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DEVELOPMENT OF ABB SINGLEDRIVE RETROFIT FRAME SOLUTION

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MASTER THESIS

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Tallinn, 2019

AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

“27” May 2019

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Accepted for defence

“.......”....................201… .

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Thesis topic:

DEVELOPMENT OF ABB SINGLEDRIVE RETROFIT FRAME SOLUTION

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Thesis main objectives:

1. Create functional mechanical design
2. Design improvements
3. Cost calculation

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Design tasks definition	29.03.19
2.	Design concept completion	15.04.19
3.	Design analysis	02.05.19
4.	Design improvements	15.05.19
5.	Design cost calculations	20.05.19
6.	Summary and conclusions	26.05.19

Language: English **Deadline for submission of thesis:** “27” May 2019

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Supervisor: Kristo Karjust ……….............................“.......” ....201….a

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PREFACE

In the modern world, our everyday lives rely on electric motors. In order for electric motors to function as desired, safely and reliably, electrical drives are needed. Typically, the life span of electric motor exceeds the product life cycle of a drive. Therefore, to extend the life span of a drive a retrofitting solution is offered as a preventive measure.

The thesis was initiated by the need of new design for ABB OY drives service for ACS880-01 industrial drive retrofit and is intended to provide functional design, ready for prototype building and testing.

I wish to express my gratitude to my colleagues form order based engineering and form research and development teams, for sharing valuable knowledge and know-how, supporting the research. I would also like to thank my managers, order based engineering team leader Jaanus Karu and sales support manager Niko Tervaskari, for opportunity to conduct such substantial design project.

In addition, I wish to thank my family and friends for diverse support during all my studies that had led to this point. Especially inspiring person during this path have been my grandmother, who has taught me that hard work pays off.

List of abbreviations and symbols

AC – Alternating current

BOM – Bill of material

CAD – computer aided design

CMF – Common Mode filtering

DC – Direct current

DTC - Direct torque control

FEA – finite element analysis

ICD – Industrial Cabinet Drive

IGBT – Insulated gate bipolar transistor

IP – ingress protection

RFI – Radio frequency interference

SynRM - Synchronous reluctance motor

INTRODUCTION

The aim of the thesis is to create a functional and efficient design for low voltage inverter drive retrofitting solution. Retrofit as a service is offered to expand the life span of cabinet-built AC drives, which has reached a stage in product life-cycle where after sales support is no longer provided by manufacturer. In this case user or end customer has an option to replace the complete unit with new product or get retrofit solution with up to date components and additional functionality.

AC drives, in general, are used for controlling electric motors by converting fixed frequency and voltage from the electrical grid to a variable frequency and voltage suitable for desired operation of electric motor. The ACS880-01 series drives are used for controlling asynchronous AC induction motors, permanent magnet synchronous motors, AC induction servomotors and ABB synchronous reluctance motors (SynRM motors). AC drives are used in large variety of industrial applications, most commonly for electric motors that are driving fans, pumps, winders, conveyors, cranes and other industrial equipment.

The main circuit of inverter module consists of (Figure 1):

1. Rectifier which converts alternating current and voltage to direct current and voltage
2. DC link is DC circuit between rectifier and inverter
3. Inverter converts direct current and voltage to the desired alternating current and voltage
4. Brake chopper conducts surplus energy caused by braking of high inertia motor to dedicated resistor packs, that can be ordered as option for drive setup.

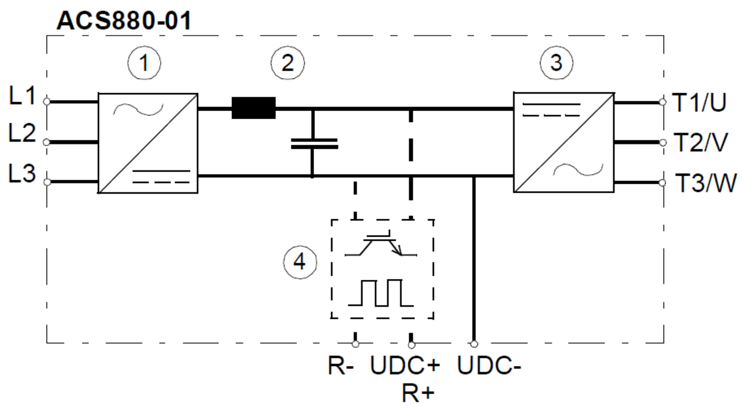


Figure 1. Inverter module main circuit [1]

IGBTs are used for rectifying and modulating frequency.

History of company ABB for which the thesis research work is done dates back to 1883. ABB as company known today, was formed in 1988 by merger of two companies: ASEA - Allmänna Svenska Elektriska Aktiebolaget, established in 1890 and BBC - Brown, Boveri & Cie, established in 1891 [2].

Nowadays ABB Group is divided into four divisions: power grids, electrification products, industrial automation, robotics and motion. ABB operates globally in 100 countries and has 693 offices world wide (Figure 2) [3].

Drives business unit operates under robotics and motion division. The drives business unit was incorporated to ABB through acquisition of finish company Strömberg OY in 1987. Nowadays, the drives portfolio is divided into drives products and system drives. The products that are subject in this thesis are ACS880 series industrial drives which are categorized under system drives.

Figure 2. ABB global locations [3]

1 DESIGN INPUTS

When creating a new design concept, several aspects have to be met. Since the shell of existing cabinet drive unit remains, the new design has to be compatible with existing one. Secondly new components that are going to be retrofitted have to be laid out functionally, safely and according to industry standards.

1.1 Retrofitting background

ABB industrial drives life cycle is divided into four stages (Figure 3). Retrofit solution is generally offered for products in limited and obsolete phases. The need for this study derives from product life cycle statement, which states that the ACS604/607/627 R8 to 2xR9 (110 to 630 kW) are in the limited phase since 1.1.2019 and it is planned to keep the ACS604/607/627 R8 to 2xR9 in the limited phase until 31.12.2021, after which these will be transferred to the obsolete phase [4].

Figure 3. ABB industrial drives life cycle phases [4]

These products have limited to no after sales support from manufacturer. Such products life cycle has reached the point where spare parts are no longer manufactured and in the case of a failure these cannot be repaired or replaced like for like. Due to the high cost of stoppages in manufacturing, drive failures are prevented by scheduled maintenance. As legacy products can no longer be maintained, there are options to replace the old setup with a complete new system or to retrofit new components in the existing drive cabinet. ABB offers retrofits to its old product series: Sami Star, ACV700 and ACS600. This thesis focuses on ACS607 single drive setup retrofits.

Existing cabinets that are going to be retrofitted are ACS600 series cabinet drives that were manufactured from 1998 to 2019. Regarding the naming, ACS607 represents a cabinet built drive and ACS604 the inverter module, used in ACS600 series cabinet drives. Industrial cabinet drives are divided into sections. Sections are defined by the width starting from 200 mm and increasing in 100-200 mm steps up to 1000 mm wide sections. The height and depth of the cabinet at universal at 2000 and 600 mm respectively. Derived from ACS880 R9 power rating, the ACS607 drive cabinets have two different layout designs: a single 800 mm wide cabinet and an 800 mm with adjacent 400 mm cabinet. The 400 mm section is included when optional main switch and RFI filter are included (Figure 4).

For newly developed retrofit design, all components that are going to be fitted, will be incorporated into a single unit and fitted only in 800 mm wide section, not depending on whether existing ACS607 setup is 800 or 800 plus 400 millimetres wide.

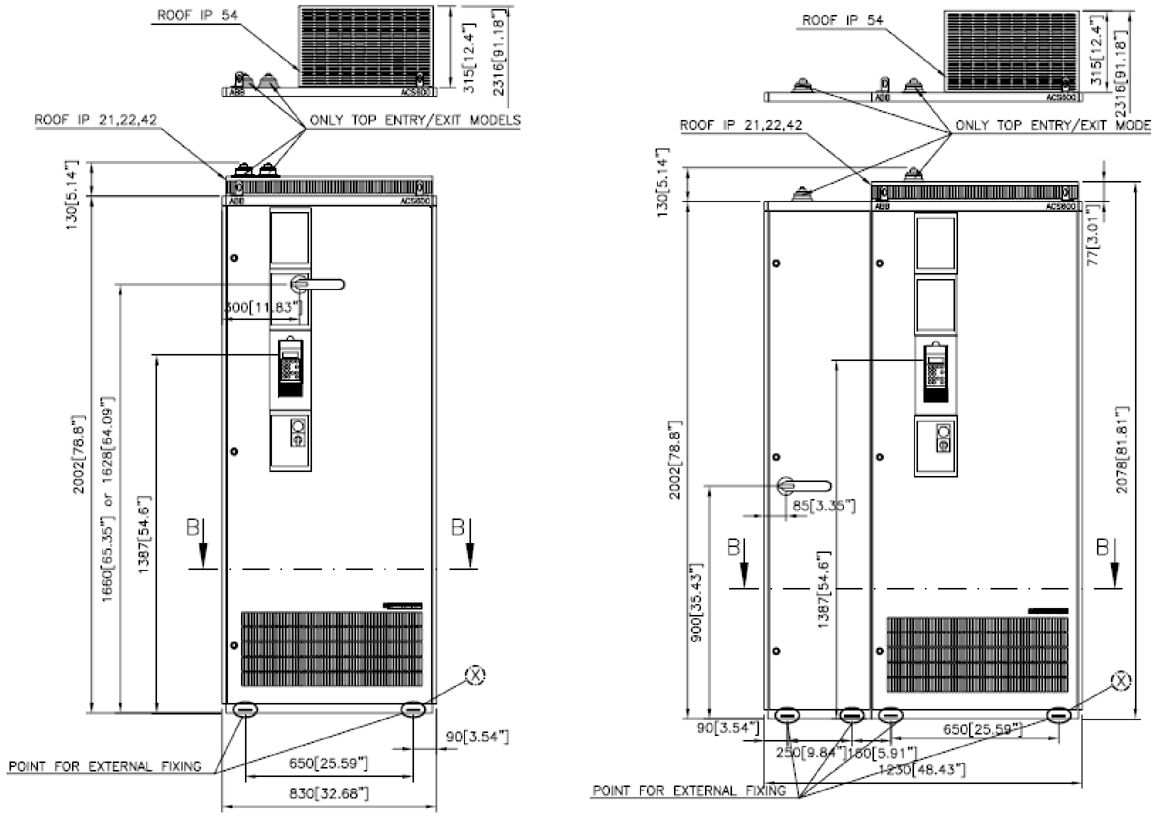


Figure 4. ACS607 800 mm wide and 400+800 mm wide cabinet

1.2 Basis of retrofit design: active standard products and available retrofits

New retrofit design is based on ACS880 series products, which are actively in production. ACS880 product series includes a large variety of low voltage industrial drives solutions with wide spectrum of power ratings. There are two main product groups of low voltage drives: multi drives, for high complexity solutions and single drives, for single motor management and lower complexity. Single drive products are divided to low power 45 – 710 kW and high power, up to 2800 kW products. For lower power needs ACS880 micro drives are available, starting from 0,1kW. Regarding voltage ratings low voltage drives are available with 400V, 500V and 690V ratings. Regarding naming, ACS880-07 stands for cabinet built common purpose singe drive and ACS880-01 is inverter module, which is used in cabinet built drive. Low power cabinet built single drives are available in frame sizes R6 to R11. From ACS880-01 inverter modules point of view R6 to R8 modules can utilize universal design for retrofitting due to similar module dimensions, same applies to R10 to R11 modules. Due to that, R9 module requires specific design derived from its physical dimensions (Appendix 1) [5].

The reason why ACS880-01 R9 module retrofit is primarily needed, is to cover all products in ACS880-01 low power single drives product family for retrofitting. Retrofit designs for ACS880-01 R6-R8 and R10-R11 are already existing. The ACS604 power ranges that can be replaced by ACS880-01 R9 modules are given in table 1.

Table 1. ACS600 replacement coverage of ACS880 [6]; [7]

New ACS880 series	Old ACS600 series
ACS880-01-363A-3 (R9)	ACx 604/607-0260-3 (R9) ACx 604/607-0320-3 (R9)
ACS880-01-430A-3 (R9)	ACx 604/6x7-0400-3 (2xR8)
ACS880-01-361A-5 (R9)	ACx 604/607-0320-5 (R9)
ACS880-01-414A-5 (R9)	ACx 604/607-0400-5 (R9)
ACS880-01-210A-7 (R9)	ACx 604/607-0210-6 (R8)
ACS880-01-271A-7 (R9)	ACx 604/607-0260-6 (R8)

But the replacement table (table 1), does not define finite retrofitting capability of new R9 retrofit design. The developed product can replace other custom solutions or even competitors' industrial drives setups, as long as it fits the enclosure for safe operation. In this case, the parameters that have to be met are motor nominal current I_N and nominal voltage U_N. If the motor and drive are not of the same size, the following operation limits
of the drive control program have to be considered:

• motor nominal voltage range ${}^{1}/_{6} \dots 2 * U_N$

• motor nominal current range ${}^{1}/_{6} \dots 2 * I_N$ of the drive in DTC control and $0 \dots 2 * I_N$

in scalar control. The control mode is selected by a drive parameter [1]. Depending on customer needs, requirements and motor setups, different range of ACS604 or other inverter modules can be replaced with new ACS880-01 R9 modules.

To define the initially required components for retrofit design, ABB configuration tool ADG2 for standard ACS880 products generation is used to generate part list and electrical circuit diagrams (Figure 5). For this design purpose, the highest power rating R9 module and full options of mechanically significant components configuration is used, to ensure that complementing parts are rather over sized for component capacity, not under. Final components choice is done in design development phase with collaboration of electrical engineer.

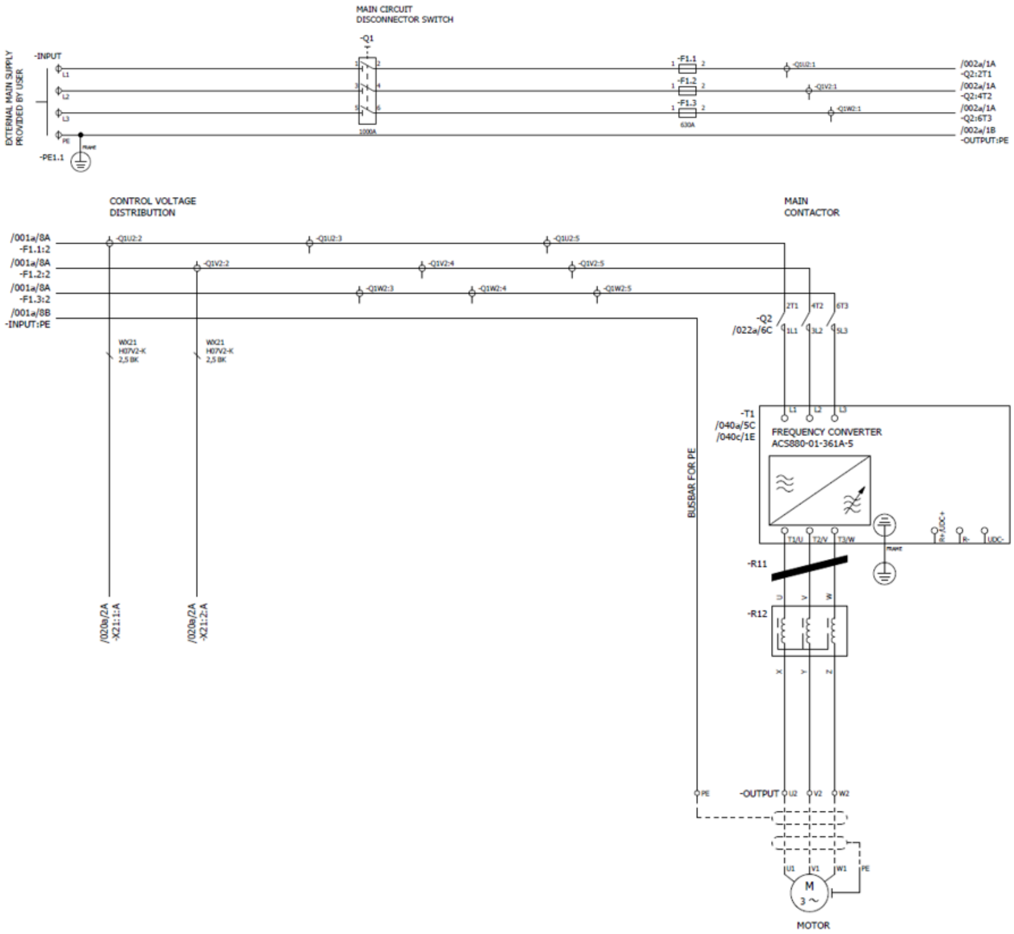


Figure 5. ACS880-07-0361A-5+E205+E208+F250 Main electrical circuit diagram generated with ADG2 configurator (Appendix 2)

Based on circuit diagram and part list, initial selection of components that influence mechanical design, can be listed.

Main circuit disconnector switch (Q1) (Figure 6) The switch-disconnector switches the main voltage to the drive on and off.

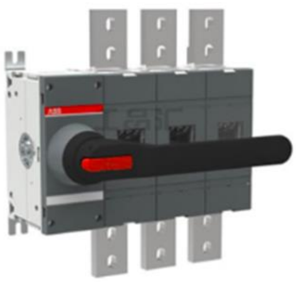


Figure 6. OT1000E12 Main disconnector switch [8]

Fuses (F1.1/F1.2/F1.3) (Figure 7) Square body Bussmann high speed fuses

Figure 7. Bussmann 170M type fuse [9]

Main contactor (Q2) (Figure 8) option code +F250 is magnetically operated AC switching device, used in combination with safety options. For voltage ratings 400V and 500V AF370 type contactor is used, for 690V AF265.

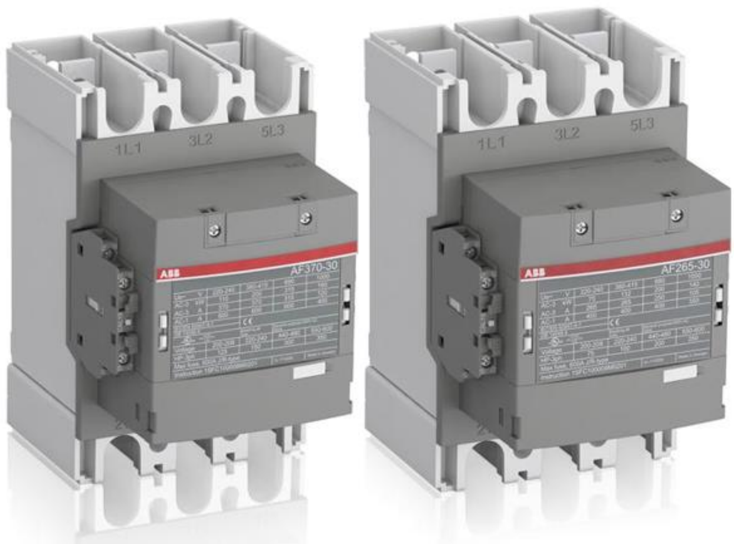


Figure 8. AF370-30-22-13 (400V; 500V) - 3AXD50000025711; AF265-30-22-13 (690V) - 3AUA0000145463 [10]

Frequency converter (T1) (Figure 9) previously mentioned ACS880-01 series inverter module. Most cabinet built drive functionality is packed into the frequency converter which converts supplied AC current from the grid to direct current, modulates it and coverts it back to AC with desired frequency. Other components around frequency converter have complimentary or supportive functions. ACS880-01 R1-R9 frequency converters can also be wall mounted and operate independently.

Figure 9. ACS880-01 R9 frequency converter industrial drive [5]

Common mode filter (R11) (Figure 10) option code +E208. The common mode filter contains ferrite rings mounted around the motor output of the drive. The filter protects the motor bearings by reducing the bearing currents [1].

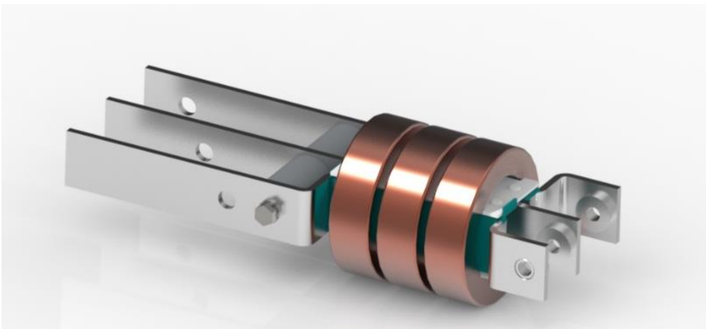


Figure 10. Common mode filter with ferrite rings

Du/Dt filter (R12) (Figure 11) option code +E205. The du/dt filter protects the motor insulating system by reducing the voltage rise speed at the motor terminals. The filter also protects the motor bearings by reducing the bearing currents [1].

Figure 11. FOCH type DU/DT Filter

Output filters, in general, are used because the drive employs modern IGBT inverter technology. Regardless of frequency, the drive output comprises pulses of approximately the drive DC bus voltage with a very short rise time. The pulse voltage can almost double at the motor terminals, depending on the attenuation and reflection properties of the motor cable and the terminals. This can cause additional stress on the motor and motor cable insulation.

Modern variable speed drives with their fast rising voltage pulses and high switching frequencies can generate current pulses that flow through the motor bearings, which can gradually erode the bearing races and rolling elements [11].

Another aim of the new design is to offer a more complete product compared to existing retrofit designs and implement improvements that have come from previous projects and customer cases. Since the standard ACS880 product is taken as the basis for retrofit electrical design (Figure 12), existing mechanical designs and parts should also be used for efficiency, because there is already stock of materials for standard product and sourcing higher volume of parts reduces price per each piece.

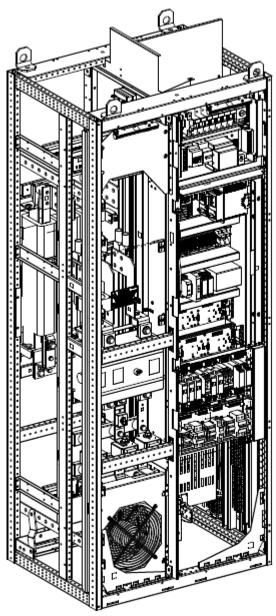


Figure 12. Standard ACS880-07-R9 cabinet assembly with all options, no covers and no shrouds 3AUA0000093714

Existing retrofit designs are mostly for multi drives but also single drives. For single drives two different approaches are used for retrofitting. First is built-in solution, which is same as in multi drives, where components, smaller sub units and assembly plates are prepared in production and then assembled on site into the old frame. For example ACS607 with double inverters, whether two times R8 or R9 inverter modules. Which is three times 700 mm wide cabinet setup (Figure 13).

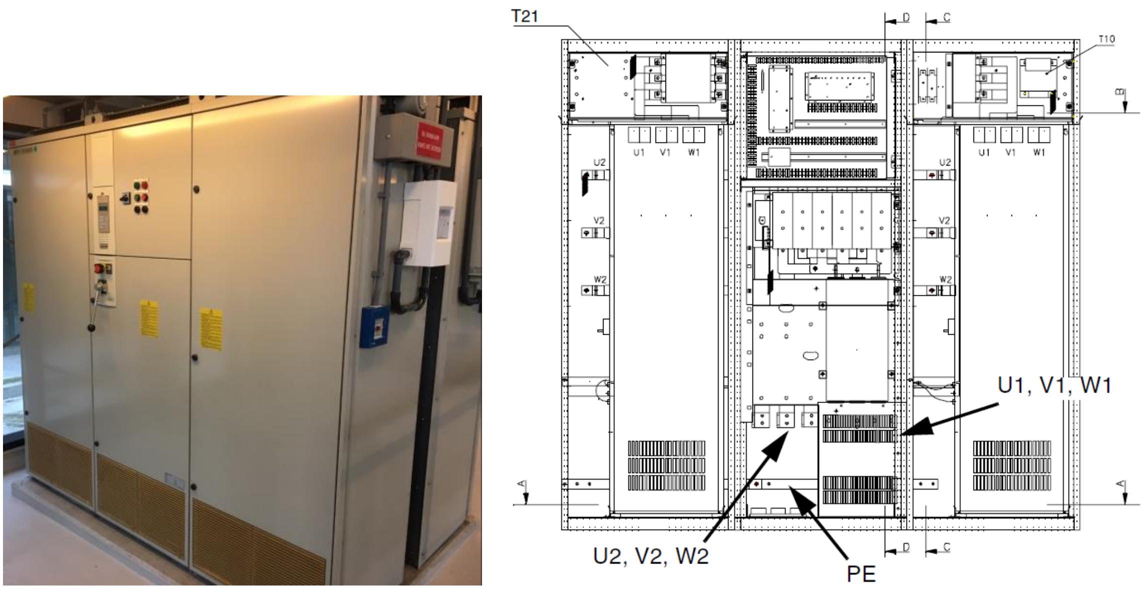


Figure 13. ACS607-400-3 cabinet drive on client site and internal layout with 2xR8 inverter modules [12]

For this setup, a built-in retrofit design is offered, where double ACS604 R8 or R9 inverter modules are replaced with single ACS880-01 R11 module (Figure 14). The R11 retrofit design also utilizes limited modularity of frames. In left section du/dt filter and in right section inverter module is built into frame. Middle section for connecting and distributing functionalities is assembled on site using pre-assembled component plates.

Figure 14. ACS880R-07F11-650A-3, built-in ACS880-01 R11 retrofit

The other, more complete and desired retrofitting solution is a frame solution, which is completely assembled in production and inserted to old enclosure on site (Figure 15). This way, costly technician work hours in commissioning are minimised and drive operational down time for the client is reduced. Such retrofit designs are utilized for R6 to R8 and R10 ACS880-01 modules, to replace ACS607 R9 cabinet drives (Figure 16). The same design philosophy will be implemented for the newly developed R9 retrofit design.

