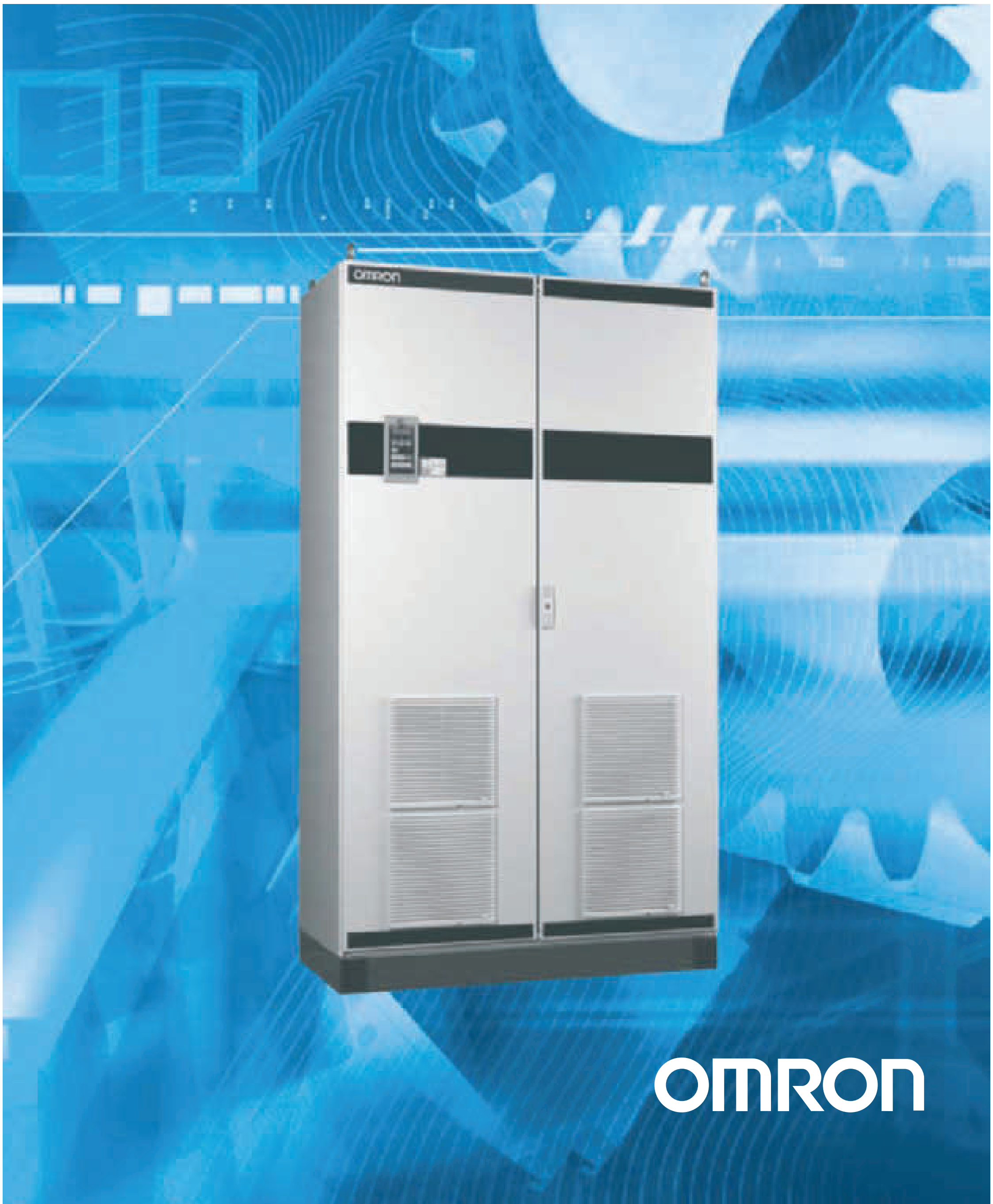
Cat. No. I121E-EN-01B

SX-AFE

Design Guide



SX AFE Design Guide

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CHAPTER 1 GENERAL

1.1 Active Front End- AFE drives

These are network friendly low harmonic and regenerative drives.
The demand for network friendly power electronic equipment is continuously increasing. Low harmonic drives are the answer to this challenge, improving reliability and reducing investment costs in applications such as pumps and fans in the mining, marine and process industries.

1.2 Extremely low harmonic distortions

OMRON Low harmonic drives produce typically less than THDI 5% compared to 30%-50% in conventional drives, thereby fulfilling the IEEE-519 standard. Reduced power losses eliminate the need to over dimension cables and transformers. Lower distortions also cause fewer malfunctions in other electronic equipment.

1.3 Energy saving regenerative drives

OMRON Regenerative drives, in addition to low harmonics, offer energy savings in applications with frequent braking, such as cranes, centrifuges, test benches, winders and ski lifts. They provide robust yet fast and smooth control, and allow uninterrupted power flow to and from the mains supply. Regenerative units can also be supplied as DC-bus feeder units.

1.4 Regenerative braking

OMRON Regenerative drives offer the option of feeding braking energy back to the mains instead of dissipating it via brake resistors. This will save considerable energy costs as well as the cost of investing in brake resistors, equipment that has limited lifetime and require cooling or external installation. The regenerative drives are rated for four quadrant operation with 100% power in both directions, ensuring continuous full braking power.

1.5 Trouble-free operation

The AFE drives are non sensitive to voltage drops or harmonics from other equipment which otherwise could cause it to trip or break down. Voltage boosting also assures full motor power in case of mains voltage fluctuations.

1.6 Reactive power compensation

The AC drive is rated for 100% power in both directions. It provides genuine unity power factor, which allows for optimized sizing of the distribution transformer and can lower the electricity transfer tariff. It also provides the possibility of reactive power compensation.

1.7 6 pulse AC drive system

The standard conventional variable speed drive is based on a 6 pulse rectifier technology. This concept is based on a voltage source drive system. This means that the drive provides a 3 phase artificial mains supply to the motor (inductive load) and will source this motor with enough power to fulfil the motor power specifications. The modulation is mostly based on the PWM principle (Pulse Width Modulation).

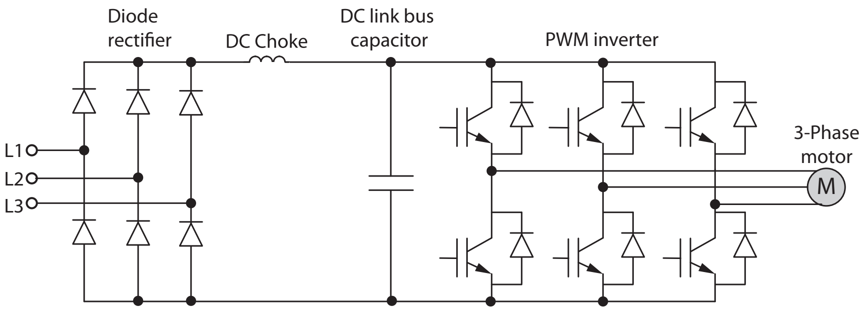


Fig. 1 6-pulse AC drive system

This concept was introduced in middle of the 1970's and is very well proven and is used in most of the variable speed drives at this moment. Still due to increased use of these kinds of drives nowadays also the limitations of such a system come more in site.

1.8 Limitations

- Difficult to reduce the higher harmonic currents on the input side.
- Only 2Q (quadrant) operation possible
- Power factor is <1

1.9 Improvements of this system

With new technology and a different system setup it is possible to take away these limitations like higher harmonic currents and make use of 4Q operation. All these improvements will directly lead to a much more efficient system and will directly save electrical energy. This of course depend a lot on the application were the system is used and how the application is loaded over a longer period of time.

CHAPTER 2 HARMONICS

In the discrete frequency domain any arbitrary periodic signal can be expressed using harmonics. A harmonic is a sinusoidal component with a frequency being an integer multiple of the fundamental frequency of the periodic signal to investigate. When e.g. investigating a supply current with a frequency of 50 Hz the fundamental or first harmonic has also a frequency of 50 Hz. The second harmonic has a frequency of 2*50 Hz = 100 Hz. The thirds harmonic has a frequency of 3*50 Hz = 150 Hz etc. The original periodic signal can be reconstructed by adding the harmonics taking into account their magnitude and their angle.

Example:
The following is a simple example showing that with adding the harmonics the original signal can be reconstructed. Any wave signal is formed by a number of higher harmonics as a multiple of the 1st harmonic (fundamental). So e.g. a square wave can be composed by a fractional sum of the uneven harmonics, 1st, 3rd, 5th, 7th and so on.

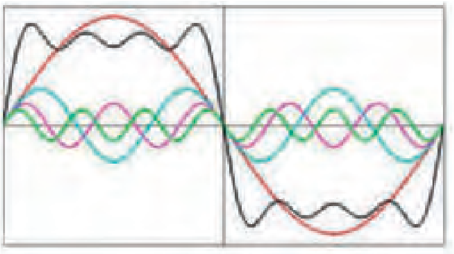


Fig. 2 Example of harmonics and square waves

In general Harmonic current are generated by non-linear loads like,

- Fluorescent lights
- Computers and CRT's
- And other single phase office equipment
- Rectifiers
- Welding machines
- Arc furnaces
- UPS and DC power supplies
- DC Drives & AC Drives

The main problems associated with harmonics are;

- Mains voltage distortion
- Loss of energy
- Power factor goes down,
- Harmonic resonance with power factor correction capacitors,
- Overheating of transformers. Transformers run at rated temperature with only 75% of full load current!
- Increased I2R and Eddy Current Losses In Transformers, Generators and Cables

2.1 Harmonic currents in a drive

The input current of 6 pulse drive is not sinusoidal, because the rectifier gives a non-linear load.

