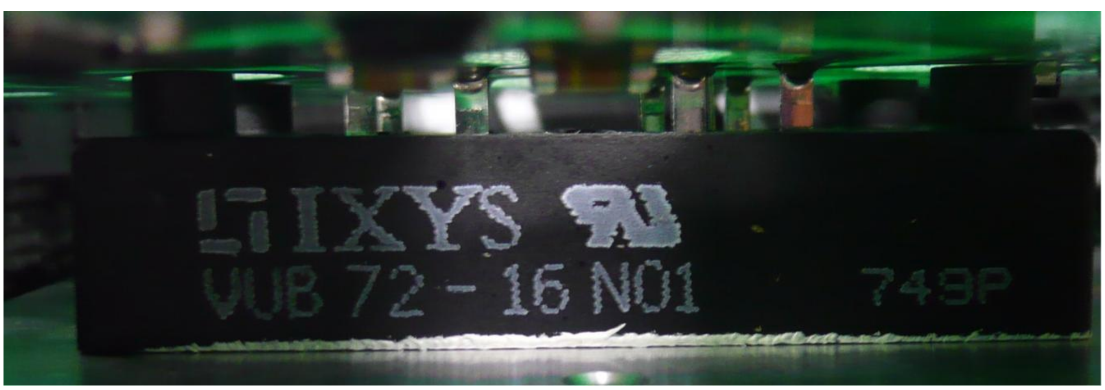

Figure 16: IGBT from lenze 9400 5,5kW inverter axis unit and heatsink

The cooling of the IGBT-modules was always handled by using an aluminum heat sink that was connected to the module with thermal paste or glue. In Lenze's 9400 inverter axis modules there was also a thermal probe attached to the heat sink to monitor and prevent the module from overheating. In case of Lenze 9400 1,5 kW axis inverter there was also a small 40 mm fan attached to the bottom of the axis inverter module to increase airflow through casing and cool down the heat sink. In the same power class B&R's Acopos there was no fan attached to the drive module but the heat sink was in that case considerably larger.

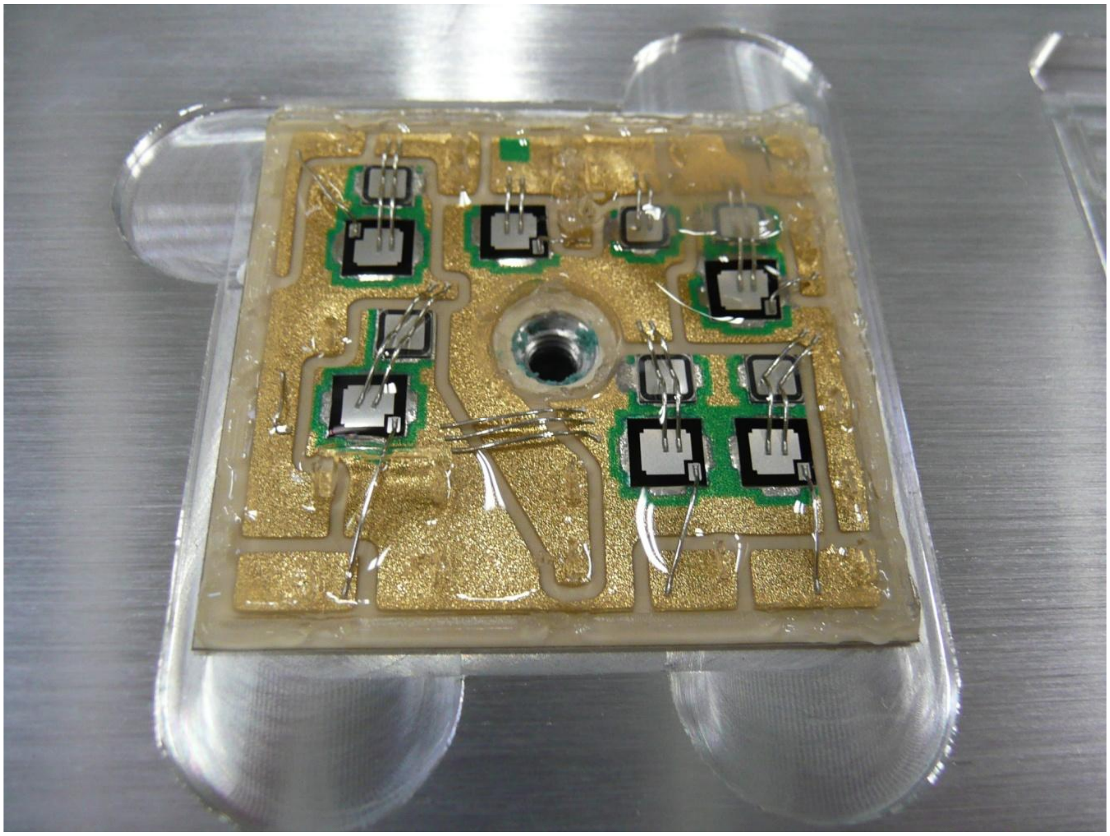

Figure 17: Bosch Rexroth's double-axis (2x 2,2 kW) inverter module IGBT which case came off during the disassembling.

Bosch Rexroth had embedded the IGBT modules inside the heatsink by working a hole in the aluminum to increase the heat conductivity and probably mostly to decrease the wideness of the modules since the IGBT usually makes its own addition to the depth of the circuit board.

4.2.2 IGBT Module Dimensioning in Servo Drives

The dimensioning of IGBT modules affects strongly the bill of materials when designing servo drives. As servo drives have considerably higher over torque values than conventional drives the sizing of the IGBT module must be made accurately so that the over torques can be handled without breaking the IGBT unit. The modules were studied from Lenze 9400, B&R Acopos and Bosch Rexroth Indradrive M multi-axis systems.

Different current values for IGBTs were found from the datasheets of modules and comparison was performed between the current promised for the axis and their corresponding IGBT module values.

Manufacturer	**Lenze**	**Lenze**	**Lenze**	**B&R**	**Bosch Rexroth**
Model	**9400 1,5kW inverter axis**	**9400 5,5kW inverter axis**	**9400 0,37kW inverter**	**Acopos 1,4kW inverter axis**	**Indradrive M 5,6 kW**
Ordering code	**E94AMHE0044E22ETNN**	**E94AMHE0044E22ETNN**		**8BVI0014HWS0.000-1**	**HMS02.1N.W0028**
Power of axis [kW]	1,5	5,5	0,37	1,46	5,6
Overload for axis	150% for 60s in 3 min cycle, 300% for 0,5s in 5s cycle	150% for 60s in 3 min cycle, 300% for 0,5s in 5s cycle	150% for 60s in 3 min cycle, 300% for 0,5s in 5s cycle	250 %	200 %
Continuous current per motor connection [A]	**4**	**13**	**1,5**	**1,9**	**13,82**
Overload current max/Peak current [A]	7,5 for 60s or 16,0 for 0,5	24,4 for 60s or 39,0 for 0,5s	2,8 for 60s or 6 for 0,5 s	4,7	28,3
DC bus voltage [V]	260-775	260-775	-	750-900	254-750
IGBT module	**FS25R12YT3**	**FS50R12KE3**	**FP15R12YT3**	**SK 25 GD 126 ET**	**13AC126V1**
Casing	NA	NA	NA	Semitop 3	NA
IGBT continuous DC-collector current max [A] T_c= 25°C	**40**	**75**	**25**	**32**	**41**
IGBT continuous DC-collector current max [A] Tc = 80°C	25	50	15	23	31
IGBT peak DC-collector current [A] max ≤ 1ms Tc= 25°C	NA	NA	NA	64	82
IGBT peak DC-collector current [A] max ≤ 1ms Tc= 80°C	50	100	30	46	62
Diode DC forward current [A] @ 25°C	25	50	15	28	30
Diode repetitive peak forward current t =1 ms, [A] @ 25°C	50	NA	NA	62	60
Cooling	120 mm x 91 mm x 24 mm, weight: 342 g heatsink and fan 40mm	180mm, 94mm, 67mm 1,330 kg, 100mm fan	-	-	Heatsink + 40mm fan
Notes	Temperature sensor attached to heatsink also	Temperature sensor attached to heatsink also	-	Considerably larger heatsink than in the Lenze 9400 about same size of inverter axis, (fan?)	-
DC 80c max collector current / continous max motor connection current	6,25	3,85	10,00	12,11	2,24
DC 80c max collector current / motor peak current	1,56	1,28	2,50	4,89	1,10

Table 6: IGBT comparison table of dissembled modules

The compared axis were in the power range of 0,37 – 5,6 kW with overload currents of 150% - 300%. In the datasheets for the IGBT modules there are many values for DC collector current values and for the calculations the value of 80°C was chosen because in real life servo drive situations the temperatures inside the semiconductors are higher than the ambient temperature of the industrial environment. The peak values for the IGBTs were given in 1ms time which doesn't correspond with the overload times of the selected servo axis so they were not considered as comparable values.

It was found out that all the values for the axis didn't take maximum possible currents from the IGBT components but in some cases the safety range came close to the promised values. When comparing the DC collector maximum current at 80°c temperature to the continuous servo motor currents it can be seen that the IGBT modules are not taken to their maximum limits yet. When the promised overload currents of the modules are compared to the IGBT maximum limits the differences have narrowed closer to each other. The Indradrive M 5,6 kW module is being driven closest to its IGBT current limits and in overload situations there is only a 10% reserve left to the absolute maximum ration. On the other hand B&R Acopos multi 1,46 kW axis still has multiple times of current reserve left. [16,17]

4.2.3 DC charging circuit

When considering Lenze 9400 it was found out that drive the axis were separated from the common DC bus with a ceramic 50 ohm resistor which is seen as R1 in the schematic below connected parallel with a relay which is switched on when the intermediate DC circuit has charged up enough to prevent straight high current flown from a common DB bus to cause damage to the electrolytic capacitor bank C1 as shown in the schematic below.

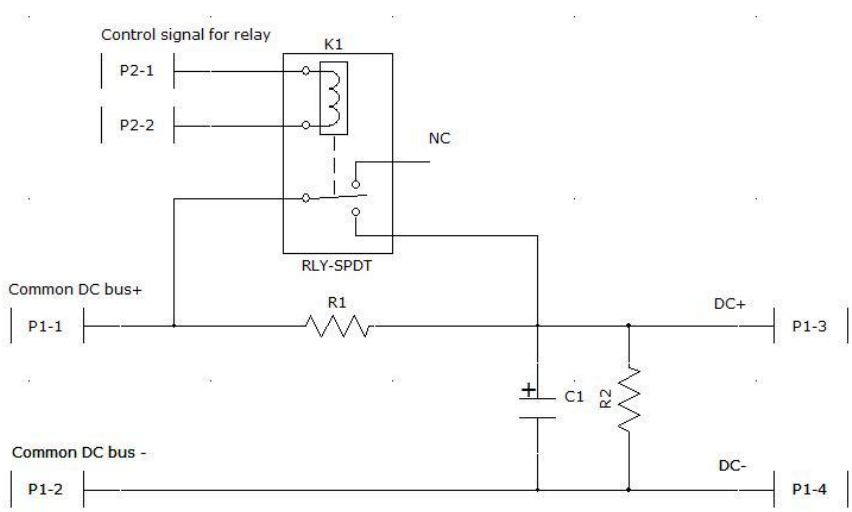

Figure 19: The idea of charging circuit of inverter axis and regenerative power supply

Loading time of the capacitors can be defined with following equtation.

T = RC

And voltage rise in the capacitor:

$$V_C(t) = V\left(1 - e^{-\frac{t}{RC}}\right)$$

Equation 3

In figure 19 the purpose of the resistor R2 is to discharge the intermediate circuit capacitor from dangerous voltage when the drive module is turned off from operation. These discharging resistors typically are valued with high resistance when compared to the resistor of the charging circuit but they can also be physically smaller since the power dissipated in them is being rather small.

4.2.4 Capacitor banks comparison

Large electrolytic capacitor banks are known to affect cost efficiency of the drive module and they can also be seen as space taking components. Although their roles are crucial for keeping the feeding voltage for servo motors high enough which have a nature of executing high 200-300% overload torques. It also raises the current overload by 200-300% for short period of times. For the puposes of comparison some of the DC intermediate circuit capacitance values were taken as reference from a bachelor's thesis on low cost micro drives comparison by Lauri Järvinen.

In the axis there was an intermediate circuit which could be separated directly from the common DC bus by switching the loading circuit relay off and leaving the 50 ohm resistor to prevent high loss of current from the capacitor banks. When the axis unit is working in normal condition as a part of the multi-axis servo drive its intermediate circuit capacitance is a part of the common DC bus capacitance. It is unlikely that all of the axis would be accelerating at full speed at the same time which would stress the capacitance of the common DC bus the most. So in normal operation the axes that are driven at full overload torque can have added help from the capacitances of the other axes. The capacitor banks were formed in the Lenze 9400's case from 330 µF 400V capacitors which were connected in series to increase the maximum tolerated voltage to the value of 800 volts. When the output power increased on the axis module more such capacitors were connected on parallel in series of 2. Intermediate circuit capacitance was discharged in with 150,6 kilo ohm resistor per capacitor which causes a power loss of 1,07 Watts power capacitor if the voltage of the intermediate circuit is held all the time at the maximum 800 Volts.

