ACS 6000AD

Power Cables Specification

In this document, three types of cables are specified.

Chapter 1 specifies ARU (Active Rectifier Unit) and INU (INverter Unit) cables. Power-cables for the connections between ARU and transformer as well as INU and machine have to fulfill these requirements.

Chapter 2 specifies 12p LSU (Line Supply Unit) cables. As the demands to 12p LSU cables are weaker than those of ARU/INU cables it is possible to realize all power connections with ARU/INU cables.

Chapter 3 specifies BCU (Braking Chopper Unit) cables. Power-cables for the connections between BCU and braking resistor have to fulfill these specified demands.

Contents

1 Specification of power cables for INU/ARU-power modules

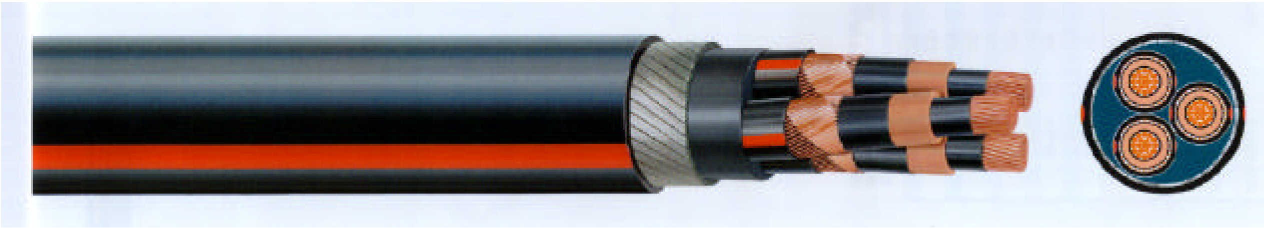
1.1 General requirements

Topic	Notation	Value / Description	Unit	Comment
Converter type		3-level voltage source inverter		
Rated voltage (fundamental)	U_1	3300	V	
Max. voltage slope	du/dt_{max}	< 3	kV/µs	1.
Cable insulation		6 (nominal) / 10 (peak)	kV	
Max. cable length	l_{max}	300	m	2.
Max. number of parallel cables		4 or 8		3.
Derating factors			%	4.
Total equivalent cable shield cross section	∅ Shield	0.5 x cross section of one phase conductor	mm^2	
Shield current		$I_{peak} = 250$, $I_{rms} = 20$	A	

Required cable is provided with the following general characteristics:

- Screened cables are mandatory. The screen provides potential grading and limiting of the electrical field (EMC requirements), conduction of grounding and common-mode currents as well as touch protection.
- Three-phase cables with individually shielded conductors are the preferred solution (compensation of the field). In case of short cables (< 100m), it is possible to use single-phase cables only if they are installed in triangle (see paragraph “installation requirements”). Otherwise bearing currents cannot be avoided.
- A galvanized steel armor shall be used, which fulfills the function of an additional common screen (filtration of the magnetic field produced by the single cables). The armoring is mainly given from project requirements, like routing on cable trays, ducts or direct in the ground, flame retardant or resistant, vermin proof, mechanical protection of the cable.
- It is recommended to use copper conductors in order to minimize the diameter of the cables (smaller bending radius).
- If aluminum cables are used, specially coated terminations must be applied.
- The cable cross-section shall be selected such that the number of parallel conductors is minimized. It is recommended to use cables with conductor cross-section of $3x240mm^2$ and a shield of $3x35mm^2$.
- A final specification of the cable must also consider the method of installation, voltage drop due to cable length, heating from neighboring cables, maximum allowed conductor temperature or maximum ambient temperature as well as local regulations. In general we also refer to the specifications of the cable manufacturer.
- An additional grounding wire along the power cable prevents screen overloading because of potential differences in the plant. It is needed, if the cross section of the cable screens is less than 50% of the cross section of one phase conductor.

- A typical example of a cable that meets all requirements is the GKT-FT 10/6 kV type manufactured by Brugg Kabel AG in CH-5201 Brugg, Switzerland.



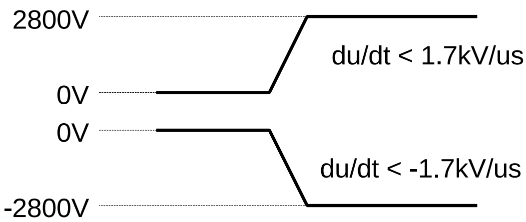
1.2 List of comments

1. Insulation requirements

Due to the operation principle of the converter (snubberless, DTC) the cable must withstand special voltage waveforms including rapid du/dt-effects and reflections. Therefore insulation for converter use has to be stronger than in sinusoidal supply, which results in a cable with nominal voltage of 6 kV and peak voltage of 10 kV. 6 kV is the maximum appearing peak voltage between core and armor during steady state operation. 10 kV is the maximum voltage that can appear during an earth fault.

- The cable insulation has to withstand:
  - Average switching frequency: 500-700 Hz on motor side, 700-900 Hz on mains side
  - Voltage pulse steps: ±2800 V at converter end
  - maximum du/dt: < 3kV/µs at motor terminals
    (this value is depending on the cabling between converter and machine)

  Maximum guaranteed converter output voltages:



- Typical insulation material:
  - EPR (Ethylene-Propylen-Rubber)
  - XLPE (Cross-linked Poly-Ethylene)

2. Maximum cable length

Long motor cables are causing oscillations to inverter output currents and to motor terminal voltages. The EMC filter is damping oscillations above ≈ 100kHz. Also the current measurement chain, realized as a cascade of filters, is designed to cut frequencies above 80kHz.

In order not to disturb the DTC control algorithm, which is based on control decisions calculated with instantaneous current, an oscillation frequency below 80kHz should be avoided. This condition is limiting the maximum possible cable length.

The cable oscillation frequency is given by the specific cable parameters (inductance, capacitance, length) and is calculated as following:

$$\text{fosc} = \frac{1}{4 \cdot \text{length} \cdot \sqrt{L' \cdot C'}}$$

With the minimum oscillation frequency of 80kHz, the maximal cable length is then given by:

$$\text{lengthmax} = \frac{1}{4 \cdot \text{foscmin} \cdot \sqrt{L' \cdot C'}} = \frac{1}{4 \cdot 80\text{kHz} \cdot \sqrt{L' \cdot C'}}$$

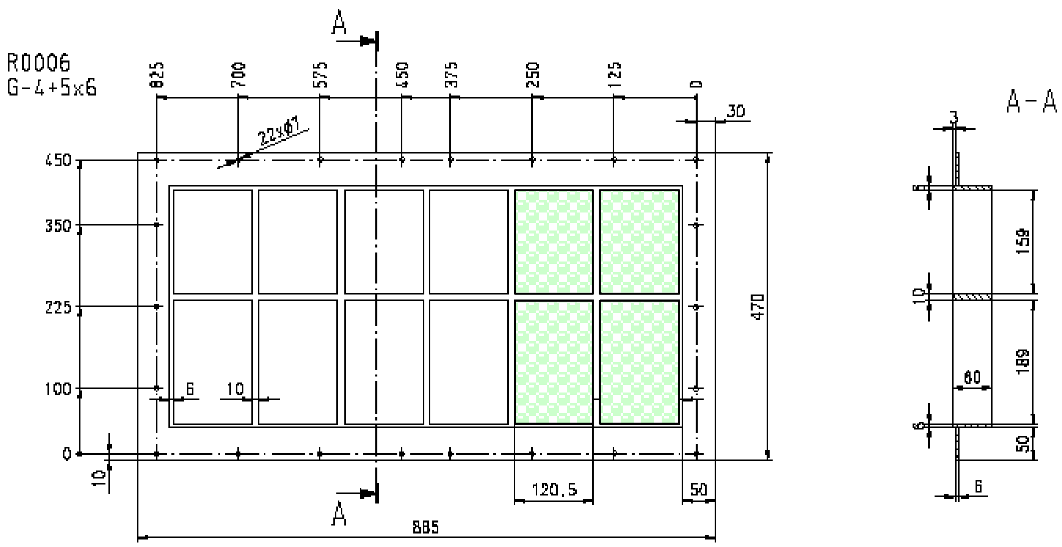
For further information refer also to chapter 1.5.

3. Maximum number of cables

For high power ratings more than one cable per phase is permitted.
For each INU/ARU power section the gland plate of the terminal unit (TEU) limits the number of parallel cables and their diameter. For each cable entry, two different frame versions are available providing different cable diameters and parallel cable number.