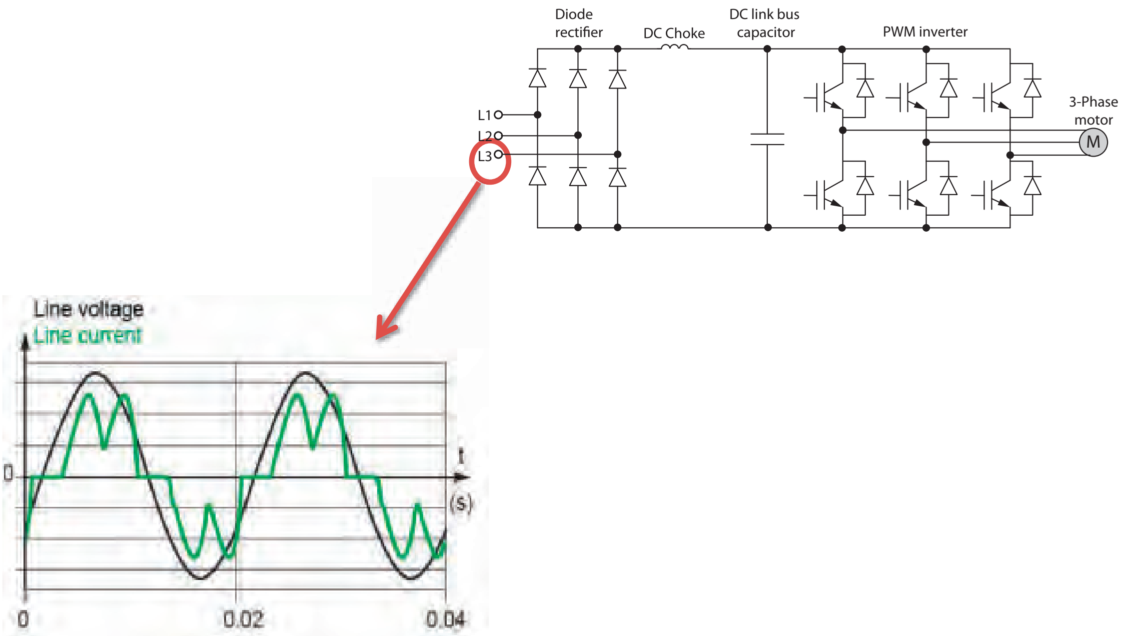


Fig. 3 Harmonic currents

This picture shows 2 things:

- The angle difference phi between current and voltage is close to zero. Only with a theoretical perfect supply with zero impedance (Z=0) the cosphi would be 1, but in practise any supply has a certain inductance (so Z>0) e.g. a small drive on a “strong” supply will have a higher cosphi, then a bigger drive on a “weak” supply.
- The power factor is also less than 1, because the current has higher harmonics, not 100% sinusoidal, the wave form is distorted

2.2 THDI (Total Harmonic Distortion of the Current)

With a spectrum analyser the content of the higher harmonics can be measured and visualized:

Motor

Power [kW]	30
Current [A]	60
Frequency [Hz]	50

Mains

Voltage [V]	400
Current [A]	51
THD [% of I1]	30

Harmonics	Ih [A]	Ih/I1 [%]
I1	48.0	100.0
I5	12.4	25.8
I7	5.33	11.1
I11	3.44	7.2
I13	2.44	5.1
I17	1.63	3.4
I19	1.33	2.8
I23	0.989	2.1
I25	0.817	1.7
I29	0.627	1.3
I31	0.542	1.1
I37	0.351	0.7
I41	0.310	0.6

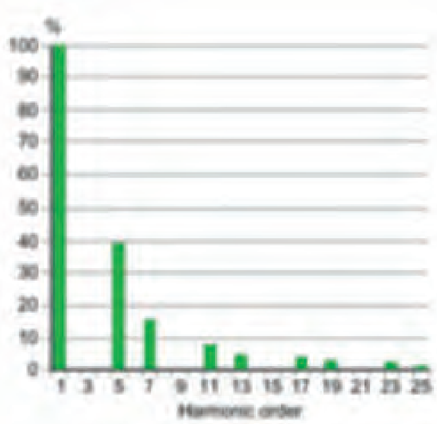


Fig. 4 THDI

The 5th and 7th are the most dominant harmonics. The total harmonic current can be calculated.
The total RMS current will be higher due to a higher Total Harmonic Distortion of the current (THDI).

We can calculate that the THDI in this case is 30% of the fundamental.
In this example the fundamental RMS current is 48 A, but the total RMS current will be 51 A.

(formulas:) $THD\% + \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 ... + I_n^2}}{I_1} * 100$ $\quad I_{RMS} + \sqrt{I_1^2 + I_2^2 + I_3^2 + ... I_n^2}$

2.3 THDU (Total Harmonic Distortion of the Voltage)

The total Harmonic Distortion Voltage (THDU) depends on the impedance of the supply and the impedance of the VSD (choke capacitor combination).

If the impedance is high, then also the voltage distortion will be high, it is proportional to the THDI and the supply impedance Z.

2.4 Norms and Standards

Although we talk a lot about Harmonic currents, the most of the European and world standards are based on limitation of the Total Harmonic Voltage distortion THDU. Important to realize is that the values given here are always related to the impedance of the supply. This is always indicated as the ratio between the short circuit capacity of the supply and the drive nominal load current. The drive can meet the requirements if a balanced mains supply is used. Unbalances in the supply will have effect on the harmonic content.

Drives < 75A

The standard IEC/EN 61800-3, International standard for Power drives system, with references to IEC61000-3-2, IEC61000-3-4 and IEC61000-3-12. This standard is used in Europe

I line Drive	Residential **directly connected onto the public network** (1st Environment)				Industrial MV/LV transformer (2nd Environment)
	Professional equipment		**Non professional equipment**		
	Standard	**THDI**	**Standard**	**THDI**	
<= 16A	IEC 61000-3-12	<=48%	IEC 61000-3-2	<5%	no requirment
16A < I <= 75A	IEC 61000-3-12	<=48%	IEC 61000-3-12	<=48%	no requirment
>=75A	IEC 61000-3-4	<=48%	IEC 61000-3-4	<=48%	no requirment

Note: The Rsc values in the table for the OMRON drives are specified with a short circuit ratio of 250(Rsc=Isc/Iln). The short circuit ratio says something about how “weak” or “strong” the supply transformer is. A strong transformer allows higher THDI values. If the ratio is smaller, then the maximum allowed THDI will also be smaller.

Minimum Rsc (Isc/Iln)	Admissible Individual Harmonic Current In/I1				THDI	PWHD
	I5	**I7**	**I11**	**I13**		
33	10.7%	7.2%	3.1%	2%	13%	22%
66	14%	9%	5%	3%	16%	25%
120	19%	12%	7%	4%	22%	28%
250	31%	20%	12%	7%	37%	38%
350	40%	25%	15%	10%	48%	46%

Further we see that there are no requirements if the drive is not connected to a public network (1st environment). Also the specific maximum values of the 5th, 7th,11th, and 13th harmonic are given. (PWHD= Partial Weighted Harmonic Distortion, for selected group harmonics). Normally the supplier of the drive will have a “Certificate For Mains Harmonics” available for each size of drive.

Drives > 75A

For the higher powers the IEEE 519:1992 standard is also used. This standard is based on a “Plant” approach. This means that this standard has a maximum THDU at the so-called “Point of Common Coupling” of the power system. This standard is used in Europe, USA, Canada and parts of Asia.

2.5 PCC Point of Common Coupling

PCC is the closest point on the utility side of the customer's service where another utility customer is or could be supplied. Normally that is the connection to the public supply (1st Environment), see PCC in Fig. 5: *PCC according to IEEE 519*. The PCC is a point of metering, or any point as long as both the utility and the consumer can either access the point for direct measurement of the harmonic indices meaningful to both or can estimate the harmonic indices at point of interference.

If a drive is connected in a 2nd Environment then the PCC will be on the primary side of the incoming transformer, see Industrial customer 3 in Fig. 5: *PCC according to IEEE 519*.

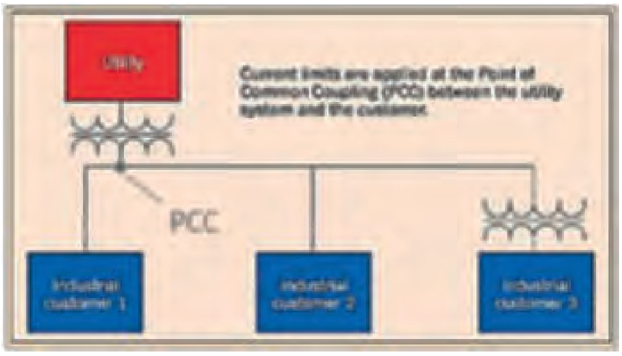


Fig. 5 PCC according to IEEE 519

Important difference to the standard IEC/EN 61800-3 is that the Total Harmonic Distortion of the complete plant is measured at this point. The Voltage distortion at the PCC is in that case leading. Of course the voltages distortion depends on the current distortion, but this is relative to ALL equipment connected to the supply. So even if a single drive has a high THDI, this one drive can result in a small THDU distortion at the PCC.

Also here the short circuit ratio of the supply has effect on the maximum level. This standard will give the maximum depending on the application. For the majority of applications this will be for General systems

From Table 10.2 p77 in the standard IEEE 519:1992 Low-Voltage System Classification and Distortion Limits	
Low-Voltage Systems	
Application	**Maximum THDU (%)**
Special Applications - hospitals and airports	3,0%
General System	5,0%
Dedicated System - exclusively converter load	10,0%

For all normal applications with drives, most of the maximum THDU on the PCC will be 5%.
A dedicated system means a supply system dedicated to the drive only, so no other users or equipment.