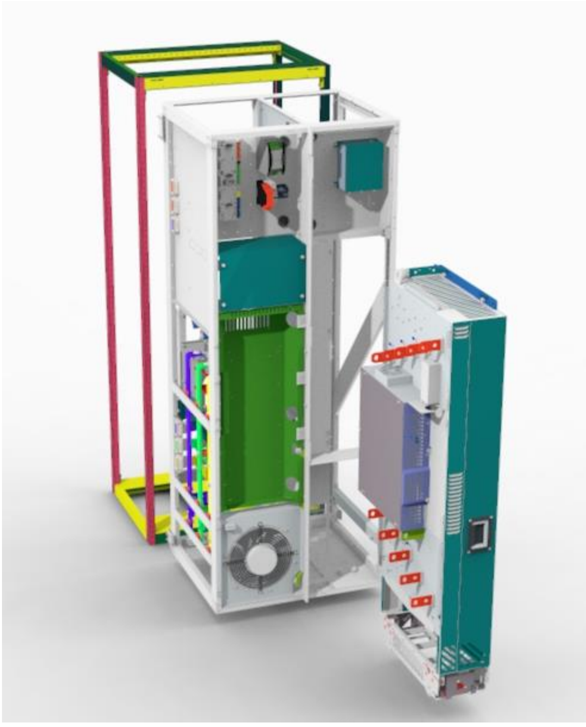


Figure 15. ACS880R-07F6-505A-3 frame built R10 retrofit design

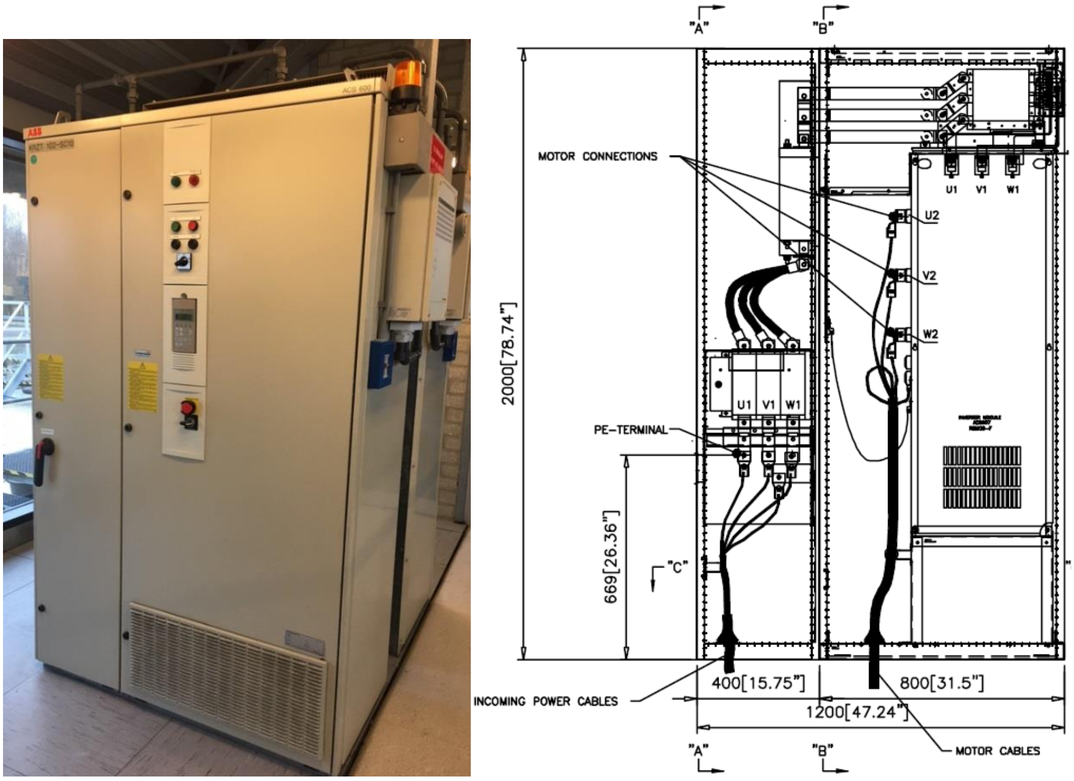


Figure 15. ACS607-320-3 cabinet drive on client site and internal layout with R9 inverter module

For the ease of setting up and designing the frame solution, all components should be fitted into one section of the cabinet. Another critical task for the new design, apart from updating components for the main circuit, is to enable the installation and use of lot of other electrical components as options. Mostly all these components can be mounted on din rails but have to have dedicated places on side plates or other assembly plates.

1.3 Design supplements from site commissioning

Previous retrofit designs have been lacking passive safety features. Such as simple enclosures for covering live connections which can be hazardous in case of human contact. Despite having simple design and purpose, protective shrouds and plates design have to be taken into consideration from the very beginning of new design. The safety of electrical equipment enclosures is regulated by international standard IEC 60204-1:2016. Live parts shall be located inside enclosures that provide protection against contact with live parts of at least IP2X. All live parts, (including those on the inside of doors) that are likely to be touched when resetting or adjusting devices intended for such operations while the equipment is still connected, shall be protected against contact to at least IP2X. Other live parts on the inside of doors shall be protected against unintentional direct contact to at least IP1X [13]. Example case of R11 cabinet drive where behind the doors there were designed cover plates to ensure IP2X protection class (Figure 17). As some signal cable terminals were behind these plates during commissioning, these protective plates were removed to access the terminal blocks, which caused free access to live parts.

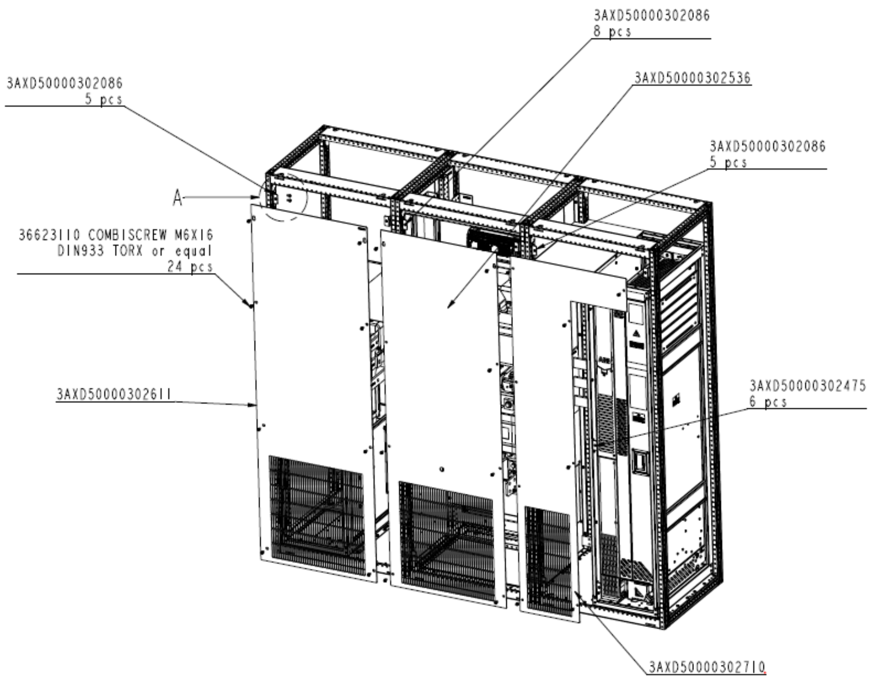


Figure 17. protection plates to ensure IP2X class when doors are opened

Resolution for that was to design extra shielding for live parts to ensure IP1X protection class (Figure 18).

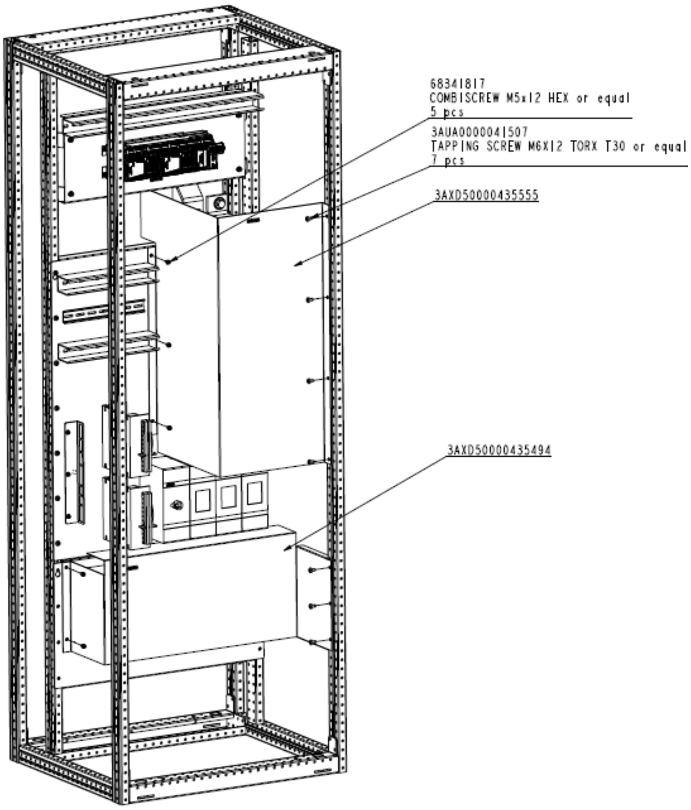


Figure 18. Additional protective shrouds to ensure IPX1 class

Implementing components and functions that were not initially considered in a design is challenging. That is why it is extremely important to consider a broad range of requirements and options from the beginning of creating a new design. Such an example is the modified section of the same industrial drive cabinet, where the common bottom entry cable setup was redesigned to be suitable for a top entry configuration (Figure 19). The initial design requirement was to separate the main electrical circuit from components that require access during drive operation. For that purpose, adequate space was planned to fit assembly plates and protective mesh inside the doors and before live parts. The assembly plates give easy access and flexibility to position client specific electronics and terminals while being safely separated from live parts.

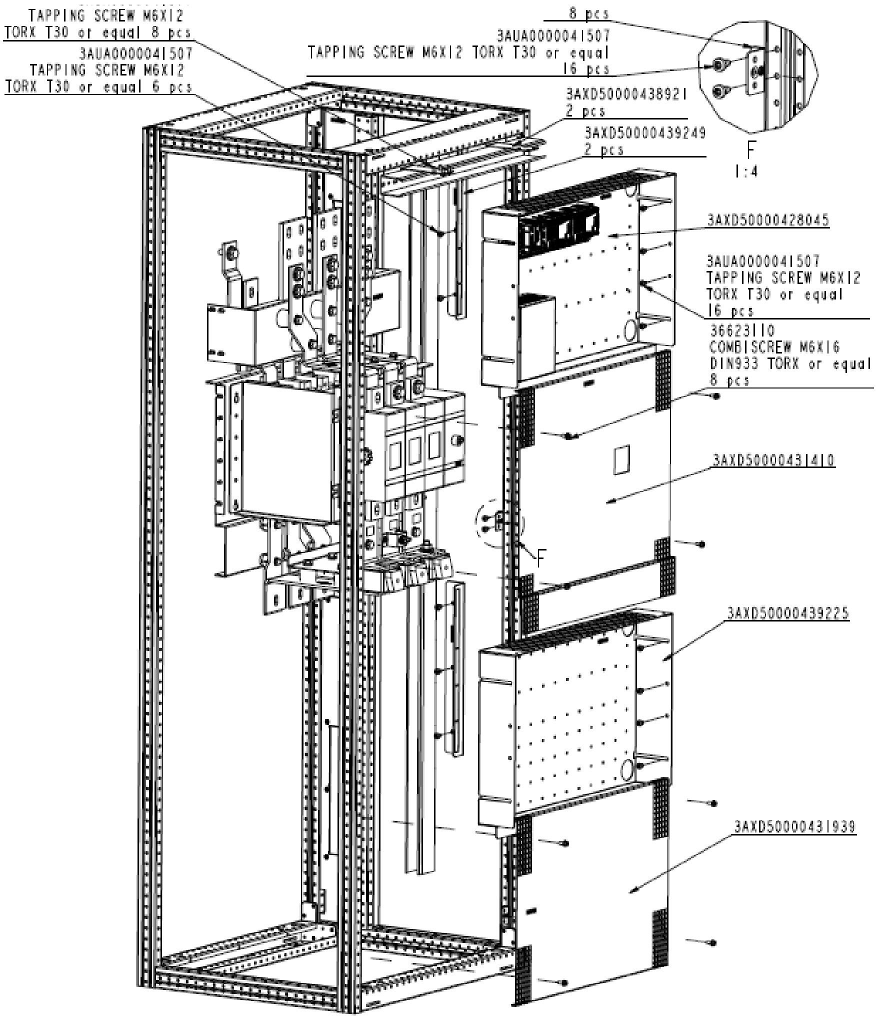


Figure 19. design for top entry, main circuit components are behind component plates

2 ACS880-01 R9 RETROFIT DESIGN DEVELOPMENT

The backbone and initial envelope of design are defined by the frame. Therefore, in order to start generating concept the first step would be to establish frame design. Once the frame design is defined, components layout can be considered. Previously listed main circuit electrical components have highest impact on how and where components are laid out and connected to one another.

2.1 Frame

For frame creation, designs that are currently in use are utilized as often as possible. The existing standard ACS880 design can be and is reasonable to utilize for this design. For 800 mm wide ACS607 retrofit, the latest generation ACS880 700 mm wide frame and components are used.

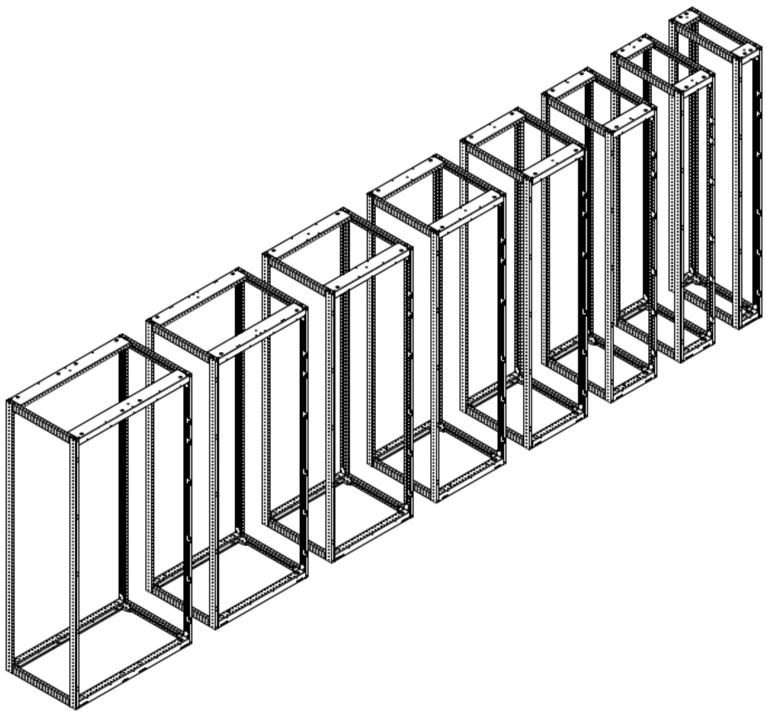


Figure 20. ACS880 frames line-up 3AUA0000108908

To make the standard frame fit in 800mm wide enclosure, 100 mm narrower base frame of ACS880 is taken as basis. Height is reduced by 125 mm and depth by 50 mm. Which means modifying corner and transverse beams lengths. Middle beams are taken from standard ACS880 R9 design and shortened to fit L-brackets for mounting. Middle beams are positioned so that right side would be identical width wise to standard ACS880 R9 design. This means the same mounting beams and rails for inverter module attachment can be used.

Figure 21. Rendering of R9 retrofit frame

For cable connections coming from the bottom of the cabinet, a special frame design feature is required. The back left side of the frame has to be open in order to slide the frame into the cabinet without removing supply or motor cables. As these are fixed to the floor plate and due to thickness, can't be bent. To meet this requirement, the back beam is modified, a corner bracket is made and an upper horizontal support beam is designed. New retrofit frame for 800 mm wide cabinet (Figure 21) will be taken as a basis for future retrofit frame solutions.

2.2 Industrial drive cabinet main circuit connections

In order to distribute electrical current and voltage between electrical components in the main circuit, a system has to be developed. For transferring electric current between components, bus bars or cables made from highly conductive materials, such as aluminium or copper alloys are used. Initial parameters of distributed electrical current for conductive elements dimensioning have to be set:

- Highest nominal current rating for ACS880-01 R9 module 430 A for 400 V voltage rating
- Highest voltage rating available for ACS880-01 R9 is 690 V

- In main circuit only alternating current is distributed
- Highest output frequency without derating from nominal current is 120 Hz, maximum output frequency from ACS880-01 R9 is 500 Hz, at derated current of 236 A [5]

Power cables provide greater flexibility then bus bars, though at same thermal efficiency, cables take a lot more room. Secondly, from a manufacturing stand point pre-fabricated busbars are easier to install than producing different length cables for assembly. Whereas the cost of bus bars is higher, the ease of installation, higher efficiency and reliability pays back. Therefore only bus bars are used for main circuit current distribution. Bus bars can be made whether from sheet or bar material. Manufacturing from bar is preferred due to lower cost, but for special design bus bars can be made up to 5 mm thick sheet material.

Bus bar dimensioning - Material choice

When choosing material for connecting elements, primary parameter is conductivity. Conductivity is defined by the material inner resistance. The better conductive material, the lower resistance. For conductivity measurement is electrical resistivity, the dimension is ohms per meter $\rho = {}^{\Omega}/_{m}$. Poor conductivity causes unwanted heat generation, but can be compensated by increasing the cross section of conducting element. Common materials for making conductive elements in comparison are aluminium (1350) with resistance of $28{,}3\, {}^{n\Omega}/_{mm}$ and copper (C101) $17{,}2\, {}^{n\Omega}/_{mm}$ [14]. Mechanical strength properties are not heavily weighted in this material choice due to the condition that electrical connections should not bear any significant structural loads. When mechanical strength is not the main requirement, the copper thickness is defined by the input and output terminal connectors. As illustrated by figure 22, given the maximum current density $J = {}^{A}/_{mm^2}$ and the length l available, the thickness t is calculated to keep the current density within its specification [15].

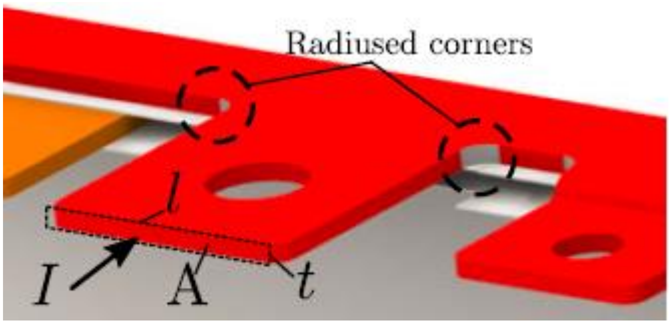


Figure 22. Bus bar thickness design considerations based on maximum current density $J = {}^{A}/_{mm^2}$ [15].

The rule of thumb of current density for dimensioning copper bus bars is $2\, {}^{A}/_{mm^2}$ [16].

Due to different electrical components terminals length and sheet material production constraints, $2\ {}^{A}/_{mm^2}$ current density requirement cannot always be followed. Dedicated thermal simulations are required if the current density requirement is not fulfilled.

The current-carrying capacity of a busbar is limited by the maximum acceptable working temperature of the system. Upper temperature limits were chosen to limit the potential for surface oxidation of conductor materials and to reduce the mechanical stress at joints due to cyclic temperature variations. A nominal rise up to 60°C above an ambient of 40°C is allowed by EN 60439-1:1994 provided that suitable precautions, such as plating, are taken. [14].

Since space is a primary constraint of the design from the beginning, lower resistance material is preferred to utilize smaller cross section bus bars design. Taking in account all previous aspects, copper is the chosen material for connecting bus bars. Regarding company agreements with suppliers CW008A - EN 13601:2013 standard copper material is used for bus bars manufacturing from bar material and ISO 1337 for sheet material.

Minimal cross-section (A) for copper bus bars that can be used without additional analysis is $215\ mm^2$ (2.1)

$$A = \frac{I_{nom}}{J} = \frac{430}{2} = 215\ mm^2 \tag{2.1}$$

Insulation The selection of the electrical insulation is driven by the operating voltage, the operating temperature, and the environment in which it has to function. The operating voltage dictates the required dielectric strength of the insulation which in turn depends

on the material used [15]. Bus bar connections can be designed in a way that these are fixed securely and do not have any slack when assembled. Insulation would not be needed if creepage and clearance requirements are assured. According to IEC standard protection by insulation of live parts: live parts protected by insulation shall be completely covered with insulation that can only be removed by destruction. Such insulation shall be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which it can be subjected under normal operating conditions [13]. In this case it is not applicable, because if bus bars are insulated, the connections between bus bars isn’t. Therefore, protection should be provided by enclosure in which connections are assembled, already mentioned in section 1.3.

The clearance requirement is defined by voltage and environment. Insufficient clearance could cause shortages in electrical circuits. The creepage distance, which can cause short circuits, should be considered as well and is dictated by the exterior material of the insulation film (bare film or coated with resin) and the environment it is in. If the surface of the bus bar (between two potentials) has moisture or has dirt or debris on it, the creepage distance may be significantly reduced and the current can track along the surface of the insulation easier to create a short. The severity of the contamination is typically defined by the pollution degree rating [15]. For the purpose of evaluating creepage distances and clearances, the following four degrees of pollution in the micro-environment are established:

- Pollution degree 1

  No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
- Pollution degree 2

  Only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation is to be expected.
- Pollution degree 3

  Conductive pollution occurs or dry non-conductive pollution occurs which becomes conductive due to condensation which is to be expected.
- Pollution degree 4

  Continuous conductivity occurs due to conductive dust, rain or other wet conditions. [17]

In given case pollution degree 3 should be taken account, because this is distinctive for industrial environment. Since highest voltage for given design will be 690V AC current, according standard sufficient creepage distance for material group 2 and pollution degree 3 is 11 mm (Table 2) and clearance for inhomogeneous field is 1,5 mm (Table 3).

Table 2. Creepage distances [18]

Column 1	2	3	4	5	6	7	8	9	10	11	12
Working voltage (r.m.s.)	PWBs [a]		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
				Insulating material group				Insulating material group			
(V)	b	c	b	I	II	IIIa	IIIb	I	II	IIIa	IIIb
≤ 2	0,025	0,04	0,056	0,35	0,35	0,35		0,87	0,87	0,87	
5	0,025	0,04	0,065	0,37	0,37	0,37		0,92	0,92	0,92	
10	0,025	0,04	0,08	0,40	0,40	0,40		1,0	1,0	1,0	
25	0,025	0,04	0,125	0,50	0,50	0,50		1,25	1,25	1,25	
32	0,025	0,04	0,14	0,53	0,53	0,53		1,3	1,3	1,3	
40	0,025	0,04	0,16	0,56	0,80	1,1		1,4	1,6	1,8	
50	0,025	0,04	0,18	0,60	0,85	1,20		1,5	1,7	1,9	
63	0,04	0,063	0,20	0,63	0,90	1,25		1,6	1,8	2,0	
80	0,063	0,10	0,22	0,67	0,95	1,3		1,7	1,9	2,1	
100	0,10	0,16	0,25	0,71	1,0	1,4		1,8	2,0	2,2	
125	0,16	0,25	0,28	0,75	1,05	1,5		1,9	2,1	2,4	
160	0,25	0,40	0,32	0,80	1,1	1,6		2,0	2,2	2,5	
200	0,40	0,63	0,42	1,0	1,4	2,0		2,5	2,8	3,2	
250	0,56	1,0	0,56	1,25	1,8	2,5		3,2	3,6	4,0	
320	0,75	1,6	0,75	1,6	2,2	3,2		4,0	4,5	5,0	
400	1,0	2,0	1,0	2,0	2,8	4,0		5,0	5,6	6,3	
500	1,3	2,5	1,3	2,5	3,6	5,0		6,3	7,1	8,0	
630	1,8	3,2	1,8	3,2	4,5	6,3		8,0	9,0	10,0	
800	2,4	4,0	2,4	4,0	5,6	8,0		10,0	11	12,5	e
1 000	3,2	5,0	3,2	5,0	7,1	10,0		12,5	14	16	

Table 3. clearance distances [18]

Column 1	2	3	4	5	6
Impulse voltage (Table 7, Table 8, 4.3.6.3)	*Temporary overvoltage* (crest value) for determining insulation between surroundings and circuits or *Working voltage* (recurring peak) for determining *functional insulation*	*Working voltage* (recurring peak) for determining insulation between surroundings and circuits	Minimum clearance mm		
			Pollution degree		
(V)	(V)	(V)	1	2	3
N/A	≤ 110	≤ 71	0,01	0,20 [a]	0,80
N/A	225	141	0,01	0,20	0,80
330	340	212	0,01	0,20	0,80
500	530	330	0,04	0,20	0,80
800	700	440	0,10	0,20	0,80
1 500	960	600	0,50	0,50	0,80
2 500	1 600	1 000	1,5		

Larger clearances may be required due to mechanical influences such as vibration or applied forces, which why company inner requirements for clearance and creepage are 14 mm and 21,6 mm for up to 1000 V AC or DC current (Table 3).

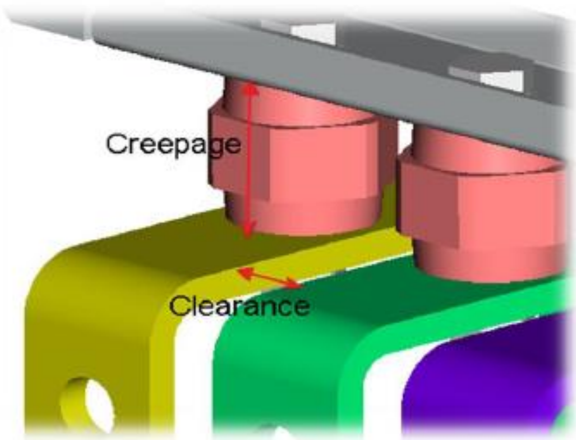


Figure 23. Most common view of creepage and clearance in drive cabinets

Table 4. ABB standard for clearance and creepage [16]

Voltage (V) AC or DC **	Clearance (mm) Between uninsulated live parts or uninsulated grounded part	Creepage (mm) Between uninsulated live parts or uninsulated grounded part	Shortest distance (or clearance & creepage for 601-1000 V) (mm) Between uninsulated live part and metal enclosure wall
51-150	3.2	6.4	12.7
151-300	6.4	9.5	12.7
301-600	9.5	12.7	12.7
601-1000	14.0	21.6	Clearance 20.3, Creepage 25.4
1001-1500	17.8	30.5	Clearance 30.5, Creepage 41.9

** Voltage refers equipment's input voltage AC r.m.s. or DC, not the working voltage over the insulation.

Bus bars are manufactured without insulation for new design development, because required IP protection class, clearance and creepage requirements are followed.

Plating choice

Main purpose of bus bar plating is to improve corrosion resistance and connections conductivity. Bus bars manufacturing typically uses CW008A (C103) type copper, which is known as 'oxygen-free high conductivity copper' and is normally produced by melting and casting under a protective atmosphere. The result is a high purity product containing 99.95% copper [14]. To maintain such good properties oxidation of the material should be prevented, which means some kind of plating should be used. Secondly, from bus bar to bus bar or bus bar to component connections, when one piece of metal is applied to another, contact is not made over entire contact area. Two metal components are in contact only at certain number of points called "elementary contacts". Total area of elementary contacts in cross section is effective contact area (Figure 24) [19].

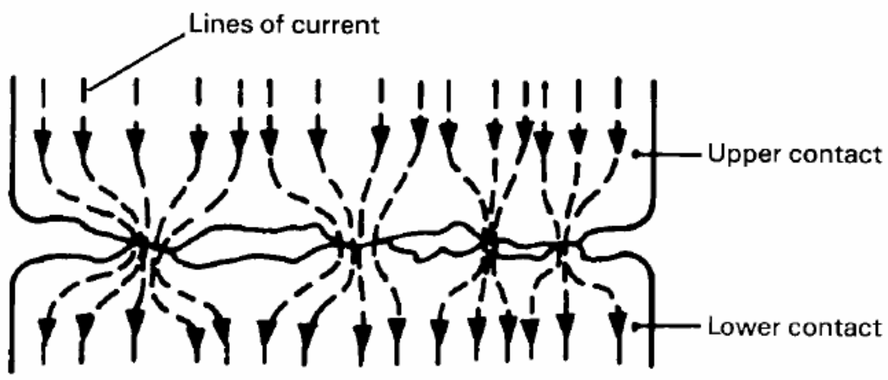


Figure 24. Cross section of contact presenting effective contact areas [19]

To ensure better contact by larger effective contact area, surface quality of connections can be improved by plating. For plating, tin is used, as it is more cost effective than silver to use and has lower contact resistivity compared to bare copper which oxidizes over time (Table 5).