The charge time of 165µF capacitance through 50 ohm resistor would be

$4RC$ = 4 × 50Ω × 10^{-6}F = 0,033s

The discharge time with 150,2 kilo ohms would be:

$4RC$ = 4 × 150200Ω × 330 × 10^{-6}F = 198,264s

The amount of capacitance on the intermediate circuit of each axis was recorded in to the following table 7 where micro drives class frequency inverters were compared with multi-axis servo drives.

	Micro drives											AVG micro
Manufacturer	Danfoss	Danfoss	Hitachi	Hitachi	KEB	KEB	Omron	Omron	Omron	Schneider	Yaskawa	
Model	VLT MicroDrive FC51	VLT MicroDrive FC51	X200	X200	Combivert B6 A3A	Combivert B6 A3B	V1000	V1000	VS mini J7	Altivar 312	A1000	
Input	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	3-phase 400V	
Nominal power [kW]	2,2	0,75	2,2	0,75	1,5	4	0,75	2,2	2,2	4	2,2	
Overload	150 %	150 %	150 %	150 %	180 %	180 %	150 %	150 %	150 %	150 %	150 %	1,55
Intermediate circuit capacitance [µF]	420	135	340	135	195	390	250	375	330	550	250	306,36
[uF]/[kW]	190,91	180	154,55	180	130	97,5	333,33	170,45	150	137,50	113,64	167,08
With overload [µF/kW	127,27	120	103,03	120	72,22	54,17	222,22	113,64	100	91,67	75,76	109,09

Table 7: Intermediate circuit capacitance comparison of micro class drives

From the micro class only frequency converters with a 3-phase 400V supply voltage were considered in the table due to their similarity with multi-axis servo system drives which use the same input voltage, although the axis are still fed from the common DC supply that is formed after the power supply unit. A factor of [µF/kW] was created and calculated to be able to compare the capacitances between the servo drive axis and low cost frequency inverters. Also the current consumption during the overload torque was noticed as increased value of power. It was expected that servo-axis drives would have considerably higher intermediate circuit capacitances to cover their possible higher overload ratings. Also the more high-end price tag would allow servo drives to have more intermediate circuit capacitance because of the competition in pricing is not as crucial as in the market of micro class drives. In the table 4.2.3.1 it is possible to see that the amount of [µF/kW] in the intermediate circuit varies from Omron V1000 0,75 kW unit's value of 333,33 [µF/kW] to KEB Combivert B6 nominal power 4 kW value of

97,50 [µF/kW] without the overload factor taken in to consideration. The average value of capacitance per power was 167,08 [µF/kW].

In the case of overload torques which will have direct a relation to the overload current the values were naturally lower. The average capacitance per power was 109,09 [µF/kW].

	Servo drives				AVG servo
Manufacturer	Lenze	Lenze	Lenze	B&R	
Model	9400	9400	9400	Acopos	
Input	3-phase 400V	Common DC bus	Common DC bus	Common DC bus	
Nominal power [kW]	0,37	1,5	5,5	1,5	
Overload	300 %	300 %	300 %	250 %	2,88
Intermediate circuit capacitance [µF]		660	990	165	605,00
[uF]/[kW]	0	440	180	110	182,50
With overload [µF/kW	0	146,67	60	44	62,67

Table 8: Comparison of servo-axis modules intermediate circuit capacitance

The comparison showed that there was no significant difference in the capacitance values of servo axis to the micro class frequency converters. However for some multi-axis servo drives there are extra capacitor bank modules offered to increase the common DC bus capacitance value which provides more currents to the intermediate circuits which become part of the common DC bus after the loading circuit is switched off from the circuit. [13]

4.2.5 Single- and double-axis comparison

Single and double-axis units were compared by their structures and different implementations for both were found. Bosch Rexroth double axis unit 2x 2,2 kW was disassembled for this study and it was compared to the single-axis units from Lenze 9400 servo and B&R Acoposmulti. The first thing that was found out was that draws in the board were made as jump leads from the common DC bus connector to the IGBT modules and from there to the motor connectors. This kind of structure most likely has to be made by hand since it would be hard to assemble by machinery and it increases the costs but by doing this Bosch Rexroth is probably able to achieve such thin modules and the power electronics PCB is rather small when comparing to the corresponding power value of competitor boards.

Another discovery was that there are no electrolytic capacitors to support the common DC bus capacitance which also saves space in the circuit board but moves problem to be solved for the DC capacitor bank module which is really needed to keep the common DC bus voltage at the desired values. However three large plastic capacitors have been added in different sides of the board to add 4,56 µF of capacitance to the common DC bus.

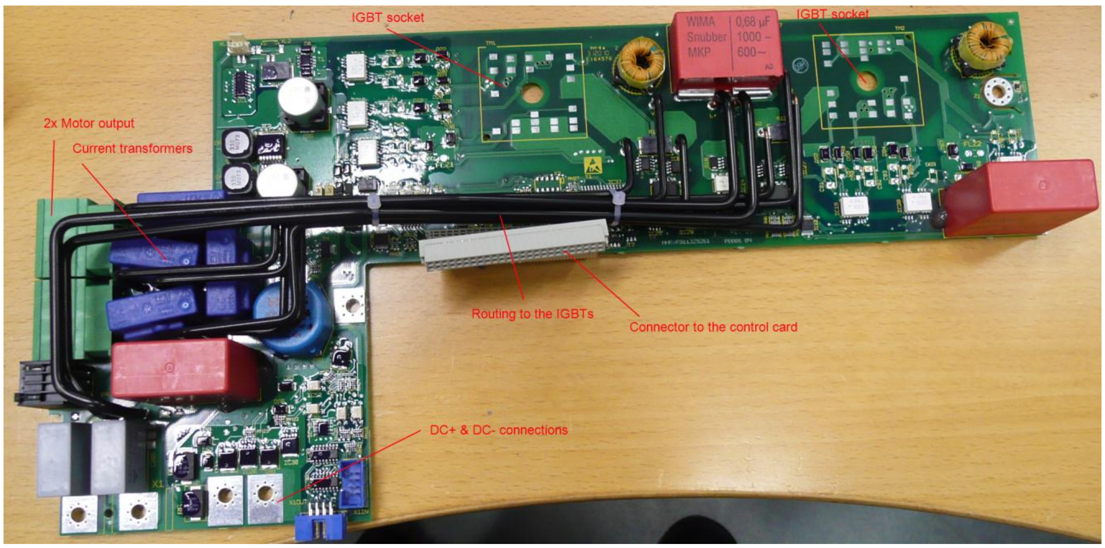

Figure 19: Double axis inverter power electronics PCB from Bosch Rexroth

As can be seen from figure 19 the connection of the IGBT modules is implemented differently when comparing to the other manufacturers. Bosch Rexroth had decided to embed the IGBT modules inside the heatsink to decrease the height of the circuit board and to increase the conductivity of the heat.

4.2.6 Processor comparison

Every axis is controlled with its own microprocessor which calculates the switching of the IGB transistors and handles the communication through the communication busses. In motor feedback some processing of data is also needed to identify the position of the motor shaft and the process the counter measures to control the motor in the desired way. In servo drives faster processors are needed to handle larger amounts of information quickly when compared to the more conventional frequency inverters.

Module	Lenze Servo drives 9400 E94AMHE0044E22ETNN (1,5 kW inverter module)	B&R Acopos 8BVI0014HWS0.000-1 (1,46 kW inverter module)	Bosch Rexroth Indradrive M HMS02.1N-W0028-A-07-NNNN (5,6 kW inverter)	SEW Moviaxis MX81A-004-503-00 (2,2 kW inverter)
Processor card	E94ACMH000-000P 1A	NA	MNR.R911320644	18210430.16.27
Main processor	ARM Dual core DCIC 9907, 485728, 1009, K4VD9T03, (128 MHz 2x cores)	Toshiba TMPR4925XBG-200, 64 bit, 200 MHz	ST40RA200XH6, 64-bit, 166 MHz	Infineon TriCore SAK-TC1796-256F150E (150 MHz)
Resolver A/D converter	Texas Instruments 05DC9ET, ADS7869I	Altera Max II		DSP6F801
FPGA	No	Altera Cyclone II	Xilinx Spartan XC2S50E	Altera cyclone
Memory	12x ISSI IS61LV5128AL-10TL1/DOGO21D1 1019	1x 48LC2M32B2 DRAM module.	1x ISSI IS42S32200E-6TL (64 Mb)	1x ISSI IS61WY25616BLL-10TLI

Table 9: Comparison table of data processing components in processor boards

A processor card was found in every axis module. In Lenze 9400 all the processor cards were the same ones but in the scoped Bosch Rexroth Indradrive M the different control units, which include the processors can be chosen from different variations. In the chosen models the processors were found to be 128 – 200MHz in their clock speed with external RAM memory of 64 megabytes. Also an external A/D converter chip was located in the control electronics circuit and its goal is to transform the data from the resolver-interface to a digital data that the FPGA interprets.

4.3 Fusing policy

Fusing of the common DC bus was one of the central interests in this study. Fusing is the most efficient and cost effective way to protect the inverter axis from short circuit currents and incase of malfunction of one axis the other axes can be still be kept operational. It was found out that Lenze 9400 has fuses installed in the mounting plates of the modules which also makes them easy to replace if needed.

On the other hand there was no common DC bus fusing provided in the SEW Moviaxis either in the Indradrive M common DC busses and incase of malfunction or motor short circuit the shut down of the whole system is necessary and it could affect the break-down of many modules in the system. [12, 20]

4.4 DC link discharge module

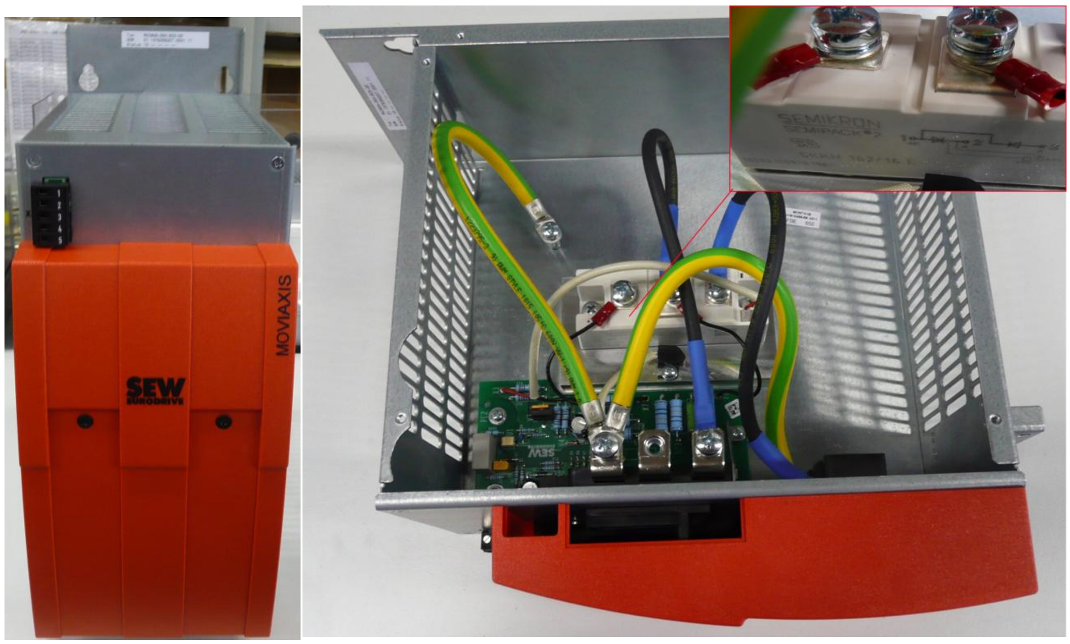

Figure 21 & 22: SEW Moviaxis DC link discharge module front and opened.

The only model that provided DC link discharge modules was Moviaxis and it is developed to discharge energy of 5000 Joules from the common DC bus to prevent sensitive machines and tools from colliding. The DC link discharge module is basically a brake chopper thyristor which is being launched externally by control signal. It has a small control electronics PCB to drive the thyristor and requires also +24 VDC control voltage. An external braking resistor is needed to dissipate the discharged energy as heat. SEW gives example resistance value of 1 Ohm to make the module operate correctly and fast enough to discharge 5000 Joules of energy in 1 second or less. The module needs a recovering time of 60 seconds to execute a discharge operation again. A closer inspection showed that SKKH 16 2/16E Semikron thryristor was fitted inside the module. [18, 19]

4.5 Capacitor modules

Figure 23: PCB of Bosch Rexroth's 2,1 mF capacitor bank

The purpose of the capacitor modules is to increase the common DC bus capacitance of the multi-axis servo system. The capacitor banks studied were the Bosch Rexroth's Indradrive M 2,4 mF HLC01.1C-02M4-A-007-NNNN and SEW Moviaxis 4,92 mF capacitor bank HLC01.1C-02M4-A-007-NNNN. It was noted that the Indradrive M module consisted of small 220µF 400V capacitors that were most likely connected parallel in series of two to forming a common capacitance of 2400µF. Also discharging resistors were added to cause the capacitor bank to discharge slowly when the multi-axis servo system is switched off from operation.