From Table 10.3 p78 in the standard IEEE 519:1992 Current Distortion Limits for General Distribution Systems(120 V Through 69,000 V)						
Maximum Harmonic Current Distortion in Percent of Iload						
Isc/Iload	**<11**	**11<=h<17**	**17<=h<23**	**23<=h<35**	**35<=h**	**TDD (%)**
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above						
Isc=maximum short circuit current at PCC						
Iload=maximum demand load current (fundamental frequency component) at PCC						

The maximum THDI is given as TDD, this means the Total Demand Distortion, so you can say the THDI relative to full load of all loads (linear and non-linear) connected to the supply. Also here the short circuit ratio is affecting the max allowed TDD.
In general when Non-Linear Loads exceed 30% - 50% of total load, then a harmonic analysis of the plant one-line load diagram should be performed. Software tools for these kind of complex calculations can be very helpful.

2.6 Reduction of the THDI

Most common reduction methods:
Note: a 6 pulse drive with no DC Choke or Line reactor will have a THDI of up to 80%.

- Line reactor THDI 40%
- DC Choke THDI 30%-35%
- 12 pulse supply THDI 10%-12%
- Passive Filter THDI 5-10%
- 18 pulse supply THDI 6%-8%
- Active filter (AFE), THDI <5%

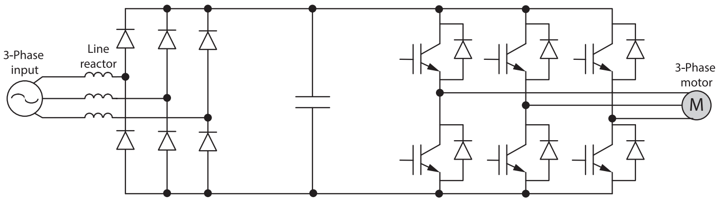


Fig. 6 Line reactor

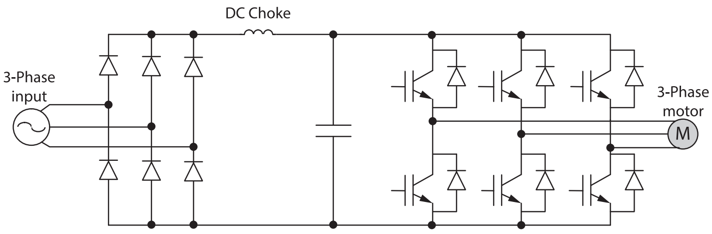


Fig. 7 DC-choke

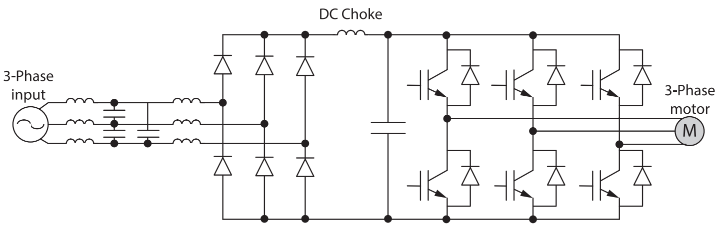


Fig. 8 12 pulse supply

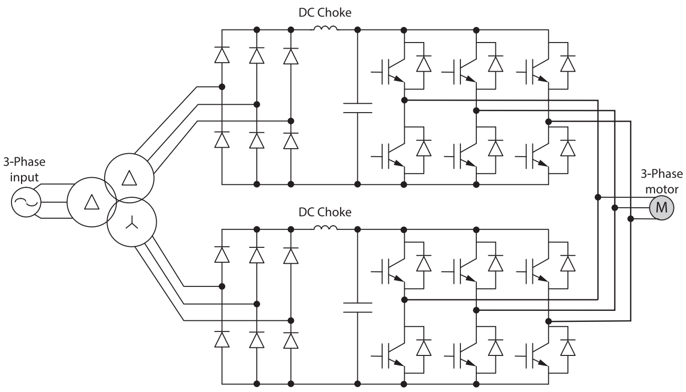


Fig. 9 18 pulse supply

CHAPTER 3 2 QUADRANT AND 4 QUADRANT OPERATION

A standard drive is able to operate the motor in generator mode for a short time with a limited braking torque.

If a drive can operate the motor in 2 speed directions motoring then we call this 2 quadrant operation.
If a drive is also able to operate in generator mode with full torque continuously, then this is called 4 Quadrant operation. So motoring and generating in both speed directions.

The AC motor has the capability to operate as motor, but also as generator. So if the drive is able to deal with the generator current, then 4 quadrant operations is possible. See picture

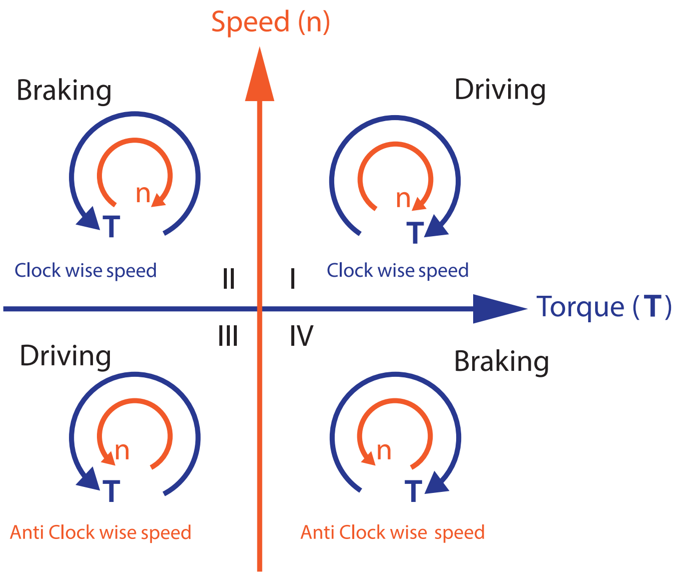


Fig. 10 4 Quadrant operation

The standard drive can be in generator mode with a small braking torque corresponding to the losses of motor and drive. In generator mode any remaining energy will be transferred to the DC link capacitors via the freewheeling diodes and the DC link voltage will increase.

The rectifier diodes prevent any energy to be fed back into the mains. Additional braking torque can be achieved by using vector braking which is increasing the motor losses.

To increase the available braking torque the most common method is to use an external brake resistor. This resistor is connected to DC-link via an IGBT. The IGBT will switch on if the DC-Link voltage increase and then the braking energy will be dissipated by the external brake resistor. This method is normally used for lower powers or for shorter duration braking such as stopping. But if e.g. to be used on a crane hoist then a lot of energy is wasted (dissipated). Furthermore at higher powers the brake resistor will increase in size and price, also measures must be taken to get rid of the heat dissipated in the big resistors (banks).

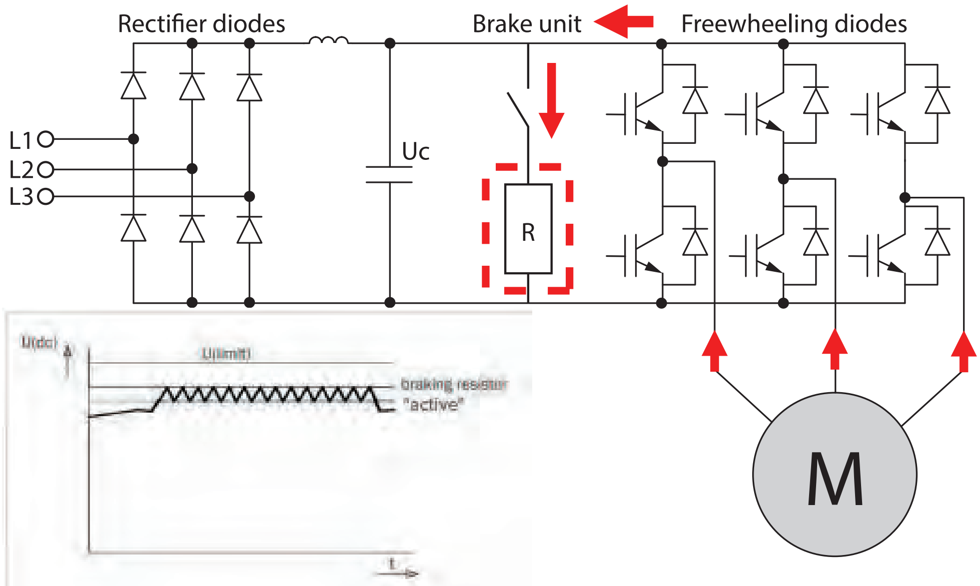


Fig. 11 Electrical braking

CHAPTER 4 ACTIVE FRONT END – AFE

4.1 Active front end - AFE technology

The OMRON concept of AFE is based on the existing Power Module concept (PEBB). This means that we use almost the same parts as with the standard drives. This gives us the advantage that we have only limited spare parts, but that it fits perfectly in the drive concept of the OMRON SX generation. Not only as standard air-cooled, but also the liquid cooled option is possible.
This has the consequence that the volume of the complete system will be a bit higher compared with a system using AFE-optimised modules.

4.2 Working principle

Active Front End means that we have a front end rectifier which can operate active towards the supply, compared to the standard drive where the rectifier is passive (diodes). To make the front end active we replace the diode bridge with IGBT's, the same as used for the motor output inverter.

This is a so-called B2B (Back to Back) configuration. AFE <> VSI (Voltage Source Inverter = motor inverter bridge) .
This input IGBT bridge cannot be used for charging up the DC-link, a separate charging circuit is needed.
The input IGBT bridge is able to generate energy back to the mains supply.
The VSI is the motor inverter part which works as a normal drive (Standard SX), but without input rectifier or DC choke.
It is possible to have multiple VSI's on the DC bus of an AFE. A DC bus system can be configured using standard SX drives connected to the DC bus. This makes it possible to have a full 4 Quadrant operation.
Furthermore we have full control over the mains current. The AFE control plus LCL filter makes it possible to have an almost 100% sinusoidal input current.