Table 5. Typical values of tunnel resistivity [19]

Metal	State	$\sigma_0 = \Omega m^2$
Copper	New Oxidised Tinned	$2 * 10^{-12}\ to\ 3 * 10^{-11}$ 10^{-10} $10^{-12}\ to\ 4 * 10^{-11}$
Silver		$4{,}6 * 10^{-13}\ to\ 4 * 10^{-12}$
Aluminium		$7 * 10^{-11}\ to\ 10^{-9}$

For bus bars coating ISO 2093 CU/SN 8 tin is used, according company sourcing policies. Material and plating choice is universal for all main circuit connecting bus bars, first to reduce sourcing and manufacturing and secondly attaching metal surfaces with different properties might cause unpredictable chemical reactions under electrical and thermal stress and load.

Connections

Possibilities for bus bars connections are welding, tongue mounting, clamping and more traditional bolt joint. For different electrical components such as contactor and switch the designated connecting method is only bolt joints, which are pre-defined by mounting holes diameter, given by manufacturer. Bolt joints are also cheap to make, need no maintenance and give desired effective contact surface if tightened according specified tightening torque values. Bolt joints are dimensioned according to the nominal current value. For given design, mostly M12 connections are required (Table 6). If connections require a smaller fastener size, voltage drop and temperature rise has to be taken into account and considered when conducting thermal simulation. Tightening torque for M12 bolt joint is 54 Nm [Table 4], which corresponds to company standard (Table 7).

Table 6. Bus bars bolt joints [16]

Bolt size	Current (A)	Torque (Nm)
M3 (8.8)		0,5
M4 (8.8)		1-2
M5 (8.8)	63	3-4
M6 (8.8)	100	6-9
M8 (8.8)	200	15-22
M10 (8.8)	400	30-44
M12 (8.8)	800	50-75
M16 (8.8)	1500	-

Table 7. Nominal torque values for bus bars bolt joints [20]

Diameter of Bolts			Torque		
in.	mm#	Material	N-m	lb-ft	lb_f-in.
1/4	(6.3)	SB	9	7	80
5/16	(7.9)	SB	20	15	180
3/8	(9.5)	SB	27	20	240
1/2	(12.7)	SB	54	40	480
5/8	(15.9)	SB	75	55	660
3/4	(19.1)	SB	118	87	1050
3/8	(9.5)	LA	19	14	168
1/2	(12.7)	LA	34	25	300
5/8	(15.9)	LA	54	40	480
3/4	(19.1)	LA	73	54	650

Other general acknowledgements of bus bar design

When dimensioning two or more parallel connections such as three phase AC connection, bus bar positioning symmetry relative to electrical components connections have to be considered. Sharp corners and bends can cause eddy currents and consequently voltage drops, which results in losses and heat generation [15]. To prevent such occurrences, it is suggested to use a radius, approximately equal to material thickness, in corners and bends (Figure 25).

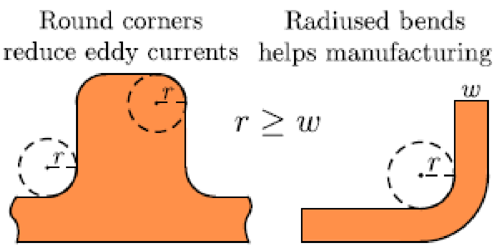


Figure 25. Suggested corner and bend radiuses to prevent excessive heat generation [15]

From a design versus manufacturing point of view, although the general shape of a bus bar is dictated by component layout and other routing possibilities, the manufacturability and cost efficiency have to be taken into consideration. This means making designs that require less manufacturing operations, as each individual manufacturing operation have their own associated costs, such as: general run-time cost, setup cost and unique operations which need special tools [15]. When designing bus bars manufacturing process specific accommodations have to be made, for example, inside bends have to have bend radius at least material thickness, outside bends have to have inside radius at least width of raw material bar [16]. Bearing in mind all previous requirements for bus bars design and dimensioning, all of these cannot be applied to the final design due to different constraints. Therefore, a thermal simulation using FEM will be carried out.

2.3 Process sequence of main circuit layout design

To get initial picture of which parts the assembly should include and how much space each will occupy, the initial lay out concept was created The numbering represents the order which current is distributed between different components (Figure 26). Primary and most crucial component of the design is the inverter module (4) which takes the most space and is the central element of whole design. The frame is separated into two sections, the right section consists of the components generating the most heat emission, which requires forced air ventilation. The left side contains cabling terminals for incoming supply cables (1) and outgoing motor cables (7). Other components are the ones used in ACS880-07 R9 industrial drive cabinet, where main switch (2), contactor (3) and CMF (4) models are selected according to the highest power rating R9 module's nominal current value. The du/dt filter (6) is, in this case, over dimensioned to reduce variations of filters needed for different power ratings of R9 modules.

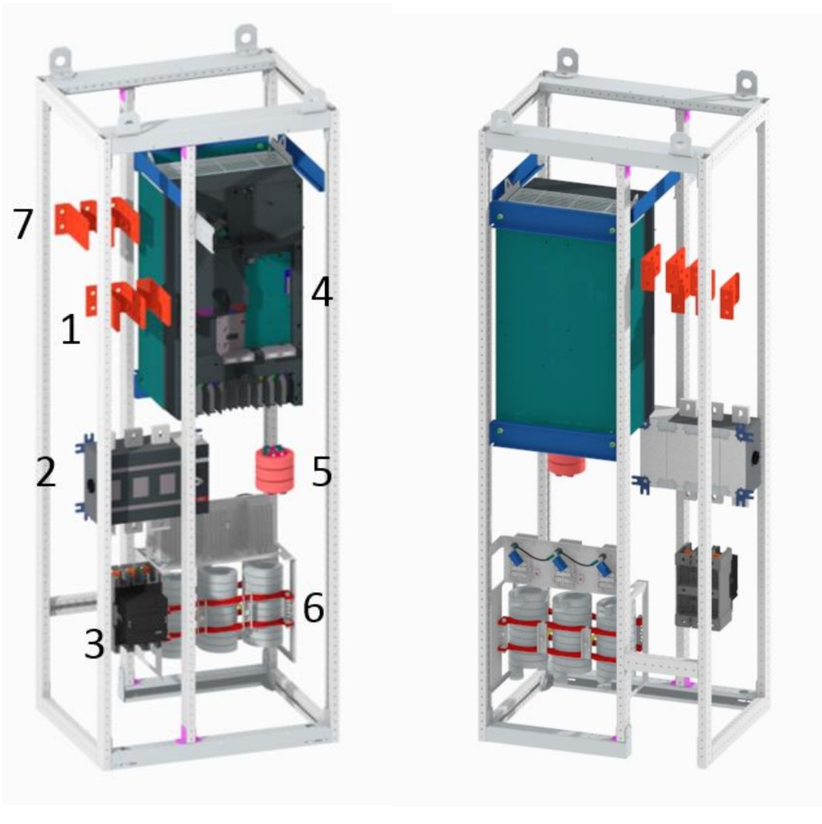
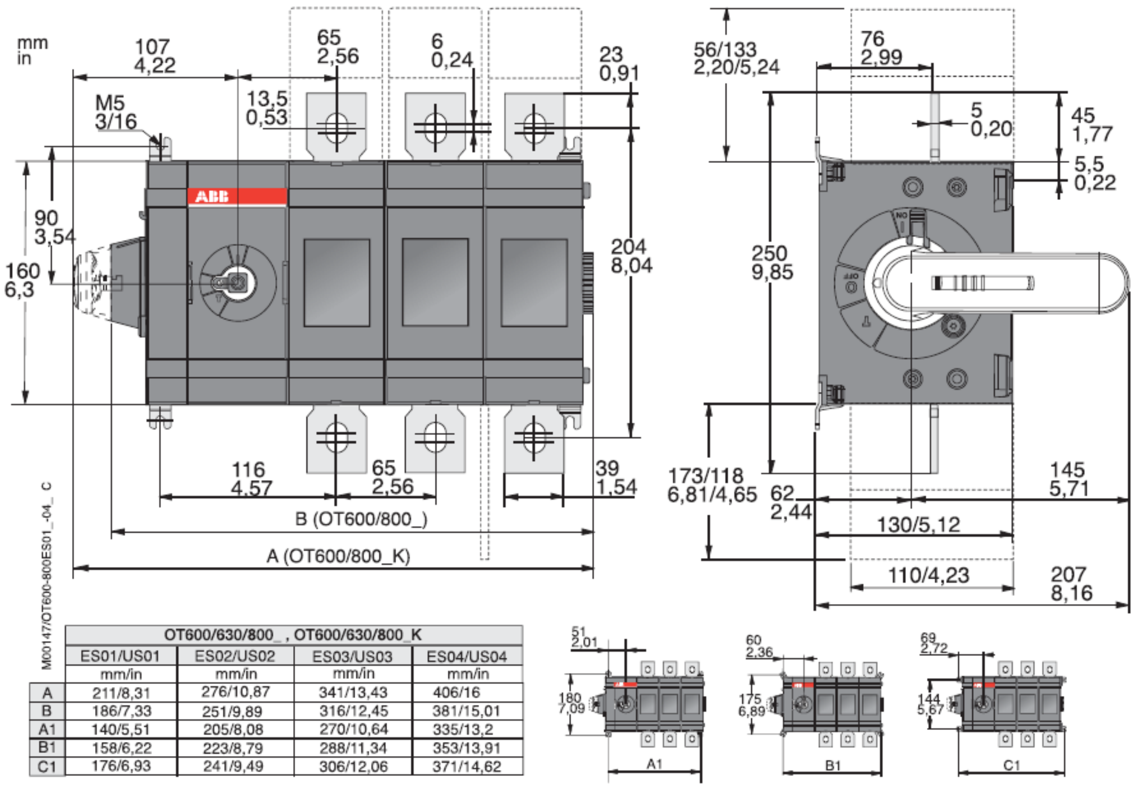


Figure 26. Initial layout of components fitted into new frame

2.3.1 Cabinet input sub-assembly

The initial layout shows that in order to fit components into the two sections, the main switch has to be placed in the right side section, which consumes a lot of valuable space especially because fuses also have to be included for this kind of switch setup. Second concern would be restricted airflow to cool other components. Therefore, alternative switch design is used, which can be fitted into cabinet sideways and is operated from the side not front (Figure 27).



	OT600/630/800_ , OT600/630/800_K			
	ES01/US01	ES02/US02	ES03/US03	ES04/US04
	mm/in	mm/in	mm/in	mm/in
A	211/8,31	276/10,87	341/13,43	406/16
B	186/7,33	251/9,89	316/12,45	381/15,01
A1	140/5,51	205/8,08	270/10,64	335/13,2
B1	158/6,22	223/8,79	288/11,34	353/13,91
C1	176/6,93	241/9,49	306/12,06	371/14,62

Figure 27. Side operated main switch OT 800ES [8]

Due to the switch choice, given OT 800ES needs external fuses, which are positioned after switch and have to be accessible in order to be replaced if needed. The design will be executed in stages which are represented as sub-assemblies, first of which is input subassembly (Figure 28).

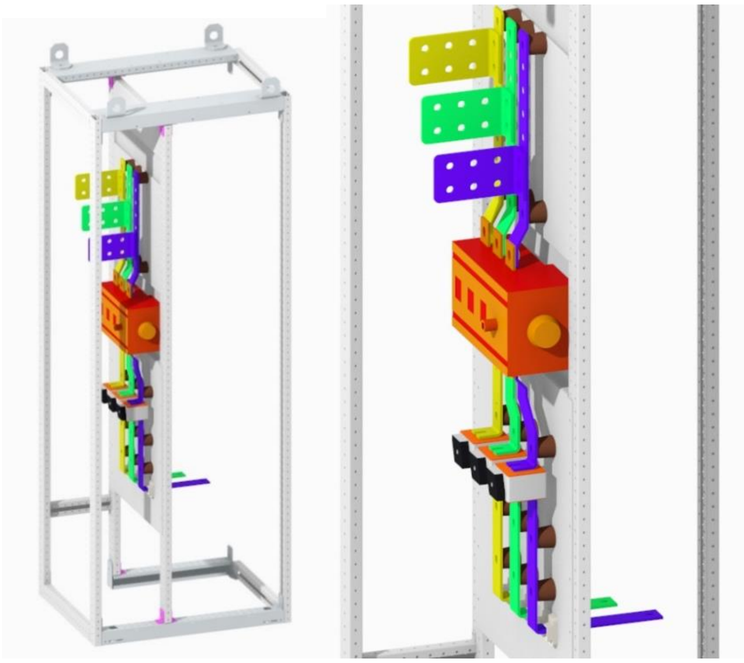


Figure 28. Input subassembly, including cable connections, main switch and fuses

2.3.2 Inverter module sub-assembly

For attaching ACS880-01 R9 module to the retrofit frame, rails from standard ACS880-07 design are used. Module is bolted to mounting beams at the back of the frame, which are also used in standard ACS880-07. To insert the module, special rails are used which allow to insert and remove the inverter module more easily (Figure 29). The purpose of the rail system is to increase serviceability - the module has to be replaceable with removing as few components from cabinet as possible. Mounting rails and beams are tested and approved components in standardized products, but the side plates on which these are going to be attached are newly designed parts and require strength analysis. Back beams for mounting are fixed to the retrofit frame. For this FEM analysis will be carried out. The module weighs 95 kg [5] which is distributed evenly on two rails during installation and additionally to two back beams when installed.

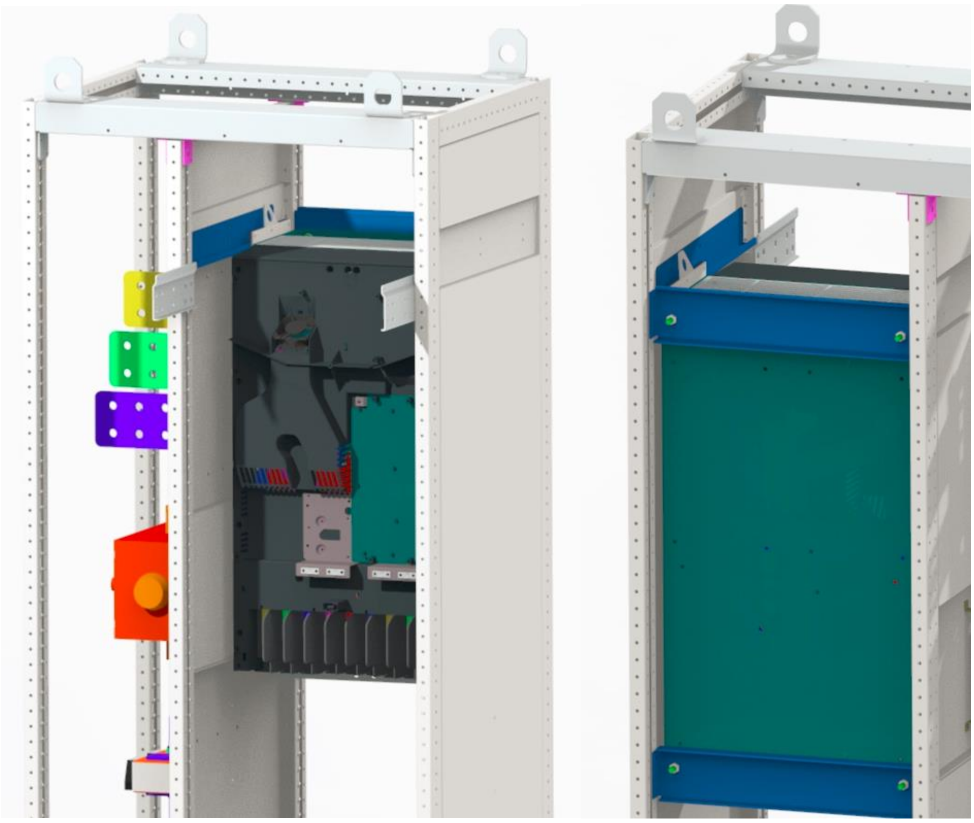


Figure 29. Inverter module subassembly

2.3.3 Module input output sub-assembly

The sub-assembly for the module input and output bus bars is the most complex sub-section of the whole design due to the bus bars clearance and cross-sectional requirements. It also incorporates components such as contactor and common mode filter (Figure 30). All bus bars are specially designed for this application, whereas the common mode filter is reengineered. In particular design serviceability is kept in mind – bus bars that directly connect to the inverter module terminals have to be easily removable, so that module can be replaced without dismantling the entire input and output sub assembly unit. Design also takes into consideration that the setup can be ordered without a contactor or CMF, so that these can be replaced with bus bars.

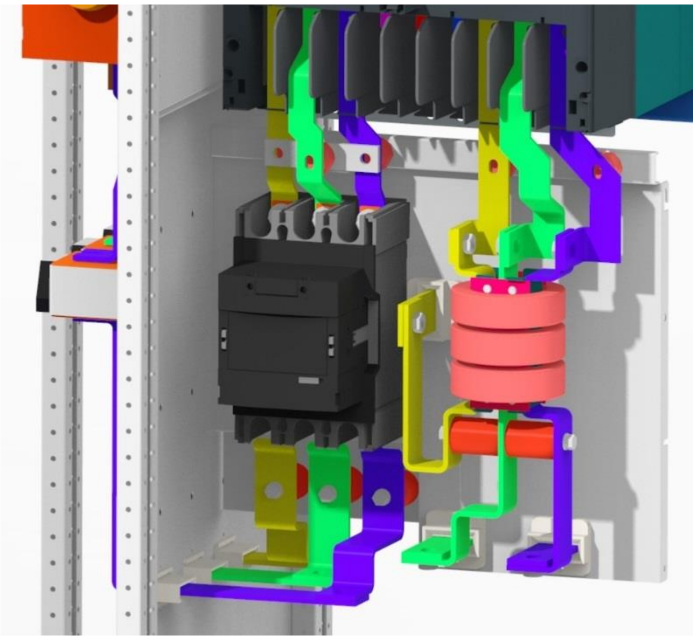


Figure 30. Module input and output sub-assembly with contactor (left) and CMF (right)

2.3.4 Du/Dt filter sub-assembly

From the initial design plan, it was proposed to use one universal du/dt filter for all R9 power ratings. Since R10 and R11 use a BOCH type filter the intention was to incorporate this into the design, but due to electrical requirements and inductivity mismatch, two different types of FOCH type du/dt filter have to be used. Due to that, filter input and output bus bars have to be engineered so that they will fit with both variations (Figure 31).

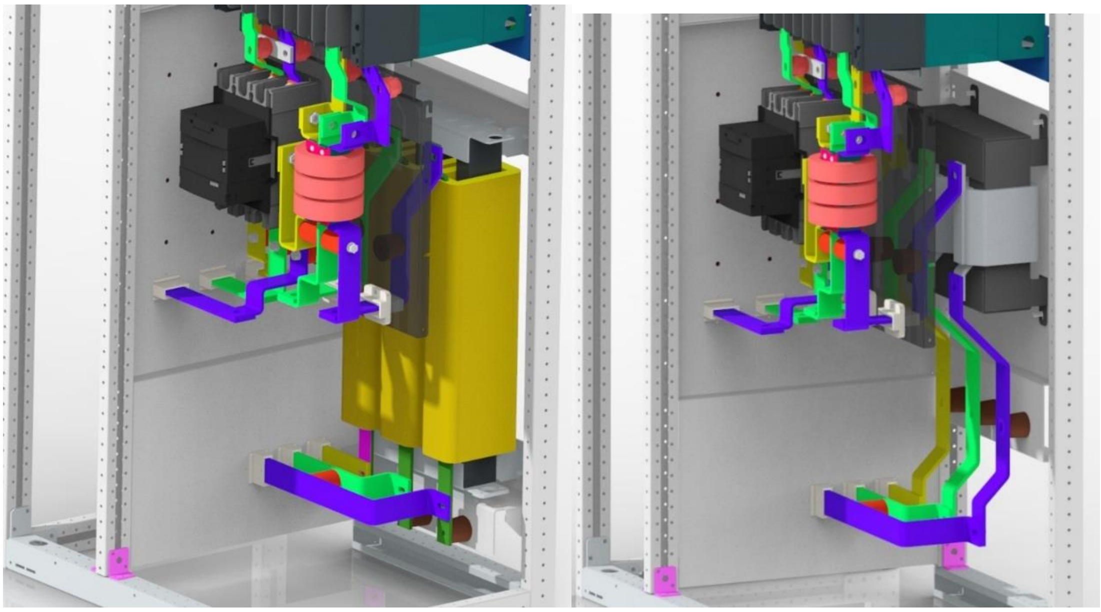


Figure 31. FOCH type Du/Dt filter variations for 400V and 500V (left) for 690V (right)

2.3.5 Output for motor connections

Motor connection terminals have been placed on one assembly plate, which can be placed at different heights (Figure 32). For bottom output, down near bottom and for top output, above main switch. Connection from du/dt output to terminals is made by cables in production.

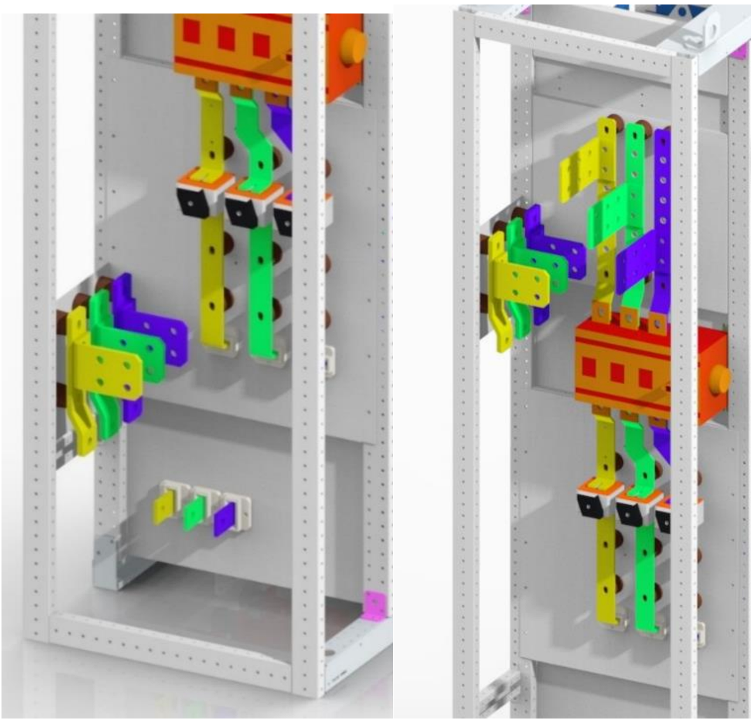


Figure 32. Output terminals for motor cables, bottom output (left) top output (right)

2.3.6 Miscellaneous additional design features

Turn frame is used for additional electrical components placement, for example supply, control unit and other safety or optional accessories. The turn frame uses components from standard ACS880-07 R9 design whereas the hinges are modified to make it fit for this retrofit design.

Fan assembly is providing improved airflow for the right side of the cabinet, where components are tightly packed and have higher heat emission like the du/dt filter and the inverter module itself.

Front covers are made of steel mesh and provide protection against contact with live parts.

Transformer will be placed after thermal analysis to most optimal place.

2.4 Module mounts stress analysis

The module weighs 95 kg [5] which is distributed on the right side and middle plates. Both of these plates are new design parts which need stress analysis in order to be sure these can bear the loads as intended. If necessary, design improvements have to be made.

Left side middle plate 3AXD50000453566

Constraints for the simulation is set to the holes in the sides of the plate. Each of the ten holes represent screw mounts to the frame. The load is defined as half of the module weight evenly distributed to six holes in top section where the guide rail is mounted. Approximately 77,7 N for each hole. For four switch mounting holes in bottom section, load of 5,5 kg switch and bus bars is distributed, resulting 28,2 N of force to each mounting hole. Additionally is added force of gravity, effective on middle plate (Figure 33).