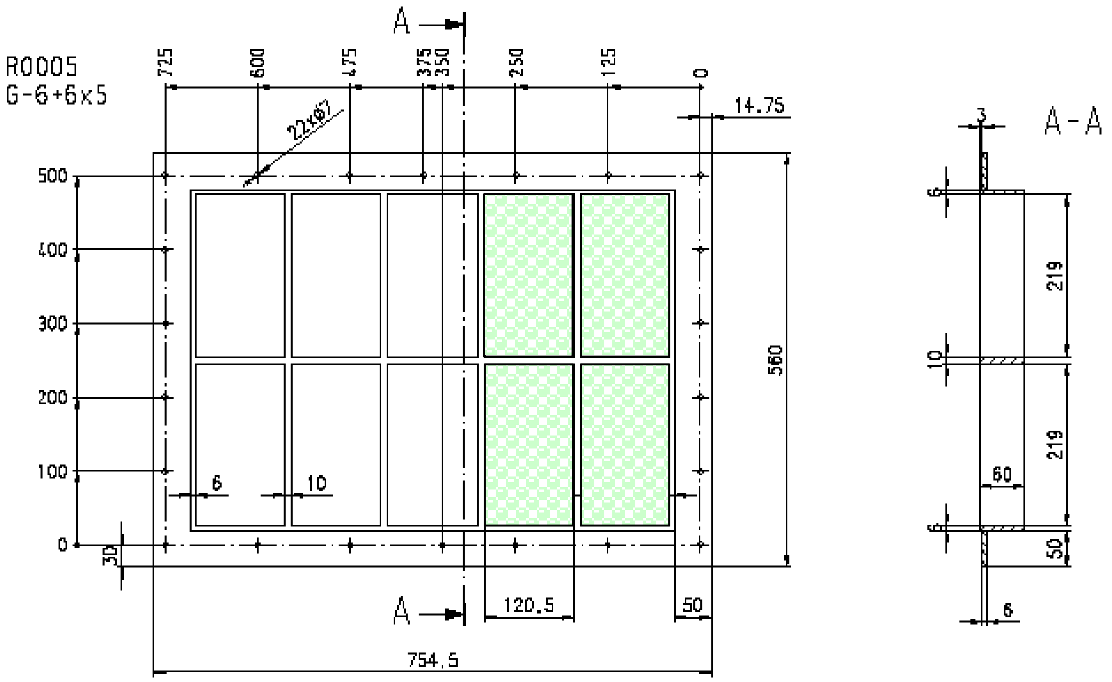
Version 1

- Maximum **4** three-core cables with a diameter of ∅ **68-99 mm**
- One cable per ROX-field
- Frame part belonging to inverter unit see colored area in picture below, white part belongs to LSU cable entry



Version 2

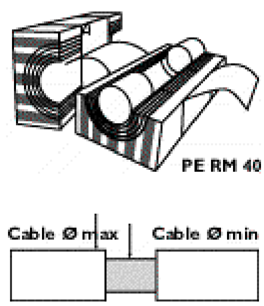
- Maximum **8** three-core cables with a diameter of ∅ **48-71 mm**
- Two cables per ROX-field
- Frame part belonging to inverter unit see colored area in picture below, white part belongs to LSU cable entry



These frames, which are delivered with the drive, can be equiped with different filler modules. The modules have to be provided from the customer. The following table shows the range of available modules:

Rox System Modules for ES (electronic shielding) and PE (potential equalization)

Module type	For Cable/pipe [mm] Ø min - max	External dim. [mm] [heightxwidthxdepth]
ES or PE RM 20	Ø 4-13,5	20x20x60
ES or PE RM 30	Ø 12-22	30x30x60
ES or PE RM 40	Ø 22-32	40x40x60
ES or PE RM 60	Ø 28-50	60x60x60
ES or PE RM 90	Ø 48-71	90x90x60
ES or PE RM 120	Ø 68-99	120X120X60



Further information about ROX-system can be obtained from: http://www.roxtec.com/power/

Thus the terminal part of each ARU/INU module can be equipped with:

- In case of frame version 1: Up to 4 modules of the type RM120
- In case of frame version 2: Up to 8 modules of the type RM 90

Additional some modules of the type RM30 for installing the earthing cables are necessary. In both versions there is space left for these additional RM30 modules.

Further information is provided in chapter 1.3.

4. Derating factors

Depending on the converter operation principle, the following derating factors have to be taken into account

Cable	Operation principle	Current rating in percents of the nominal
To motor	DTC operation	85%
To motor	Overmodulation	70%
To transformer	Optimized pulse patterns	85%

Additonal derating (see also manufacturer datasheet):

- Conversion factor of current loading capacity by varying ambient temperature (about 10% reduction per 10°C temperature rise).

  The heat dissipation per unit length of a cable in air is given by:

  $$W = a\ p\ D\left[q_s - q_a\right]^{5/4}$$

  where

  α is the heat transfer coefficient
  D is the overall diameter of the cable
  θ are the surface and ambient temperatures respectively (see index)

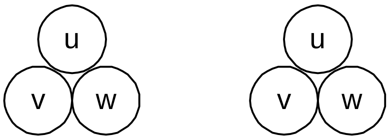
- Conversion factor of current loading capacity in case of parallel laying of cables (between 0 and 30% depending on three- or single-phase cables, diameter of cables, number of cables in parallel, distance between the cables).

  According to “Electrical Engineering Handbook”, Siemens, Heyden, for paper and plastic insulated multi cables, arranged freely in air, the following factors should be considered

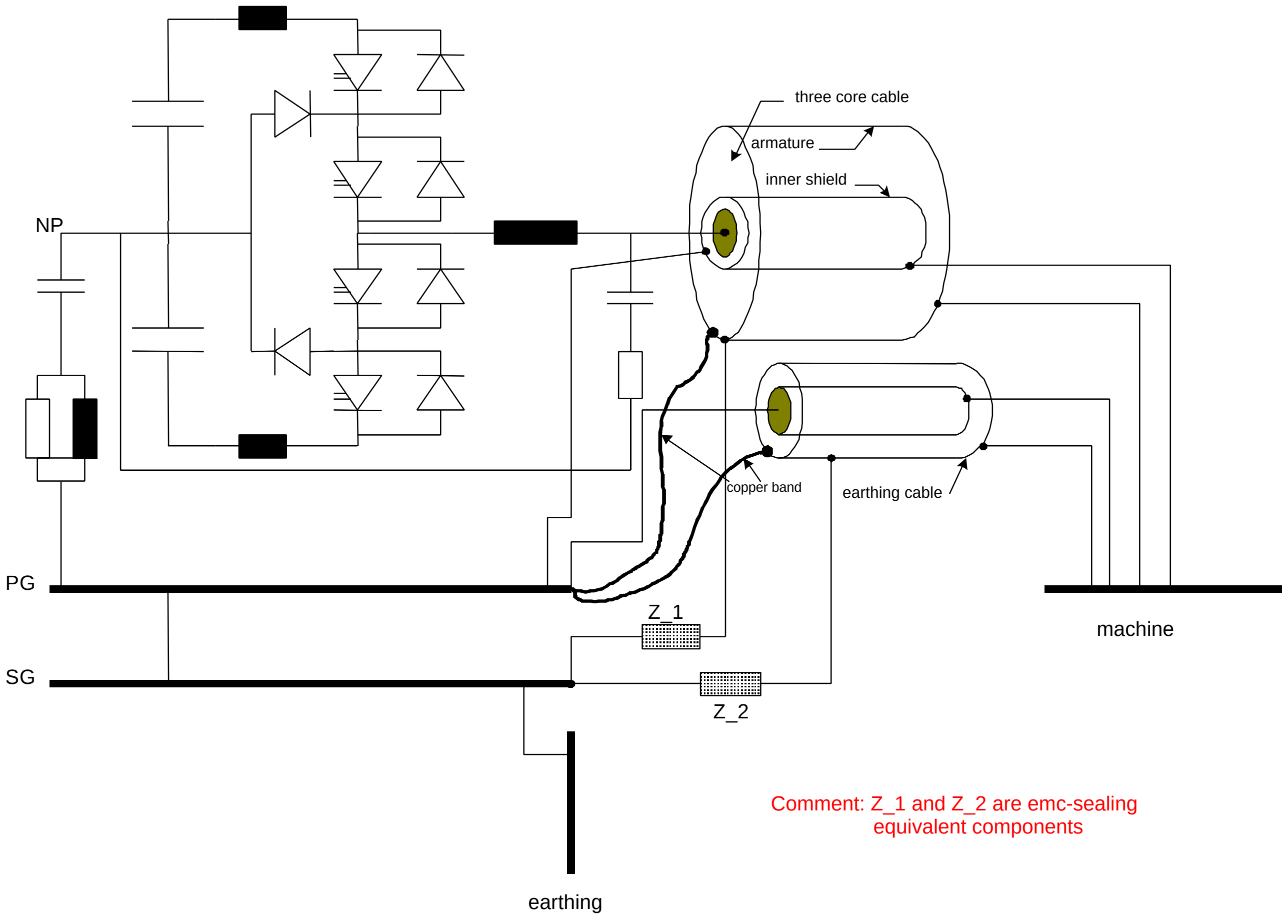
Voltage	Current rating in percents of the nominal		
	1 cable	3 cables side by side	6 cables side by side
5.8/10kV to 11.6/20kV cable spacing = cable diameter	90%	85%	80%
5.8/10kV to 11.6/20kV mutual contact		75%	70%