As the AFE has full control of the DC-link, it´s able to keep the DC–link voltage constant and without ripple. So the fluctuations from the mains supply are automatically adjusted. Voltage dips up to 50% can be overcome.

Because the DC-link level is higher than the peak rectified value of the mains supply the drive is not any more controlled by the freewheel diodes over the output IGBT's, therefore it can keep the DC-Link voltage on a fixed level and is able to control the generator current back into mains. The LCL filter makes sure that the wave form is sinusoidal and the control systems takes care that the 3 phases are synchronized with the mains input phases.

The AFE also has a reactive power control. This feature gives the possibility to decrease the reactive power consumption in the system. Reactive power consumption by other 3 phase equipment can be compensated.

4.3 STANDARD 6 pulse DFE Diode Front End

- Simple, robust design
- 2 Q operation only
- DC link is varying , depending on line fluctuations(udc ~1,35 X Uline),
- Line fluctuations also affect the motor voltage.
- DC choke needed
- THDI 30%-35%

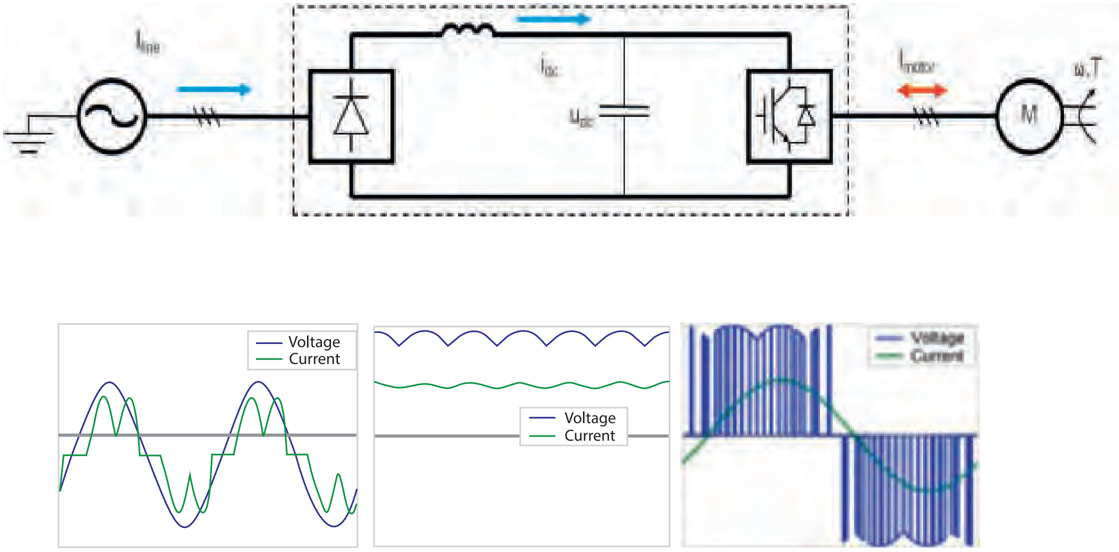


Fig. 12 DFE 6 -pulse

4.4 AFE Active Front End

- Modular design (PEBB)
- B2B
- Full 4 Q operation with 100% continuous regeneration- Stable DC link, so stable and efficient motor control
- Line quality has no effect to the DC link and the motor voltage
- Voltage dips up to 50% dips will not disturb the drive.
- Sinusoidal input current power factor is close to 1
- THDI <5%
- Reactive power compensation possible for other equipment

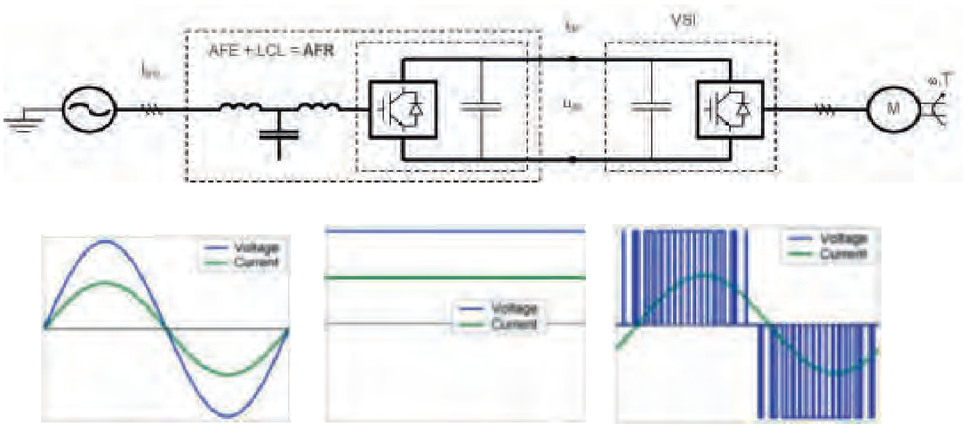


Fig. 13 AFE

AFE	=	Active Front End
LCL	=	Input filter
AFR	=	Active Front-end Regenerative
VSI	=	Variable Speed Inverter (drive)

4.5 FFE Fundamental Front End

Another concept is FFE, this is a similar concept as the AFE but only designed for regenerative mode, so it has still a THDI of 30%, there is no sine wave input current, no DC-link boost or control, no low harmonic functions. OMRON is not providing this type of system.

CHAPTER 5 THE OMRON AFE CONCEPT

5.1 Supply voltage rating:

460 V and 690 V. 460 V type is used for US and Latin America.
These are based on the standard 480 V and 690 V PEBB's. The 460 V AFE rating is lower than the original. 480 V PEBB, this is because of the maximum allowed DC-link voltage on the capacitors of the 480 V PEBB. Due to the voltage boost in the AFE the nominal voltage rating is lowered to 460 V

5.2 Type configuration

There are 3 configurations possible:

Low Harmonic Drive: SX-VL and SX-FL
These are "normal" SX inverter. The AFE part is set for LOW HARMONIC, so the input current is sinusoidal and the max THDI <5%. The drive has normal braking capacity, so no full 4Q regeneration possible

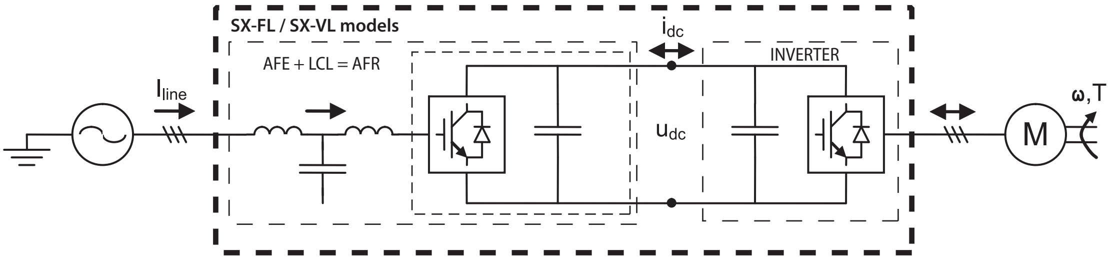


Fig. 14 Low harmonic

Regenerative + Low Harmonic drive: SX-FR
This is the same as the Low Harmonic drive, but now the full 4Q regeneration function. This is only sold in the OMRON SX-F drive.

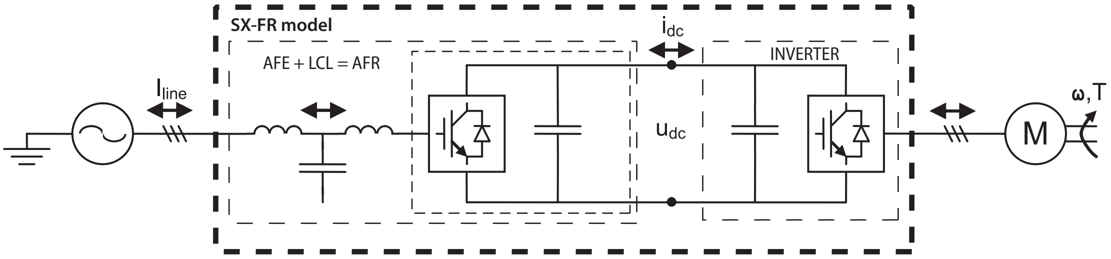


Fig. 15 Regenerative low harmonic

Regenerative + Low Harmonic drive DC bus supply unit AFR:
Now the AFE acts as a DC bus supply. On the DC bus several “drives” (VSI’s) can be connected. The VSI is a standard PEBB without input rectifier and DC choke. The VSI can be OMRON SX V/Hz control and/or SX vector control drive. Also the smaller drive sizes B, C and D can be connected to the DC bus.