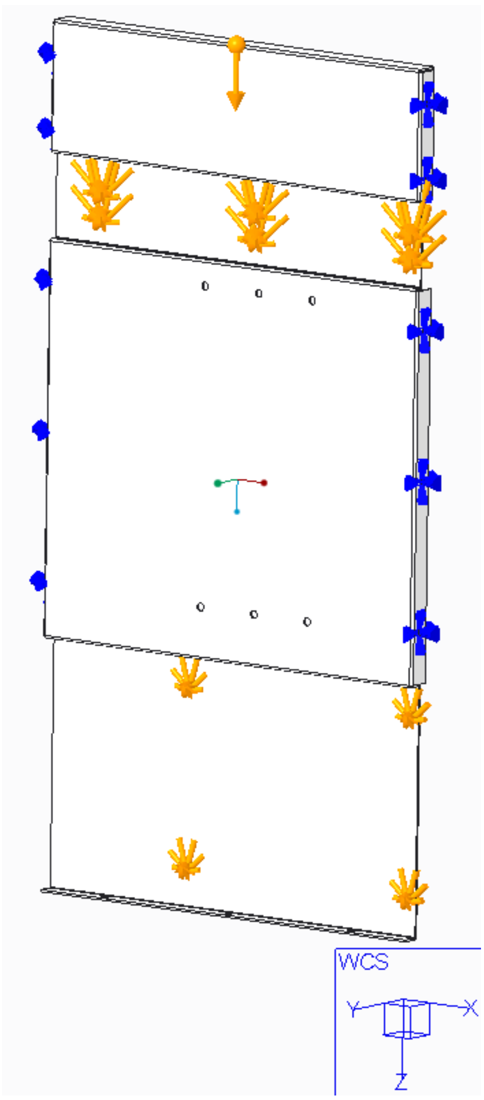


Figure 33. Representation of loads (yellow) and constraints (blue)

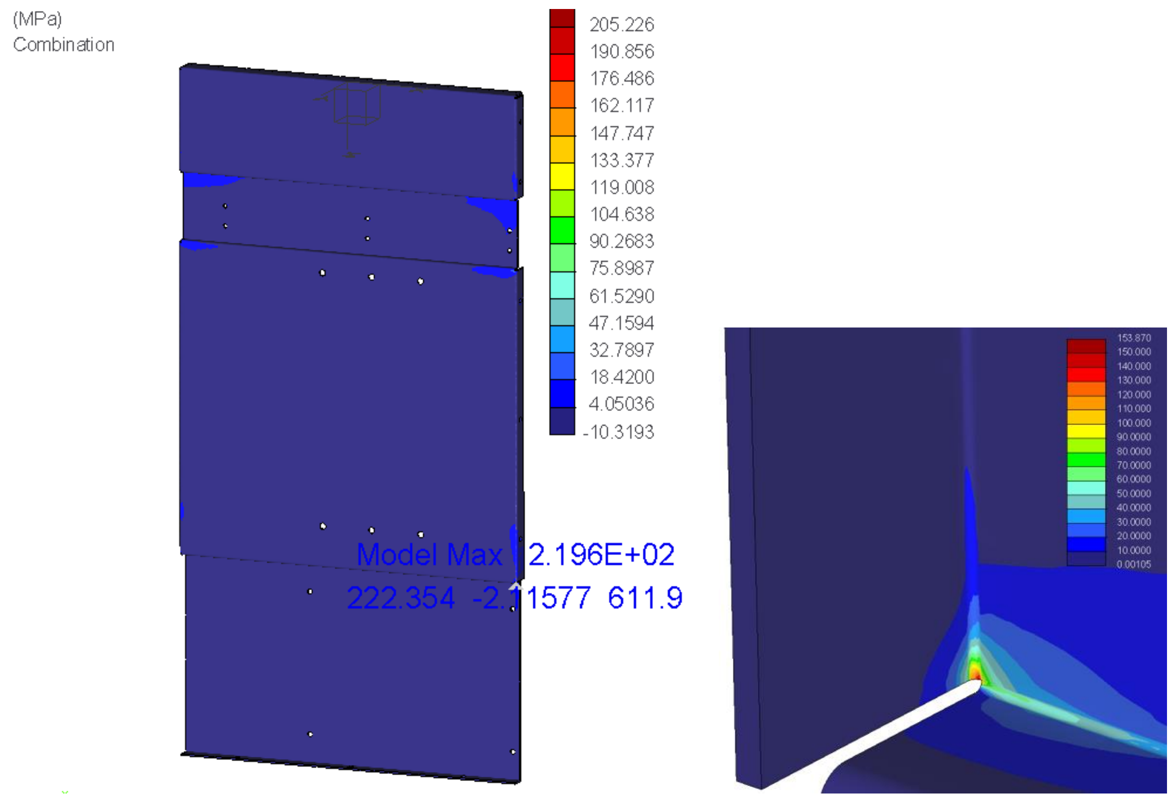


Figure 34. Initial stress analysis and stress concentrator

The highest stress occurs in the bends edge corners, formed when two bends are close to each other and right-angled. Maximal stress of 220 MPa occurs, which does not exceed maximal yield strength of 235 MPa. Such high stress is caused by concentrator (Figure 34). The high concentration could be caused of the FEM analysis peculiarity, which does not take into account that in real life perfect right-angled cuts do not exist, that causes deviation in mathematical accuracy. Therefore to mitigate stress concentration in particular problem spots, corner reliefs were made in each critical corner. As a result the maximal stress decreased to 125 MPa (Figure 35). In which case a 1,88 factor of safety is reached. The design is suitable to bear given statical loads if made from structural steel S235.

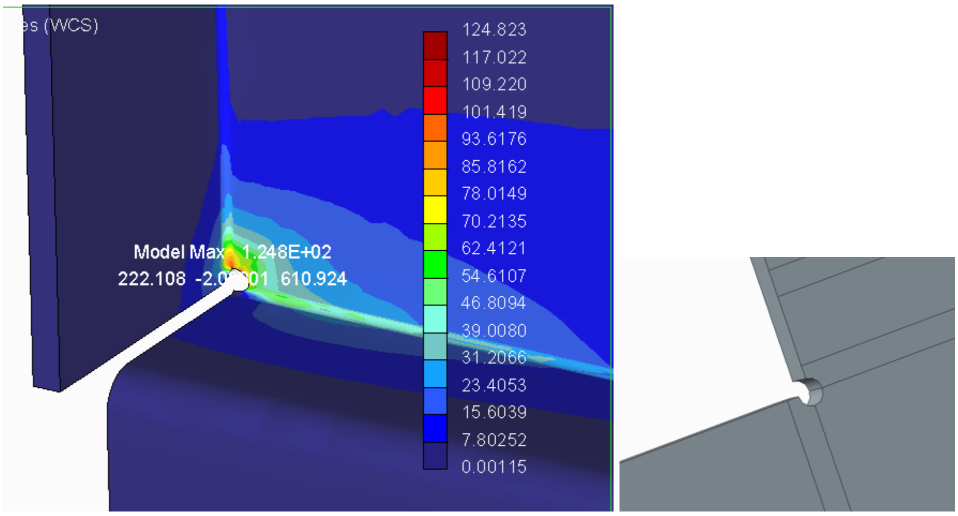


Figure 35. Maximal stress with corner relief, flat pattern of corner

Right side plate 3AXD50000451715

Like the middle plate, the right side plate is mounted to the frame by screw joints on the sides, which are defined as constraints in simulation. Six holes for inverter module rail fastening represent bearing loads, each 77,7 N (Figure 36). Also gravitational force is added to represent the sheet plate’s own weight. In real life the plate is supported from the bottom, where it meets the frame base beam, but is not taken account for simulation.

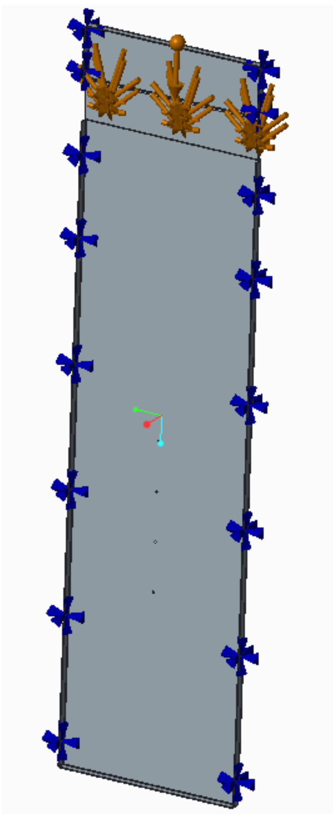


Figure 36. Representation of loads (yellow) and constraints (blue)

As a result of simulation, maximal stress is 66,1 MPa, which gives for factor of safety 3,5 when part is made from steel S235 (Figure 37). In this case corner reliefs are not necessary.

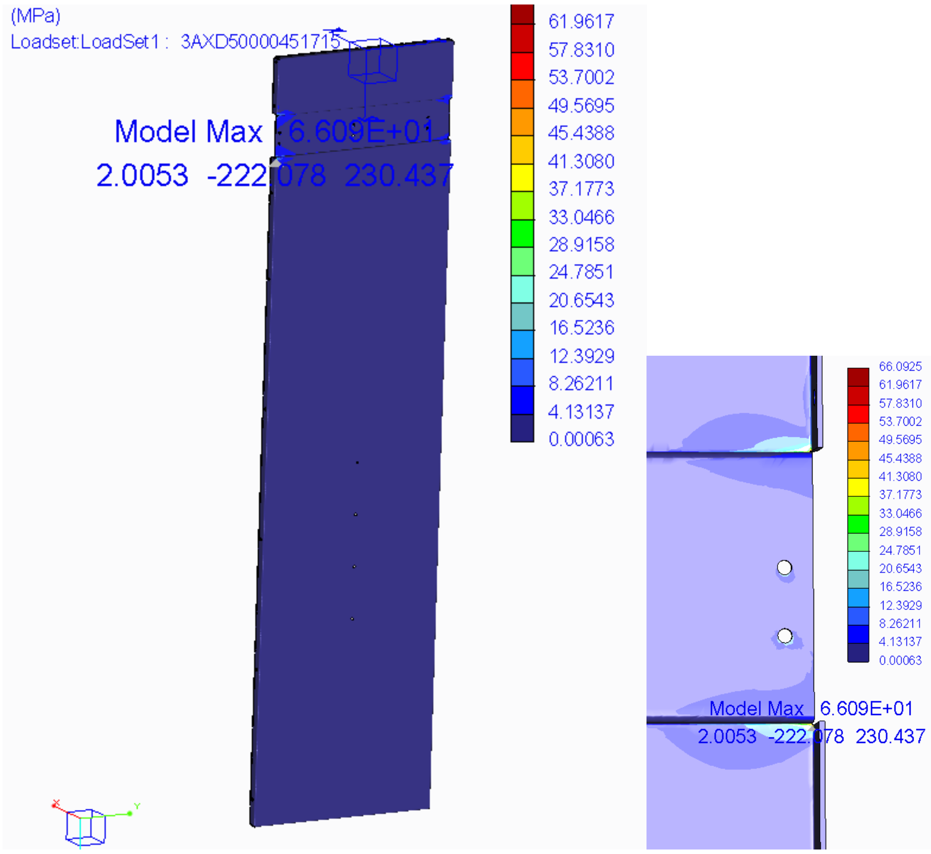


Figure 37. Maximal stress representation of right side plate

2.5 Fluid dynamics analysis

To check if the design has any flaws that haven't been accounted for and would need enhancements, thermal simulation analysis is carried out with FloEFD finite element method software. Since not all bus bars are designed with suggested cross section requirement, the heat generation and dissipation have to be analysed, as well du/dt and inverter module section, which has highest heat emission from all of the design. For simulation inputs ambient temperature is set to 50°C at sea level. In the model most important heat sources are defined, such as all bus bars, fuses, contactor, du/dt filter and inverter module. Heat loss values of different components are given in company internal research documents. For bus bars heat loss calculations, a special tool has been developed inside the company (Figure 38). Air inlet is in the front from the door and improved by 250 mm axial fan. Outlets are on both front and rear on top of the existing cabinet (Figure 39). Bus bar cross-section and resistance of busbar material depending on temperature is used to calculate power losses in watts per meter. This is then multiplied by bus bar length in flat state. The tool uses Ohm’s law to calculate heat loss (2.2), where resistivity depends on temperature, the higher temperature creates higher resistance, for copper typically 0,017 $\frac{\Omega * mm^2}{m}$ at 20°C and 0,023 $\frac{\Omega * mm^2}{m}$ at 100°C. For the AC bus bars heat loss calculations, skin effect can be a required consideration. For particular calculations skin effect factor can be ignored as current frequencies in the bus bars do not reach high enough to cause significant skin effect. The tool uses safety factor coefficient of 1,1 as additional measure to provide rather higher value than low in order to reduce possible error of dimensioning bus bars.

$$P = I^2 R \tag{2.2}$$

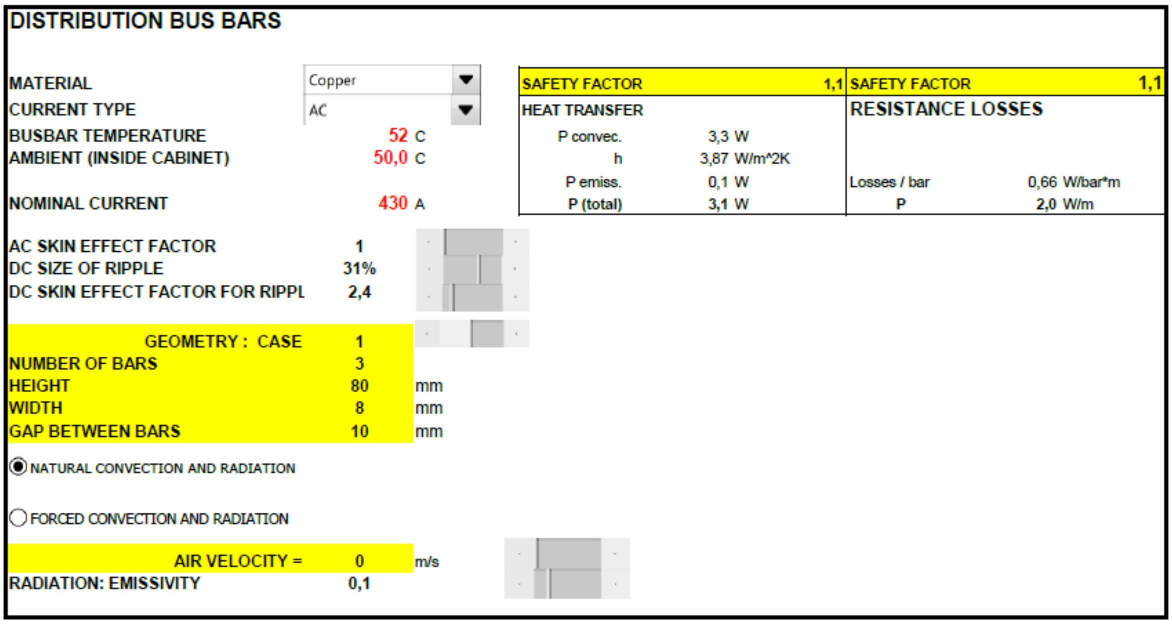


Figure 38. Bus bars dimensioning tool

Model is refined and simplified so that meshing properties could be less complex while reducing geometry accuracy as little as possible. For example, the module shell is made with rough outer dimensions and all heat dissipation is defined from a heatsink in the module, because in the context of this study the subject of analysis is the cabinet overall design not what occurs withinin the inverter module but how the air enters and exits and which temperature. Therefore, the simplified model mimics double inlet fans in the bottom and outlet opening on the top. To evaluate overall performance and functionality, simplified model is sufficient enough if there will be room for safety factor margin of error ±10%.

The primary interest for analysis is the air flow trajectories relative to temperature in certain points in the cabinet (Figure 40). Critical areas air temperature wise are pinpointed. As seen from simulation representation, critical areas are between du/dt filter and top outlet, where cut plane is made for closer examination (Figure 41). Based on that it can be concluded that inverter module inlet air temperature is around 52°C and top exhaust temperature reaches up to 65°C.

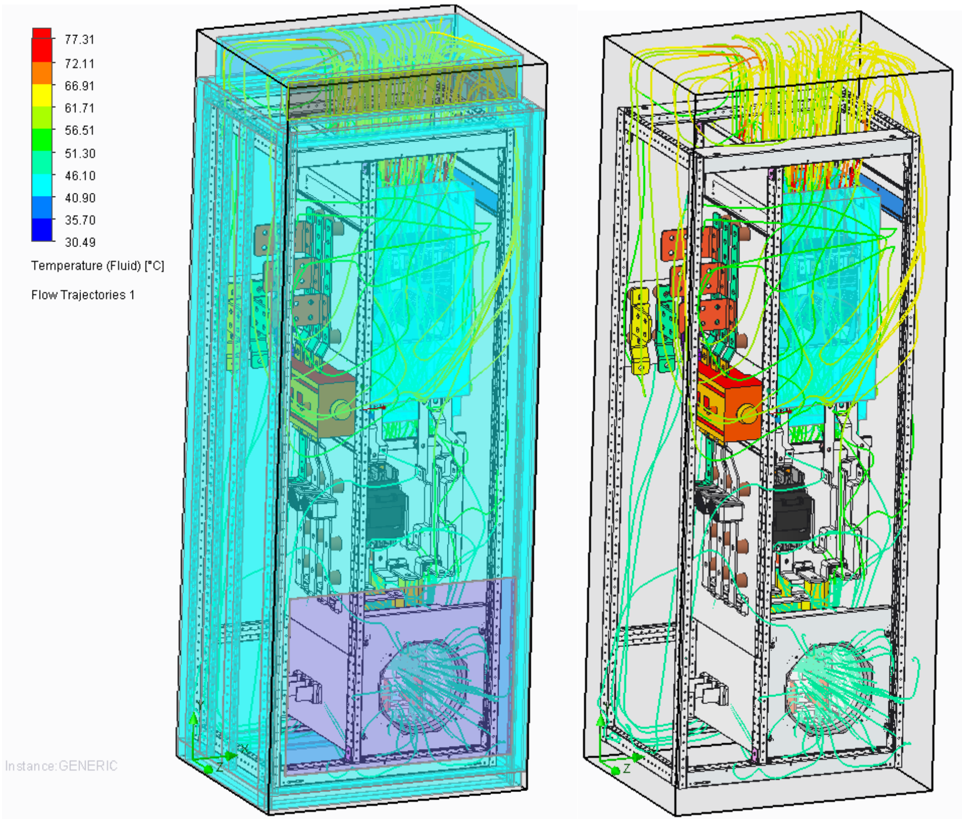


Figure 39. Retrofit frame in existing enclosure inlet and outlets representation

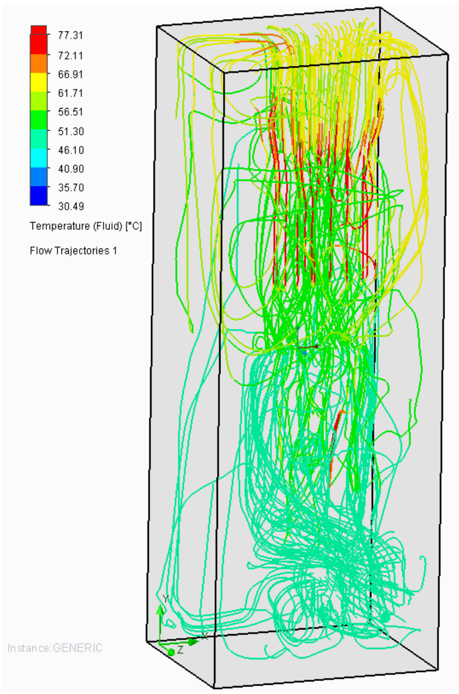


Figure 40. View of the cabinet without geometry for hotspots identification

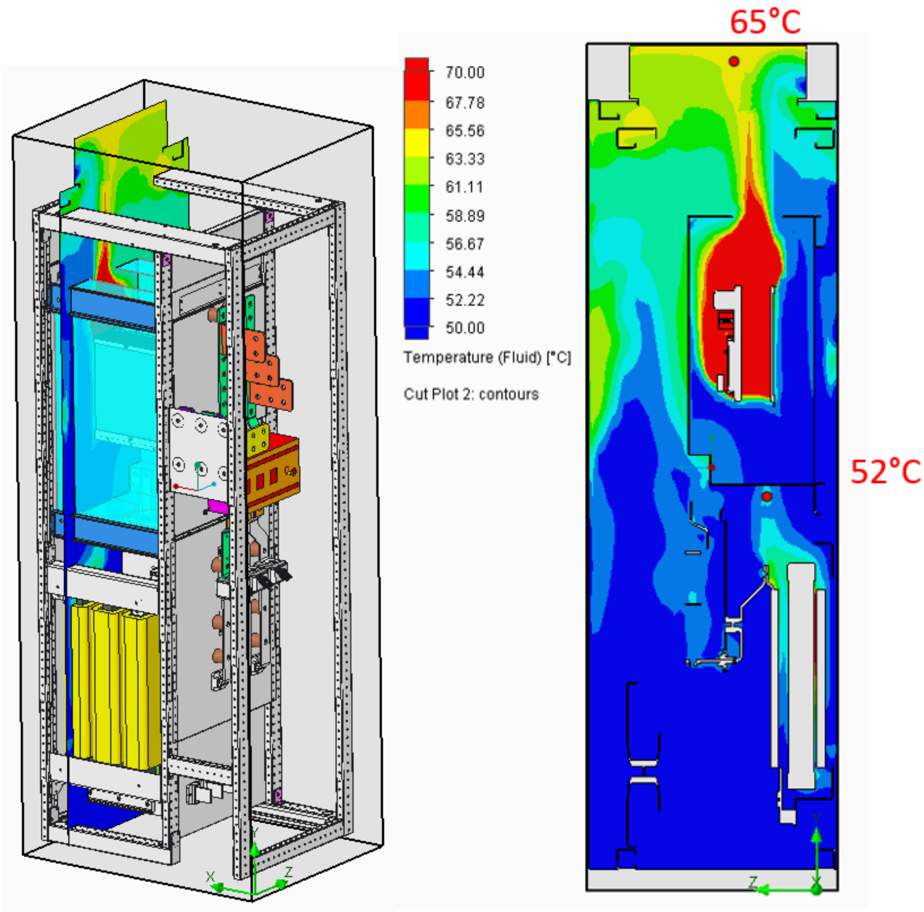


Figure 41. Cut plane placement (left) temperatures in critical points (right)

For solid bodies thermal analysis, the temperature peaks of bus bars are critical. Practical experience shows that over 100°C copper starts diffusing through tin and starts forming oxide layer [21]. Whereas according to power drives systems standard, bus bar maximal heat can not exceed insulation components critical temperature, which are used for bus bars fixing [18]. All insulation support used in this design withstand at least 100°C. Therefore, to generalise the result, bus bars with smallest cross-sections are analysed. Based on heat generation principles in metal conductors, it can be presumed that highest heat dissipation would be created by the bus bars connecting the contactor to the inverter module (Figure 42).

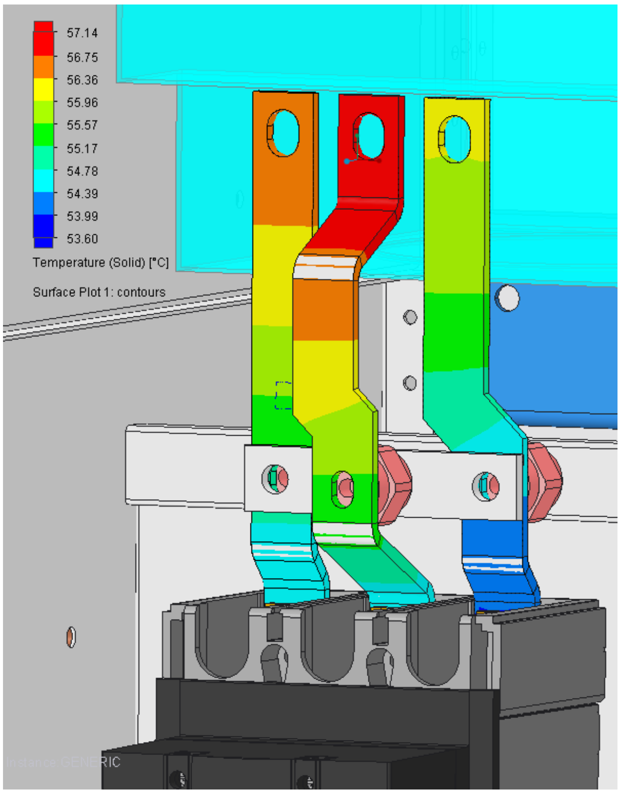


Figure 42. Temperature extremes of module input bus bars

In real life the bus bars projection of heat distribution would look different, because there would be heat concentrations at places where bus bar connections are made, corner cuts, bends and around bolt holes. But for peak values representation, temperature values are reliable enough. Even if there is added safety margin of 10%, the highest peak would be around 63°C, which is acceptable in environment of 50°C of ambient temperature.

Design enhancements derived from simulation results

For cabinet internal air flow the free space inside the door and prior to the frame causes small anomalies of recycling air flow from the top, which should be intended to exit through the roof outlets shortest way possible. Therefore, making the retrofit frame deeper should be considered and analyzed for feasibility. Also the middle wall should be extended so it can reach close to the bottom of the cabinet, so that the left and right sections would be separated from one another. For left side section, natural convection provides enough cooling.

Initially the possibility of directing air from du/dt filter was left available, if it would have been needed. Despite the module inlet fans sucking air near du/dt filter, the temperature rise is not critical, so that the air for the module inlet and filter exhaust would not have to be separated with sheet metal guides. The inverter module power derating has to be considered in such conditions as inverter derating starts above 40°C ambient temperature (Figure 43). Inverter power rating is dropped by 1% for every 1 °C above 40 °C [5].

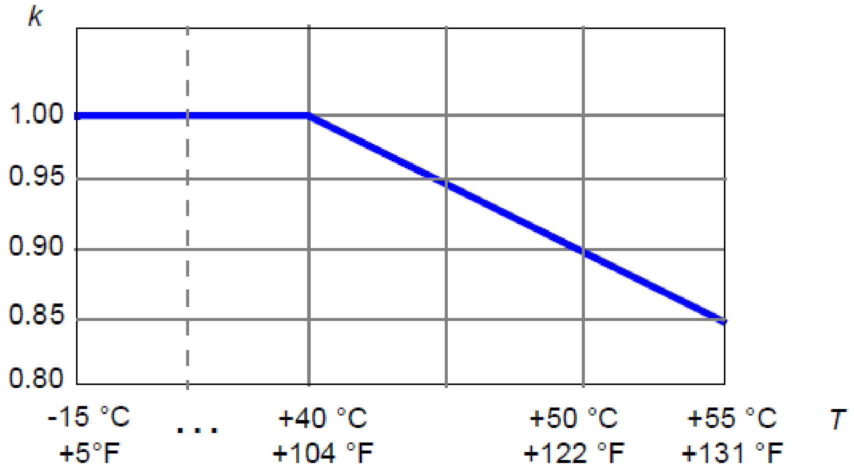


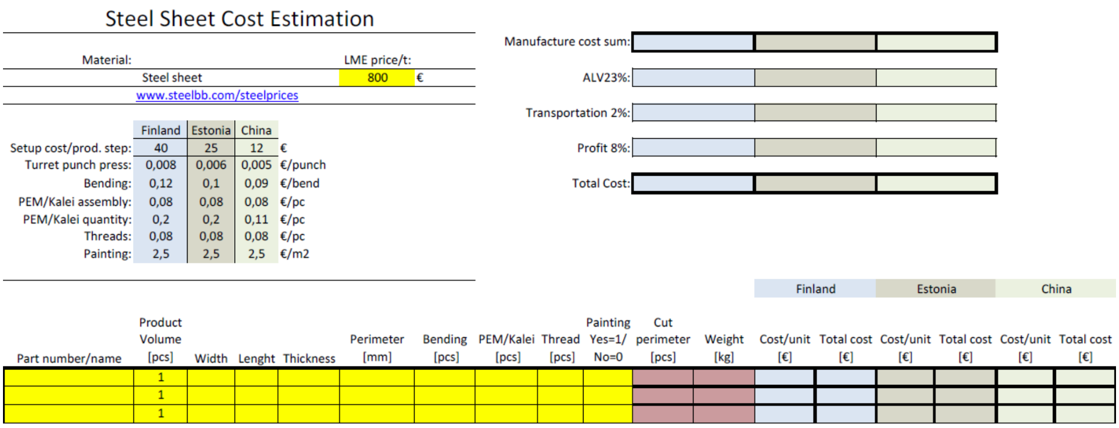
Figure 43. ACS880-01 inverter modules derating graph for IP21 protection class [5]

Transformer placement, mentioned in section 2.3.6, will be in the bottom left section on the middle partition wall, where the air temperature is around ambient. That way it gets fresh air through the door and heat is dissipated through natural convection.

3 COST CALCULATION

Since the work includes only mechanical design, the approximate cost for mechanical components will be calculated. Mechanical components make up approximately 1/4 of product's own cost. This is also the reason why electrical components are left out, as optional accessories and inverter module power rating choice influence total cost on larger scale than mechanical components. Mechanical parts of the product are from variation to variation same and do not change or have only minor variation depending on the order.

For approximate mechanical components cost calculation special tool is developed in the company (Figure 45 and 46), which is used to calculate approximate cost on sheet metal and copper parts. For sheet metal parts, cost is calculated form material volume used, amount of manufacturing operations and complexity. Price is increased when additional components are added, for example press nuts or bolts. The same logic applies also to bus bars, the difference is that bus bar can also be made of bar material, which is cheaper to use than sheet material.