1.3 Installation requirements

- A single core cable as earthing cable should be installed in parallel with the motor cables in order to prevent screen overloading due to potential differences in the plant. Its cross-section is one level lower than the cross-section of one phase cable core.
- All shields and armors from the cables between transformer and converter as well as motor and converter are grounded. On motor and transformer side they are directly connected to protective earth (PE), on converter side the connection is made via the internal power ground (PG) bus bar.
- Shields shall be terminated in the terminal fields (TEU) and grounded to the Power-Ground (PG) which is provided within the same cable connection section. Also the armoring is grounded to PG.
- In case single-phase cables are used, they need to be installed in triangle. Otherwise, this will result in bearing currents.



etc.



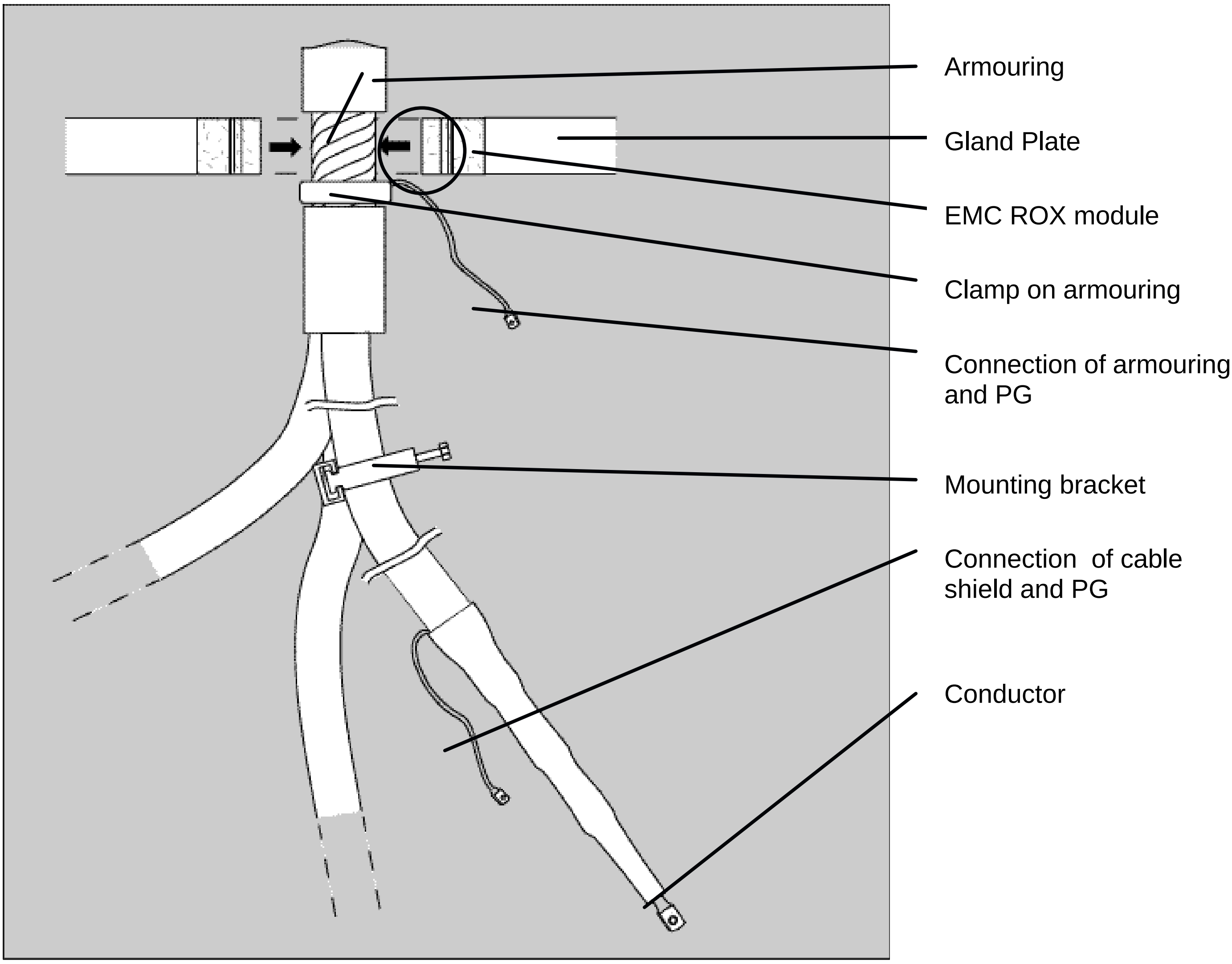
1.3.1 Standard solution for cable entry with ROX system

Mains and motor cables lead-through is from below or top of the TEU cabinets (must be specified at time of order). The special gland plate into which the EMC ROX modules are inserted is pre-mounted on top or at the base of the terminal unit.

The bare armors must be in contact with the EMC ROX modules as shown in the figure below. If cables without armor are used, the cable screens must contact the EMC ROX modules. Cables without screens are not allowed.

Cables must not touch the terminals of any other phase. A minimum clearance of 40mm must be maintained between each cable and the terminals of any other phase.

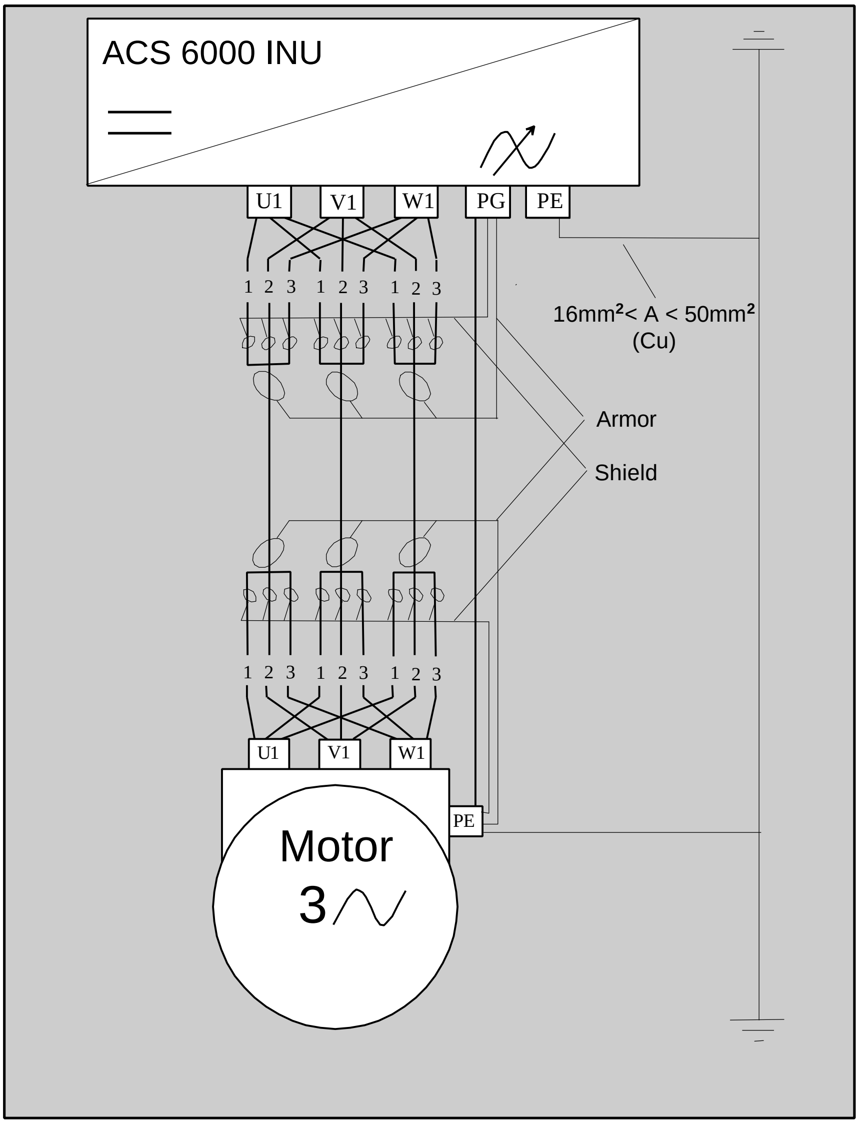
The minimum required creep-distance is guaranteed with the distances between the individual terminals.