	B&R	SEW		Beckhoff	Bosch Rexroth			Siemens
	Capacitor module	**Capacitor module**	**Buffer module**	**Capacitor module**	**Capacitor module**	**Capacitor module**	**Capacitor module**	**Capacitor module**
	8B0K	MXC80A-050-503-00	MXB80A-050-503-00	AX5001-0000	HLC01.1C-01M0-A-007-NNNN	HLC01.1C-02M4-A-007-NNNN	HLC01.1D-05M0-A-007-NNNN	6SL3100-1CE14-0AA0
Capacitance [mF]	1,65	4920	4920	NA	1	2,4	5	4
Voltage tolerance [V]	900	560 (nominal)	560 (nominal)	NA	>750	>750	>750	600
Note: Lenze, Baumuller, KEB are not offering capacitor modules								

Table 4.5.1 Available capacitor modules for multi-axis servo systems

The Lenze 9400 doesn't provide any capacitor modules in the catalog and they rely on the common DC bus capacitance given by the axis and the power supply module which in case of being passive does not provide common DC bus capacitance in large figures.

The reverse engineered schematic of the Bosch Rexroth's Indradrive M 2,4 mF HLC01.1C-02M4-A-007-NNN has been added to the appendices of this study. It was observed that there were no fuses or relays to separate the capacitors from the common DC bus and in malfunction situations a short circuit of one drive could discharge all the capacitors and cause damage to the other axis or destroy the capacitors. A total capacitance of 2,1 mF is achieved by using 36 pieces of 270µF 450V 105°c connected parallel in series of 2 and every capacitor also has a discharge resistor whose value is 68 kilo ohms. It can be calculated that the discharging resistors cause a power dissipation of 14,12 Watts by following

$$P = \frac{\left(U_{L-L}\sqrt{3}\right)^2}{R}$$

Equation 4

$$\frac{\left(400V \times \sqrt{3}\right)^2}{34 \times 10^3\Omega} = 14{,}12\ W$$

And the discharge time can be calculated as follows:

$$T = RC = 34 \times 10^3\Omega \times 2{,}1 \times 10^{-3}\mathrm{F} = 71{,}4\mathrm{s}$$

$$4T = 4 \times 71{,}4s = 4\ minutes\ 45{,}6\ seconds$$

The SEW Moviaxis capacitor module has been added with some extra features when comparing it to a simpler Indradrive M such as current monitoring and possibility to isolate the module from common DC bus with IGBT switch. The structure of the module consisted of two different PCBs that both have large electrolytic 450V 880µF capacitors added.

4.6 24V DC supply comparison

Lenze provided their 9400 multi-axis system with a compact solution of a 24 VDC power supply which had the capacity to deliver up to 20 Amps of current. The power supply uses 3-phase 380-480V supply voltage which is the same that the other power modules that feed the common DC bus are using. SEW had implemented their 24 VDC power supply as one of the modular modules of the multi-axis servo system. The input voltage was provided from the common DC bus when there is no need to provide separate 3-phase AC supply wires for the power supply module.

Another way to implement such a system could be flyback switching regulator type power which takes its power from the common DC bus supply or as another option to use a 1-phase 230 V plug to supply power to the switching regulator. Bosch Rexroth Indradrive M does not provide 24 VDC power supply as own module in their module catalog. In automation environments such voltage is usually easily available or such power supply units with high loadbility can be easily purchased from other manufacturers.

5 CONCLUSIONS

In this study the multi-axis servo systems were examined and models were ordered and their power electronics solutions were studied and reverse engineered. The different parts were compared to each other. The general supply in the multi-axis servo system markets was also scoped and conclusions from different power classes and input voltage ratings were made. As there are many ways to implement a multi-axis servo system, many kinds of different solutions are available in the market, but the systems have common qualities.

While the idea of a common DC bus remains the same in all systems, the implementation of it can be different. Capacitor banks can either be integrated to the axis modules or focused on separate capacitor modules, which can be added to the system as many as needed. Separate capacitor modules clearly form great space savings in module widths as the example of Bosch Rexroth's Indradrive M shows. Although larger axis still seem to contain electrolytic capacitors but clearly not in as wide numbers as conventional single drives have in their intermediate circuit.

Surprisingly only Lenze 9400 had fuses the between common DC bus feeding rail and modules. The fuses were installed in the backplane of the system which made them easy to replace if needed. Such type of system planning is somewhat confusing, but fusing of the common DC bus seems to be the policy of only some manufacturers thus current monitoring and protection is left for the control electronics. The lack of fuses could cause a breakdown of several modules or even the whole system in fault situations. The downside of using fuses between the common DC bus rail and modules is their physical size and they also increase the costs of the system.

Applications that demand numerous axis gain benefits in size, costs and number of components when two-axis modules are used. It wouldn't be impossible to see modules that support even three or four axis since there are no big technical obstacles for implementing so. As more axes are added to each piece of the system, the cost per axis for end user decreases. Two-axis inverter modules from power class of 0,75 kW up to 10 kW per axis seem to be the current trend. Most of the applications which require several servo motors have a power demand of below 15 kW per axis.

Regenerative braking is a possibility on almost all of the systems, especially when power ratings increase. In motion control applications servo motors are accelerated and decelerated continuously the energy is transformed from electrical energy to kinetic energy and then back to electrical energy. In systems where several servo motors are used, it may be advantageous to have a power configuration where there is a single AC to DC converter feeding the common DC bus, which then feeds multiple axes. Regenerative braking increases the energy efficiency of the multi-axis servo drive system and generates savings in energy consumption. Regenerative braking can be implemented by using a separate braking module or integrate it with the supply module. Also mains chokes are required to decrease interferences with the supply network. Mains chokes are conventionally heavy and big components decrease the compactness of the system and the compared manufacturers have not wanted to create it as a modular solution instead of delivering it as a big component to be positioned on the ground.

Dimensioning of the IGBT modules was studied in this thesis and as outcome there were different dimensioning requirements for different manufacturers. The rated overload current ratings were always below the absolute maximum continuous current of the IGBT module at the temperature of 80ºc, which is of course presumed but the gap between module maximum current ratings compared to the maximum current ratings of the different axis was between 10 - 389%. However the average value of the gap was 61% without considering the most highly overrated module that was included in this study so the recommended value for dimensioning the IGBT H-bridge could be around 50% oversized maximum current wise with a sufficient cooling solution.

The popularity of the multi-axis servo drives is increasing and providing customers with more compact and cost efficient solutions for demanding motion control applications.