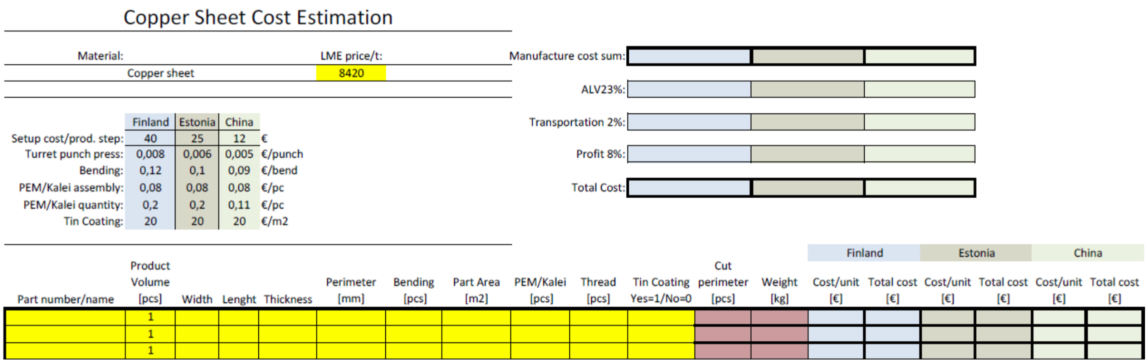
Steel Sheet Cost Estimation

Material:	LME price/t:	
Steel sheet	800	€
www.steelbb.com/steelprices		

	Finland	Estonia	China	
Setup cost/prod. step:	40	25	12	€
Turret punch press:	0,008	0,006	0,005	€/punch
Bending:	0,12	0,1	0,09	€/bend
PEM/Kalei assembly:	0,08	0,08	0,08	€/pc
PEM/Kalei quantity:	0,2	0,2	0,11	€/pc
Threads:	0,08	0,08	0,08	€/pc
Painting:	2,5	2,5	2,5	€/m2

Part number/name	Product Volume [pcs]	Width	Lenght	Thickness	Perimeter [mm]	Bending [pcs]	PEM/Kalei [pcs]	Thread [pcs]	Painting Yes=1/ No=0	Cut perimeter [pcs]	Weight [kg]	Finland Cost/unit [€]	Finland Total cost [€]	Estonia Cost/unit [€]	Estonia Total cost [€]	China Cost/unit [€]	China Total cost [€]
	1																
	1																
	1																

Figure 45. Cost estimation tool for sheet metal



Copper Sheet Cost Estimation

Material:	LME price/t:
Copper sheet	8420

	Finland	Estonia	China	
Setup cost/prod. step:	40	25	12	€
Turret punch press:	0,008	0,006	0,005	€/punch
Bending:	0,12	0,1	0,09	€/bend
PEM/Kalei assembly:	0,08	0,08	0,08	€/pc
PEM/Kalei quantity:	0,2	0,2	0,11	€/pc
Tin Coating:	20	20	20	€/m2

Part number/name	Product Volume [pcs]	Width	Lenght	Thickness	Perimeter [mm]	Bending [pcs]	Part Area [m2]	PEM/Kalei [pcs]	Thread [pcs]	Tin Coating Yes=1/No=0	Cut perimeter [pcs]	Weight [kg]	Finland Cost/unit [€]	Finland Total cost [€]	Estonia Cost/unit [€]	Estonia Total cost [€]	China Cost/unit [€]	China Total cost [€]
	1																	
	1																	
	1																	

Figure 46. Cost estimation tool for copper sheet

Estimated cost of each part is brought out in section 3.1, where it is multiplied by a coefficient in order to hide real sourcing prices for different components. As BOM concludes the total cost in value units (Table 8), it can be brought out that total cost for mechanical components for prototype build is around 2000€. Since most electrical components used for prototype build are so called dummy parts, that do not have internals, the cost of mechanical components is adequate to evaluate how much the prototype will cost.

3.1 Bill of material

The BOM gives a detailed view of prototype build specific parameters of parts and assemblies.

Table 8. Bill of material

Part description	Part code	QTY	Price per piece	Price total	Standard/new design
MASTER ASSEMBLY	**3AXD50000450411**		Value units		
FRAME SUBASSEMBLY					
BASE BEAM, STEEL	3AUA0000103329	1	2,80	2,80	Standard part
BASE BEAM, STEEL	3AXD50000447718	1	2,98	2,98	New
SUPPORT, STEEL	3AXD50000447398	1	4,29	4,29	New
BEAM, STEEL	3AXD50000293476	4	2,19	8,75	New
BASE BEAM, STEEL	3AUA0000119153	2	3,15	6,30	Standard part
BEAM, STEEL	3AUA0000093036	4	0,77	3,08	Standard part
FASTENING ANGLE	6456 0557	7	0,05	0,37	Standard part
LIFTING ACCESSORIES	64327151	4	0,30	1,19	Standard part
BEAM, STEEL	3AXD50000450367	2	2,29	4,59	New
SUPPORT, STEEL	3AXD50000450169	1	0,96	0,96	New
MODULE SUBASSEMBLY					
SUPPORT	3AUA0000111233	2	0,35	0,70	Standard part
RAIL	3AUA0000109168	2	0,93	1,86	Standard part
SUPPORT	3AUA0000093912	2	1,00	2,00	Standard part
RAIL	3AUA0000111303	2	0,70	1,40	Standard part
SERVICE RAIL	3AUA0000111307	2	0,46	0,91	Standard part
INPUT SUBASSEMBLY					
SIDE PLATE, STEEL	3AXD50000453566	1	45,50	45,50	New
BUS BAR, BAR, CU	3AXD50000453047	3	19,25	57,75	New
SIDE PLATE, STEEL	3AXD50000456550	1	30,98	30,98	New
BUS BAR, CU	3AXD50000457014	1	1,75	1,75	New

BUS BAR, CU	3AXD50000453023	1	3,50	3,50	New
BUS BAR, CU	3AXD50000453030	1	3,50	3,50	New
BUS BAR, CU	3AXD50000453146	1	5,25	5,25	New
INSULATING SUPPORT	09707255	15	0,51	7,61	Standard part
CABLE PLATE CAB/P	64728105	3	2,89	8,66	Standard part
BUS BAR, CU	3AXD50000468348	1	5,25	5,25	New
BUS BAR, CU	3AXD50000468140	1	5,25	5,25	New
SIDE PLATE, STEEL	3AXD50000451715	1	33,25	33,25	New
BUSHING_INSULATOR	57067608	6	0,30	1,79	Standard part
BUS BAR, CU	3AXD50000473250	1	5,25	5,25	New
BUS BAR, CU	3AXD50000473144	1	5,25	5,25	New
BUS BAR, CU	3AXD50000473069	1	5,25	5,25	New
INSULATOR 50MM	09707301	1	0,58	0,58	Standard part
MODULE I/O SUBASSEMBLY					
INSULATOR 50MM	09707301	3	0,58	1,73	Standard part
BUS BAR, CU	3AXD50000455140	1	5,25	5,25	New
BUS BAR, CU	3AXD50000455430	1	5,25	5,25	New
BUS BAR, CU	3AXD50000455560	1	5,25	5,25	New
BUS BAR, SHEET, CU	3AXD50000453306	1	5,25	5,25	New
BUS BAR, CU	3AXD50000453610	1	8,75	8,75	New
BUS BAR, CU	3AXD50000453498	1	7,00	7,00	New
BUSHING_INSULATOR	57067608	3	0,30	0,89	Standard part
BUS BAR, CU	3AXD50000457618	1	8,75	8,75	New
BUS BAR, CU	3AXD50000459469	1	7,00	7,00	New
BUS BAR, CU	3AXD50000457472	1	5,25	5,25	New
BUS BAR, CU	3AXD50000460076	1	5,25	5,25	New
BUS BAR, CU	3AXD50000459544	2	5,25	10,50	New
INSULATING SUPPORT	09707255	2	0,51	1,02	Standard part
INSULATION PLATE	3AXD50000468331	1	1,75	1,75	New
Insulator	6457 5945	5	0,46	2,28	Standard part
COMMON MODE FILTER					
FERRITE RING	64308998	3	5,60	16,80	Standard part
INSULATING SHEET	3AUA0000095112	2	0,46	0,91	Standard part
INSULATING SHEET	3AUA0000095113	2	0,26	0,53	Standard part
BUS BAR, CU	3AXD50000458806	1	2,63	2,63	New
BUS BAR, CU	3AXD50000459650	1	2,14	2,14	New
INSULATOR 50MM	09707301	2	0,58	1,16	Standard part
BUS BAR, CU	3AXD50000458998	1	2,77	2,77	New

FAN ASSEMBLY					
ASSEMBLY PLATE, STEEL	3AXD50000468447	1	1,72	1,72	New
BRACKET	63986992	4	0,06	0,24	Standard part
TURNFRAME ASSEMBLY					
FRAME	3AUA0000098805	1	46,20	46,20	Standard part
HINGE MOUNT	3AXD50000468638	1	1,75	1,75	New
HINGE	61239472	2	0,18	0,35	Standard part
DU/DT FILTER ASSEMBLY					
690V					
ASSEMBLY PLATE, STEEL	3AXD50000466436	1	44,10	44,10	New
BUS BAR, CU	3AXD50000473502	3	5,25	15,75	New
INSULATING SUPPORT	09707255	3	0,51	1,52	Standard part
400V; 500V					
SUPPORT BEAM, STEEL	3AXD50000467686	1	42,70	42,70	New
SUPPORT BEAM, STEEL	3AXD50000467761	1	42,00	42,00	New
INSULATING SUPPORT	09707255	3	0,51	1,52	Standard part
OUTPUT SUBASSEMBLY					
ASSEMBLY PLATE, STEEL	3AXD50000473816	1	28,35	28,35	New
INSULATING SUPPORT	09707255	6	0,51	3,05	Standard part
BUS BAR, BAR, CU	3AXD50000297535	3	11,18	33,55	Standard part
BUS BAR, SHEET, CU	3AXD50000297580	3	9,14	27,41	Standard part
COVERS					
Bracket		14	0,06	0,83	Standard part
Left cover		1	2,80	2,80	New
Right cover		1	2,10	2,10	New
			TOTAL	**672,53**	

SUMMARY

The design development or ACS880-01 R9 retrofit frame solution started by defining key points for input. First, main circuit electrical components were defined, based on standard ACS880-07 R9 cabinet built industrial drive. Then the frame for design backbone were established, using standard product frame components, followed by initial layout for component placement and to get vision in which sequence the design has to start to evolve. The logic behind design process flow was to start from input terminals, where current is applied and to follow the sequence how current is distributed in main circuit until the end to output terminals.

To check and justify design choices and approaches, finite element analysis for stress and thermal simulations were carried out. The stress calculations were applied to sheet metal constructions that have to bear highest statical loads in the design. Thermal analysis was conducted to point out flaws in air flow and to make sure that critical temperatures for cabinet inside air and components would not be exceeded.

At this point, the design of ACS880-01 R9 frame solution for ACS607 retrofit ready for next phase, where the actual components will be ordered and prototype is assembled. The final design with improvements is included to the drawings and incorporated to the thesis.

KOKKUVÕTE

ACS880-01 R9 inverter mooduli uuendamise raamilahenduse disain sai alguse võtmetähtsusega sõlmede defineerimisest. Esiteks defineeriti inverteri kabineti peaahela komponendid, tuginedes standardse ACS880-07 R9 ajami disainile. Disaini arendamise vundamendiks töötati välja sobiv raamilahendus olemasolevatest standardsetest raamikomponentidest. Millele järgnes esmane komponentide paigutuse planeerimine, mille põhjal disaini protsessi järjestada ning planeerida. Disaini protsessi loogika seisnes järgimist, kuidas vool sisend terminalidelt edasi liigub ning jõuab väljundterminalideni. Samas järjekorras sai ka läbi viidud disainiprotsess.

Et kontrollida ning põhjendada disaini valikuid ja ülesehitust, viidi läbi lõplike elementide metoodikat kasutava tarkvaraga tugevus ja termoanalüüs. Tugevusarvutused tehti lehtmetallist konstruktsioonidele, mis kannavad kogu disainis kõige suuremal määral staatilist koormust. Termoanalüüsi eesmärgiks oli kontrollida, kas õhuvoolud liiguvad ette nähtult, ilma mööndusteta ning et pingestatud komponendid ei ületaks neile ette nähtud kriitilist temperatuuri maksimumi.

Hetke seisuga on ACS880-01 R9 raamilahendus ACS607 kabinet ajami uuendamise järgmiseks faasiks valmis, mis on prototüübi ehitus. Lõplik disainilahendus sisaldab töös välja toodud parandusettepanekuid ning on kantud joonistele ja lisatud tööle.

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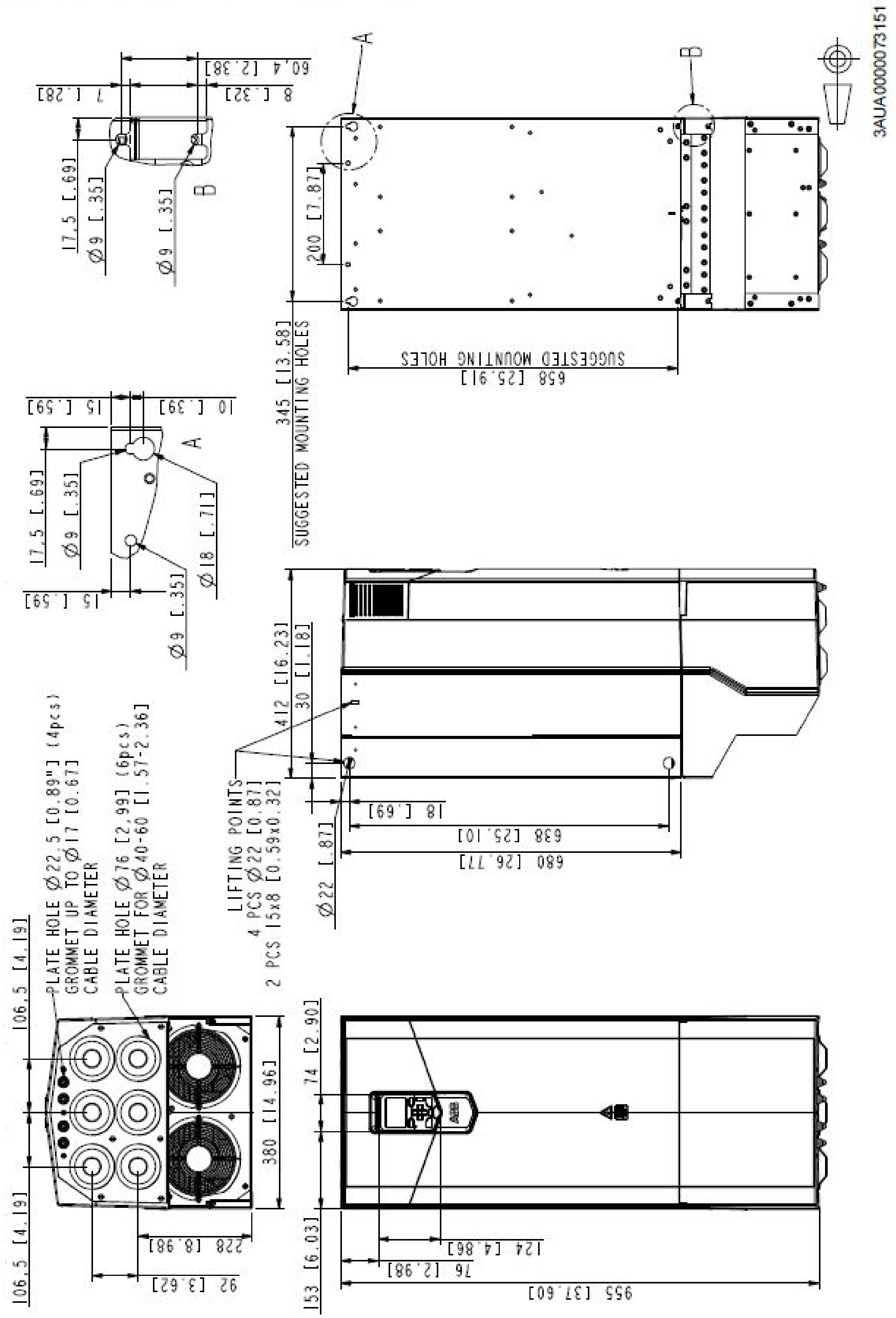
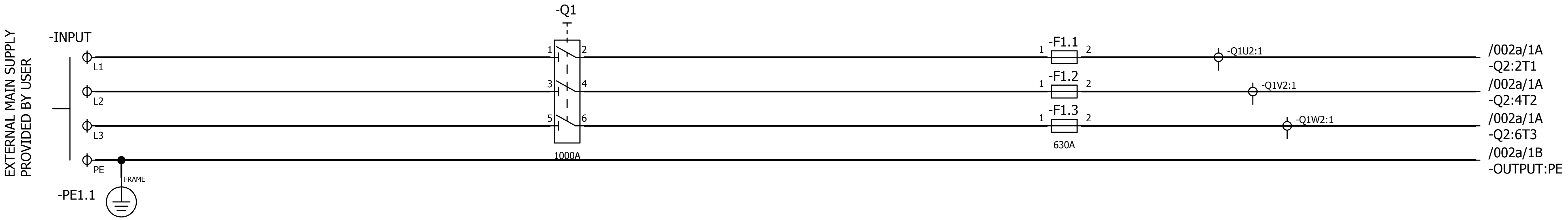
Appendix 1 – ACS880-01 R9 inverter module dimensions

Frame R9 (IP21, UL Type 1)



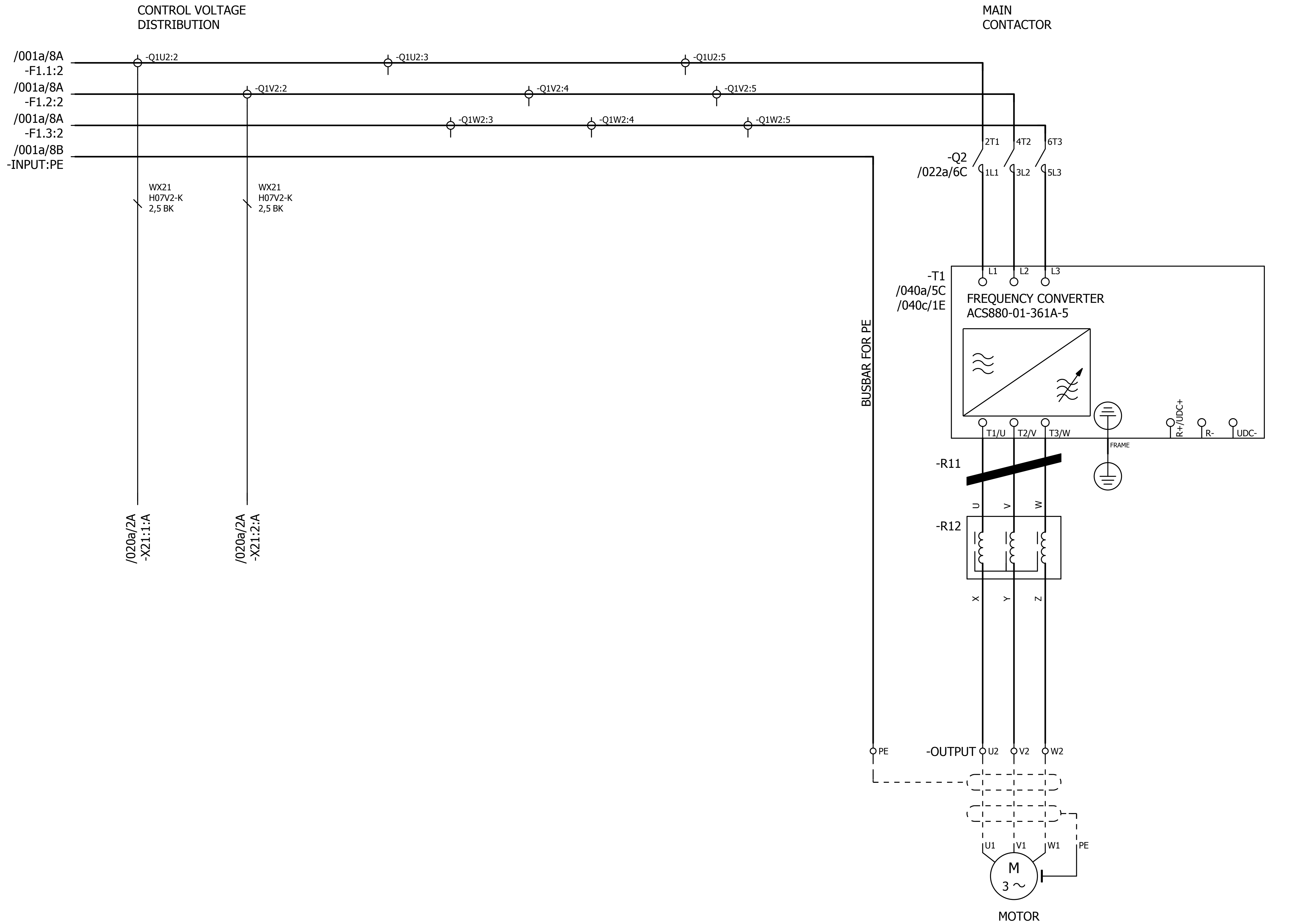
Appendix 2 – ACS880-07 R9 main circuit diagrams



P159217

Cust. Doc. No.	Prep. Andry Aasamae 19.03.2019	Title Drive main circuit (1/2) ACS880-07-0361A-5 SINGLE DRIVE	Circuit diagram EFS2
Cust. Ref. No.	App.		SAP Doc. No.
Customer	Project		EPLAN Doc. No. 010
		ABB	ABB Ref. No.
			Resp. Dept.

Item Des.	= 01 +01.1
Rev. .1	Sheet 001a
Cont.	002a



P159217

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Cust. Ref. No.	App.		SAP Doc. No.		
Customer	Project		EPLAN Doc. No. 010		
		ABB	ABB Ref. No.	Rev. .1	Sheet 002a
			Resp. Dept.	Cont.	020a

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3AXD50000450411 (ASSEM)	-.6+	

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae	

ASSEMBLY INSTRUCTIONS

SHEET 2: Prepare and assemble frame, attach lifting lugs

SHEET 3: Install side and middle partition walls, install input subassembly components - main switch and fuses

SHEET 4: Install inverter module mounts and rails, prepare module for installation by adding lifting accessories

SHEET 5 & 6: Install Du/Dt filter according to voltage rating

SHEET 7: Prepare module input/output assembly - contactor and common mode filter

SHEET 8: Mount module input/output sub-assembly (sheet 7) into the main assembly frame

SHEET 9 & 10: Establish Du/Dt filter input bolt joints, attach Du/Dt filter output bus bars according to filter type

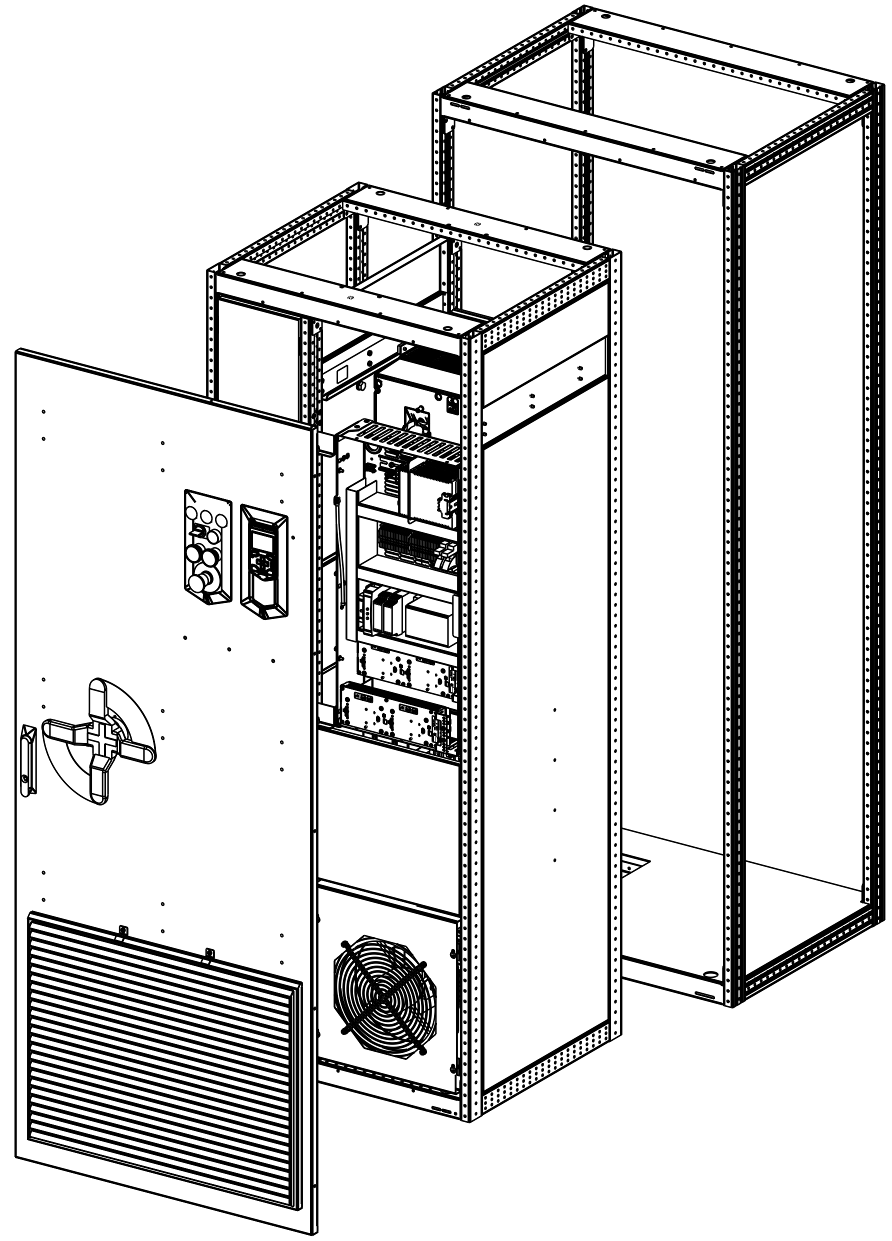
SHEET 11: Install service rails and insert module, fasten module to back beams

SHEET 12: Install output cable terminals depending on output direction requirements, prepare and install cables from Du/Dt filter output to output terminals sub-assembly

SHEET 13: Attach turn frame, fan assembly and shield covers

For door kit refer to drawing 3AXD50000322794

For electrical bolt joints refer to maanual 3AFE011876



Based on		Prepared	A.Aasamae	22-May-19
Customer		Check.	A.Vooremaa	22-May-19
		Appr.	N.Tervaskari	22-May-19
Cust. Doc. No.		Project name		
DMS Number	3AXD10000888015	Weight kg	623.12	