1.3.2 Optional solution for cable entry with aluminum-blanking plate

Instead of the standard cable entry with the ROX system, an aluminum blanking plate is available. In this case the customer has to take responsibility for EMC requirements and the mechanical fixtures of the cables. With this solution, the maximum possible number of cables does not increase.

1.3.3 Cable installation between converter and machine

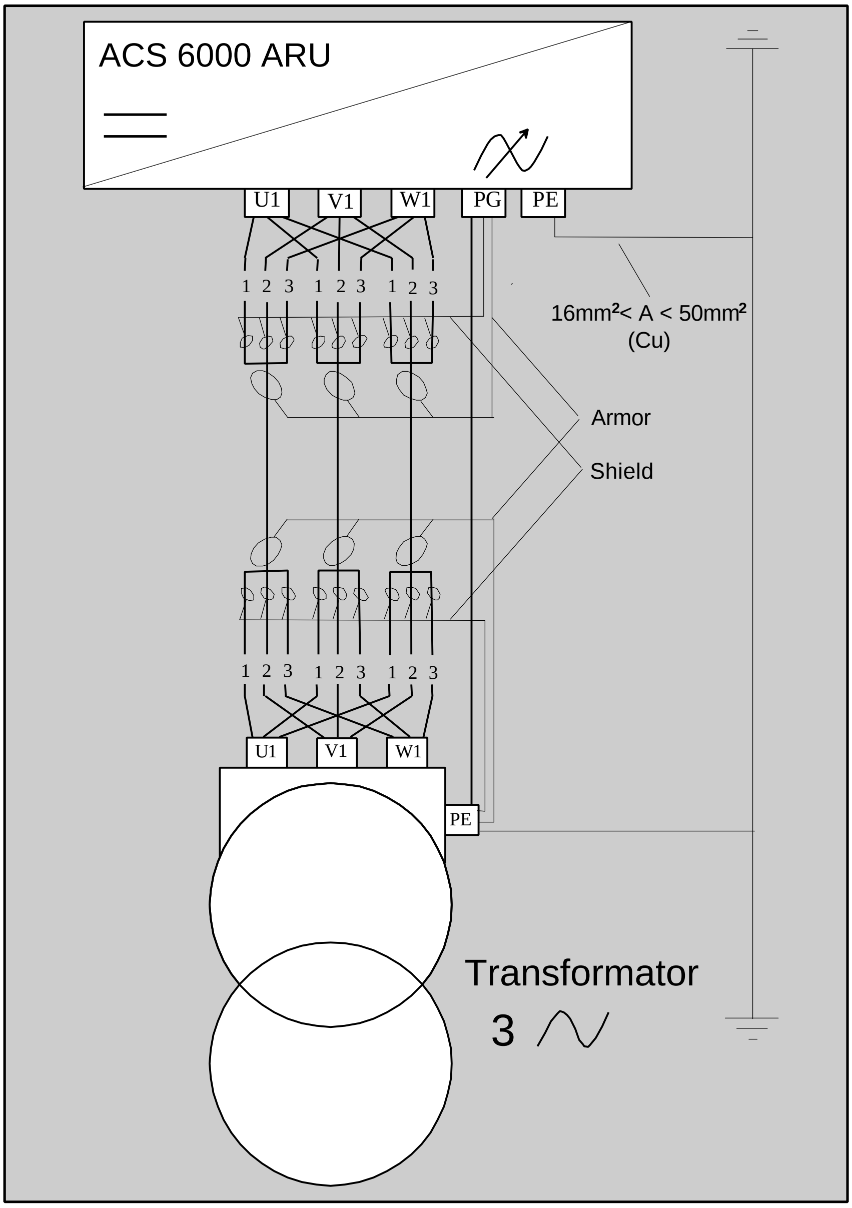


The picture presents a typical installation with three parallel 3-core-cables and an additional grounding cable.

All shields and armors on converter side are connected to power ground (PG), shields and armors on motor side are connected to protective earth (PE).

The converter itself is grounded only once to protective earth (PE).

1.3.4 Cable installation between transformer and converter with ARU



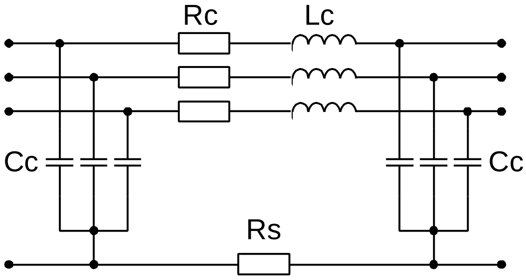
The picture presents a typical installation with three parallel 3-core-cables and an additional grounding cable.

All shields and armors on converter side are connected to power ground (PG), shields and armors on transformer side are connected to protective earth (PE).

The converter itself is grounded only once to protective earth (PE).

1.4 Shield current

The shield current requirement has been determined by simulation. The simulations were performed with a series of π-models as shown below.



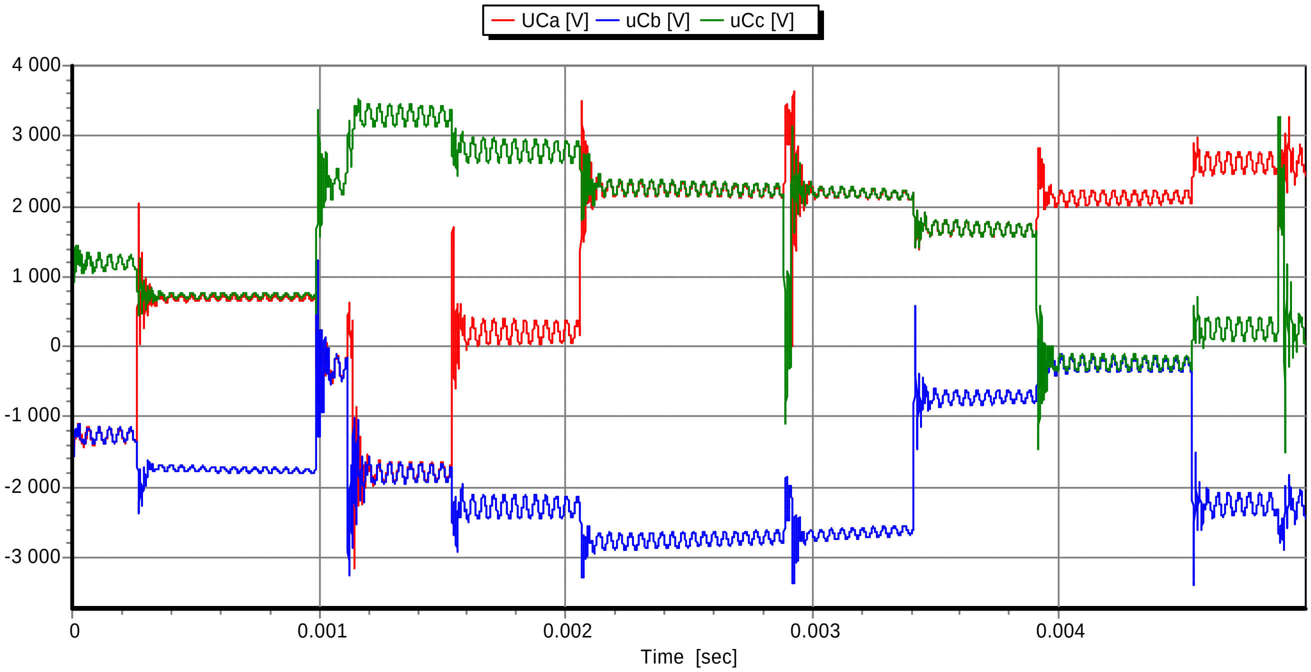
1.4.1 Shield currents simulation results

Configuration with 2x300m cables (3-phase, 240mm^2)

Cable voltage on converter end: du/dt_{max} = 1120V/µs

The maximum expected voltage gradient at the converter output is 1700V/µs. This value varies a little because of the influence of the cable capacitance. The bigger the capacitance, the smaller is the voltage gradient.
Due to reflection effects, the maximum possible du/dt can reach values up to 3000V/µs at the machine end.

Simulation results of typical cable voltages (phase voltage) on converter end are shown below.