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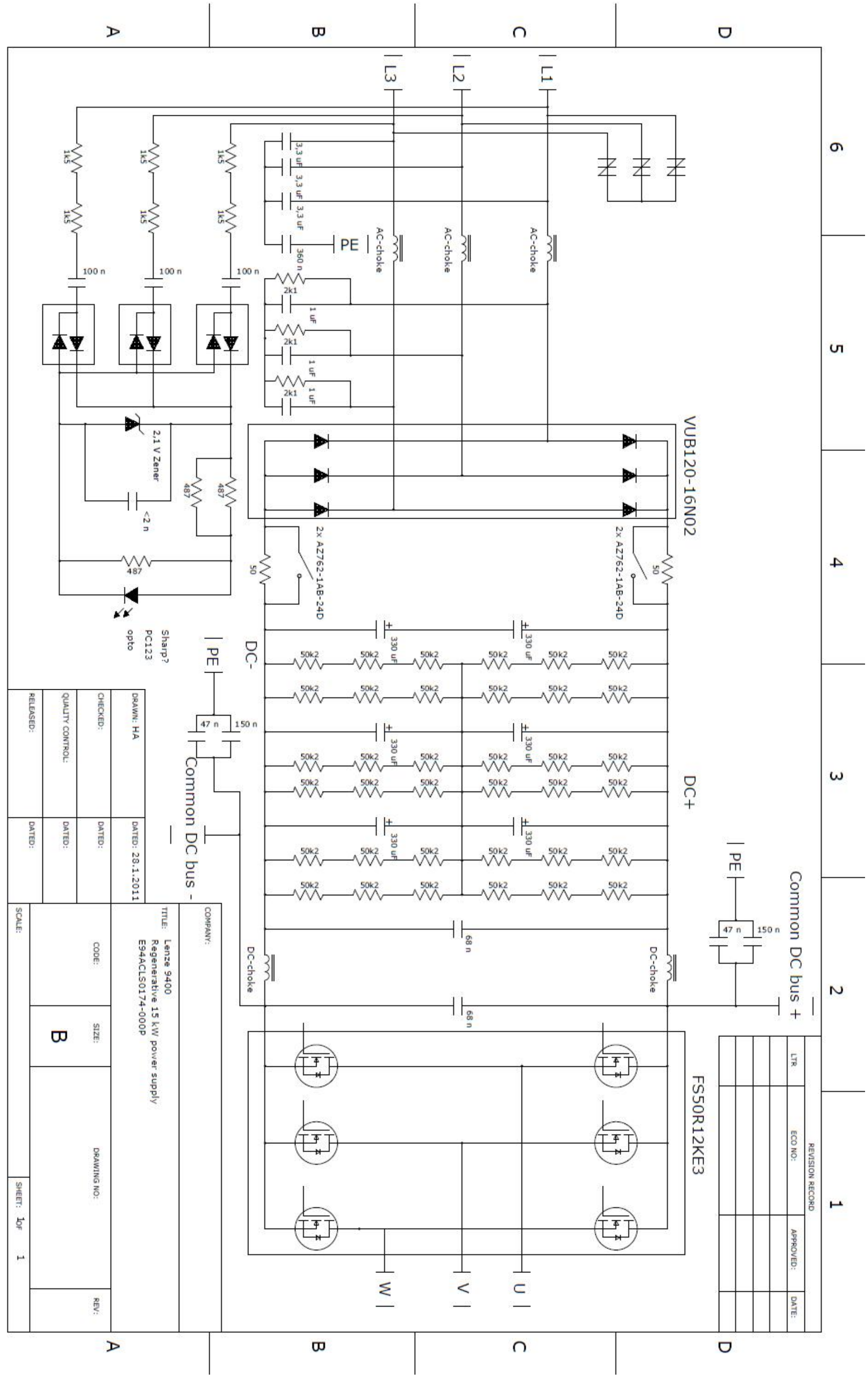
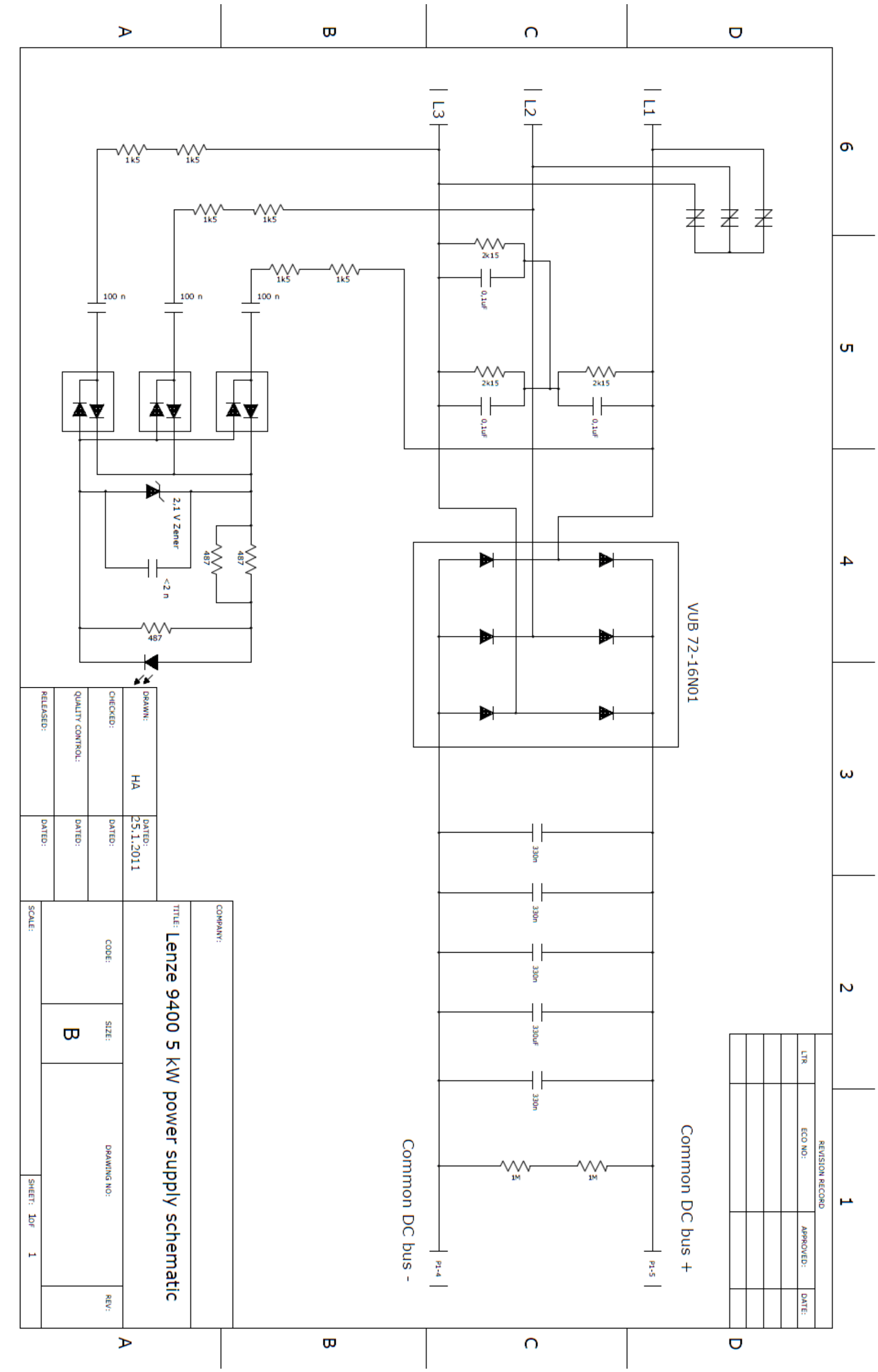
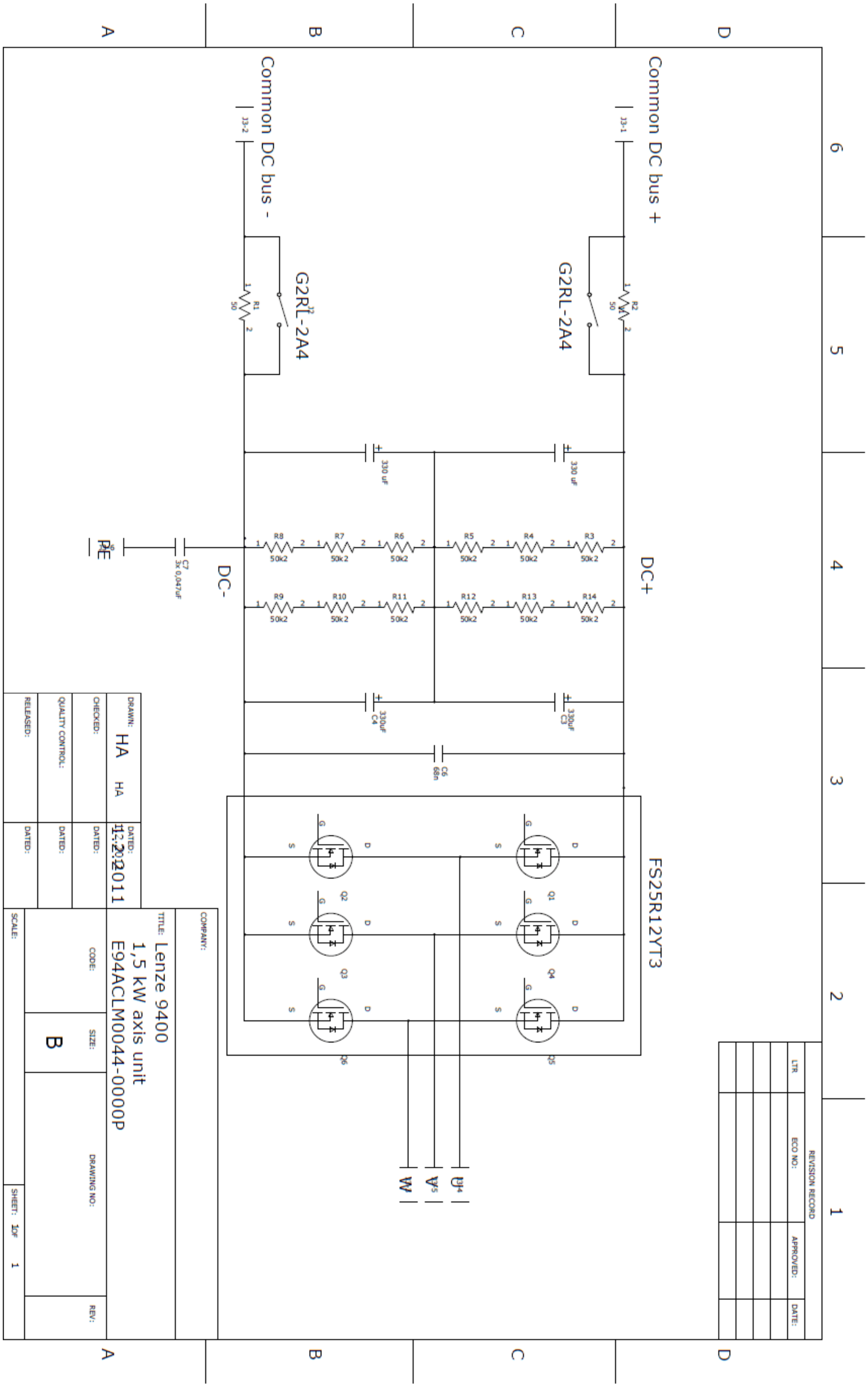
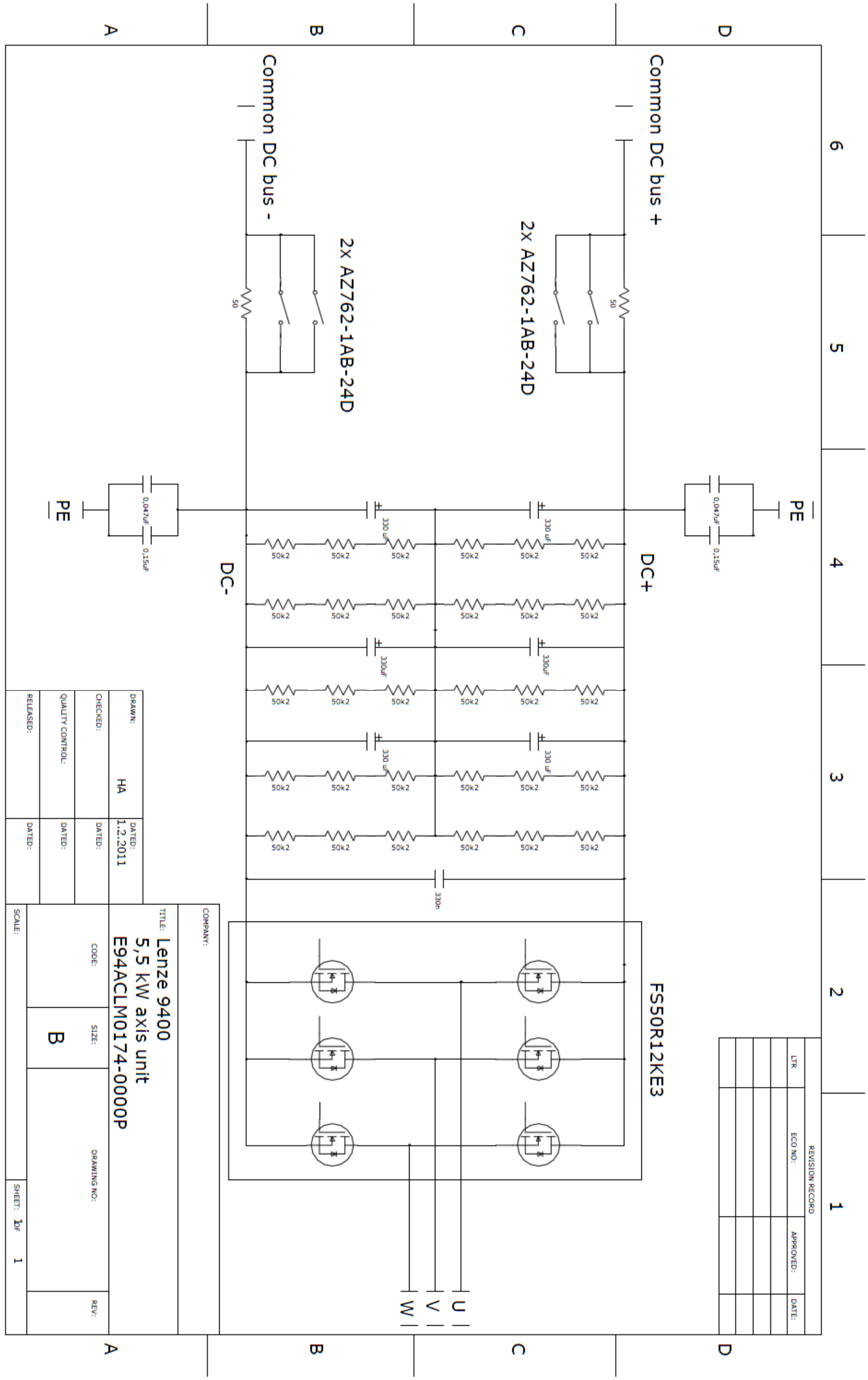
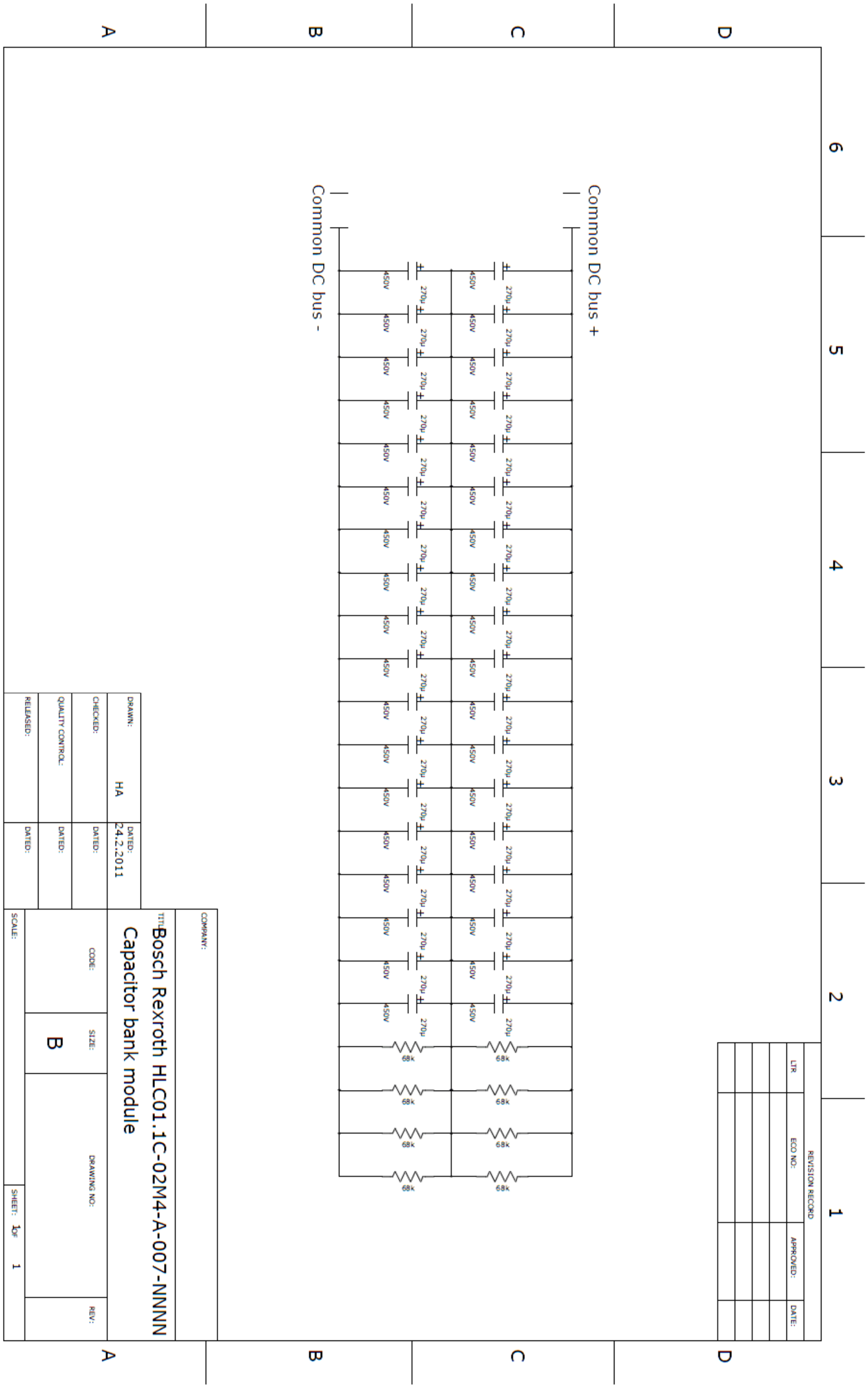
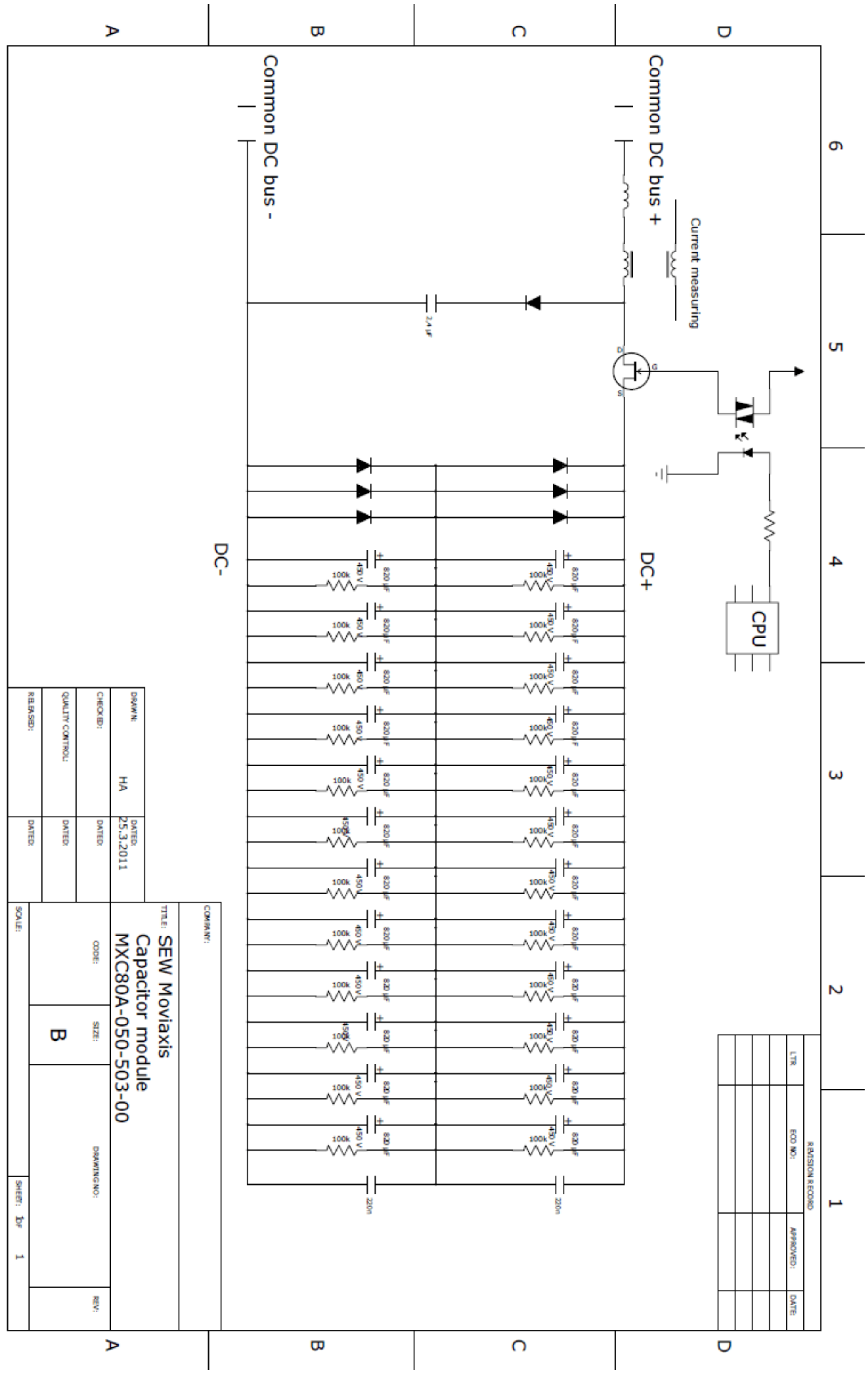