Title ASSEMBLY DRAWING
ACS880 RETROFIT
FOR R9 SINGLE DRIVE

ABB

Doc. des. ASSEMBLY DRAWING	Scale 3:50	Form A3	
Resp.dept.	Rev.ind. -.2 (DR)		Lang. EN
Doc. No. 3AXD50000450411			Sheet 1
			Total 13

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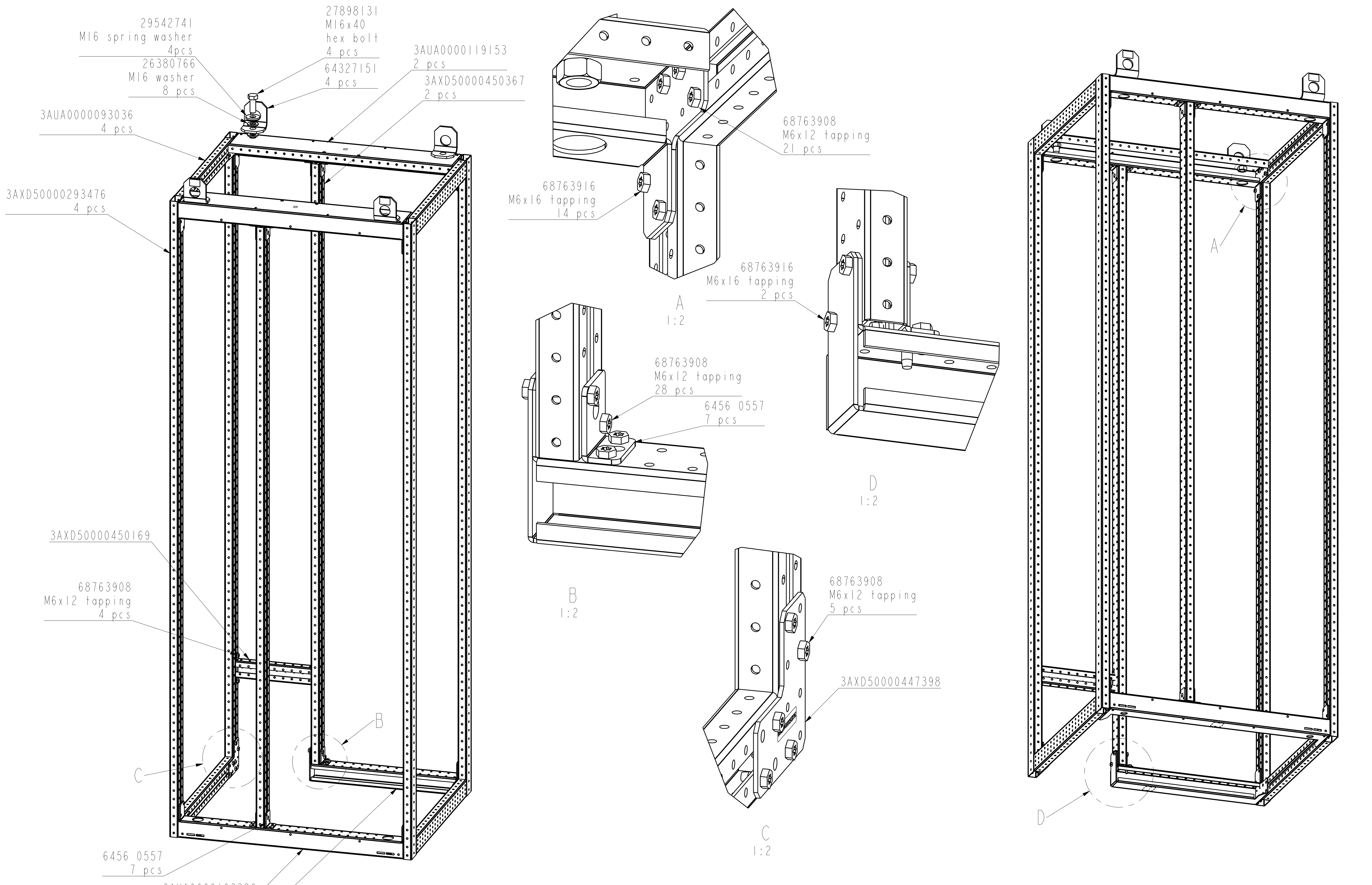
3AXD50000450411	-.2+	
3AXD50000450411 (ASSEM)	-.6+	
A	Initial Approval	22-May-19 A.Aasamae

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.



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Customer	Check. A.Vooremaa 22-May-19	ACS880 RETROFIT		
	Appr. N.Tervaskari 22-May-19	FOR R9 SINGLE DRIVE	Resp.dept. / Rev.ind. -.2 (DR)	Lang. EN
Cust. Doc. No.	Project name	ABB	Doc. No. 3AXD50000450411	Sheet 2
DMS Number 3AXD10000888015	Weight kg 623.12			Total 13

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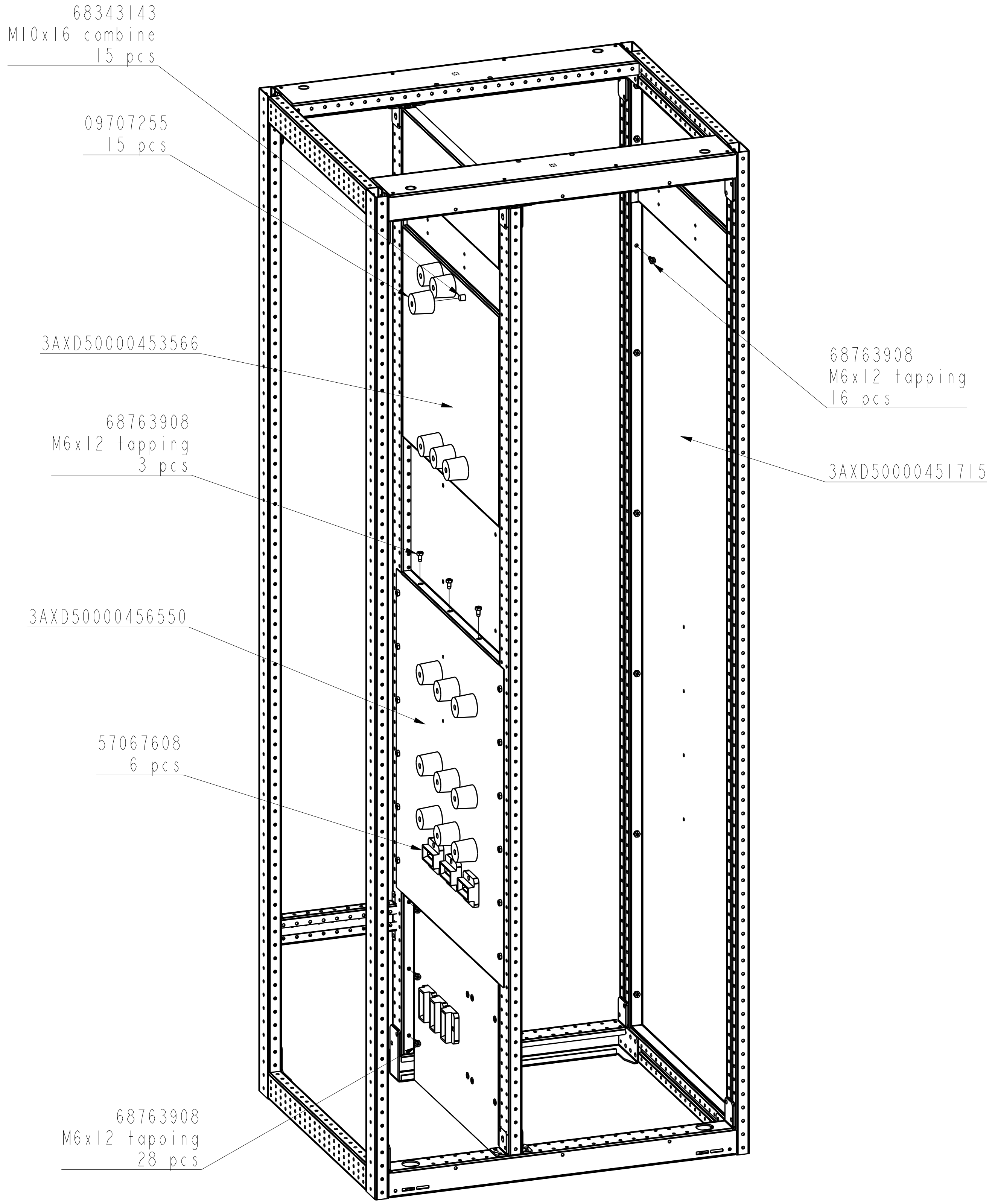
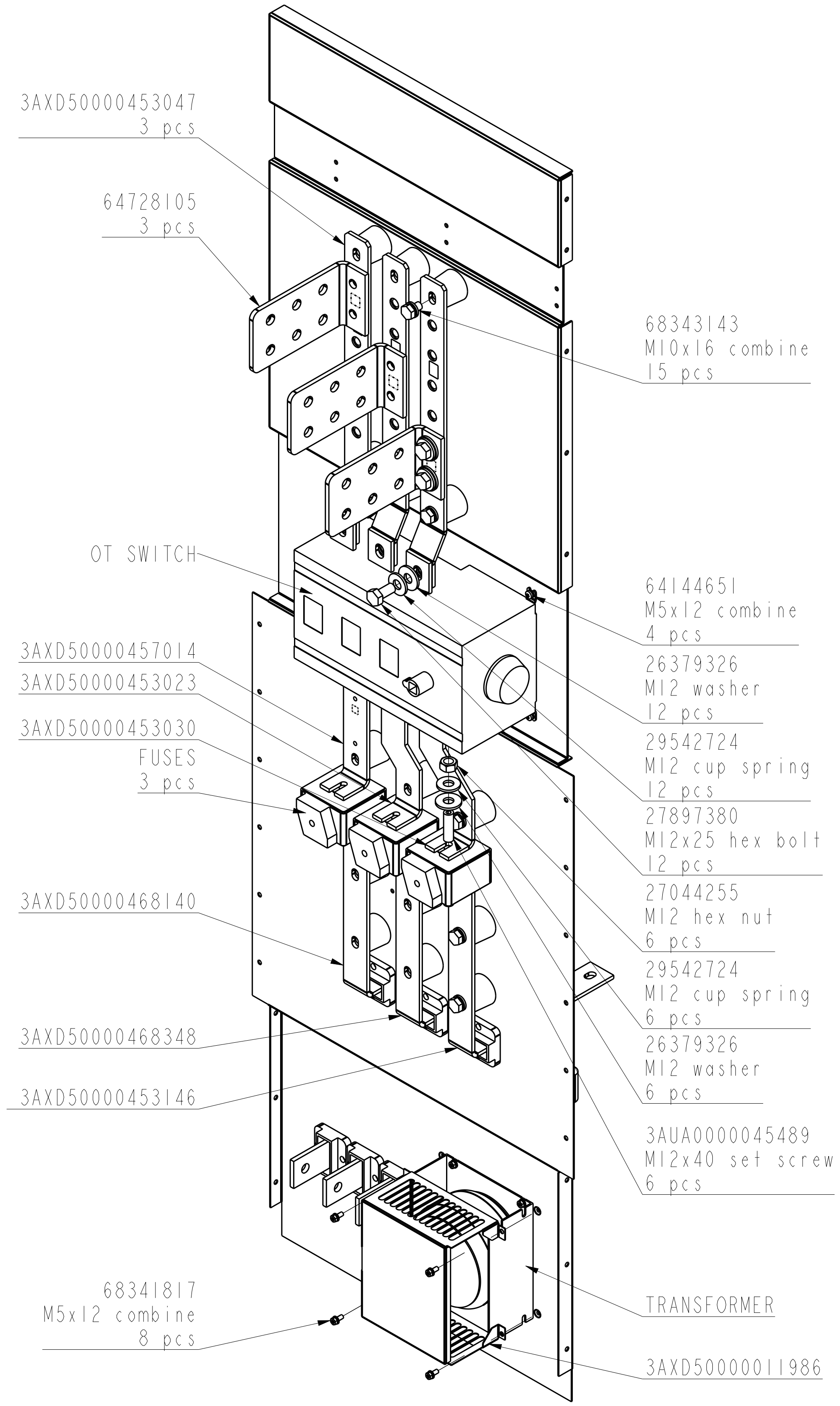
3AXD50000450411 (ASSEM)	-.6+	

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae

For mounting BUSHING INSULATORS 57067608 use 4.0 X 12 ST/ST pop rivets





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Based on	Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING ACS880 RETROFIT FOR R9 SINGLE DRIVE
Customer	Check.	A.Vooremaa	22-May-19	
	Appr.	N.Tervaskari	22-May-19	
Cust. Doc. No.	Project name			ABB
DMS Number 3AXD10000888015	Weight kg	623.12		

Doc. des. ASSEMBLY DRAWING	Scale 1:10	Form A3	
Resp.dept.	Rev.ind. -.2 (DR)		Lang. EN
Doc. No. 3AXD50000450411			Sheet 3
			Total 13

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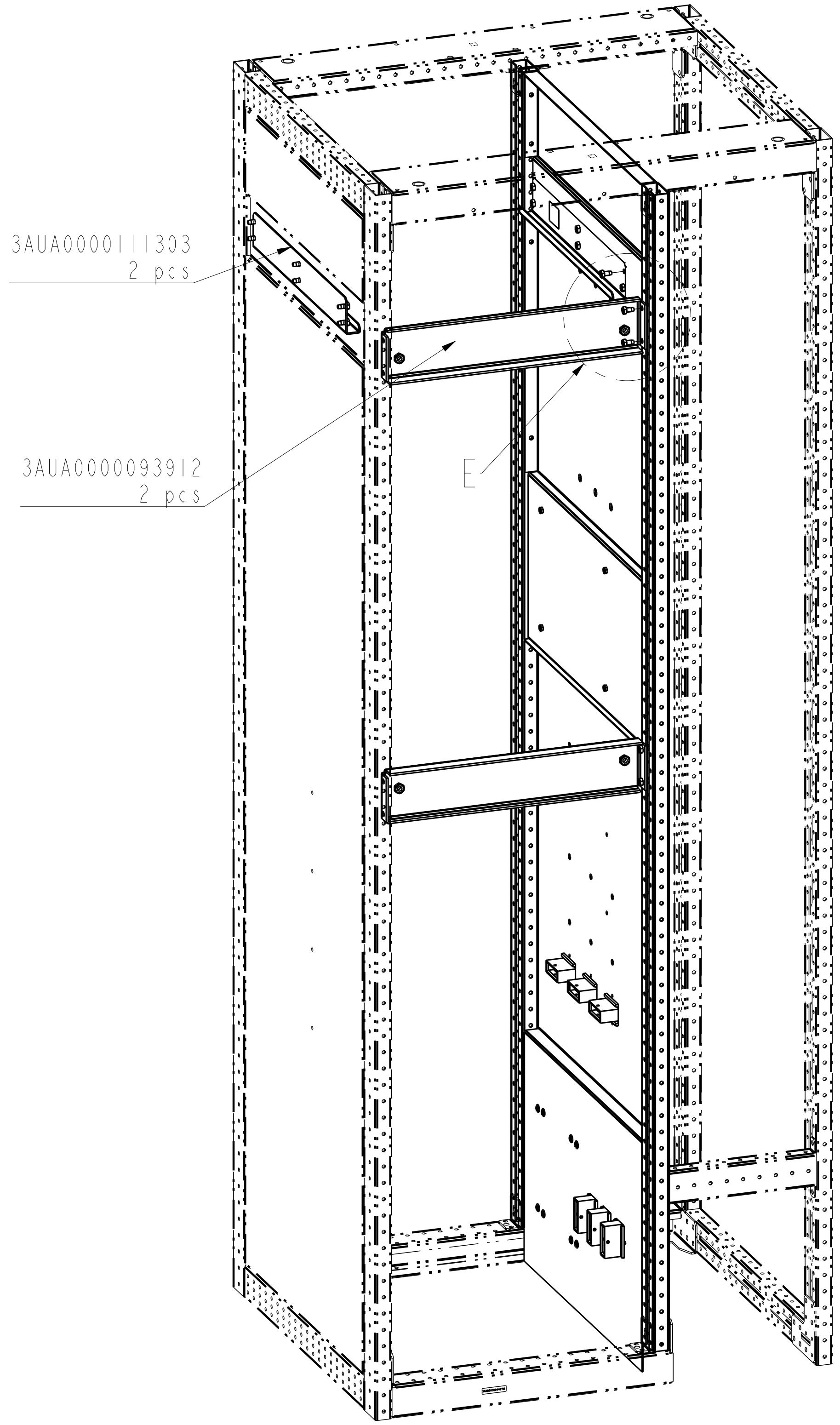
3AXD50000450411 (ASSEM)	-.6+	

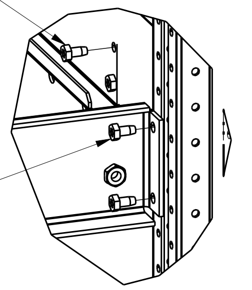
First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae



68763908
M6x12 tapping
12 pcs

68763908
M6x12 tapping
8 pcs



E
1:5

68763908
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6 pcs
68310865
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6 pcs
3AUA0000111233
2 pcs
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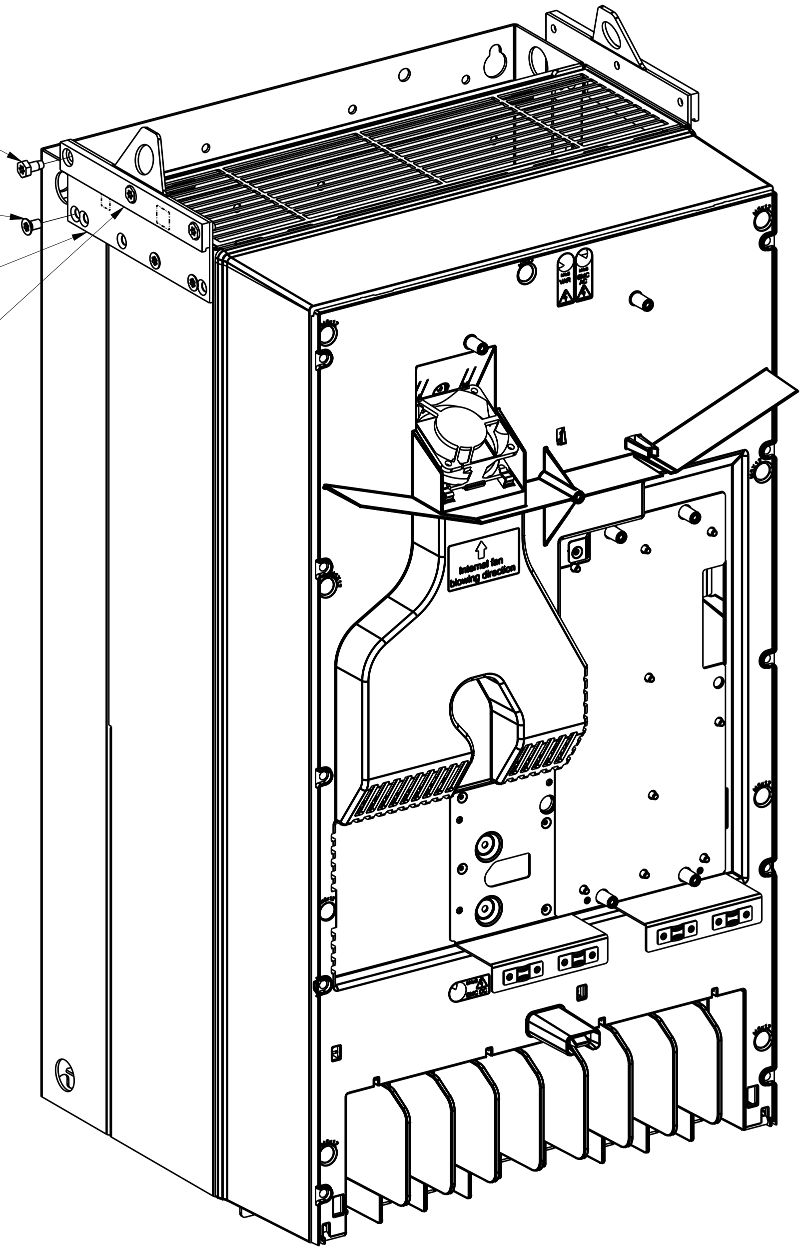
2 pcs



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Based on	Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING ACS880 RETROFIT FOR R9 SINGLE DRIVE
Customer	Check.	A.Vooremaa	22-May-19	
	Appr.	N.Tervaskari	22-May-19	
Cust. Doc. No.	Project name			ABB
DMS Number 3AXD10000888015	Weight kg	623.12		

Doc. des. ASSEMBLY DRAWING	Scale 1:10	Form A3	
Resp.dept.	Rev.ind. -.2 (DR)		Lang. EN
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			Total 13

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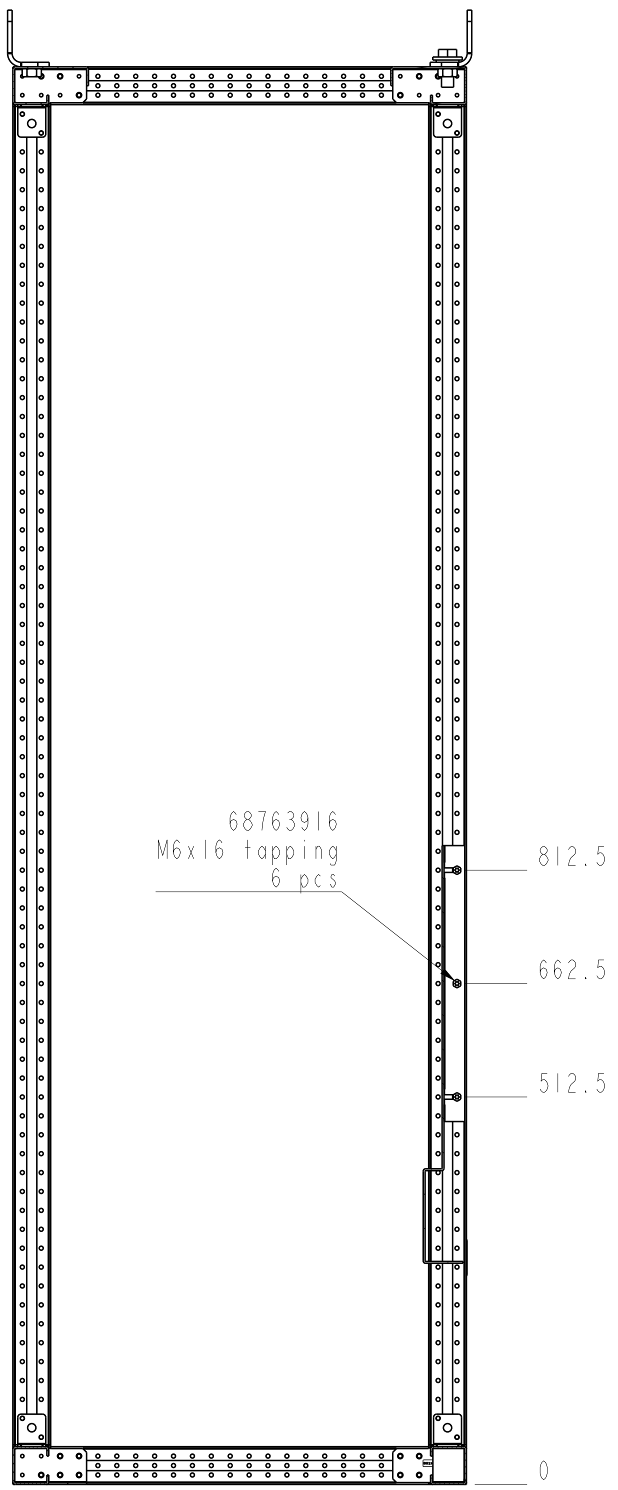
3AXD50000450411 (ASSEM)	-.6+	

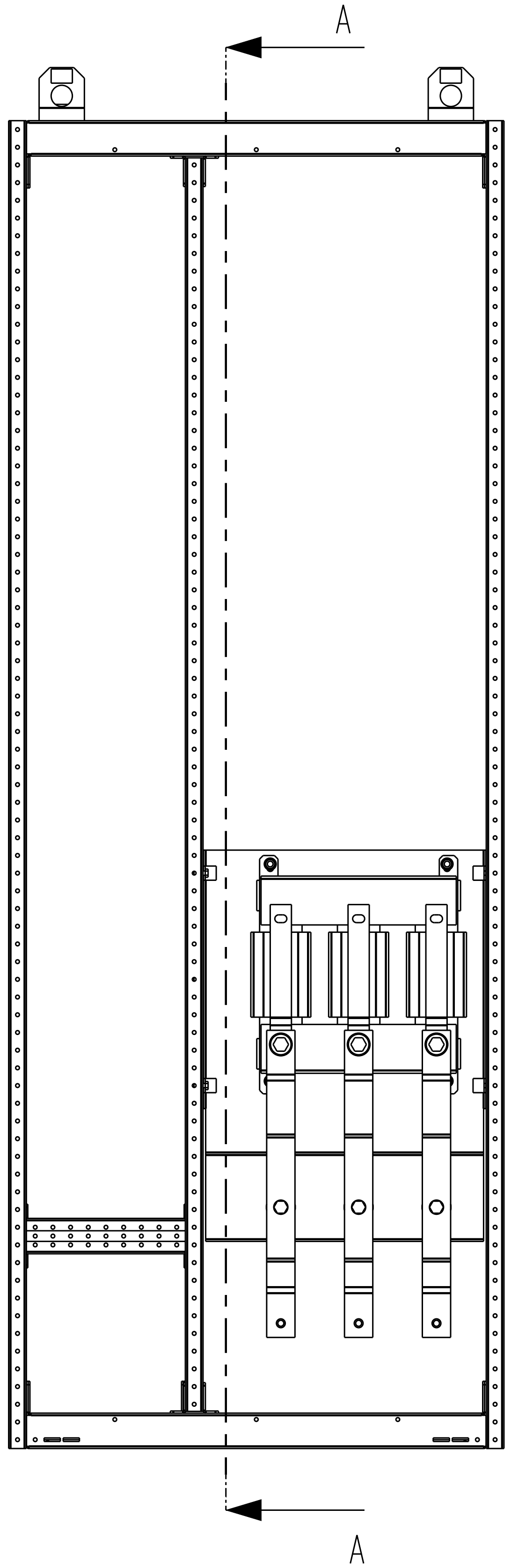
A	Initial Approval		22-May-19	A.Aasamae

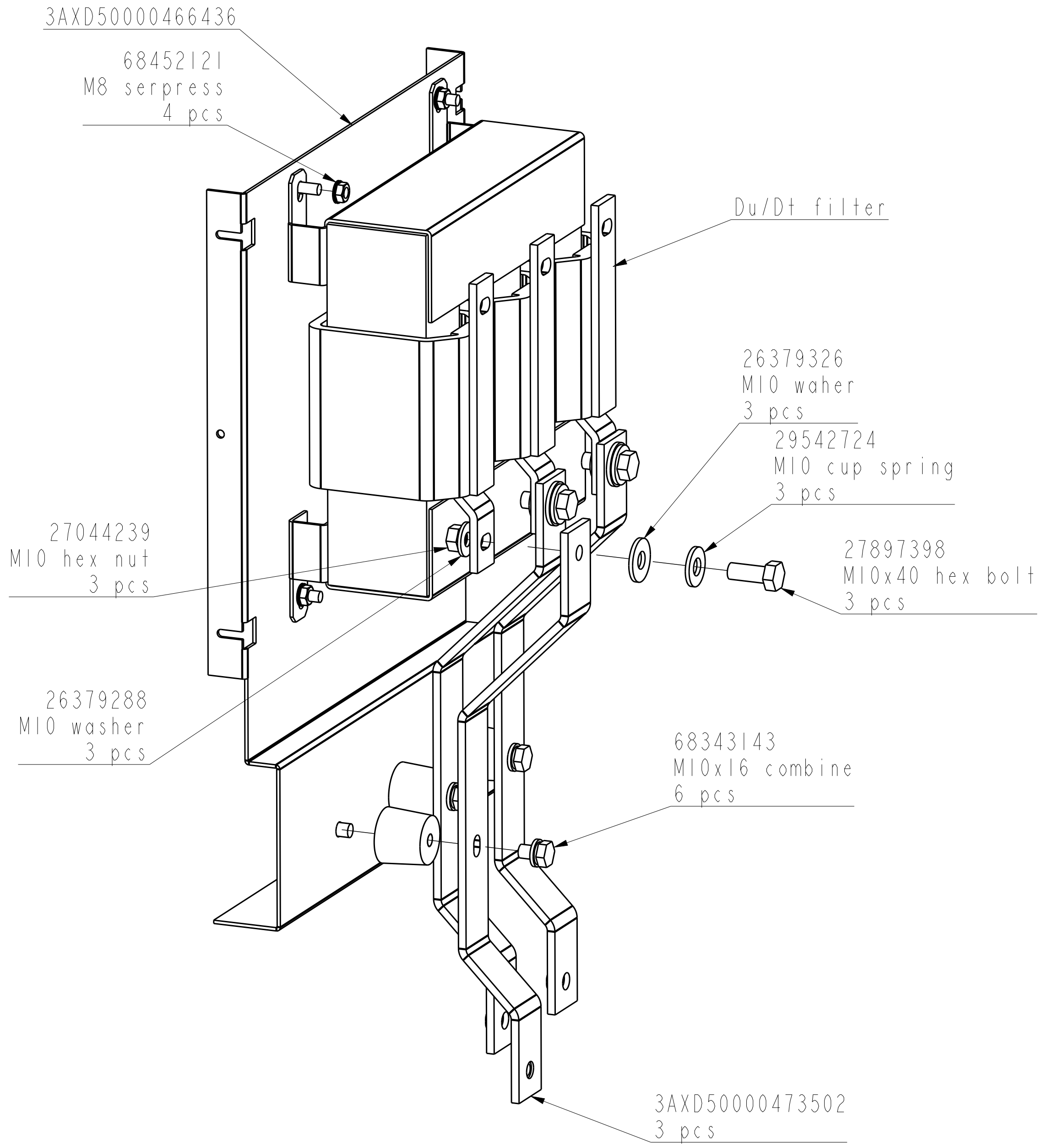
First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