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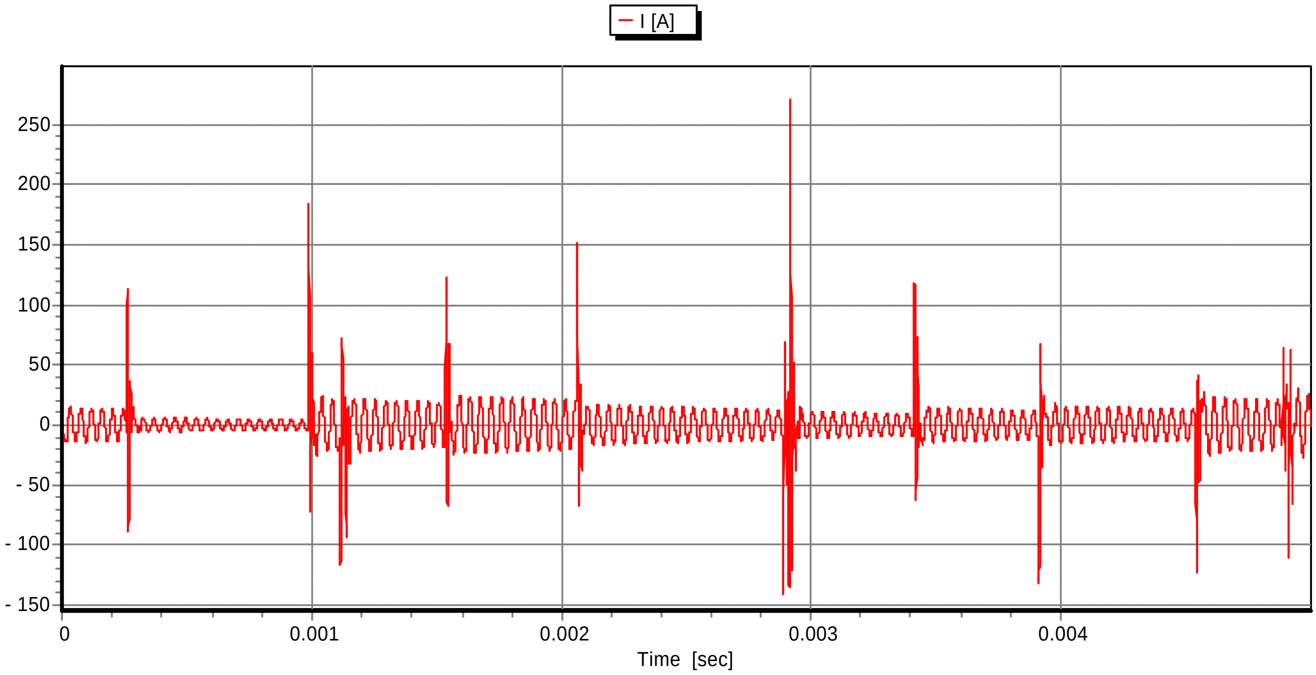
Simulation result of typical shield current:



The RMS value of the shield current is about 20A. Current peaks up to 250A are to be expected.

1.5 Selection of cables

The cable oscillation frequency depends on cable characteristics (inductance, capacitance and length).

$$fosc = \frac{1}{4 \cdot length \cdot \sqrt{L'C'}}$$

Due to restrictions from control, the minimum allowed oscillation frequency is 80kHz. With known cable parameters and cable length it can easily be checked whether a certain type of cable fits to the application.

With the minimum allowed oscillation frequency of 80kHz, for a certain type of cable the maximum possible cable length is given by:

$$lengthmax = \frac{1}{4 \cdot foscmin \cdot \sqrt{L'C'}} = \frac{1}{4 \cdot 80kHz \cdot \sqrt{L'C'}}$$

For a selection of different cables, these values have been calculated. The results are shown in the following tables.

In column **fosc** the oscillation frequency is calculated, dependent on the characteristic inductance and characteristic capacitance of the cable and the cable length.

In column **max. length** the maximum allowed length of the cable is calculated, dependent on the characteristic inductance and characteristic capacitance of the cable.

*Selection of **1-phase** cables (undesirable solution)*

Manufacturer	Type	Conductor	cross-section [mm2]	l cable [nH/m]	c cable [pF/m]	lc [m]	**fosc [kHz]**	**max. length [m]**
Brugg	GKT 6/10kV	Copper	95	697	420	100	**146.1**	**180**
	vernetzte EPR-Insulation		120	675	460	100	**141.9**	**175**
	catalog values		150	653	490	100	**139.8**	**172**
			185	630	550	100	**134.3**	**165**
			240	602	620	100	**129.4**	**159**
			300	583	680	100	**125.6**	**155**
Dättwiler	XE2213 XKDT 6/10kV	Copper	95	367	395	100	**207.6**	**256**
	XLPE-Insulation		120	351	439	100	**201.4**	**248**
	catalog values		150	341	475	100	**196.4**	**242**
			185	329	518	100	**191.5**	**236**
			240	319	583	100	**183.3**	**226**
			300	306	639	100	**178.8**	**220**
Dättwiler	XE2213 XKDT 6/10kV	Copper	95	367	299	100	**238.7**	**294**
	XLPE-Insulation		120	351	329	100	**232.6**	**287**
	calculated values		150	341	358	100	**226.3**	**279**
			185	329	392	100	**220.1**	**271**
			240	319	438	100	**211.5**	**261**
			300	306	484	100	**205.4**	**253**
Studer	GKT 6/10kV	Copper	95	350	432	100	**203.3**	**250**
	EPR-Insulation		120	340	475	100	**196.7**	**242**
	catalog values		150	330	518	100	**191.2**	**236**
			185	320	562	100	**186.4**	**230**
			240	310	637	100	**177.9**	**219**
			300	300	691	100	**173.6**	**214**
Nokia	HXCMK 6/10kV	Copper	120	370	330	100	**226.2**	**279**
	XLPE-Insulation		185	340	390	100	**217.1**	**267**
	catalog values		300	320	480	100	**201.7**	**249**

*Selection of **3-phase** cables*

Manufacturer	Type	Conductor	cross-section [mm2]	l cable [nH/m]	c cable [pF/m]	lc [m]	**fosc [kHz]**	**max. length [m]**
Brugg	GKT 6/10kV	Copper	95	350	420	300	**68.7**	**254**
	vernetzte EPR-Insulation		120	341	460	300	**66.5**	**246**
	catalog values		150	331	490	300	**65.4**	**242**
			185	325	550	300	**62.3**	**230**
			240	312	620	300	**59.9**	**221**
			300	312	660	300	**58.1**	**215**
Brugg	GKT 6/10kV	Copper	95	350	305	300	**80.7**	**298**
	vernetzte EPR-Insulation		120	341	332	300	**78.3**	**289**
	calculated values		150	331	362	300	**76.1**	**281**
			185	325	393	300	**73.7**	**273**
			240	312	436	300	**71.4**	**264**
			300	312	477	300	**68.3**	**252**
Dättwiler	XKDT -FT 6/10kV	Copper	95	345	395	300	**71.4**	**264**
	XLPE-Insulation		120	336	439	300	**68.6**	**254**
	catalog values		150	325	475	300	**67.1**	**248**
			185	314	518	300	**65.3**	**241**
			240	305	583	300	**62.5**	**231**
			300	295	639	300	**60.7**	**224**
Dättwiler	XKDT -FT 6/10kV	Copper	95	345	299	300	**82.0**	**303**
	XLPE-Insulation		120	336	329	300	**79.3**	**293**
	calculated values		150	325	358	300	**77.3**	**286**
			185	314	392	300	**75.1**	**278**
			240	305	438	300	**72.1**	**266**
			300	295	385	300	**78.2**	**289**
Studer	GKT-F 6/10kV	Copper	95	350	432	300	**67.8**	**250**
	EPR-Insulation		120	340	475	300	**65.6**	**242**
	catalog values		150	330	518	300	**63.7**	**236**
			185	320	562	300	**62.1**	**230**
			240	310	637	300	**59.3**	**219**
Nokia	AHXCMK 6/10kV	Aluminum	95	310	320	300	**83.7**	**309**
	XLPE-Insulation		120	310	340	300	**81.2**	**300**
	catalog values		150	310	370	300	**77.8**	**288**
			185	300	410	300	**75.1**	**278**
			240	280	460	300	**73.4**	**271**
			300	270	510	300	**71.0**	**262**

Cable data are taken from TN IU 970371 “Vergleich von Kabeldaten” by Dr. Ch. Stulz.