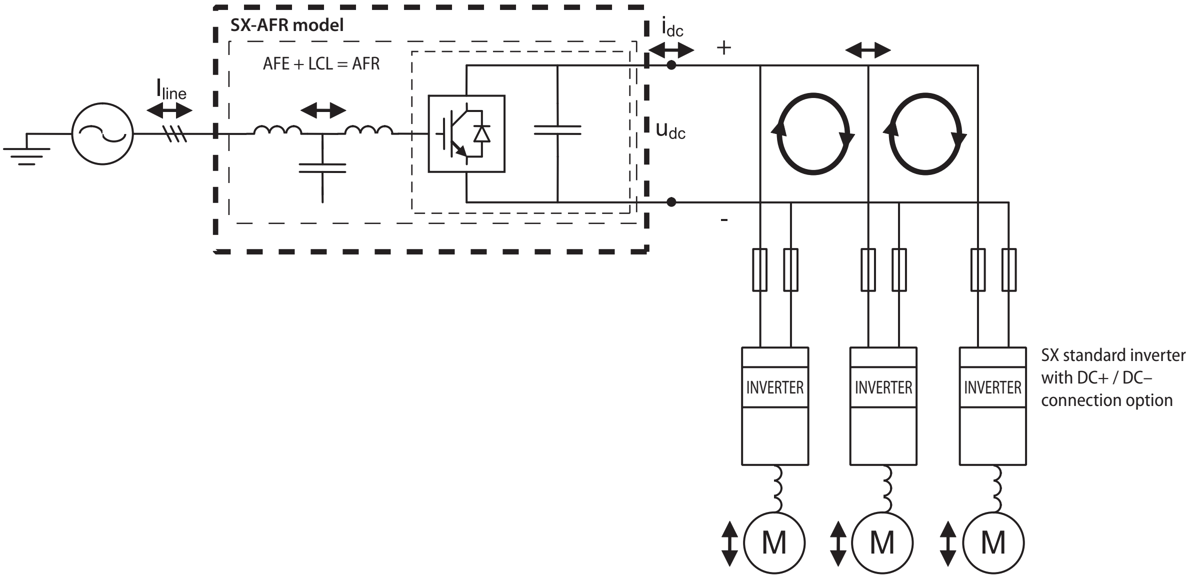


Fig. 16 Regenerative low harmonic with DC bus supply

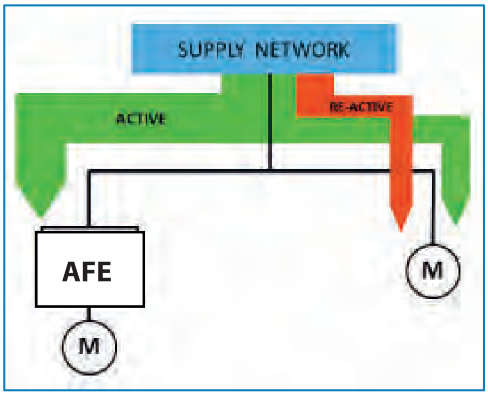
Type designations, examples:

SX-D6160-E1VL = Low Harmonic V/Hz control drive
SX-D4055-E1FL = Low Harmonic Vector control drive
SX-D4200-E1FR = Regenerative + Low Harmonic Vector control drive
SX-D4330-E1AR = Regenerative + Low Harmonic DC bus supply unit (the VSI is not included)
The VSI should have the DC+/DC– connection option.

There is no physical difference between a Regenerative drive and a Low Harmonic drive. So for service this is very efficient. The difference will be in the software of the drives.

CHAPTER 6 REACTIVE POWER CONTROL

The AFE drives has a special function “Q control”, which can be useful in those cases where not used capacity of the AFE drive can be used to compensate the reactive power on the same supply. The AFE drive can also be oversized to allow more reactive power compensation. This reactive power can be caused by e.g. a motor running DOL on the same supply (or other non-linear loads). Instead of using so-called power factor compensation capacitor banks, the “left over” power from the AFE can be used to compensate this reactive power.



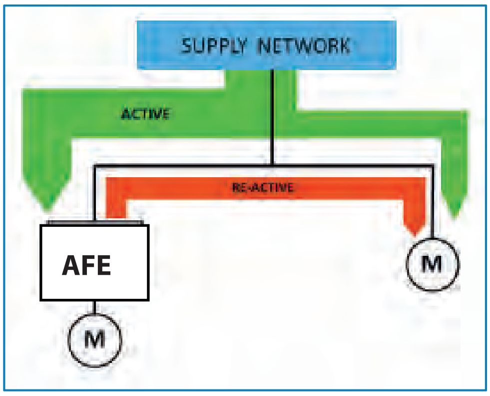


Fig. 17 Reactive power taken from the main. The AFE drive compensates the reactive power

The maximum reactive power which the AFE drive can compensate depends on 2 values:

1. The power rating of the AFE drive itself. The AFE will always limit the reactive current compensation to the maximum power of the AFE drive (100%).
2. The maximum amount of reactive compensation will be the difference between the maximum AFE power rating and the active power which the AFE is running at. So if the active power is 100%, then there is no compensation possible.

To find out how much power is “left over”, information from the AFE can be used to calculate.
In the AFE the amount of Active power can be read in menu O92 Tref, this value is a good indication of the amount of active power used.

To calculate the Qcontrol max setting (O41) in %, following formula can be used. $Q = \sqrt{1 - (\text{Pactual})^2}$

For calculating the true values in % we will use: $Q\% = \sqrt{(100\%)^2 - (O92)^2}$

Example:
Nominal power AFE: 160 Kw
Reading from O92: 75%

$Q\% = \sqrt{(100\%)^2 - (75\%)^2}$ = 66%

We know now that we have 66% of 160kW available for compensation of 105kVAr (160 x 0.66) reactive power.
So now the max setting for Qmax (O41) can be 66%. With the normal reference input/setting of the AFE control board the Qreference can be controlled internal or external (the analogue input of the AFR is already preset for Q control) (refer to the SX AFE Instruction Manual (I123E) for detailed information on the settings and the menu’s)

6.1 Customer demand

In this example we can afterwards calculate the “left-overs”.
But if the customer asks for this function specifically, then we can make a better offer to him. Important information is needed from the customer who will have to estimate the reactive power he wants to compensate. In that case we can offer him a bigger size AFE drive, fitted for his purpose.

AFE power size = $\sqrt{P^2 + Q^2}$

6.2 Negative Q control

The most common use of the Q control is as in the above example where we have a positive Q reference (for generating reactive power), which compensates some reactive consumption in system. However the OMRON AFE has also the possibility to have a negative Qref. This means that the AFE will consume reactive power.

One case to use this can be if AFE is to regulate power factor to 1.0 in PCC (with Q-ref created from a switchgear Q-measurement + regulator), when running in a system with an existing fixed compensation banks. During low load situations in the plant the AFE then need to consume any “overcompensation” coming from the fixed compensation banks to maintain 1.0 power factor at PCC point.

CHAPTER 7 AFE IN CABINET

OMRON will deliver the AFE as a complete drive system in a cabinet. his is based on the standard 480/690 V PEBB's and frames. The DC choke and the input rectifiers (HCB) are removed. The standard control board and control panel is used. For the AFE part the control panel is inside the cabinet. This control board has the special AFE software and is normally only used by commissioning for the service person. The "external" control panel connected to VSI is for the customer. The VSI control board has the normal drive software for OMRON SX inverter. Paralleling for higher powers is done in the same way as for the standard drives.

Note: At this moment the maximum sizes for the low harmonic and regeneration units are 1750 A for the 460 V and 1120 A for the 690 V units. The maximum AFR units are 1500 A for the 460 V and 1050 A for the 690 V units. At this moment (Q4 2013) there are investigations to parallel AFR units to get a higher power DC bus system

This cabinet will consist of the following parts:

- Power module (PEBB's) for the AFE
- Power modules for the VSI
- Pre-charging circuit for the DC-link
- Control electronics with control panel to control and start up the AFE and controlling the mains contactor and charge circuit
- Control electronics with Control panel for the VSI
- Cooling
- LCL filter

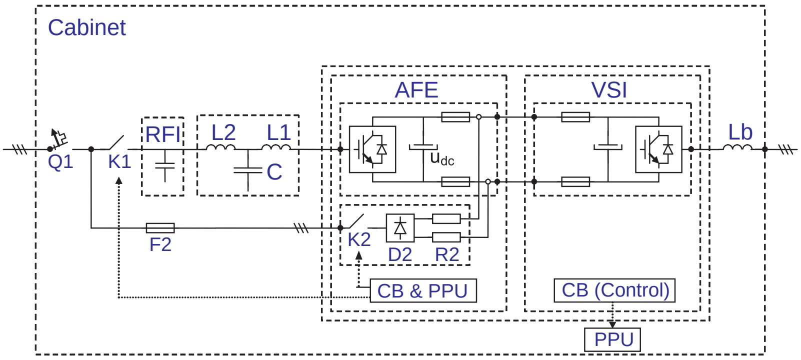


Fig. 18 AFE cabinet diagram

- Circuit breaker (Q1)
- Main Contactor (K1)
- Filter (L1,C,L2)
- EMC filter (RFI)
- Output coils (Lb)
- Pre-charge circuit (F2,K2,D2,R2)
- Control Panel (PPU) AFE; inside
- Control Panel (PPU) VSI; outside

Also a Standby Supply option is always built in for the AFE control board:

- To make correct parameter settings of AFE before first power on
- For the possibility to use the NC contact for Power up and Power down
- To update firmware in the control boards. This cannot be done if the AFE is powered up.