IF 690 V VOLTAGE RATING



A-A





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Based on		Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING ACS880 RETROFIT FOR R9 SINGLE DRIVE
Customer		Check.	A.Vooremaa	22-May-19	
		Appr.	N.Tervaskari	22-May-19	
Cust. Doc. No.		Project name			ABB
DMS Number	3AXD10000888015	Weight kg	623.12		

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Resp.dept.	Rev.ind. -.2 (DR)		Lang. EN
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			Total 13

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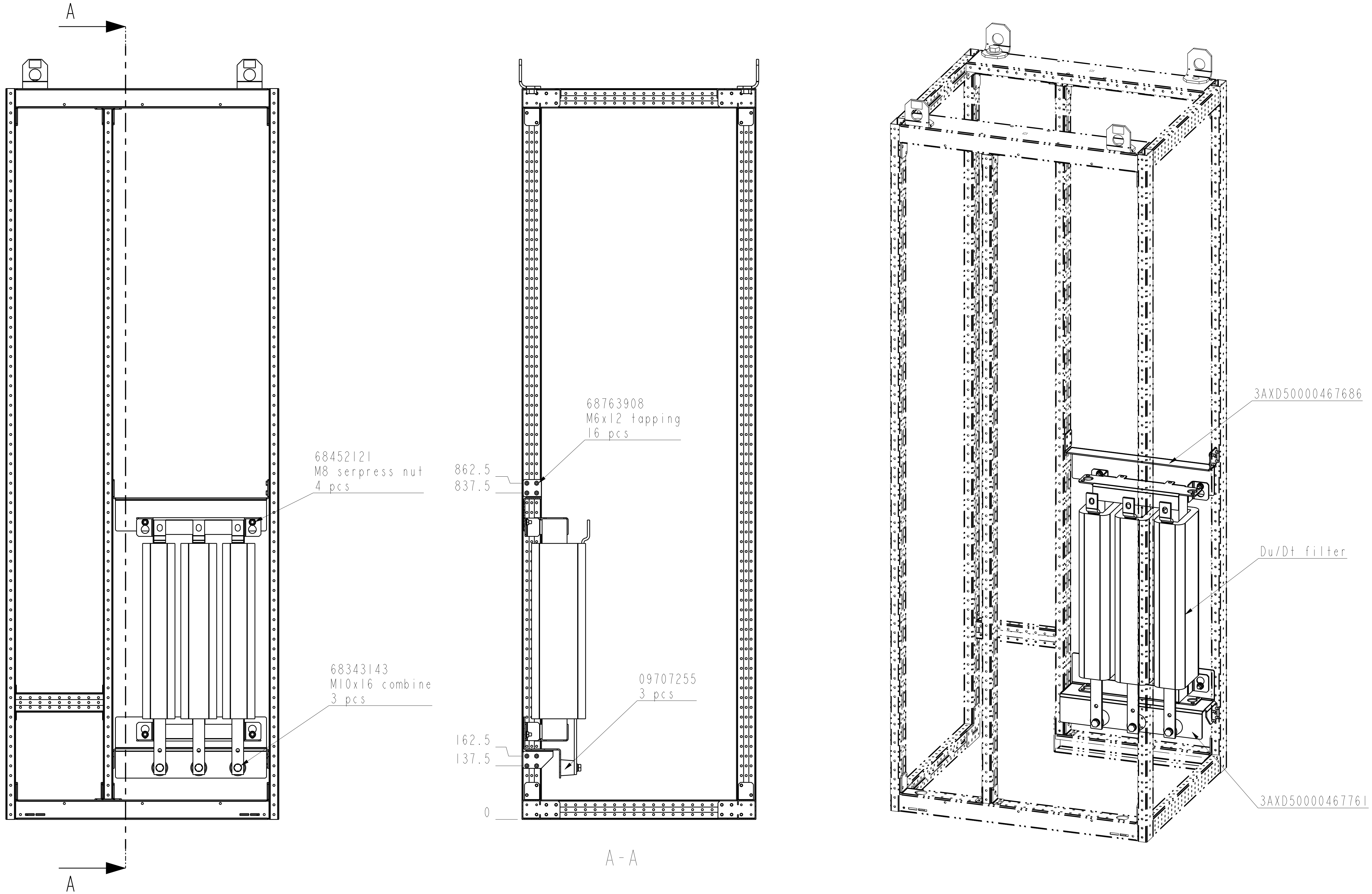
3AXD50000450411 (ASSEM)	-.6+		
A	Initial Approval	22-May-19	A.Aasamae

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

IF 400 OR 500 V VOLTAGE RATING



Based on	Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING	Doc. des. ASSEMBLY DRAWING	Scale 1:10 / Form A3
Customer	Check.	A.Vooremaa	22-May-19	ACS880 RETROFIT	Resp.dept.	Rev.ind. -.2 (DR) / Lang. EN
	Appr.	N.Tervaskari	22-May-19	FOR R9 SINGLE DRIVE		
Cust. Doc. No.	Project name			ABB	Doc. No. 3AXD50000450411	Sheet 6
DMS Number 3AXD10000888015	Weight kg	623.12				Total 13

1	2	3	4	5	6	7	8

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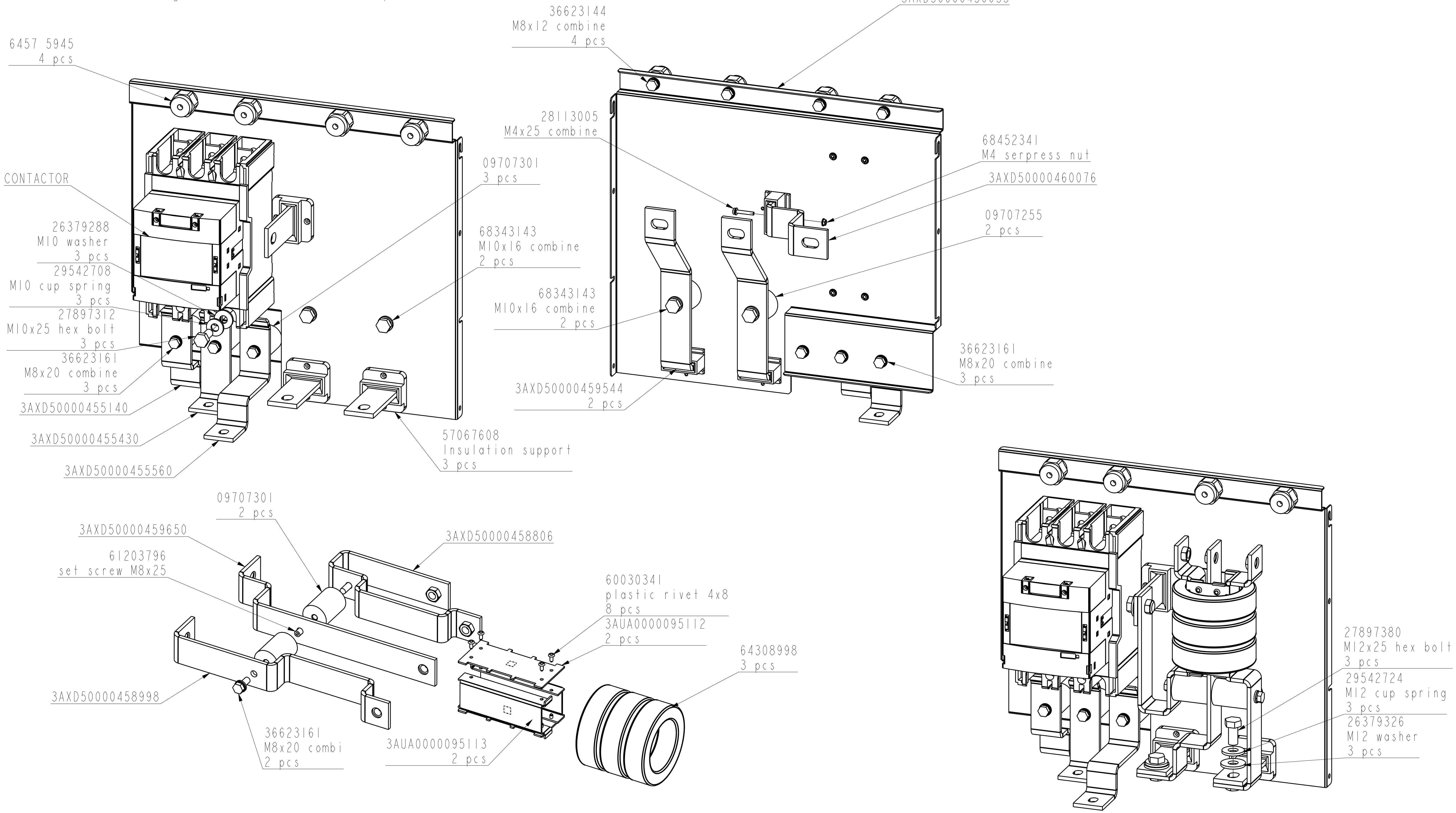
3AXD50000450411 (ASSEM)	-.6+	

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae

For mounting BUSHING INSULATORS 57067608 use 4.0 X 12 ST/ST pop rivets
For CONTACTOR mounting use bolts included with component



Based on		Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING ACS880 RETROFIT FOR R9 SINGLE DRIVE
Customer		Check.	A.Vooremaa	22-May-19	
		Appr.	N.Tervaskari	22-May-19	
Cust. Doc. No.		Project name			ABB
DMS Number	3AXD10000888015	Weight kg	623.12		

Doc. des. ASSEMBLY DRAWING	Scale 1:5	Form A3	
Resp.dept.	Rev.ind. -.2 (DR)		Lang. EN
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			Total 13

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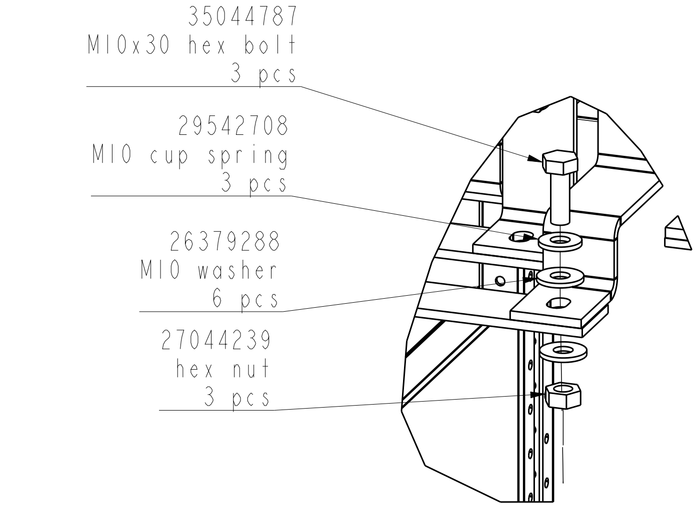
3AXD50000450411 (ASSEM)	-.6+	

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae



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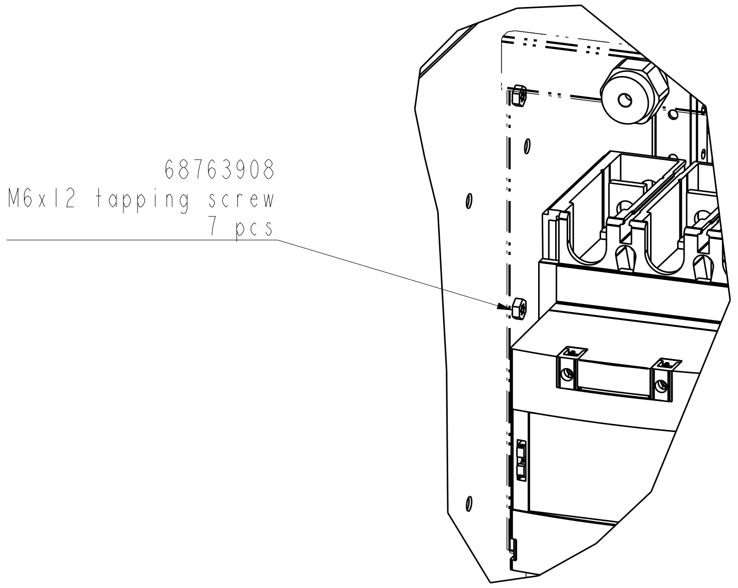

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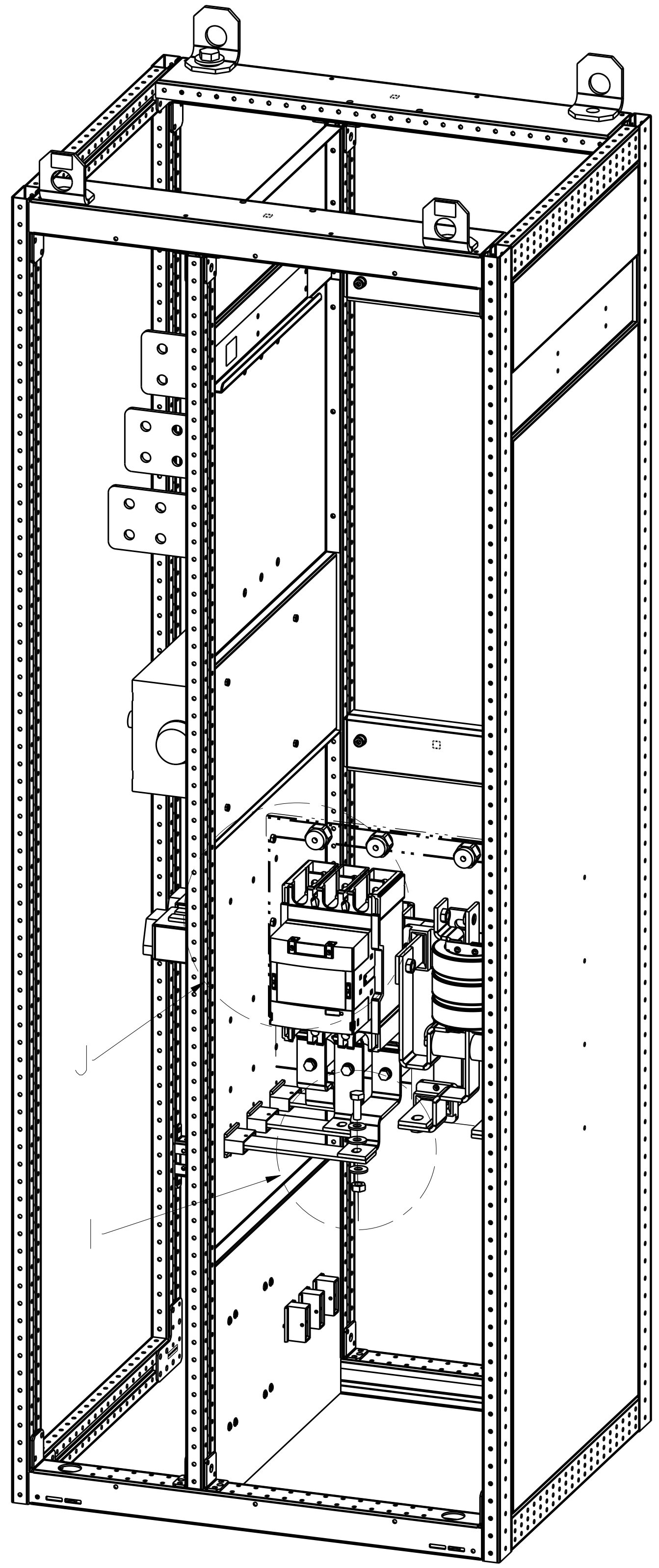

Based on		Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING ACS880 RETROFIT FOR R9 SINGLE DRIVE
Customer		Check.	A.Vooremaa	22-May-19	
		Appr.	N.Tervaskari	22-May-19	
Cust. Doc. No.		Project name			ABB
DMS Number	3AXD10000888015	Weight kg	623.12		

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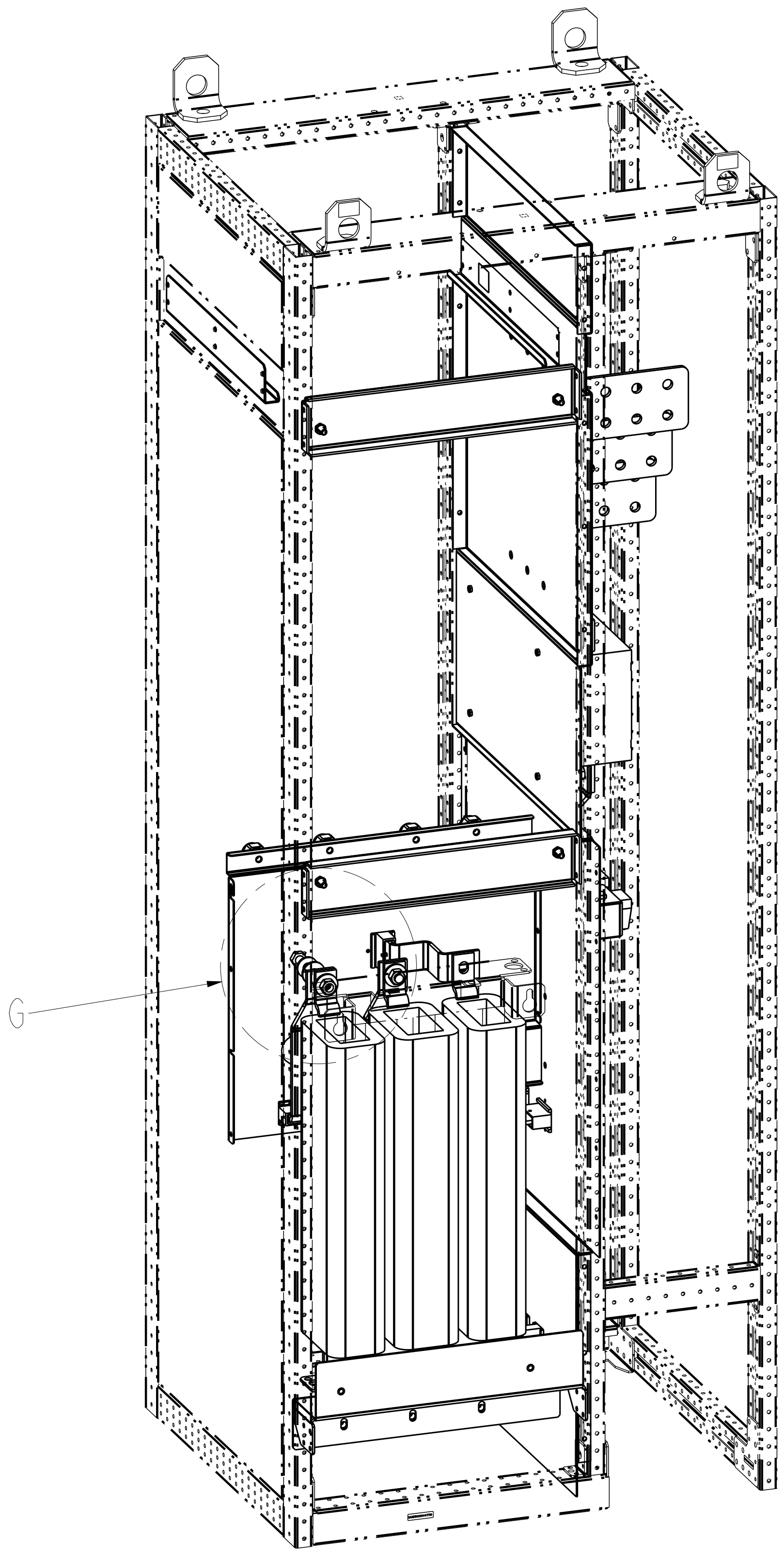
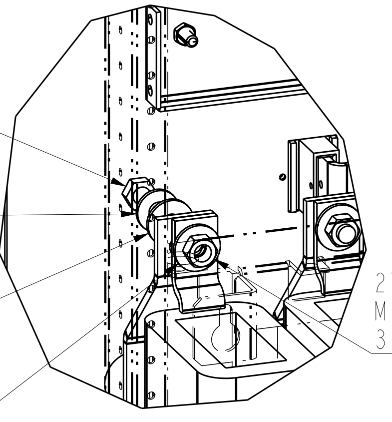
3AXD50000450411	-.2+		
3AXD50000450411 (ASSEM)	-.6+		
A	Initial Approval	22-May-19	A.Aasamae

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

IF 400V or 500V SETUP





G
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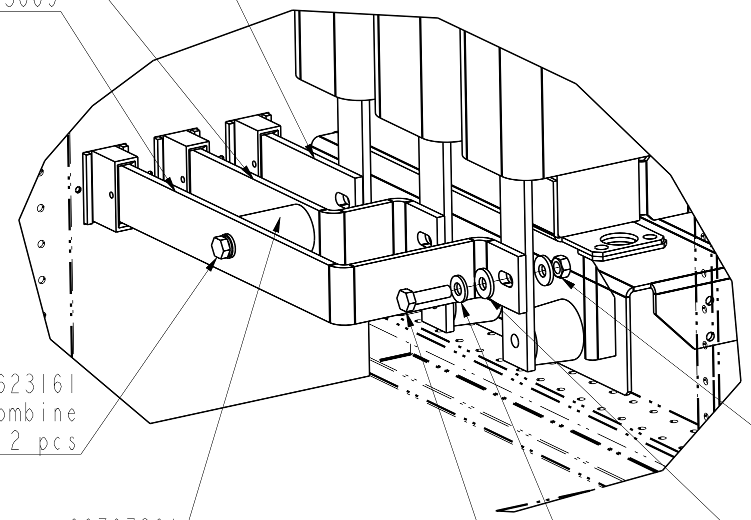

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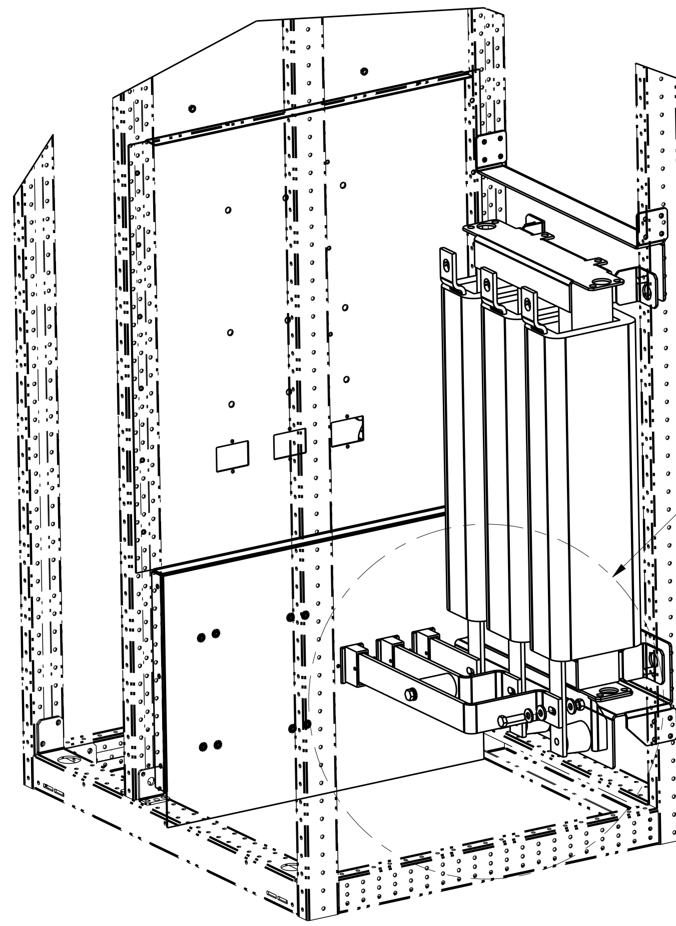

Based on	Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING
Customer	Check.	A.Vooremaa	22-May-19	ACS880 RETROFIT
	Appr.	N.Tervaskari	22-May-19	FOR R9 SINGLE DRIVE
Cust. Doc. No.	Project name			ABB
DMS Number 3AXD10000888015	Weight kg 623.12			