2 Specification of power cables for 12p LSU-modules

2.1 General requirements

Topic	Notation	Value / Description	Unit	Comment
Converter type		12 pulse diode bridge		
Rated voltage (fundamental)	U_1	1700	V	
Cable insulation		3.3 (nominal) / 6 (peak)	kV	
Max. cable length	l_{max}	300	m	
Max. number of parallel cables		8 or 12		1.
Derating factors			%	2.
Total equivalent cable shield cross section	∅ Shield	0.5 x cross section of one phase conductor	mm^2	
Shield current		I_{peak} = 100, I_{rms} = 10	A	

Required cable is provided with the following general characteristics:

- Screened cables are mandatory. The screen provides potential grading and limiting of the electrical field (EMC requirements), conduction of grounding and common-mode currents as well as touch protection.
- Three-phase cables with individually shielded conductors or shielded single-phase cables can be used. Single-phase cables should be installed in triangle (see paragraph “installation requirements”).
- A galvanized steel armor shall be used, which fulfills the function of an additional common screen (filtration of the magnetic field produced by the single cables). The armoring is mainly given from project requirements, like routing on cable trays, ducts or direct in the ground, flame retardant or resistant, vermin proof, mechanical protection of the cable.
- An additional grounding wire along the power cable prevents screen overloading because of potential differences in the plant. It is needed, if the cross section of the cable screens is less than 50% of the cross section of one phase conductor.
- It is recommended to use copper conductors in order to minimize the diameter of the cables (smaller bending radius).
- If aluminum cables are used, specially coated terminations must be applied.
- The cable cross-section shall be selected such that the number of parallel conductors is minimized. It is recommended to use cables with conductor cross-section of $3x240mm^2$ and a shield of $3x35mm^2$.
- A final specification of the cable must also consider the method of installation, heating from neighboring cables, maximum allowed conductor temperature or maximum ambient temperature as well as local regulations. In general we also refer to the specifications of the cable manufacturer.

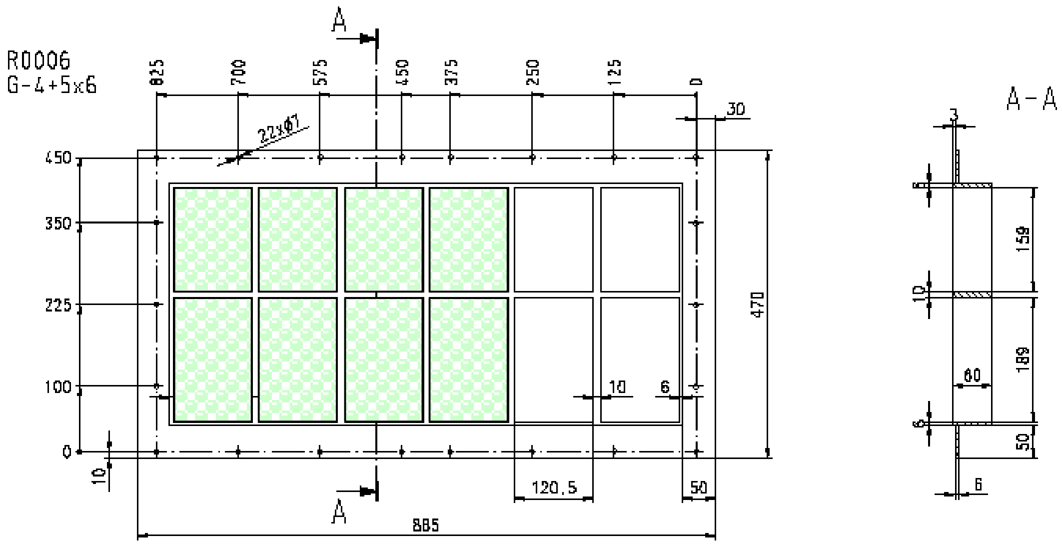
2.2 List of comments

1. Maximum number of cables

For high power ratings more than one cable per phase is permitted.
For each LSU power section the gland plate of the terminal unit (TEU) limits the number of parallel cables and their diameter. For each cable entry, two different frame versions are available providing different cable diameters and parallel cable number.

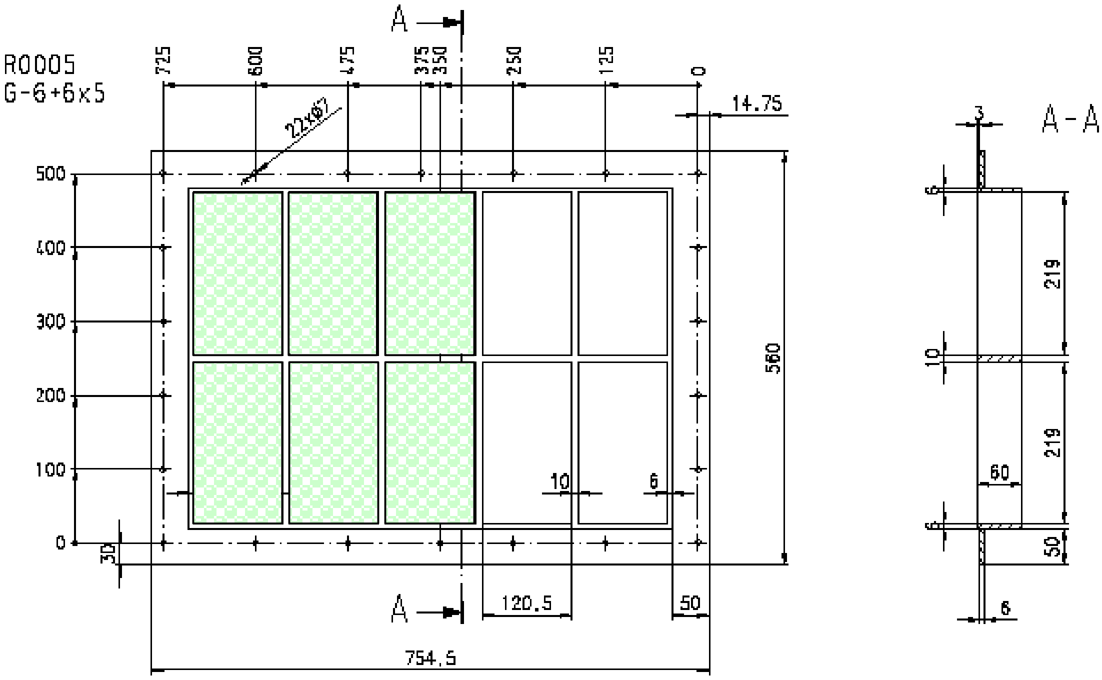
Version 1

- Maximum **8** three-core cables with a diameter of ∅ **68-99 mm**
- One cable per ROX-field
- Frame part belonging to LSU see colored area in picture below, white part belongs to inverter unit cable entry



Version 2

- Maximum **12** three-core cables with a diameter of ∅ **48-71 mm**
- Two cables per ROX-field
- Frame part belonging to LSU see colored area in picture below, white part belongs to inverter unit cable entry



These frames, which are delivered with the drive, can be equiped with different filler modules. The modules have to be provided from the customer. The following table shows the range of available modules:

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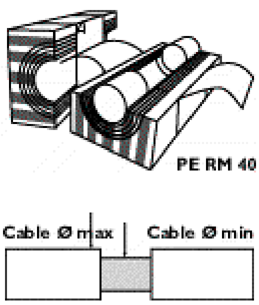
Module type	For Cable/pipe [mm] Ø min - max	External dim. [mm] [heightxwidthxdepth]
ES or PE RM 20	Ø 4-13,5	20x20x60
ES or PE RM 30	Ø 12-22	30x30x60
ES or PE RM 40	Ø 22-32	40x40x60
ES or PE RM 60	Ø 28-50	60x60x60
ES or PE RM 90	Ø 48-71	90x90x60
ES or PE RM 120	Ø 68-99	120X120X60



Further information about ROX-system: http://www.roxtec.com/power/

Thus the terminal part of each LSU module can be equipped with:

- In case of frame version 1: Up to 8 modules of the type RM120
- In case of frame version 2: Up to 12 modules of the type RM 90

Additional some modules of the type RM30 for installing the earthing cables are necessary. In both versions there is space left for these additional RM30 modules.

2. Derating factors (see also manufacturer datasheet)

- Conversion factor of current loading capacity by varying ambient temperature (about 10% reduction per 10°C temperature rise).

  The heat dissipation per unit length of a cable in air is given by:

  $$W = a\ p\ D\left[q_s - q_a\right]^{5/4}$$

  where

  α is the heat transfer coefficient
  D is the overall diameter of the cable
  θ are the surface and ambient temperatures respectively (see index)

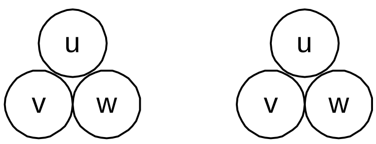
- Conversion factor of current loading capacity in case of parallel lay of cables (between 0 and 30% depending on three-or single-phase cables, diameter of cables, number of cables in parallel, distance between the cables).