7.1 Dimensioning AFE

Low harmonic drives

Table 1 SX-VL and SX-FR 400 V (SX-FL also possible)

SX-VL/SX-FR model	Max output current Imax [A][*1]	Normal duty 120%, 1 min every 10 min		Heavy duty 150%, 1 min every 10 min		Frame	Dimensions Height = 2,250 mm Depth = 600 mm **Width [mm]**	Weight [kg]
		Rated current Inom [A]	Power @400 V [kW]	Rated current Inom [A]	Power @400 V [kW]			
SX-D4055-E1_L/R	131	109	55	87	45	E46+E=G	800	380
SX-D4075-E1_L/R	175	146	75	117	55	E46+E=G	800	400
SX-D4090-E1_L/R	210	175	90	140	75	E46+E=G	900	480
SX-D4110-E1_L/R	252	210	110	168	90	F46+F=H	900	500
SX-D4132-E1_L/R	300	250	132	200	110	F46+F=H	900	500
SX-D4160-E1_L/R	360	300	160	240	132	F46+H=I	1,300	700
SX-D4200-E1_L/R	450	375	200	300	160	G46+G	1,500	750
SX-D4220-E1_L/R	516	430	220	344	200	G46+H	1,500	830
SX-D4250-E1_L/R	600	500	250	400	220	H46+H	1,500	880
SX-D4315-E1_L/R	720	600	315	480	250	H46+I	1,900	1,040
SX-D4355-E1_L/R	780	650	355	520	315	I46+I	2,200	1,210
SX-D4400-E1_L/R	900	750	400	600	355	I46+I	2,200	1,210
SX-D4450-E1_L/R	1,032	860	450	688	400	I46+J	2,500	1,370
SX-D4560-E1_L/R	1,200	1,000	560	800	450	J46+J	3,000	1,600
SX-D4630-E1_L/R	1,440	1,200	630	960	500	J46+KA	3,300	1,700
SX-D4800-E1_L/R	1,800	1,500	800	1,200	630	K46+K	4,500	2,250
SX-D4900-E1_L/R	2,100	1,750	900	1,400	800	K46+L	On request	

[*1] Available for a limited time and as long as drive temperature permits.

Low harmonic drives

Table 2 SX-VL and SX-FR 690 V (SX-FL also possible)

SX-VL/SX-FR model	Max output current Imax [A][*1]	Normal duty 120%, 1 min every 10 min		Heavy duty 150%, 1 min every 10 min		Frame	Dimensions Height = 2,250 mm Depth = 600 mm **Width [mm]**	Weight [kg]
		Rated current Inom [A]	Power @690 V [kW]	Rated current Inom [A]	Power @690 V [kW]			
SX-D6110-E1_L/R	131	109	110	87	90	F69+F69=H69	800	410
SX-D6132-E1_L/R	175	146	132	117	110	F69+F69=H69	800	430
SX-D6160-E1_L/R	222	185	160	148	132	F69+F69=H69	900	540
SX-D6250-E1_L/R	300	250	250	200	200	H69+H69	1,800	870
SX-D6315-E1_L/R	360	300	315	240	250	H69+H69	1,800	870
SX-D6355-E1_L/R	450	375	355	300	315	H69+H69	1,800	910
SX-D6450-E1_L/R	516	430	450	344	355	I69+I69	2,800	1,350
SX-D6560-E1_L/R	672	560	560	448	450	I69+I69	2,800	1,390
SX-D6710-E1_L/R	900	750	710	600	600	J69+J69	On request	
SX-D61K0-E1_L/R	1,200	1,000	1,000	800	800	K69+KA69	On request	
SX-D61K1-E1_L/R	1,344	1,120	1,100	896	900	K69+K69	On request	

[*1] Available for a limited time and as long as drive temperature permits.

7.2 AFR DC bus system

The AFR is feeding selected VSI´s via DC bus. This system can be configured depending on the project.

There is no type number for the complete assembly of AFR with VSI's. The type numbers are always individual. So you will have the AFR type and the type numbers of the connected VSI's (OMRON SX inverter). In this document the VSI's are listed as PEBB modules. However any other SX drive can be connected to the bus system. This means that the SX sizes B and C can be connected if they are ordered with the DC bus terminals.

For the size D and bigger this is not possible without modification, because the D series & up have a HCB input rectifier. This HCB charging circuit will give error messages, so the size D drives & up must be adapted for this use, this is done in the service menu.

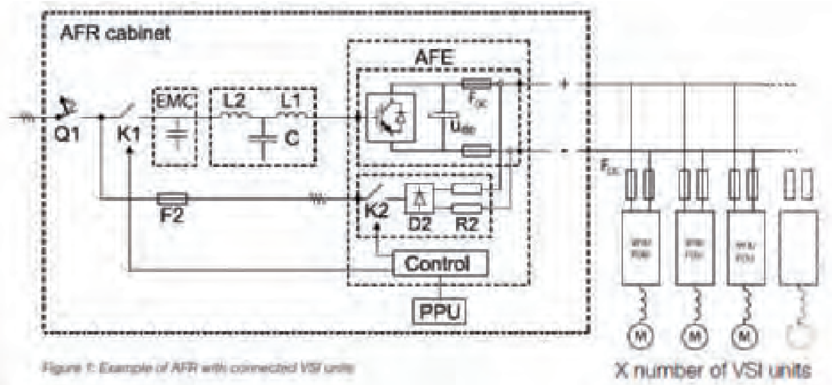


Fig. 19 AFR DC bus system

Basic calculation of the AFR power

To calculate the nominal power of the AFR, the total drive power of the VSI's in "worst case" maximum driving situation is needed. The Electrical motor power is equal to the needed DC power from the AFR. So first calculate the Electrical motor power, this is then equalized to the DC power. Then the DC current can be calculated. The AFR type selection is based on the DC current of the AFR see table 3 on page 22. The DC power in the AFR is calculated with VDC × 1.05, this is the "boosted" DC voltage in AFE. (VDC reference)

1 First calculate the ELECTRICAL motor power: $\mathbf{P_E = P_{MOTOR} / \eta}$
2 Then the DC power: $\mathbf{P_{DC} = V_{DC} \times I_{DC}}$
→ $\mathbf{P_E = P_{DC}}$
3 Then the DC current: $\mathbf{I_{DC} = P_{DC} / V_{DC}}$

Example: Motor: 450 kW, Motor efficiency: 0.85, Input voltage: 400 VAC

1 P_E = 450 kW / 0.85 = **530 kW**
2 $P_{DC} = P_E$ = 400 VAC × √2 × 1.05 × I_{DC}
→ I_{DC} = 530 kW / 595 VDC = **890 A**
3 Selection: **SX-D4660-E1AR**

7.3 Control connections to the VSI's

It is important that the control connections between the AFR and the VSI's are done in a proper way so that under all conditions the complete drive can operate safely if trips occur in VSI or AFR. But also that the starting and stopping of the AFR is controlled in a good way.

- Connect all GND of all control boards to each other
- Use the I/O option cards, because they have isolated inputs and outputs, so less possible problems with interference
- Also solutions using PLC and fieldbus are possible, this will give less cabling and option boards.

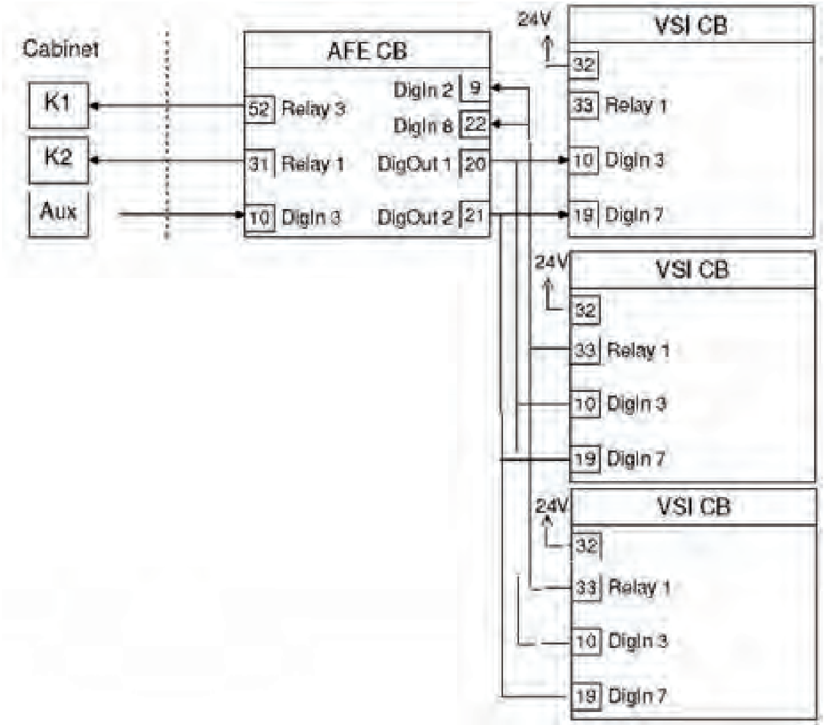


Fig. 20 Example of internal connections between AFR and VSI´s

7.4 AFR power can be smaller than the total driving power

Important is that in the total power calculation the AFR can supply the total maximum driving power of all connected VSI's together. It is however possible that the load profile is such that some of the connected VSI's always deliver energy back and some of the VSI's consume energy. In this case the AFR can be smaller than the total power of the connected VSI's.

This calculation must also be made for the total regeneration power. So if it is possible that all connected VSI's can be in regeneration mode at the same time then the AFR size should be selected from max simultaneous braking power.

Table 3 OMRON SX-AFR output DC power at mains voltage 400 V

Model	**Max Input current Imax** [A][*1]	**Normal duty 120%, 1 min every 10 min**		**Frame**	**Dimensions** Height = 2,250 mm Depth = 600 mm **Width [mm]**	**Weight [kg]**
		Rated Input current Inom [A]	**Output DC power @400 V AC [kW]**			
SX-D4115-E1AR	210	175	115	E46	600	290
SX-D4165-E1AR	300	250	165	F46	800	400
SX-D4250-E1AR	450	375	250	G46 (2 x E)	1,000	560
SX-D4330-E1AR	600	500	330	H46 (2 x F)	1,200	660
SX-D4500-E1AR	900	750	500	I46 (3 x F)	1,500	830
SX-D4660-E1AR	1,200	1,000	660	J46 (4 x F)	1,800	1,100
SX-D41K0-E1AR	1,800	1,500	1,000	K46 (6 x F)	2,700	1,600

[*1] Available for a limited time and as long as drive temperature permits.