L1
L2
L3
AC-choke
AC-choke
AC-choke
PE
3,3 uF
3,3 uF
3,3 uF
360 n
2k1
1 uF
1k5
100 n
2,1 V Zener
487
<2 n
Sharp?
PC123
opto
VUB120-16N02
2x AZ762-1AB-24D
50
330 uF
50k2
DC-
DC+
47 n
150 n
Common DC bus -
Common DC bus +
68 n
DC-choke
FS50R12KE3
U
V
W
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
DRAWN: HA
DATED: 28.1.2011
CHECKED:
DATED:
QUALITY CONTROL:
RELEASED:
COMPANY:
TITLE: Lenze 9400
Regenerative 15 kW power supply
E94ACLS0174-000P
CODE:
SIZE:
B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1


L1
L2
L3
1k5
2k15
0,1uF
100 n
VUB 72-16N01
2,1 V Zener
487
<2 n
330n
330uF
1M
Common DC bus +
Common DC bus -
P1-5
P1-4
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
DRAWN: HA
DATED: 25.1.2011
CHECKED:
QUALITY CONTROL:
RELEASED:
COMPANY:
TITLE: Lenze 9400 5 kW power supply schematic
CODE:
SIZE: B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1

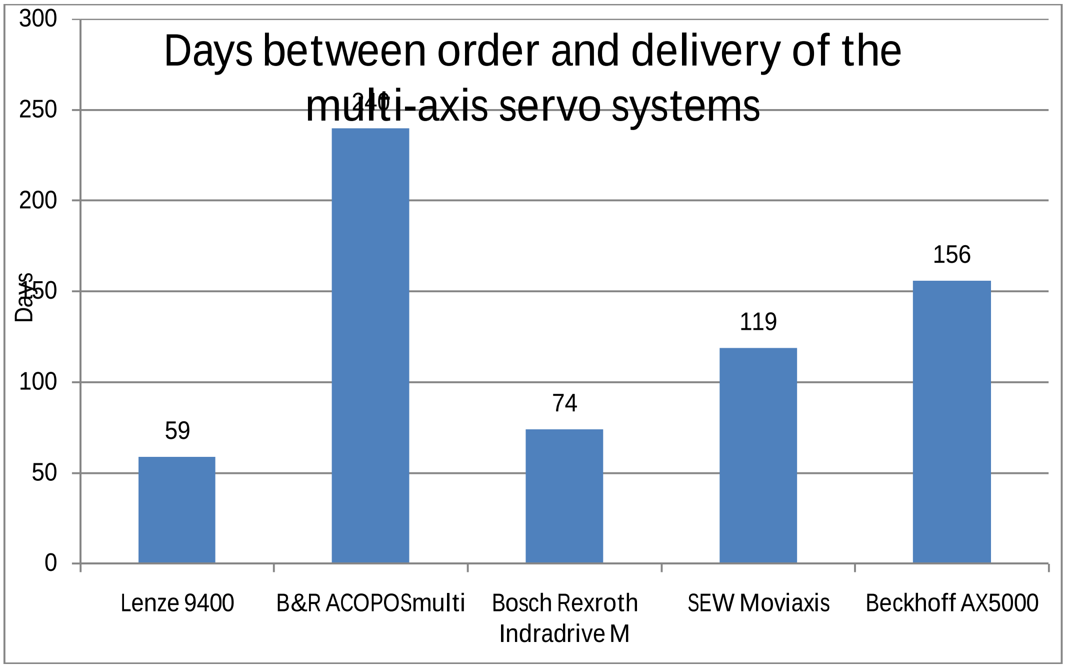

Common DC bus +
Common DC bus -
G2RL-2A4
G2RL-2A4
330 uF
330 uF
330uF
330uF
C6 68n
C7 3x 0,047uF
DC+
DC-
PE
50k2
FS25R12YT3
U
V
W
REVISION RECORD
LTR.
ECO NO:
APPROVED:
DATE:
DRAWN:
HA
CHECKED:
QUALITY CONTROL:
RELEASED:
DATED:
COMPANY:
TITLE: Lenze 9400
1,5 kW axis unit
E94ACLM0044-0000P
CODE:
SIZE:
B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1


Common DC bus +
Common DC bus -
2x AZ762-1AB-24D
2x AZ762-1AB-24D
PE
PE
DC+
DC-
0,047uF
0,15uF
330 uF
330uF
50k2
330n
FS50R12KE3
U
V
W
DRAWN: HA
DATED: 1.2.2011
CHECKED:
QUALITY CONTROL:
RELEASED:
COMPANY:
TITLE: Lenze 9400
5,5 kW axis unit
E94ACLM0174-0000P
CODE:
SIZE: B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:


Common DC bus +
Common DC bus -
270u
450V
68k
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
COMPANY:
TITLE:
Bosch Rexroth HLC01.1C-02M4-A-007-NNNN
Capacitor bank module
DRAWN: HA
DATED: 24.2.2011
CHECKED:
DATED:
QUALITY CONTROL:
DATED:
RELEASED:
DATED:
CODE:
SIZE: B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1
A
B
C
D
1
2
3
4
5
6


Common DC bus +
Common DC bus -
Current measuring
CPU
DC+
DC-
2,4 µF
820 µF
450 V
100k
220n
REVISION RECORD
LTR.
ECO NO:
APPROVED:
DATE:
DRAWN:
HA
DATED:
25.3.2011
CHECKED:
DATED:
QUALITY CONTROL:
DATED:
RELEASED:
DATED:
COMPANY:
TITLE:
SEW Moviaxis
Capacitor module
MXC80A-050-503-00
CODE:
SIZE:
B
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1

Module	Lenze Servo drives 9400 E94AMHE0044E22ETNN (1,5 kW inverter module)	Lenze Servo drives 9400 E94AMHE0134E22ETNN (5,5 kW inverter module)	Lenze Servo drives 9400 E94ARNE0134A22NNET (15 kW regenerative module)	Lenze Servo drives 9400 E94APNE0104 (5 kW passive power supply)	B&R Acopos 8BVI0014HWS0.000-1 (1,46 kW inverter	Bosch Rexroth Indradrive M (5,6 kW inverter)	Bosch Rexroth Indradrive M (2x 1,5 kW inverter)	SEW Moviaxis 2,2 kW inverter
Power electronics card	E94ACLM0044-0000P	E94ACLM0174-0000P	E94ACLS0174-000P	E94ACLP0104-000P1B	NA	HMS02.1N.W0028	SN3252626-06076	NA
IGBT component	FS25R12YT3	FS50R12KE3	FS50R12KE3	-	SK 25 GD 126 ET	13AC126V1	NA	NA
Rectifier	No	No		VUB 72-16N01 (Rectifier)		No	-	-
DC bus Capacitors	4x Jamicon 330 µF/400V (105°C) as in series of 2 and pararlel	6x Jamicon 330 µF/400V (105°C) as in series of 2 and pararlel	6x Jamicon 330 µF/400V (105°C) as in series of 2 and pararlel	5x 0,33µF	2x capacitor, 165µF to DC bus capacitance	2x 270µF	NA	NA
Current transducer (tarkista!)	LA25-NP (closed loop)	LAH 100-P/SP10	LAH 100-P/SP10	-			NA	NA
Fan	Embpast 24VDC 95mA 2,3W 40mm diameter	2 Fans: IGBT heatsink cooler: Ebmpapst 24V 245mA 6W fan 100mm, Switching regulator cooler: Ebmpapst 24V 95mA 2,3W 50mm.	2 Fans: IGBT heatsink cooler: Ebmpapst 24V 245mA 6W fan 100mm, Switching regulator cooler: Ebmpapst 24V 95mA 2,3W 50mm.	Embpast 24VDC 95mA 2,3W 40mm diameter		40mm	NA	NA
Heatsink (LxWxD)	120mm, 90mm, 20mm, 342 g	180mm, 94mm, 67mm 1,330 kg	180mm, 94mm, 67mm, 1,319 kg		NA	NA	NA	NA
Gate driver transformer	EPCOS (Lenze 345916)	EPCOS (Lenze 345916)		No	NA	NA	NA	NA
Charging circuit relay	GR2L-2A4		4x AZ762-1AB-24D	No	NA	NA	NA	NA
Charging circuit resistors	Flat resistor element 2 sides (55,7 and 50,1 ohms)	2x flat resistor elements 2 sides (55,2 and 50,0 ohms) (52,0 and 47,6 ohms)	-	No	NA	NA	NA	NA
Switched-mode supply	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA
Notes	Lots of coating on the PCB	Lots of coating on the PCB	Lots of coating on the PCB	Lots of coating on the PCB	-	-	-	-
Processor card	E94ACMH000-000P 1A	E94ACMH000-000P 1A	E94ACMH000-000P 1A	E94ACMP000-000P	NA	MNR.R911320644	MNR.R911320644	NA
Main processor	ARM Dual core DCIC 9907, 485728, 1009, K4VD9T03, (128 MHz 2x cores)	ARM Dual core DCIC 9907, 485728, 1009, K4VD9T03, (128 MHz 2x cores)	ARM Dual core DCIC 9907, 485728, 1009, K4VD9T03, (128 MHz 2x cores)	No	Toshiba TMPR4925XBG-200, 64 bit, 200 MHz	ST40RA200XH6, 64-bit, 166 MHz	ST40RA200XH6, 64-bit, 166 MHz	Infineon TriCore SAK-TC1796-256F150E (32 bit 150 MHz)
Resolver A/D converter	Texas Instruments 05DC9ET, ADS7869I	Texas Instruments 05DC9ET, ADS7869I	Texas Instruments 05DC9ET, ADS7869I	No	-	-	-	DSP6F801
FPGA	No	No	No	No	Altera Cyclone II, Altera Max II	Xilinx Spartan XC2S50E	Xilinx Spartan XC2S50E	Altera cyclone
Memory	12x ISSI IS61LV5128AL-10TL1/DOGO21D1 1019 + 1 different but number of part remains unkown (too much coating on the PCB)	12x ISSI IS61LV5128AL-10TL1/DOGO21D1 1019 + 1 different but number of part remains unkown (too much coating on the PCB)	12x ISSI IS61LV5128AL-10TL1/DOGO21D1 1019 + 1 different but number of part remains unkown (too much coating on the PCB)	No	1x 48LC2M32B2 DRAM module.	1x ISSI IS42S32200E-6TL (64 Mb)	1x ISSI IS42S32200E-6TL (64 Mb)	1x ISSI IS61WY25616BLL 10TLI
Notes	Lots of coating on the PCB	Lots of coating on the PCB	Lots of coating on the PCB	24 Power input, digital I/Os, mains selection and status leds	-	Also Sercos microchip SERCON816	Also Sercos microchip SERCON816	-
Connection board	E94ACBS0030-000P	E94ACBS0240-000P 1A	E94ACBS0240-000P 1A	No	No	No	No	
Notes	6x PCI style connectors from PC + 1 connection to such in Power card	6x PCI style connectors from PC + 1 connection to such in Power card	6x PCI style connectors from PC + 1 connection to such in Power card	-	-	-	-	-