  According to “Electrical Engineering Handbook”, Siemens, Heyden, for paper and plastic insulated multi cables, arranged freely in air, the following factors should be considered

Voltage	**Current rating in percents of the nominal**		
	1 cable	3 cables side by side	6 cables side by side
5.8/10kV to 11.6/20kV cable spacing = cable diameter	90%	85%	80%
5.8/10kV to 11.6/20kV mutual contact		75%	70%

2.3 Installation requirements

- A single core cable as earthing cable should be installed in parallel with the transformer cables in order to prevent screen overloading due to potential differences in the plant. Its cross-section is one level lower than the cross-section of one phase cable core.
- All shields and armors from the cables between transformer and converter are grounded. On transformer side they are directly connected to protective earth (PE), on converter side the connection is made via the internal power ground (PG) bus bar.
- Shields shall be terminated in the terminal fields (TEU) and grounded to the Power-Ground (PG) which is provided within the same cable connection section. Also the armoring is grounded to PG.
- In case single-phase cables are used, they should preferably be installed in triangle in order to minimize transformer screen and cable shield currents.



etc.

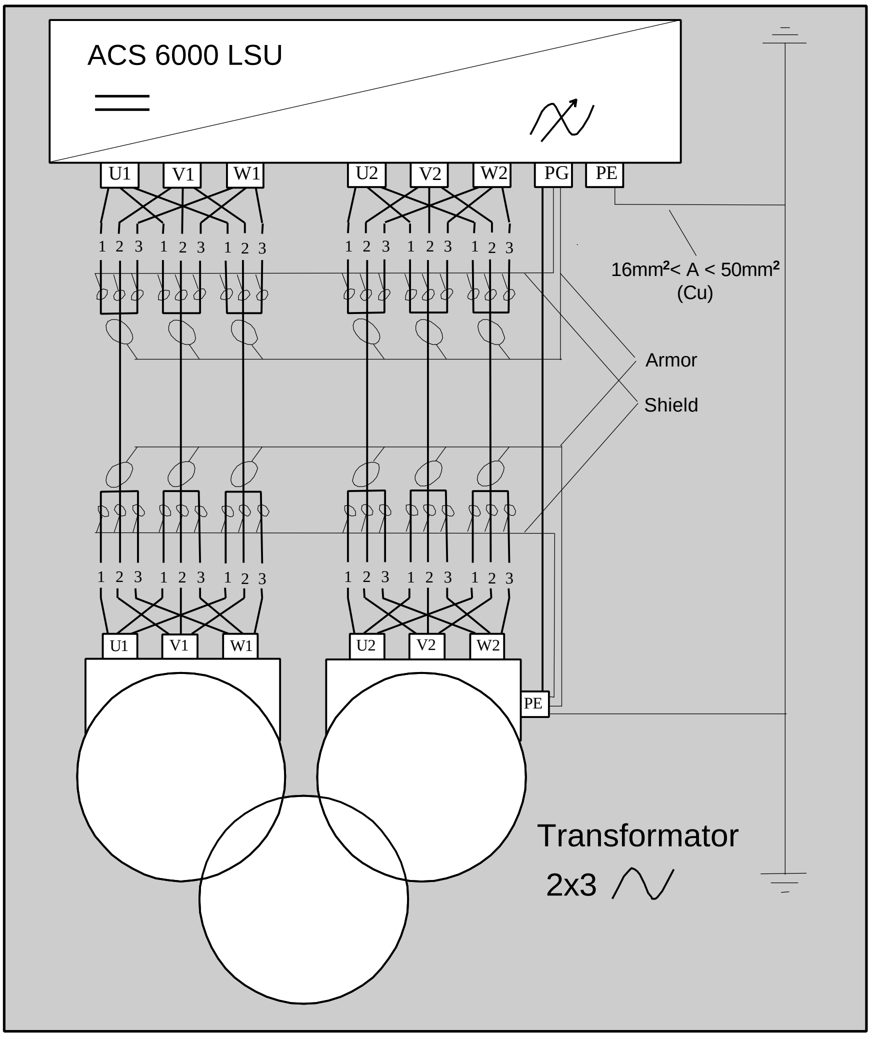
2.3.1 Standard solution for cable entry: ROX system

Cable entry installation-requirements with ROX system are the same is as for ARU/INU cables (see chapter 1.3.1).

2.3.2 Optional solution for cable entry with aluminum-blanking plate

Instead of the standard cable entry with the ROX system, an aluminum blanking plate is available. In this case the customer has to take responsibility for EMC requirements and the mechanical fixtures of the cables. With this solution, the maximum possible number of cables does not increase.

2.3.3 Cable installation between transformer and converter with LSU



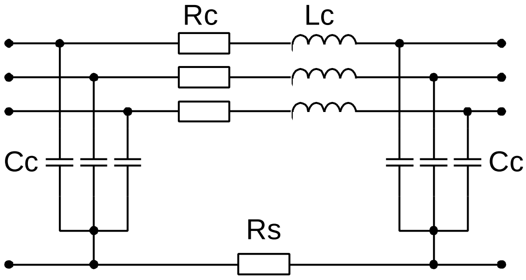
The picture presents a typical installation with three parallel 3-core-cables and an additional grounding cable.

All shields and armors on converter side are connected to power ground (PG), shields and armors on transformer side are connected to protective earth (PE).

The converter itself is grounded only once to protective earth (PE).

2.4 Shield current

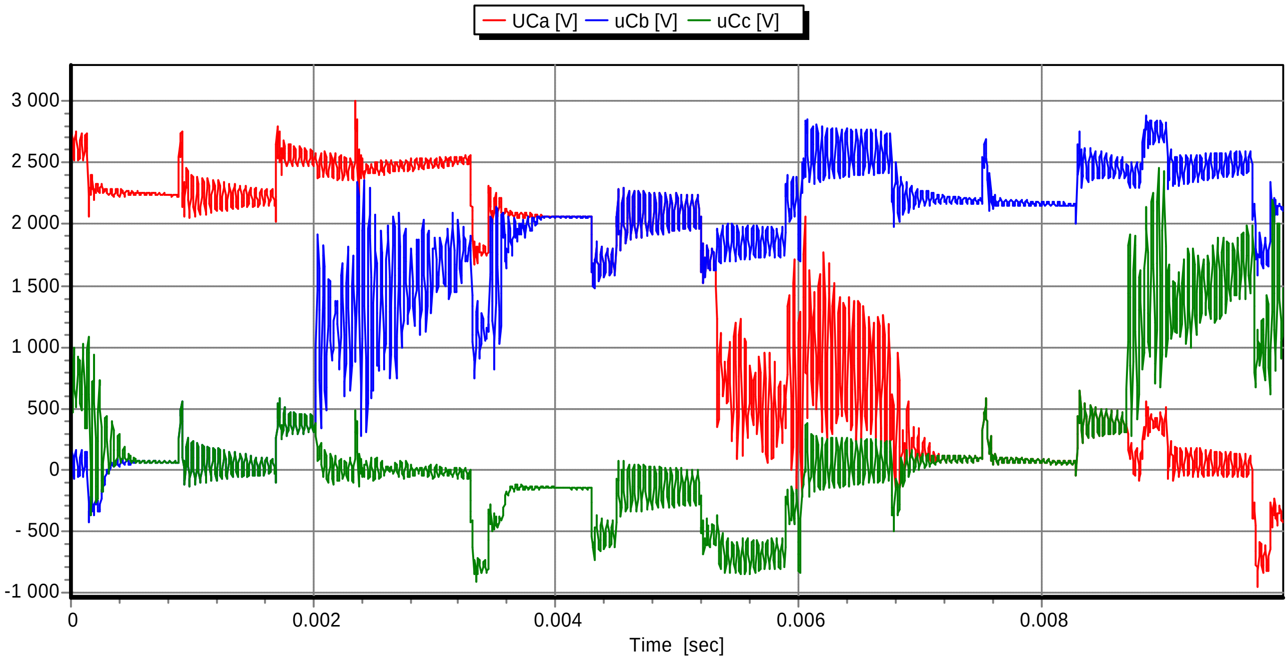
The shield current requirement has been determined by simulation. The simulations were performed with a series of π-models as shown below.