Table 4 OMRON SX-AFR output DC power at mains voltage 690 V

Model	**Max Input current Imax** [A][*1]	**Normal duty 120%, 1 min every 10 min**		**Frame (PEBB´s)**	**Dimensions** Height = 2,250 mm Depth = 600 mm **Width [mm]**	**Weight [kg]**
		Rated Input current Inom [A]	**Output DC power @690 V AC [kW]**			
SX-D6200-E1AR	210	175	200	F69	800	320
SX-D6400-E1AR	420	350	400	H69 (2)	1,200	590
SX-D6600-E1AR	630	525	600	I69 (3)	1,700	860
SX-D6800-E1AR	840	700	800	J69 (4)	On request	
SX-D61K2-E1AR	1,260	1,050	1,200	K69 (6)	On request	

[*1] Available for a limited time and as long as drive temperature permits.

CHAPTER 8 GENERAL ELECTRICAL SPECIFICATIONS

Table 5

General		
Mains voltage:	SX-AFR/FR/VL 400V models	380 to 460 V +10%/-15%
	SX-AFR/FR/VL 690V models	480 to 690 V +10%/-15%
Mains frequency:		48 to 52 Hz and 58 to 62 Hz
Input total power factor:		1.0
Output DC voltage:	SX-AFR	(1.0 to 1.2) * √2 * Mains supply voltage
Output AC voltage:	SX-FR/VL	(0 to 1.2) * Mains supply voltage
Output frequency:	SX-FR/VL	0 to 400 Hz
Switching frequency:	SX-AFR	3 kHz (adjustable 3 to 6 kHz)
	SX-FR/VL	3 kHz (adjustable 1.5 to 6 kHz, FDUL only)
Efficiency at nominal load:	SX-AFR	98%
	SX-FR/VL	97%
Harmonics to supply, THDI		< 5%

8.1 SX-AFR fuse data

Table 6 DC fuses used for AFR output

AFR Model	Frame	Installed DC fuses F_{DC} [A]	Bussman type	Installed AC fuses F_{AC} [A]	Bussman type
SX-D4115-E1AR	E48	400	170M2621	315	170M4815
SX-D4165-E1AR	F48	400	170M2621	400	170M2621
PEBB46-175/AFE	“E48”	400	170M2621	315	170M4815
PEBB46-250/AFE	“F48”	400	170M2621	400	170M2621
SX-D6200-E1AR	F69	315	170M4815	315	170M4815
PEBB69-175/AFE	“F69”	315	170M4815	315	170M4815

In this table the fuses of the single PEBB versions of the SX-AFR 175 A and 250 A are listed. For the multiple PEBB versions the same ratings is used for each PEBB. So in total only 3 different PEBB’s are used to cover the complete range SX-AFR/VL/FL/FR.

8.2 DC fuses for VSI units

For VSI drive units connected to the DC bus, are standard OMRON SX drive units equipped with additional DC+/DC- terminals.
Each VSI drive unit connected to the DC-bus should be fed via DC fuses. At standard no DC switches are allowed. For selection of correct DC fuse type and size, see Table below.

Table 7 Recommended DC Fuses for connected VSI drive units

VSI Model	Frame	Recommended DC fuses F_{DC} [A]	Bussman type
SX-D40P7-E_	B	25	170M4803
SX-D41P5/D42P2-E_	B	25	170M4803
SX-D43P0/D44P0-E_	B	25	170M4803
SX-D45P5/D47P5-E_	B	40	170M4806
SX-D4011/D4015-E_	C	80	170M4809
SX-A4011/A4015-E_	C2	80	170M4809
SX-D4018/D4022-E_	C	80	170M4810
SX-A4018/A4022-E_	C2	100	170M4810
SX-D4030/D4037-E_	D	160	170M4812
SX-A4030/A4037-E_	D2	160	170M4812
SX-A4045	D2	200	170M4813
SX-D4045/D4055-E_	E	200	170M4813
SX-D4055	E2	200	170M4813
SX-D4075/D4090-E_	E	315	170M4815
SX-A4075/A4090-E_	E2	315	170M4815
SX-D4110/D4132-E_	F	400	170M4821
SX-A4110/A4132-E_	F2	400	170M4821
PEBB48-175/VSI	“E”	315	170M4815
PEBB48-250/VSI	“F”	400	170M4821
SX-D6090-E_	F69	200	170M4813
SX-D6110-E_	F69	200	170M4813
SX-D6132-E_	F69	315	170M4815
SX-D6160-E_	F69	315	170M4815
SX-D6200-E_	F69	400	170M4821
PEBB69-200/VSI	“F69”	400	170M4821

8.3 Pre-charging circuit

The power-on pre-charging of the DC link capacitors in AFR inverters as well as in VSI drive unit inverters, is handled by one or more charging units located in the AFR module(s). Each charging unit can handle a limited amount of DC link capacitance, due to thermal limitation. The sum of the capacitances of the connected VSI's may not exceed the values as stated in the following table. Compare this value to the maximum capacitance value of the AFR unit used, stated in Max. total VSI capacitance value below. Capacitance values for the different sizes of VSI drive units are shown inCapacitance values for VSI units.

Table 8 Max. total VSI capacitance value

AFR Model	Frame	Charging units Included	VSI CDC max [µF]
SX-D4115-E1AR	E46	1	42,000
SX-D4165-E1AR	F46	1	40,000
SX-D4250-E1AR	G46	1	36,000
SX-D4330-E1AR	H46	1	32,000
SX-D4500-E1AR	I46	2	72,000
SX-D4660-E1AR	J46	2	64,000
SX-D41K0-E1AR	K46	3	96,000
SX-D6200-E1AR	F69	1	26,667
SX-D6400-E1AR	H69	1	21,334
SX-D6600-E1AR	I69	2	48,000
SX-D6800-E1AR	J69	2	42,668
SX-D61K2-E1AR	K69	3	64,000

Note: If total DC link capacitance is greater than the maximum value for the selected AFR, it is possible to specify increased size of AFR charging unit. This is also possible if a shorter charging time (“ready to start time”) is required.
460 V charging unit = 48,000 µF capacity
690 V charging unit = 32,000 µF capacity

Table 9 Capacitance values for VSI units

SX Model	Frame	C_{DC} [µF]
SX-D40P7-E_	B	195
SX-D41P5/D42P2-E_	B	195
SX-D43P0/D44P0-E_	B	195
SX-D45P5/D47P5-E_	B	375
SX-D4011/D4015-E_	C	750
SX-A4011/A4015-E_	C2	750
SX-D4018/D4022-E_	C	1,125
SX-A4018/A4022-E_	C2	1,125
SX-D4030/D4037-E_	D	2,250
SX-A4030/A4037-E_	D2	2,250
SX-D4045/D4055-E_	E	4,000
SX-A4055-E_	E2	4,000
SX-D4075/D4090-E_	E	6,000
SX-A4075/A4090-E_	E2	6,000
SX-D4110/D4132-E_	F	8,000
SX-A4110/A4132-E_	F2	8,000
PEBB48-175/VSI	F	6,000
PEBB48-250/VSI	F	8,000
SX-D6090-E_	F69	4,000
SX-D6110-E_	F69	4,000
SX-D6132-E_	F69	5,333
SX-D6160-E_	F69	5,333
SX-D6200-E_	F69	5,333
PEBB69-200/VSI	F69	5,333

CHAPTER 9 HIGHER POWERS

Constructing a higher power AFR than ratings in the brochure or instruction manual by paralleling multiple AFR units is only allowed when confirmed by OMRON. Dedicated calculations that take load sharing into account must confirm that no overloading can occur. Solutions for this is under investigation