Manufacturer	Lenze 9400	B&R ACO-POSmulti	Bosch Rexroth Indradrive M	SEW Mo-viaxis	Beckhoff AX5000
Offer accepted	17.9.2010	15.9.2010	22.11.2011	26.10.2011	7.12.2010
Arrived	15.11.2010	13.5.2011	4.2.2011	22.2.2011	12.5.2011

PCB E94ACMH000-000P (Lenze 9400)					PCB CSB01.1N-SE-ENS-NNN-LK1-S-.NN-FW (Bosch Rexroth Indradrive M)				
Supply voltage [V]	I [A]	24V led on	Power [W	Start at voltage	Supply voltage [V]	I [A]	24V led on	Power [W	Start at voltage
24	0,296	Yes	7,104	Starts normally	24	0,716	Yes	17,184	Starts normally
23,5	0,3	Yes	7,05	Starts normally	23,5	0,728	Yes	17,108	Starts normally
23	0,307	Yes	7,061	Starts normally	23	0,754	Yes	17,342	Starts normally
22,5	0,312	Yes	7,02	Starts normally	22,5	0,776	Yes	17,46	Starts normally
22	0,32	Yes	7,04	Starts normally	22	0,787	Yes	17,314	Starts normally
21,5	0,328	Yes	7,052	Starts normally	21,5	0,803	Yes	17,2645	Starts normally
21	0,333	Yes	6,993	Starts normally	21	0,822	Yes	17,262	Starts normally
20,5	0,343	Yes	7,0315	Starts normally	20,5	0,84	Yes	17,22	Starts normally
20	0,352	Yes	7,04	Starts normally	20	0,861	Yes	17,22	Starts normally
19,5	0,362	Yes	7,059	Starts normally	19,5	0,894	Yes	17,433	Starts normally
19	0,37	Yes	7,03	Starts normally	19	0,916	Yes	17,404	Starts normally
18,5	0,38	Yes	7,03	Flashing, no start	18,5	0,66	No	12,21	No start, fan goes to lower rev, flashing
18	0,41	Yes	7,38	Flashing, no start	18	0,04	No	0,72	No start
17,5	0,43	Yes	7,525	Flashing, no start	17,5	0	No	0	No start
17	0,412	Yes	7,004	Flashing, no start	17	0	No	0	No start
16,5	0,425	Yes	7,0125	Flashing, no start	16,5	0	No	0	No start
16	0,435	Yes	6,96	Flashing, no start	16	0	No	0	No start
15,5	0,453	Yes	7,0215	Flashing, no start	15,5	0	No	0	No start
15	0,471	Yes	7,065	Flashing, no start	15	0	No	0	No start
14,5	0,486	Yes	7,047	Flashing, no start	14,5	0	No	0	No start
14	0,505	Yes	7,07	Flashing, no start	14	0	No	0	No start
13,5	0,528	Yes	7,128	Flashing, no start	13,5	0	No	0	No start
13	0,55	Yes	7,15	Flashing, no start	13	0	No	0	No start
12,5	0,57	Yes	7,125	Flashing, no start	12,5	0	No	0	No start
12	0,597	Yes	7,164	Flashing, no start	12	0	No	0	No start
11,5	0,621	Yes	7,1415	Flashing, no start	11,5	0	No	0	No start
11	0,655	Yes	7,205	Flashing, no start	11	0	No	0	No start
10,5	0,694	Yes	7,287	Flashing, no start	10,5	0	No	0	No start
10	0,729	Yes	7,29	No	10	0	No	0	No start
9,5	0,762	Yes	7,239	No	9,5	0	No	0	No start
9	0,735	Yes	6,615	No	9	0	No	0	No start
8,5	0	No	0	No	8,5	0	No	0	No start
8	0	No	0	No	8	0	No	0	No start

Test runned only with processor card which was not connect to power card or option card
Currents measured with Fluke 175

ACSM1	Code	IP20 Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm³]	Notes
Inverter module	A	364	146	90	3	0,75	3	4,78	
Inverter module	B	380	223	100	5	4	7,5	8,47	
Inverter module	C	467	225	165	10	11	22	17,34	
Inverter module	D	467	225	220	17	30	45	23,12	
Inverter module	E	700	398	314	67	55	160	87,48	

S120	Code	IP20 Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm³]	Notes
Inverter module	A	173	145	73	1,2	0,75	1,5	1,83	
Inverter module	B	269,7	165	153,1	4	2,2	4	6,81	
Inverter module	C	333,4	185	188,4	6,5	7,5	15	11,62	
Inverter module	D	418	203,5	275	15,9	18,5	22	23,39	
Inverter module	E	498,3	203,5	275	19,8	37	45	27,89	
Inverter module	F	634	315,5	350	50,7	55	90	70,01	

Apocos	Code	IP20 Height [mm]	wall mounting Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm³]	Notes
Passive power module	8B0P0220/0440	317	263	106,5				8,88	
Power supply module	8BVP0220HW00.000-1	317	263	106,5	5,2	-	15	8,88	
Power supply module	8BVP0440HW00.000-1	317	263	106,5	5,5	-	30	8,88	
Power supply module	8BVP0880HW00.000-1	317	263	213,5	10,2	-	60	17,80	
Inverter module	8BVI0014/0028/0055/01	317	263	53	2,6	1,4	11	4,42	
Inverter module	8BVI0220/0330/0440	317	263	106,5	5,3	-	32	8,88	
Inverter module	8BVI0880	317	263	213,5	9,6	-	64	17,80	
Capacitor module	8B0K	317	263	53	3,2	-	-	4,42	1650μF 900V
Line filter passive	8B0F0300H000.000-1	270	85	50	1,2	-	22	1,15	EMC category 3
Line filter passive	8B0F0550H000.000-1	250	90	85	2	-	44	1,91	EMC category 3
Line filter	8BVF0220H000.000-1	378	212	135	NA	-	15	10,82	EMC category 3
Line filter	8BVF0440H000.001-2	378	212	135	15	-	32	10,82	EMC category 3
Line filter	8BVF0880H000.000-1	436	212	175	23,5	-	60	16,18	EMC category 3
Regeneration choke	8BVR0220H000.100-1	270	103	245	10,5	-	15	6,81	22,5 A
Regeneration choke	8BVR0440H000.100-1	285	146	251	24,1	-	32	10,44	45 A
Regeneration choke	8BVR0880H000.100-1	412	165	293	40,2	-	60	19,92	90 A
Control supply units	8B0C0160/0320	317	263	53				4,42	16/32A

9400Servo	Code	IP20 Height [mm]	wall mounting Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Inverter module 1	E9AMxE0024/34/44	350	288	60	4	0,37	1,5	6,05	
Inverter module 2	E9AMxE0074/94	350	288	90	5,3	3	4	9,07	
Inverter module 3	E9AMxE0134/174/244/32	350	288	120	8,1	5,5	15	12,10	
Power supply module 1 (AC/DC)	E94APNE0104	350	288	60	2,6	3,6	4,9	6,05	Min value if main filter used
Power supply module 2 (AC/DC)	E94APNE0364	350	288	120	5,3	13	17,5	12,10	Min value if main filter used
Power supply module 3 (AC/DC)	E94APNE1004	509	288	210	13,5	36,2	48,6	30,78	Min value if main filter used
Power supply module 4 (AC/DC)	E94APNE2454	509	288	390	28,5	88,6	119	57,17	Min value if main filter used
Regenerative power supply	E94ARNE0134/0244	350	288	120	6	15	27	12,10	Mains filter required, possible to have many modules parallel, feedback power maximums are 50% of the feeding power max
Mains filter 1	E94AZMP0084	485	261	90	8,6	4,9	4,9	11,39	A mains filter is a combination of mains choke and RFI filter in one housing, C2 EMC
Mains filter 2	E94AZMP0294	485	261	120	16,5	17,5	17,5	15,19	A mains filter is a combination of mains choke and RFI filter in one housing, C2 EMC
Mains filter 3	E94AZMP0824	490	272	270	29	48,6	48,6	35,99	A mains filter is a combination of mains choke and RFI filter in one housing, C2 EMC
Mains filter 4	E94AZMP2004	490	272	330	52	119	119	43,98	A mains filter is a combination of mains choke and RFI filter in one housing, C2 EMC
DC input module	E94AZEX100	422	95	60	0,9	-	-	2,41	With this module axis module interconnection can be suplied with power from central DC source, 100 A max
External 24V power supply	EZV1200-000	130	125	55	0,8	0,12	0,12	0,89	Multi-axis applications with multi drive axis modules require an external power supply unit to feed the control electronics.
External 24V power supply	EZV2400-000	130	125	85	1,2	0,24	0,24	1,38	
External 24V power supply	EZV4800-000	130	125	157	2,5	0,48	0,48	2,55	
External 24V power supply	EZV1200-001	130	125	73	1	0,12	0,12	1,19	
External 24V power supply	EZV2400-001	130	125	85	1,1	0,24	0,24	1,38	
External 24V power supply	EZV4800-001	130	125	160	1,9	0,48	0,48	2,60	

Moviaxis	Code	IP20 Height [mm]	wall mounting Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Power supply module 1 (AC/DC)	MXP80A-010-503-00	300	254	120	4,2	10	10	9,14	Regenerative capacity 50% of maximum power
Power supply module 2 (AC/DC)	MXP80A-025-503-00	400	254	120	10,2	25	25	12,19	Regenerative capacity 50% of maximum power
Power supply module 3 (AC/DC)	MXP80A-050/075-503-00	400	254	150	12,1	50	75	15,24	Regenerative capacity 50% of maximum power
Regenerative power supply	MXR	400	254	?				#VALUE!	
Inverter module 1	MXA80A-002/004/008-50	300	254	60	4,2	1,1	4,5	4,57	
Inverter module 2	MXA80A-012/016-503-00	300	254	90	5,2	6,7	9	6,86	
Inverter module 3	MXA80A-024/032-503-00	400	254	90	9,2	13,5	18	9,14	
Inverter module 4	MXA80A-048-503-00	400	254	120	9,2	27	27	12,19	
Inverter module 5	MXA80A-064-503-00	400	254	150	15,6	36	36	15,24	
Inverter module 6	MXA80A-100-503-00	400	254	210	15,6	56	56	21,34	
Mains filter 1	NF018-503	255	80	50	1,1	-	-	1,02	
Mains filter 2	NF048-503	315	100	60	2,1	-	-	1,89	
Mains filter 3	NF085-503	320	140	90	3,5	-	-	4,03	
Mains filter 4	NF150-503	330	155	100	5,6	-	-	5,12	
Line choke 1	ND020-013	120	85	60	0,5	-	-	0,61	
Line choke 2	ND045-013	170	125	95	2,5	-	-	2,02	
Line choke 3	ND085-013	235	185	115	8	-	-	5,00	
Line choke 4	ND150-013	230	255	140	17	-	-	8,21	
Capacitor module	MXC80A-050-503-00	400	254	150	12,6	-	-	15,24	4920mF
Buffer module (Capacitor module?)	MXB80A-050-503-00	400	254	150	11	-	-	15,24	4920mF
Master module (Motion controller)	MXM80A-000-000-00	300	254	60	2,3	-	-	4,57	
DC link discharge module	MXZ80A-050-503-00	235	254	120	3,8	-	-	7,16	
External 24V power supply	MXS80A-060-503-00	300	254	60	4,3	0,64	0,64	4,57	24V power supply 3 channels (3x10A)