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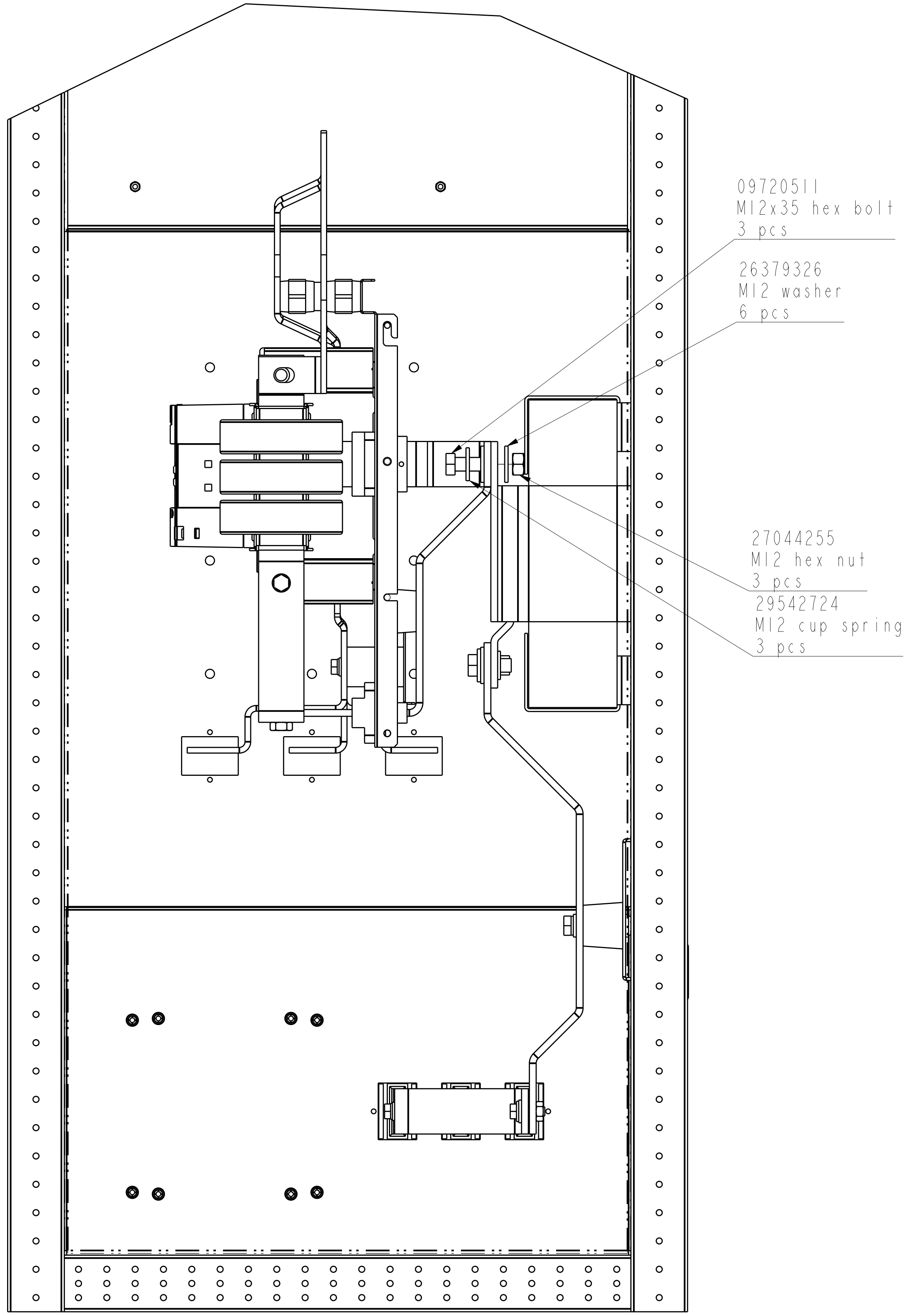
3AXD50000450411	-.2+					
3AXD50000450411 (ASSEM)	-.6+					
A	Initial Approval		22-May-19	A.Aasamae		

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

IF 690V SETUP



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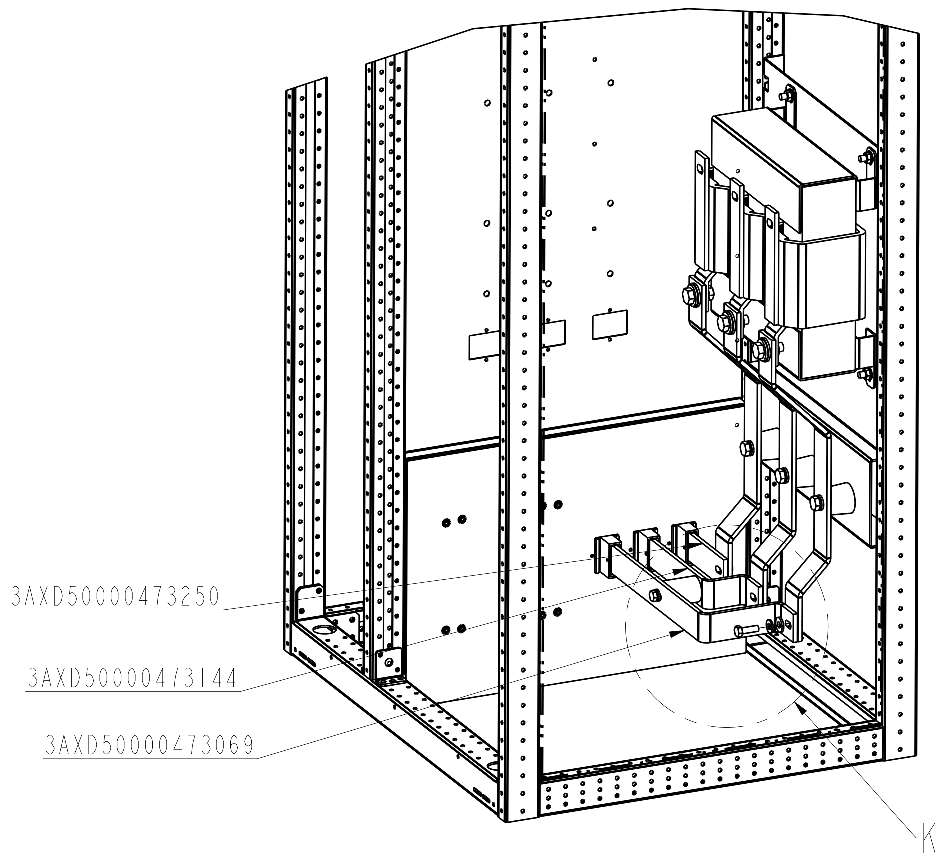

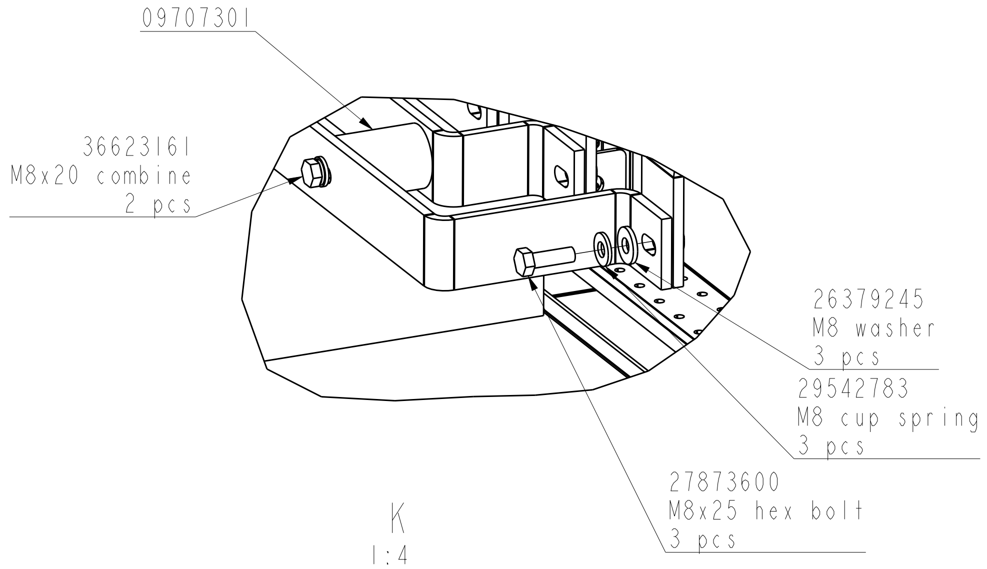

K
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Based on		Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING
Customer		Check.	A.Vooremaa	22-May-19	ACS880 RETROFIT
		Appr.	N.Tervaskari	22-May-19	FOR R9 SINGLE DRIVE
Cust. Doc. No.		Project name			ABB
DMS Number	3AXD10000888015	Weight kg	623.12		

Doc. des. ASSEMBLY DRAWING	Scale 1:10	Form A3	
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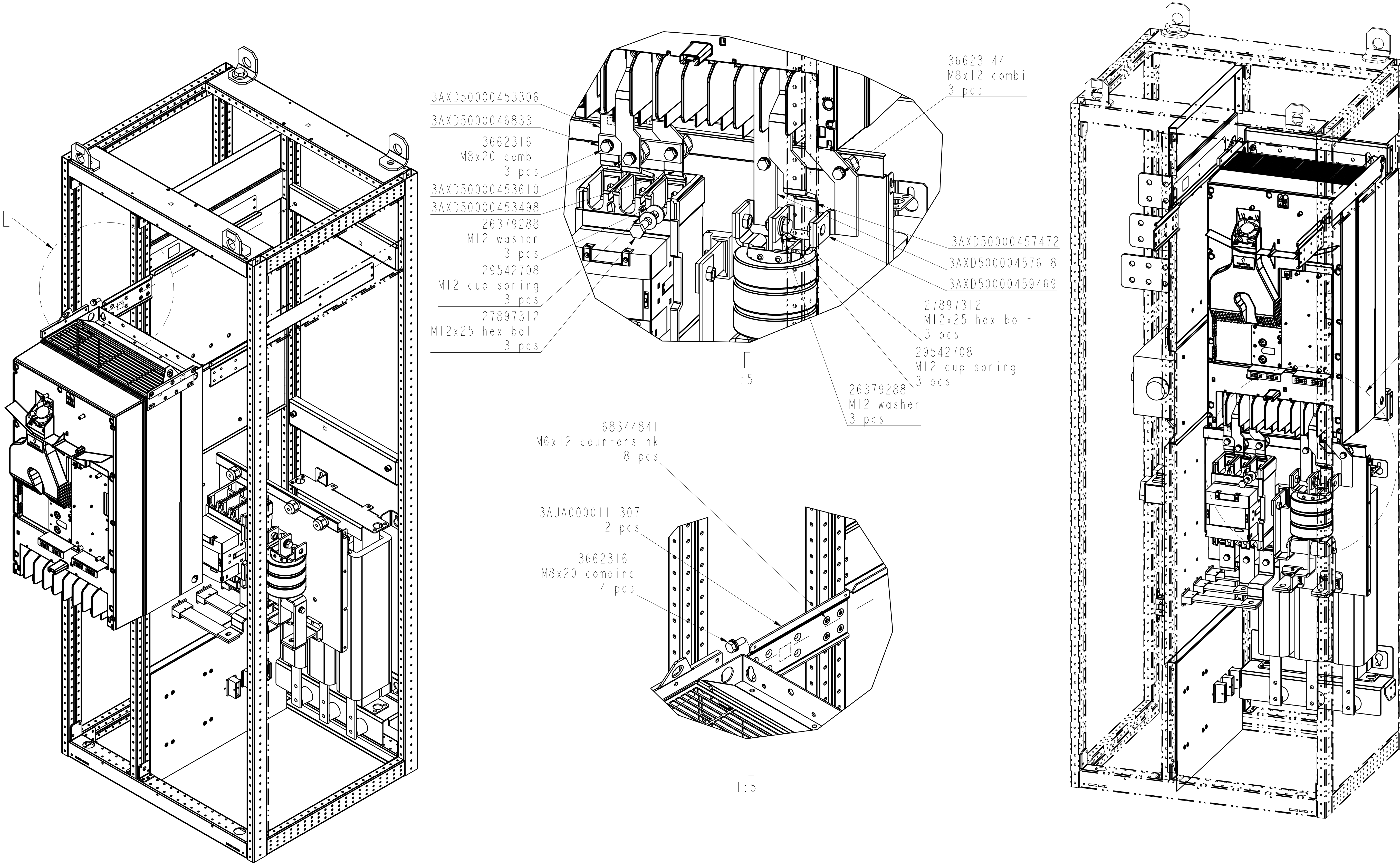
3AXD50000450411	-.2+
3AXD50000450411 (ASSEM)	-.6+

First angle projection. Original drawing made with 3D CAD. Set the correct scale factor when adding dimensions after DWG/DXF conversion.

A	Initial Approval		22-May-19	A.Aasamae



Based on	Prepared	A.Aasamae	22-May-19	Title ASSEMBLY DRAWING
Customer	Check.	A.Vooremaa	22-May-19	ACS880 RETROFIT
	Appr.	N.Tervaskari	22-May-19	FOR R9 SINGLE DRIVE
Cust. Doc. No.	Project name			ABB
DMS Number 3AXD10000888015	Weight kg	623.12		

Doc. des. ASSEMBLY DRAWING	Scale 1:10	Form A3	
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3AXD50000450411 (ASSEM)	-.6+	

A	Initial Approval		22-May-19	A.Aasamae

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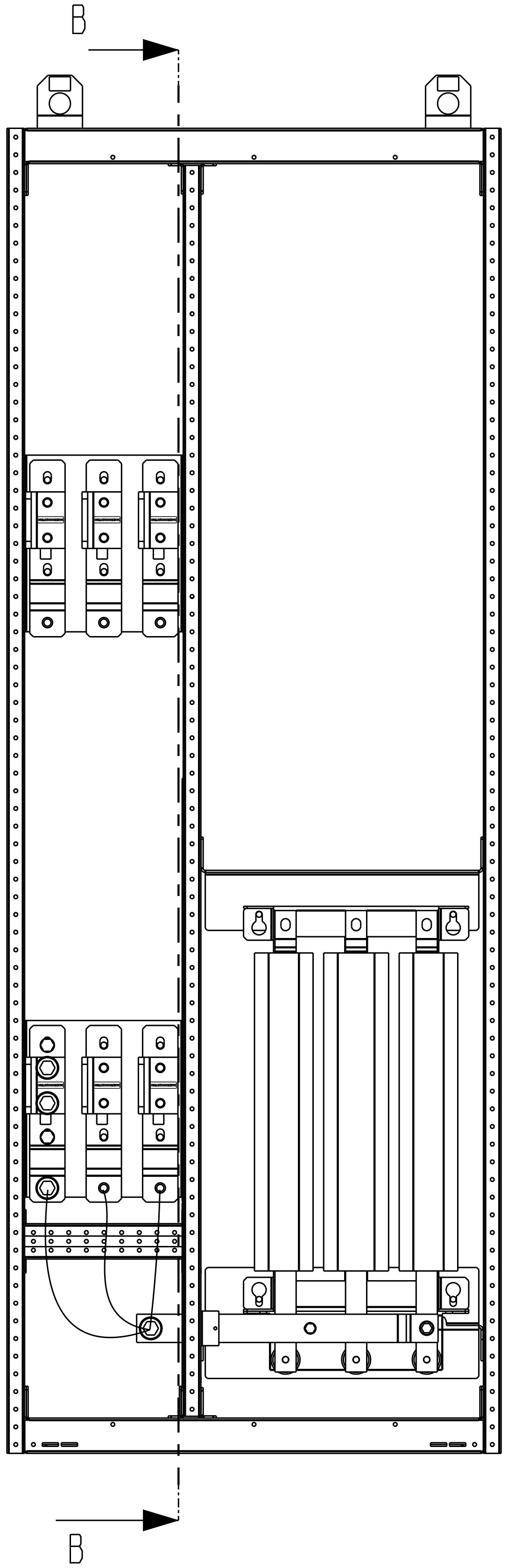

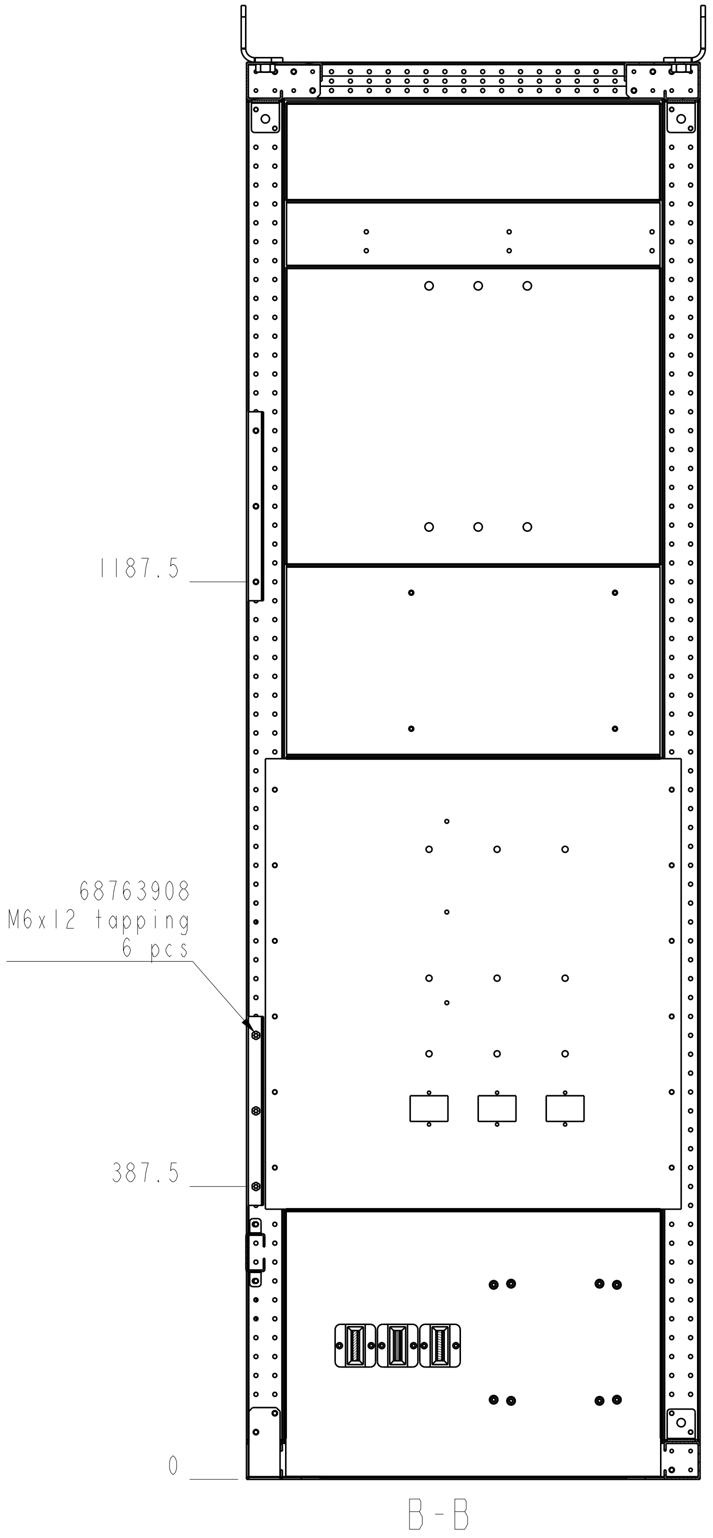

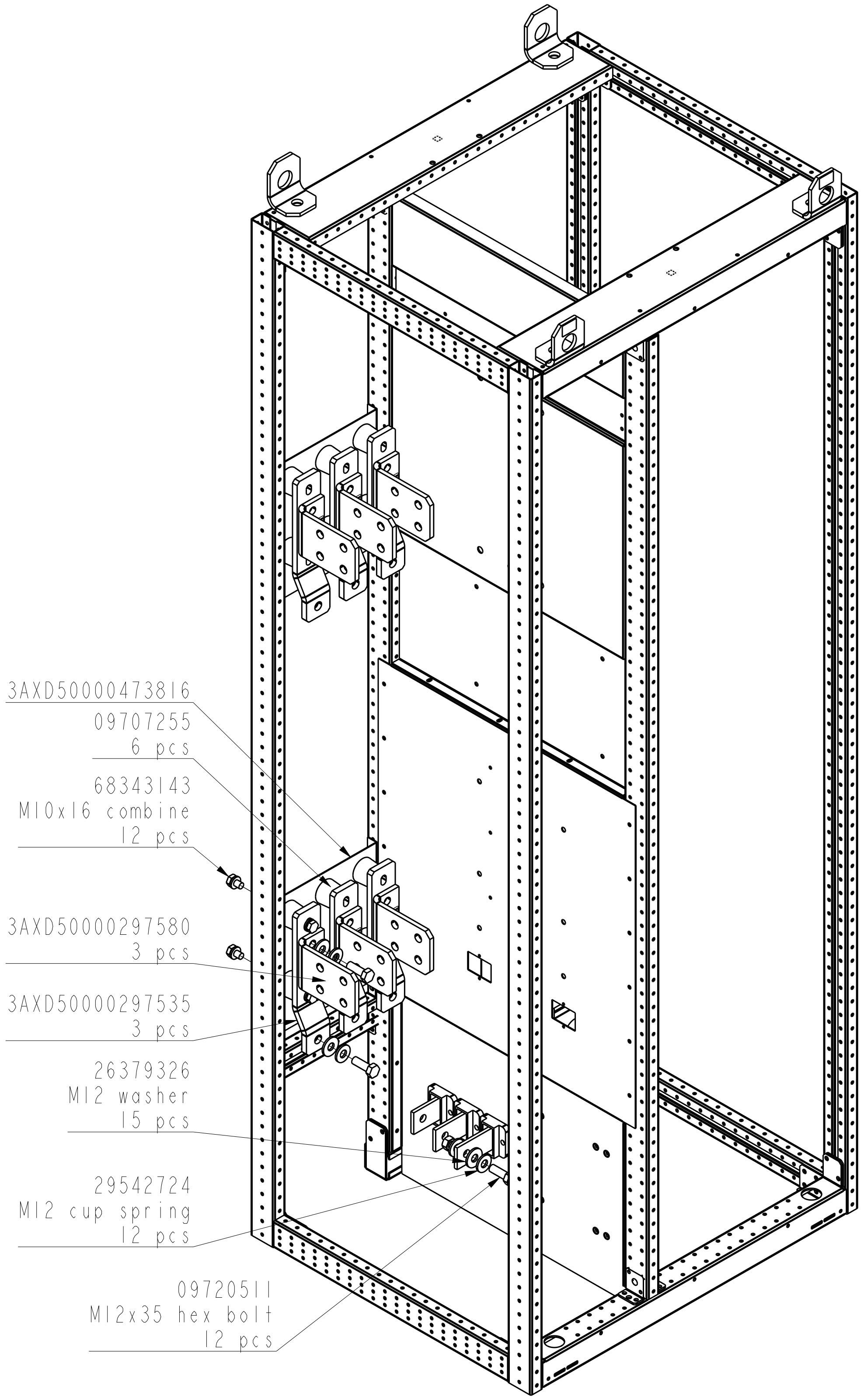

Connect output terminals to output bus bars with copper cables
CROSS SECTION 95 mm^2

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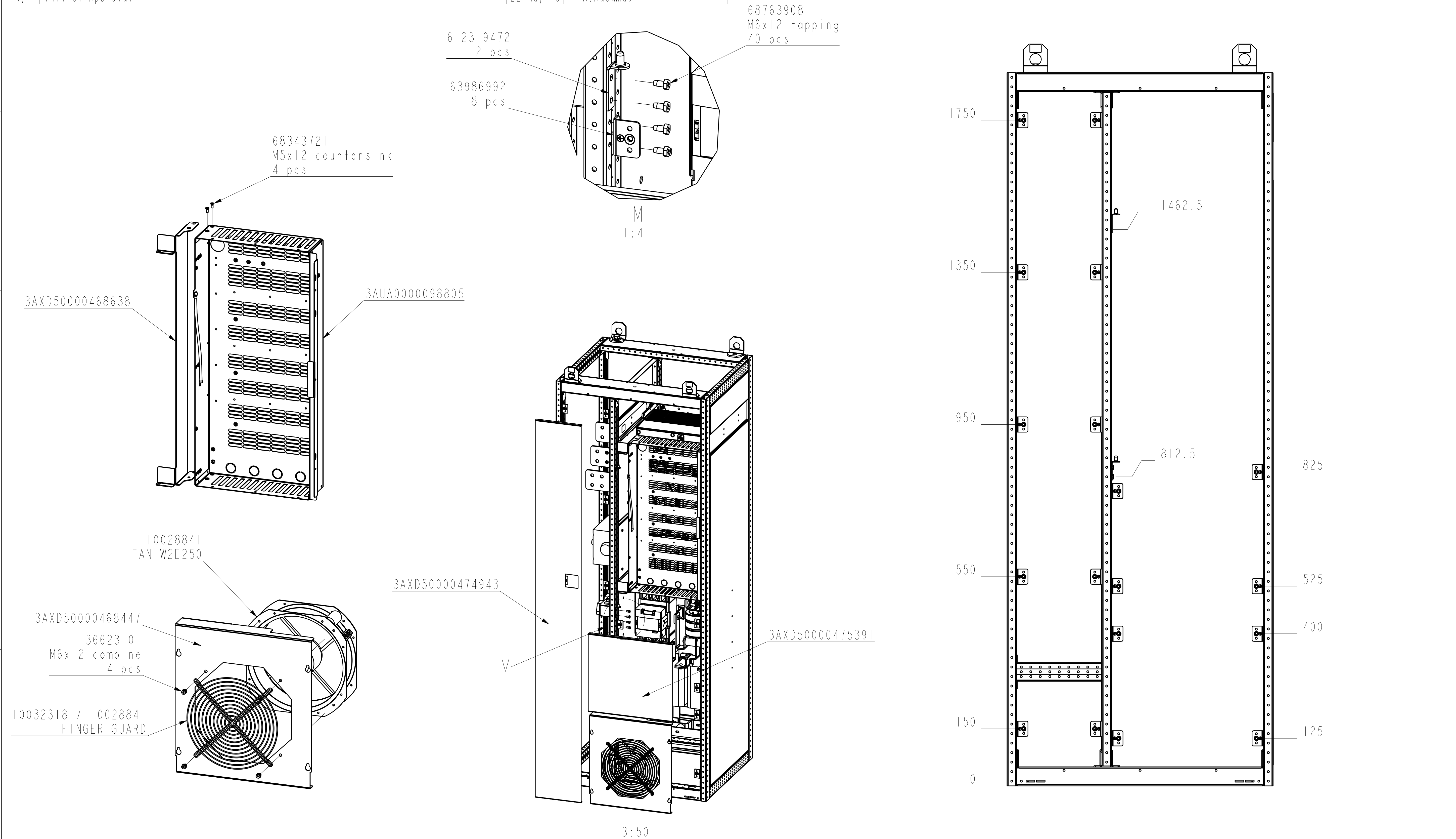

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