Fig. 21

Fig. 22

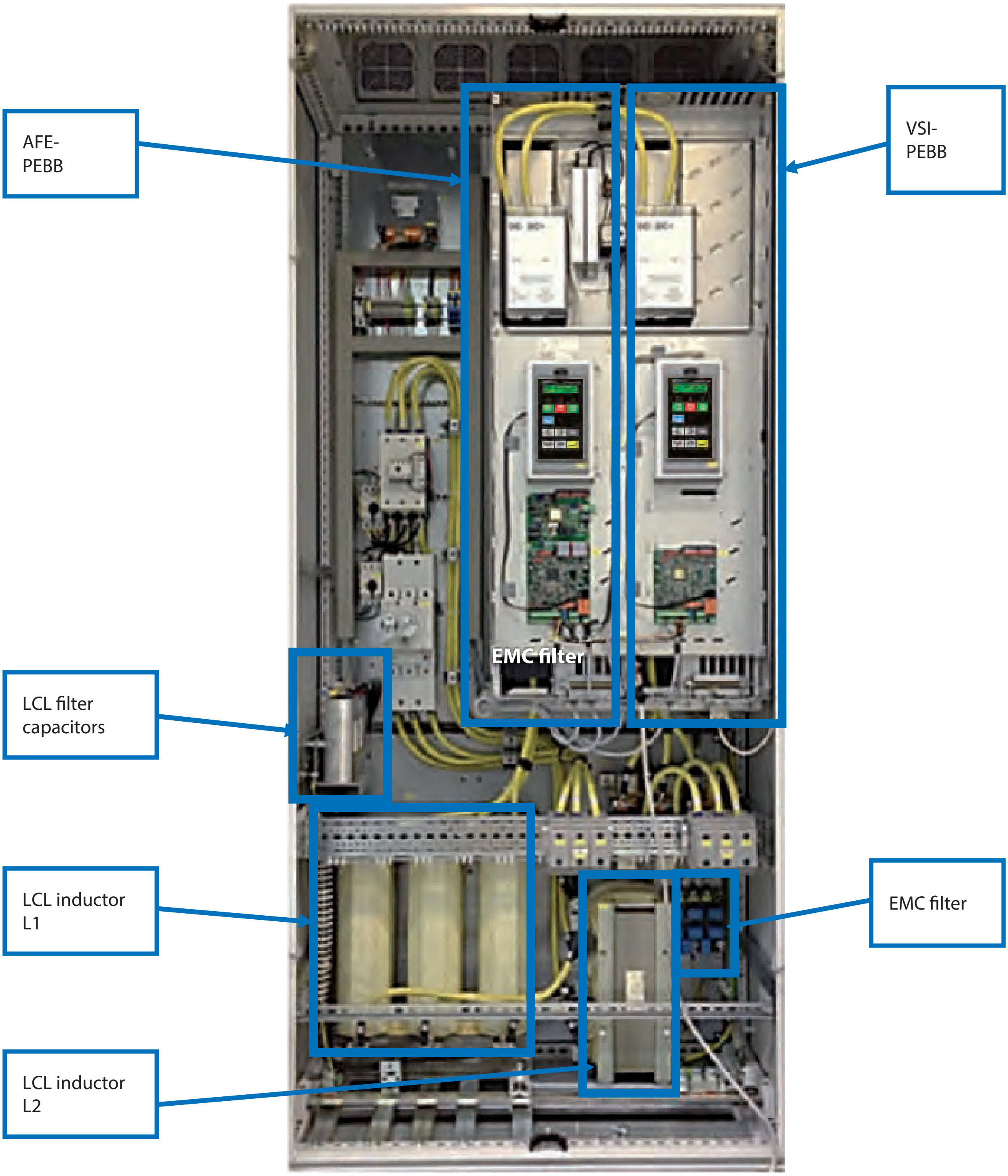


Fig. 23 Cabinet

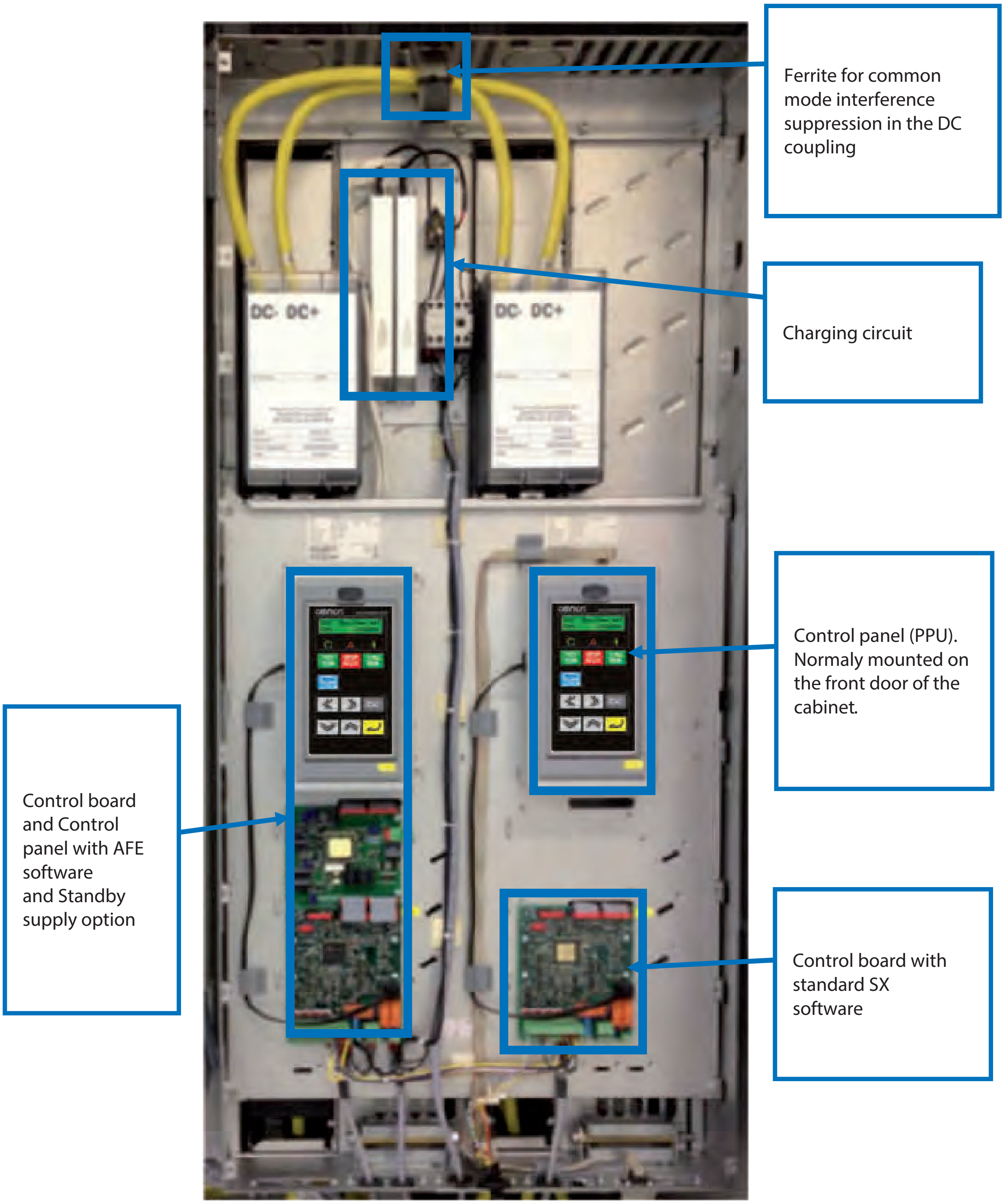


Fig. 24 AFE + VSI

AFE PEBB

VSI PEBB

Fig. 25 AFE PEBB and VSI PEBB

The main difference to a standard PEBB is that in the AFE PEBB´s and VSI PEBB´s, the input rectifier circuit and the DC choke are not mounted. Note that the AC input connection of the AFE PEBB is using the terminals normally used as AC output for the standard PEBB.

Fig. 26 Standard PEBB

9.1 PEBB powers

Important difference with the AFE and the normal drive is that the AFE part is dimensioned based on the active current. The AFE will have Power Factor of almost 1. This means that with a given motor power for the VSI "drive" the nominal current of the AFE PEBBs can be smaller.

For all configurations we only use 3 variants in power size (so all the same spare parts for the whole range) and in total 6 different PEBB´s for AFE or VSI purpose.

To give an example:
If we look in the SX AFE Instruction Manual (I123E) the AFE uses 2 × 175 A PEBB, but in the VSI part there are 2 × 250 A PEBB's used.

400 V units			
Drive	**Frame**	**AFE PEBB**	**VSI PEBB**
SX-D4055	E46+E=G	1 × 175	1 × 175
SX-D4075	E46+E=G	1 × 175	1 × 175
SX-D4090	E46+E=G	1 × 175	1 × 175
SX-D4110	F46+F=H	1 × 250	1 × 250
SX-D4132	F46+F=H	1 × 250	1 × 250
SX-D4160	F46+H=I	1 × 250	2 × 250
SX-D4200	G46+G	2 × 175	2 × 175
SX-D4220	G46+H	2 × 175	2 × 250
SX-D4250	H46+H	2 × 250	2 × 250
SX-D4315	H46+I	2 × 250	3 × 250
SX-D4355	I46+I	3 × 250	3 × 250
SX-D4400	I46+I	3 × 250	3 × 250
SX-D4450	I46+J	3 × 250	4 × 250
SX-D4560	J46+J	4 × 250	4 × 250
SX-D4630	J46+KA	4 × 250	5 × 250
SX-D4800	K46+K	6 × 250	6 × 250
SX-D4900	K46+L	6 × 250	7 × 250

690 V units			
Drive	**Frame**	**AFE PEBB**	**VSI PEBB**
SX-D6110	F69+F69=H69	1 × 175	1 × 200
SX-D6132	F69+F69=H69	1 × 175	1 × 200
SX-D6160	F69+F69=H69	1 × 175	1 × 200
SX-D6250	H69+H69	2 × 175	2 × 200
SX-D6315	H69+H69	2 × 175	2 × 200
SX-D6355	H69+H69	2 × 175	2 × 200
SX-D6450	I69+I69	3 × 175	3 × 200
SX-D6560	I69+I69	3 × 175	3 × 200
SX-D6710	J69+J69	4 × 175	4 × 200
SX-D61K0	K69+KA69	6 × 175	5 × 200
SX-D61K1	K69+K69	6 × 175	6 × 200

Note: In the 690 V drives the AFE PEBB is rated at 175 A. This is because of the higher thermal demand in the AFE part. Both 690 V PEBB's (175 A and 200 A) are physically the same part

CHAPTER 10 APPLICATIONS

- Cranes
- Conveyers (downhill /uphill)
- Wind-driven generator systems
- Test stands
- Pumping plants
- Paper and rolling mill systems
- Sheet-cutters and shears
- Elevator and hoisting systems
- Sugar centrifuges
- Marine drives
- Ski Lifts

CHAPTER 11 ABBREVIATIONS

List of abbreviations used in this document.

Abbrevation	Description	Abbrevation	Description
AFE	Active front end	PEBB	Power electronic building block
AFR	Active front end regenerative DC bus feeder unit	PWM	Pulse width modulation
DFE	Diode front end	PWHD	Partial weighted harmonic distortion
CRT	Cathode ray tube	TDD	Total Demand Distortion
IGBT	Insulated gate bipolar transistor	THDI	Total harmonic distortion of the current
Iln	Nominal load current	THDU	Total harmonic distortion of the voltage
Isc	Max. short circuit current at PCC	RMS	Root mean square
LCL	Inductance –capacitance- Inductance type of filter	Rsc	Short circuit ratio at PCC
PCC	Points of common coupling	UPS	Uninterruptible power supply

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