B maxx 5000	Code	IP20	wall mounting						
		Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Power supply module 1 (AC/DC)	5032	405	280	75		27	27	8,51	
Power supply module 1 (AC/DC)	5043	405	280	100		52	52	11,34	
Power supply module 1 (AC/DC)	5044	405	280	100		90	90	11,34	
Regenerative power supply	5143	405	280	100		52	52	11,34	
Regenerative power supply	5174	405	280	175		90	90	19,85	
Inverter module 1	5323	405	280	50		1,6	1,6	5,67	
Inverter module 2	5325	405	280	50		3,2	3,2	5,67	
Inverter module 3	5326	405	280	50		6,5	6,5	5,67	
Inverter module 4	5327	405	280	50		10,8	10,8	5,67	
Inverter module 5	5328	405	280	50		16,2	16,2	5,67	
Inverter module 6	5334	405	280	75		21,6	21,6	8,51	
Inverter module 7	5335	405	280	75		32,4	32,4	8,51	

Combivert H6	Code	IP20 Height [mm]	wall mounting Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Power supply module (AC/DC) "centr	19.H6.C.19	407	198	100	-	30	30	8,06	
Power supply module (AC/DC) "centr	20.H6.C.20	407	198	100	-	37	37	8,06	
Power supply module (AC/DC) "centr	21.H6.C.21	407	198	100	-	48	48	8,06	
Power supply module (AC/DC) "centr	24.H6.C.24	407	198	300	-	95	95	24,18	
Power supply module (AC/DC) "centr	25.H6.C.25	407	198	300	-	120	120	24,18	
Power supply module (AC/DC) "centr	27.H6.C.27	407	198	300	-	155	155	24,18	
Power supply module (AC/DC) "centr	28.H6.C.28	407	198	300	-	225	225	24,18	
"sinusoidal power supply and regener	14.H6.D14	407	198	100	-	11	11	8,06	
"sinusoidal power supply and regener	18.H6.D18	407	198	100	-	33	33	8,06	
"sinusoidal power supply and regener	19.H6.D19	407	198	200	-	42	42	16,12	
"sinusoidal power supply and regener	21.H6.D21	407	198	200	-	62	62	16,12	
"sinusoidal power supply and regener	24.H6.D24	407	198	300	-	125	125	24,18	
"sinusoidal power supply and regener	26.H6.D26	407	198	300	-	173	173	24,18	
Single axis Inverter module 1		407	198	50	-	0,75	0,75	4,03	
Single axis Inverter module 2		407	198	50	-	2,2	2,2	4,03	
Single axis Inverter module 3		407	198	50	-	4	4	4,03	
Single axis Inverter module 4		407	198	100	-	5,5	5,5	8,06	
Single axis Inverter module 5		407	198	100	-	7,5	7,5	8,06	
Single axis Inverter module 6		407	198	100	-	11	11	8,06	
Single axis Inverter module 7		407	198	100	-	15	15	8,06	
Single axis Inverter module 8		407	198	100	-	22	22	8,06	
Single axis Inverter module 9		407	198	200	-	37	37	16,12	
Single axis Inverter module 10		407	198	200	-	45	45	16,12	
Single axis Inverter module 11		407	198	200	-	55	55	16,12	
Single axis Inverter module 12		407	198	200	-	75	75	16,12	
Single axis Inverter module 13		407	198	300	-	90	90	24,18	
Single axis Inverter module 14		407	198	300	-	110	110	24,18	
Double axis Inverter module 1		407	198	50	-	2 x 0,75	2 x 0,75	4,03	
Double axis Inverter module 2		407	198	50	-	2 x 2,2	2 x 2,2	4,03	
Double axis Inverter module 3		407	198	50	-	2 x 4	2 x 4	4,03	
Motion controller "control module"	00.H6.G00	407	198	50	-	-	-	4,03	
External 24V power supply	00.H6.E00	407	198	50	-	0,5	0,5	4,03	25A output/ 500W
Line filter 1	18.E4.T60-3001	458	240	90	8	-	-	9,89	
Line filter 2	21.E4.T60-3001	458	240	120	11	-	-	13,19	
Line filter 3	26.E4.T60-3001	385	115	260	40	-	-	11,51	
Line filter 4	28.E4.T60-3001	385	115	260	40	-	-	11,51	
Mains choke 1	19.Z1.B04-1000	135	220	219	12	-	-	6,50	
Mains choke 2	20.Z1.B04-1000	150	220	219	12	-	-	7,23	

Mains choke 3	21.Z1.B04-1000	155	207	267	15,6	-	-	8,57	
Mains choke 4	24.Z1.B04-1000	225	235	316	24,8	-	-	16,71	
Mains choke 5	25.Z1.B04-1000	225	235	316	25	-	-	16,71	
Mains choke 6	27.Z1.B04-1000	230	265	352	34	-	-	21,45	
Mains choke 7	28.Z1.B04-1000	245	265	388	41,5	-	-	25,19	
AFE-Filter 1	14.H6.J4F-1000 / 2000	200	430	205		-	-	17,63	16,5A
AFE-Filter 2	18.H6.J4F-1000 / 2000	250	510	205		-	-	26,14	48A
AFE-Filter 3	19.H6.J4F-1000 / 2000	250	510	205		-	-	26,14	60A
AFE-Filter 4	21.H6.J4F-1000 / 2000	250	585	210		-	-	30,71	90A
AFE-Filter 5	24.H6.J4F-1000 / 2000	300	650	210		-	-	40,95	180A
AFE-Filter 6	26.H6.J4F-1000 / 2000	400	800	350		-	-	112,00	250A
AFE-Filter 7	18.H6.J4F-2000	200	430	205		-	-	17,63	48A I60%
AFE-Filter 8	19.H6.J4F-2000	200	430	205		-	-	17,63	60A I60%
AFE-Filter 9	21.H6.J4F-2000	250	510	205		-	-	26,14	90A I60%
AFE-Filter 10	24.H6.J4F-2000	250	585	210		-	-	30,71	180A I60%

Beckhoff AX 5000	Code	IP20 Height [mm]	wall mounting Depth [mm]	Width [mm]	Weight [kg]	kVA min	kVA max	Volume [dm³]	Notes
Capacitor module	AX5001-0000	-	-	-	-	-	-	-	
Brake module	AX5021-0000	-	-	-	-	-	-	-	
generative module	AX504x	-	-	-	-	-	-	-	
AX bridge	AX59XX	-	-	-	-	-	-	-	
Single channel servo drive	AX5160	345	240	190	13	42	42	15,73	
Single channel servo drive	AX5172	345	240	190	13	50	50	15,73	
Single channel servo drive	AX5190	540	242	280	28	62	62	36,59	
Single channel servo drive	AX5191	540	242	280	28	76	76	36,59	
Single channel servo drive	AX5192	540	322	280	32	99	99	48,69	
Single channel servo drive	AX5193	540	322	280	32	118	118	48,69	
Single channel servo drive	AX5101-0000	274	232	92	4	1,2	1,2	5,85	
Single channel servo drive	AX5103-0000	274	232	92	4	2,5	2,5	5,85	
Single channel servo drive	AX5106-0000	274	232	92	5	5	5	5,85	
Single channel servo drive	AX5112-0000	274	232	92	5	10	10	5,85	
Single channel servo drive	AX5118-0000	274	232	185	11	15	15	11,76	
Single channel servo drive	AX5125-0000	274	232	185	11	20,8	20,8	11,76	
Single channel servo drive	AX5140-0000	300	232	185	14	33	33	12,88	Not available yet, estimated 1st quarter 2011
Dual channel servo drive	AX5201-0000	274	232	92	5	2,5	2,5	5,85	
Dual channel servo drive	AX5203-0000	274	232	92	6	5	5	5,85	
Dual channel servo drive	AX5206-0000	274	232	92	6	10	10	5,85	
Mains filter	AX2090-NF50-0014	-	-	-	-	-	-	-	C2 up to 14,6A
Mains filter	AX2090-NF50-0032	-	-	-	-	-	-	-	C2 up to 32,8A
Mains filter	AX2090-NF50-063	-	-	-	-	-	-	-	C2 up to 63A
Mains filter	AX2090-NF50-0100	-	-	-	-	-	-	-	C2/C3 for AX5172/AX5190 up to 100A
Mains filter	AX2090-NF50-0150	-	-	-	-	-	-	-	C2/C3 for AX5191/AX5192 up to 150A
Mains filter	AX2090-NF50-0180	-	-	-	-	-	-	-	C2/C3 for AX5193 up to 180A
Mains choke	AX2090-ND50-0060	-	-	-	-	-	-	-	for AX5160
Mains choke	AX2090-ND50-0072	-	-	-	-	-	-	-	for AX5172
Mains choke	AX2090-ND50-0090	-	-	-	-	-	-	-	for AX5190
Mains choke	AX2090-ND50-0110	-	-	-	-	-	-	-	for AX5191
Mains choke	AX2090-ND50-0143	-	-	-	-	-	-	-	for AX5192
Mains choke	AX2090-ND50-0170	-	-	-	-	-	-	-	for AX5193
Motor choke	AX2090-MD50-0012	-	-	-	-	-	-	-	>25m up to 12A
Motor choke	AX2090-MD50-0025	-	-	-	-	-	-	-	>25m up to 25A

Lexium LXM 62	Code	Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Motion controller	LMC 100C	NA yet	NA yet	NA yet	-	-	-	-	Scheduled before end of 2010 (4 syncronizable axes)
Motion controller	LMC 200C	NA yet	NA yet	NA yet	-	-	-	-	Scheduled before end of 2010 (8 syncronizable axes)
Motion controller	LMC 300C	270	240	104	-	-	-	6,74	8 synchronizable axis
Motion controller	LMC 400C	270	240	104	-	-	-	6,74	16 synchronizable axis
Motion controller	LMC 600C	270	240	104	-	-	-	6,74	99 synchronizable axis
Motion controller	LMC 800C	270	240	104	-	-	-	6,74	Scheduled before end of 2010 (254 synchronizable axis)
Servo drive	LXM 62 D U60A	310	270	44	-	1,4	1,4	3,68	
Servo drive	LXM 62 D D15A	310	270	44	-	3,5	3,5	3,68	
Servo drive	LXM 62 D D27A	310	270	44	-	6,3	6,3	3,68	
Servo drive	LXM 62 D D45A	310	270	44	-	15	15	3,68	
Servo drive (2-axis)	LXM 62 D U60B	310	270	44	-	2x 1,4	2x 1,4	3,68	
Servo drive (2-axis)	LXM 62 D D15B	310	270	44	-	2x 3,5	2x 3,5	3,68	
Servo drive (2-axis)	LXM 62 D D27B	310	270	44	-	2x 6,3	2x 6,3	3,68	
Power supply	LXM 62 P D84 A	310	270	89	-	25	25	7,45	
Power supply	LXM 62 P Cxx A	310	270	NA yet	-	67	67	-	

IndraDrive M	Code	Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm^3]	Notes
Infeed modules	HMV01.1E-W0030-A-07-NNNN	440	309	150	13,5	18/38	18/38	20,39	With/Without choke
Infeed modules	HMV01.1E-W0075-A-07-NNNN	440	309	250	22	45/75	45/75	33,99	With/Without choke
Infeed modules	HMV01.1E-W0120-A-07-NNNN	440	309	350	32	72/120	72/120	47,59	With/Without choke
Regenerative modules	HMV01.1R-W0018-A-07-NNNN	440	309	175	13,5	18	18	23,79	Cannot be used without choke
Regenerative modules	HMV01.1R-W0045-A-07-NNNN	440	309	250	20	45	45	33,99	Cannot be used without choke
Regenerative modules	HMV01.1R-W0065-A-07-NNNN	440	309	350	31	65	65	47,59	Cannot be used without choke
Regenerative modules	HMV01.1R-W0120-A-07-NNNN	440	309	350	34,5	120	120	47,59	Cannot be used without choke
Regenerative modules	HMV02.1R-W0015-A-07-NNNN	352	252	150	9,5	15	15	13,31	Cannot be used without choke
Double-axis inverter	HMD01.1N-W0012-A-07-NNNN	440	262	50	5,5	2x 2,2	2x 2,2	5,76	
Double-axis inverter	HMD01.1N-W0020-A-07-NNNN	440	262	50	5,6	2x 3,7	2x 3,7	5,76	
Double-axis inverter	HMD01.1N-W0036-A-07-NNNN	440	262	75	7,5	2x 5,5	2x 5,5	8,65	
Single-axis inverter	HMS01.1N-W0020-A-07-NNNN	440	309	50	5,3	5,5	5,5	6,80	
Single-axis inverter	HMS01.1N-W0036-A-07-NNNN	440	309	50	5,3	11	11	6,80	
Single-axis inverter	HMS01.1N-W0054-A-07-NNNN	440	309	75	6,7	18,5	18,5	10,20	
Single-axis inverter	HMS01.1N-W0070-A-07-NNNN	440	309	100	7,9	22	22	13,60	
Single-axis inverter	HMS01.1N-W0110-A-07-NNNN	440	309	125	11	37	37	17,00	
Single-axis inverter	HMS01.1N-W0150-A-07-NNNN	440	309	150	12,7	55	55	20,39	
Single-axis inverter	HMS01.1N-W0210-A-07-NNNN	440	309	200	18,4	75	75	27,19	
Single-axis inverter	HMS01.1N-W0350-A-07-NNNN	440	309	350	31,7	125	125	47,59	