2.4.1 Shield currents simulation results

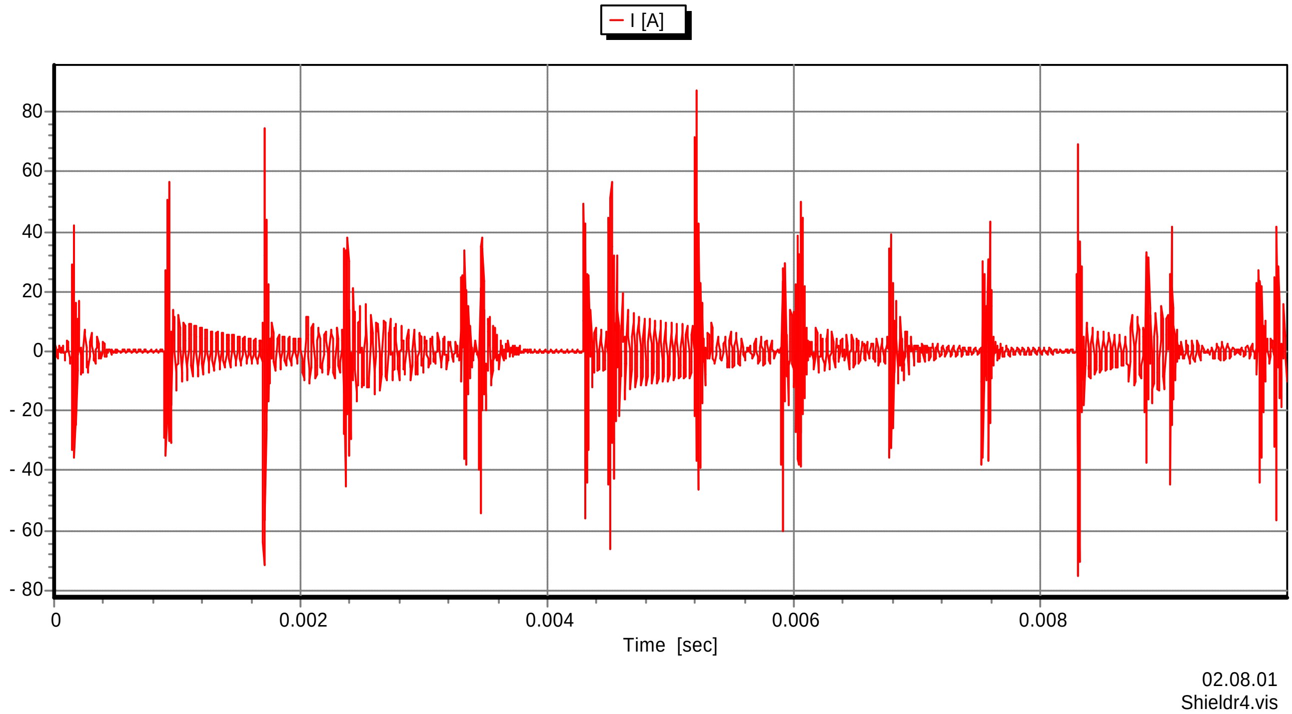
Configuration with 1x200m cables (3-phase, 240mm^2)

Simulation results of typical cable voltages (phase voltage) on converter end are shown below.



02.08.01
Cablec42.vis

Simulation result of typical shield current::



The RMS value of the shield current is about 10A. Current peaks up to 100A are to be expected.

3 Specification of power cables for BCU-modules

3.1 General requirements

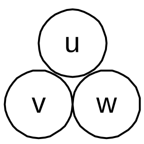
Topic	Notation	Value / Description	Unit	Comment
Module type		Braking chopper unit		
Rated voltage	U	2800	V	
Cable insulation		6 (nominal) / 10 (peak)	kV	
Max. cable length	l_{max}	100	m	
Min. conductor cross section	$\varnothing_{minconductor}$	70	mm^2	
Min. shield cross section	$\varnothing_{minshield}$	16	mm^2	

Required cable is provided with the following general characteristics:

- Screened cables are mandatory. The screen provides potential grading and limiting of the electrical field (EMC requirements), conduction of grounding and common-mode currents as well as touch protection.
- Either three 1-core cables or one 3-core cable can be used. One three-phase cable with individually shielded conductors is the preferred solution due to installation benefits. No special precaution of laying or mechanical fixation between cables is necessary.
- A galvanized steel armor shall be used, which fulfills the function of an additional common screen as well as mechanical protection of the cable, which has direct connection to the common DC bus.

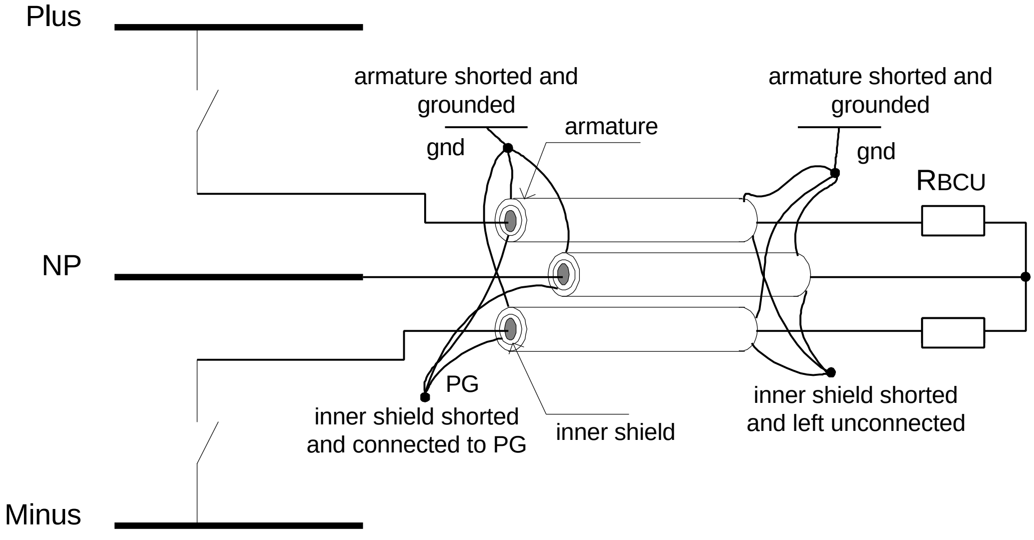
3.2 Installation requirements

- At both ends the armor will be connected to ground. On the braking resistor side the armor is directly connected to protective earth (PE), on converter side it is connected via the internal power ground (PG) bus bar.
- The inner shields will be shorted all three together on both sides of the cable.
- The inner shield common point will be connected to the power ground (PG) on the converter side.
- The inner shield common point will be left unconnected on the resistor side.
- In case single-phase cables are used, they need to be installed in triangle.



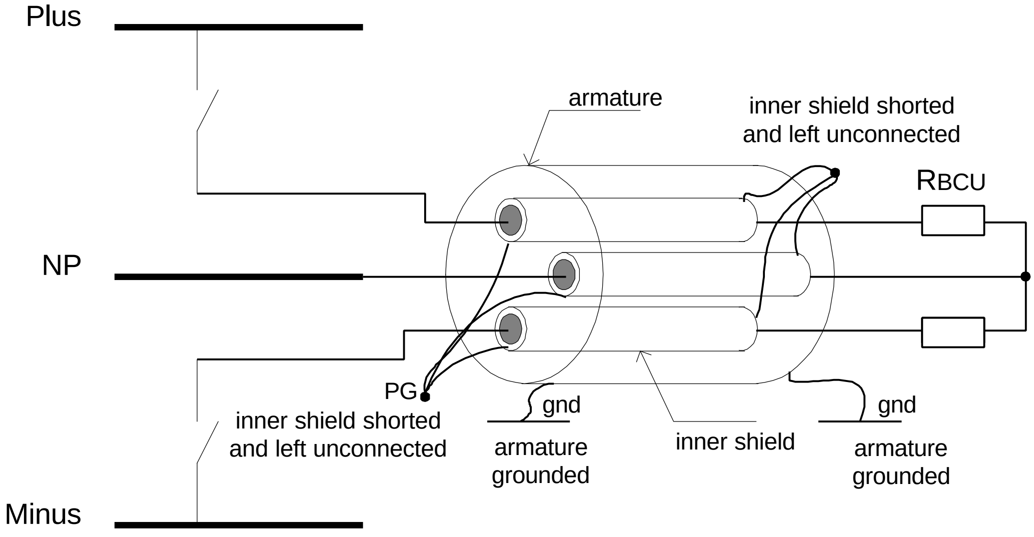
3.2.1 1-core cables

Installation with three1-core cables:



3.2.2 3-core cable

Installation with one 3-core cable:



REVISION

Rev. ind.	Page (P) Chapt.(C)	Description	Date Dept./Init.