Single-axis inverter	HMS02.1N-W0028-A-07-NNNN	352	252	50	3,5	6,9	6,9	4,44	Adds 0,14 mF for DC bus capacity
Single-axis inverter	HMS02.1N-W0054-A-07-NNNN	352	252	75	5	12,5	12,5	6,65	Adds 0,27 mF for DC bus capacity
Capacity module	HLC01.1C-01M0-A-007-NNNN	352	251,5	60	3,2	-	-	5,31	Power dissipation 12 W, Capacity 1 mF
Capacity module	HLC01.1C-02M4-A-007-NNNN	352	251,5	60	4,3	-	-	5,31	Power dissipation 24 W, Capacity 2,4 mF
Capacity module	HLC01.1D-05M0-A-007-NNNN	440	309	75	8,6	-	-	10,20	Power dissipation 13 W, Capacity 5 mF
Mains filter	HNF01.1A-F240-E0051-A-480-NNNN	440	262	100	15	-	-	11,53	
Mains filter	HNF01.1A-M900-E0051-A-480-NNNN	440	262	100	15	-	-	11,53	
Mains filter	HNF01.1A-F240-E0125-A-480-NNNN	440	262	150	18	-	-	17,29	
Mains filter	HNF01.1A-M900-E0125-A-480-NNNN	440	262	150	30	-	-	17,29	
Mains filter	HNF01.1A-F240-E0202-A-480-NNNN	440	262	150	29	-	-	17,29	
Mains filter	HNF01.1A-M900-E0202-A-480-NNNN	440	262	250	37	-	-	28,82	
Mains filter	HNF01.1A-A075-E0235-A-500-NNNN	in prep.	in prep.	in prep.	in prep.	-	-	-	
Mains filter	HNF01.1A-A075-E0309-A-500-NNNN	263	180	175	in prep.	-	-	8,28	
Mains filter	HNF01.1A-F240-R0026-A-480-NNNN	440	262	100	14	-	-	11,53	
Mains filter	HNF01.1A-M900-R0026-A-480-NNNN	440	262	150	17	-	-	17,29	
Mains filter	HNF01.1A-F240-R0065-A-480-NNNN	440	262	150	25	-	-	17,29	
Mains filter	HNF01.1A-M900-R0065-A-480-NNNN	440	262	150	26	-	-	17,29	
Mains filter	HNF01.1A-F240-R0094-A-480-NNNN	440	262	150	28	-	-	17,29	
Mains filter	HNF01.1A-M900-R0094-A-480-NNNN	440	262	150	29	-	-	17,29	
Mains filter	HNF01.1A-H350-R0180-A-480-NNNN	440	262	250	45	-	-	28,82	
Mains filter	HNS02.1A-Q200-R0023-A-480-NNNN	352	265	80	15	-	-	7,46	
Mains filter for NCS units?	NFD03.1-480-007	160	90	50	0,7	-	-	0,72	
Mains filter for NCS units?	NFD03.1-480-016	220	90	55	1	-	-	1,09	

Mains filter for NCS units?	NFD03.1-480-030	270	100	60	1,4	-	-	1,62	
Mains filter for NCS units?	NFD03.1-480-055	220	105	90	2	-	-	2,08	
Mains filter for NCS units?	NFD03.1-480-075	240	145	90	3,5	-	-	3,13	
Mains choke	HNL01.1E-1000-N0012-A-500-NNNN	164	61	120	2,7	-	-	1,20	Continous current 12 A
Mains choke	HNL01.1E-1000-N0020-A-500-NNNN	184	66,5	150	3,8	-	-	1,84	Continous current 20 A
Mains choke	HNL01.1E-0600-N0032-A-500-NNNN	184	66,5	150	4,5	-	-	1,84	Continous current 32 A
Mains choke	HNL01.1E-0400-N0051-A-480-NNNN	225	112	180	13,5	-	-	4,54	Continous current 51 A
Mains choke	HNL01.1E-0200-N0125-A-480-NNNN	295	148	230	24	-	-	10,04	Continous current 125 A
Mains choke	HNL01.1E-0100-N0202-A-480-NNNN	350	152	265	33	-	-	14,10	Continous current 202 A
Mains choke	HNL01.1R-0980-C0026-A-480-NNNN	245	172	210	16	-	-	8,85	Continous current 26 A
Mains choke	HNL01.1R-0590-C0065-A-480-NNNN	360	205	300	45	-	-	22,14	Continous current 65 A
Mains choke	HNL01.1R-0540-C0094-A-480-NNNN	385	229	340	65	-	-	29,98	Continous current 94 A
Mains choke	HNL01.1R-0300-C0180-A-480-NNNN	400	261	340	73	-	-	35,50	Continous current 180 A
Mains choke	HNL01.1R-0980-C0023-A-480-NNNN	352	115	165	14	-	-	6,68	Continous current 23 A
Mains choke	HNL01.1E-0571-N0050A-500-NNNN	238	100	183	13	-	-	4,36	Continous current 50 A
Mains choke	HNL01.1E-0362-N0080-A-500-NNNN	175	180	205	17	-	-	6,46	Continous current 80 A
Mains choke	HNL01.1E-1000-N0012-A-500-NNNN	193	210	205	17	-	-	8,31	Continous current 106 A
Mains choke	HNL01.1E-1000-N0012-A-500-NNNN	205	230	250	23	-	-	11,79	Continous current 146 A
Control unit "Basic open loop"	CSB01.1N-FC-NNN-NNN-NN-C-NN-FW	-	-	-	-	-	-	-	C-NN-FW (C=comfort model with better operating panel) Standard operating panel with code S (integrated in the power module)
Control unit "Basic analog"	CSB01.1N-AN-ENS-NNN-L1-C-NN-FW	-	-	-	-	-	-	-	
Control unit "Basic Profibus"	CSB01.1N-PB-ENS-NNN-L1-C-NN-FW	-	-	-	-	-	-	-	
Control unit "Basic SerCos"	CSB01.1N-SE-ENS-NNN-L1-C-NN-FW	-	-	-	-	-	-	-	
Control unit "Basic universal" (single axis)	CSB01.1C-SE-ENS-NNN-L1-C-NN-FW	-	-	-	-	-	-	-	

Control unit "Basic universal" (double axis)	CDB01.1C-SE-ENS-EN2-NNN-MA1-S1-S-NN-FW	-	-	-	-	-	-	-	
Control unit "Advanced"	CSH01.1C-SE-ENS-EN2-NNN-S1-S-NN-FW	-	-	-	-	-	-	-	
Mains filter with integrated mains choke	HNK01.1A-A075-E0050-A-500-NNNN	322,5	251,5	125	15	-	-	10,14	Continous current 50 A (Class A, Group 2 EMC)
Mains filter with integrated mains choke	HNK01.1A-A075-E0080-A-500-NNNN	310	270	225	20	-	-	18,83	Continous current 80 A (Class A, Group 2 EMC)
Mains filter with integrated mains choke	HNK01.1A-A075-E0106-A-500-NNNN	310	270	225	20	-	-	18,83	Continous current 106 A (Class A, Group 2 EMC)
Mains filter with integrated mains choke	HNK01.1A-A075-E0146-A-500-NNNN	380	270	350	28	-	-	35,91	Continous current 146 A (Class A, Group 2 EMC)

Kinetix 6500	Code	Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm³]	Notes
Power module with inverter	2094-BC01-MP5-M	290	290	125		6	6	10,51	4 A inverter included
Power module with inverter	2094-BC01-M01-M	290	290	125		6	6	10,51	9A inverter included
Power module with inverter	2094-BC02-M02-M	290	290	125		15	15	10,51	15A inverter included
Single-axis inverter	2094-BMP5-M	-	-	-		1,8	1,6	-	4A
Single-axis inverter	2094-BM01-M	-	-	-		3,9	3,2	-	9A
Single-axis inverter	2094-BM02-M	-	-	-		6,6	6,6	-	15A
Control module	2094-EN02D-M01-S0	-	-	-		-	-	-	EthernetIP, safe torque off
Control module	2094-EN02D-M01-S1	-	-	-		-	-	-	EthernetIP, safe speed monitoring
Control module	2094-SE02F-M00-S0	-	-	-		-	-	-	SERCOS, safe torque off
Control module	2094-SE02F-M00-S1	-	-	-		-	-	-	SERCOS, safe speed monitoring
"shunt module"	2094-BSP2	-	-	-		-	-	-	470µF capacitance
slot-filler module	2094-PRF	-	-	-		-	-	-	
Line filter	2090-XXXLF-X330B	-	-	-	2,7	-	-	-	

motiflex e100	Code	Height [mm]	Depth [mm]	Width [mm]	Weight [kg]	kW min	kW max	Volume [dm³]	Notes
Power module	MFE460A001	-	-	-	-	-	-	-	
Power module	MFE460A003	-	-	-	-	-	-	-	
Power module	MFE460A006	-	-	-	-	-	-	-	
Power module	MFE460A010	-	-	-	-	-	-	-	
Power module	MFE460A016	-	-	-	-	-	-	-	
Servo inverter	MFE460A001B	-	-	-	-	-	-	-	1,5 A
Servo inverter	MFE460A003B	-	-	-	-	-	-	-	3 A
Servo inverter	MFE460A006B	-	-	-	-	-	-	-	6 A
Servo inverter	MFE460A010B	-	-	-	-	-	-	-	10, 5 A
Servo inverter	MFE460A016B	-	-	-	-	-	-	-	16 A
Servo inverter	MFE460A021B	-	-	-	-	-	-	-	21 A
Servo inverter	MFE460A026B	-	-	-	-	-	-	-	26 A
Servo inverter	MFE460A033B	-	-	-	-	-	-	-	33,5 A
EMC filter	FI0035A00	-	-	-	-	-	-	-	8 A (3-phase 520VAC)
EMC filter	FI0035A01	-	-	-	-	-	-	-	16 A (3-phase 520VAC)
EMC filter	FI0035A02	-	-	-	-	-	-	-	25 A (3-phase 520VAC)
EMC filter	FI0035A03	-	-	-	-	-	-	-	36 A (3-phase 520VAC)
EMC filter	FI0035A04	-	-	-	-	-	-	-	50 A (3-phase 520VAC)
EMC filter	FI0035A05	-	-	-	-	-	-	-	66 A (3-phase 520VAC)
EMC filter	FI0014A00	-	-	-	-	-	-	-	16 A optional emc filter for 24 V supply
Mains filter	LRAC00802	-	-	-	-	-	-	-	3 mH, 1,5A to 3A units operating stand alone on poor quality AC
Mains filter	LRAC02502	-	-	-	-	-	-	-	1,2 mH 6A to 12A units operating stand alone on poor quality AC, 1,5 to 6A units in DC shared systems
Mains filter	LRAC03502	-	-	-	-	-	-	-	0,8 mH 10,5A to 16A units DC shared systems
Mains filter	LRAC05502	-	-	-	-	-	-	-	0,5 mH 21A, 26A and 33,5A units DC shared systems
Ethernet powerlink router	OPT036-501	115	100	23	0,116	-	-	-	Powerlink -> ethernetIP network
Motion controller	NXE100-16xxDB	-	-	-	-	-	-	-	"8, 12 or 16 axes of interpolated motion", differential stepper output, xx number of axis 08, 12 or 16
Motion controller	NXE100-16xxSB	-	-	-	-	-	-	-	"8, 12 or 16 axes of interpolated motion", single ended open collector, xx number of axis 08, 12 or 16
Servo inverter (microflex)	MFE230A003B	180	157	79,6	1,5	0,33	0,33		input 105 - 230 VAC 3A, 6A peak 3 s
Servo inverter (microflex)	MFE230A006B	180	157	79,6	1,5	0,75	0,75		input 105 - 230 VAC 6A, 12A peak 3 s
Servo inverter (microflex)	MFE230A009B	180	157	79,6	1,5	1,5	1,5		input 105 - 230 VAC, 9A, 18A peak 3s
EMC filter (microflex)	FI0029A00	-	-	-	-	-	-	-	22 A (1-phase 250 VAC)
EMC filter (microflex)	FI0015A00	-	-	-	-	-	-	-	6 A (1-phase 250 VAC)
EMC filter (microflex)	FI0015A02	-	-	-	-	-	-	-	12 A (1-phase 250 VAC)
EMC filter (microflex)	FI0018A00	-	-	-	-	-	-	-	7,7 A (3-phase 230/480VAC)
EMC filter (microflex)	FI0018A03	-	-	-	-	-	-	-	17,5 A (3-phase 230/480VAC)
EMC filter (microflex)	FI0014A00	-	-	-	-	-	-	-	16 A optional filter for 24V supply

Fantray (microflex)	FAN001-24	-	-	-	-	-	-	-	Addtional cooling fan high ambient temperatures
24V power supply	DR-75-24	-	-	-	-	-	-	-	3,2 A DIN rail mount
24V power supply	DR-120-24	-	-	-	-	-	-	-	5 A DIN rail mount
24V power supply	DR-240-24	-	-	-	-	-	-	-	10 A DIN rail mount
DC bus bar	OPT-MF-DC-A	-	-	-	-	-	-	-	Pack of 2 links for drives 1,5A to 16A
DC bus bar	OPT-MF-DC-B	-	-	-	-	-	-	-	Pack of 2 links for drives 20A to 34A