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2. Introduction

Load sharing gives the possibility to connect multiple VLT frequency converters over the same DC-link with the following benefits:

- **Energy savings**
  A motor running in regenerative mode can supply frequency converters that are running in motoring mode. Alternatively, the motor running in regenerative mode can supply brake any resistors used with the frequency converters.

- **Reduced need for spare parts**
  In most cases only one brake resistor is required for the installation instead of a brake resistor for each frequency converter.

- **Power back-up**
  In case of mains failure all VLT frequency converters can be supplied through the DC-link from a back-up. The application can thus continue running or go through a controlled shutdown process.

This application note presents all major aspects of load sharing including preconditions, possible combinations of frame sizes, and typical configurations.

2.1 Preconditions and Special Conditions

The following preconditions must be met before load sharing can be considered:

- The frequency converters must be equipped with load sharing terminals
  - *A1-A5 and B3 frame sizes* have load sharing terminals by default
  - *B, C, and F frame sizes* must be configured for load sharing during ordering. The standard load share selection in character 21 of the typecode is “D”, but other selections are possible. For more configuration options, see http://drivecat.danfoss.net
    It is not possible to retrofit load sharing terminals on B, C, and F frame sizes
  - *D and E frame sizes* must be configured for load sharing either during ordering or through use of a retrofit kit. The standard load share selection in character 21 of the typecode is “D”, but other selections are possible. For more configuration options, see http://drivecat.danfoss.net

- The product series of the applied frequency converters must be the same, for example FC 302 used with FC 302

- The frequency converters must have the same voltage rating, e.g. use T5 with T5 only.

- The frequency converters must be placed physically close to each other to allow the wiring between them to be as short as possible (max. 25 m). The wiring must be built symmetrically around the frequency converter(s) with highest power. In addition the two wires must be run closely together, and if possible twisted.

- When adding a brake resistor in a load sharing configuration, all frequency converters must be equipped with a brake chopper
  - A brake chopper is specified in the typecode during ordering and cannot be retrofitted. The standard selection in character 18 of the typecode is “B”. For A1 frame sizes, selection “U”, brake chopper + safe stop, is also a possibility.

- The fan in the D, E, and F frame sizes must be supplied from an external power supply. For more information about use of external power supply for fans, see VLT AutomationDrive High Power Design Guide, MG34SXYY

CAUTION: “Drive ready” signal monitoring

Continuously monitor the “drive ready”-signal of the frequency converters. The “drive ready” -signal impacts the overall application control.

CAUTION: Missing phase and overcurrent protection of the mains supply required.

Frequency converters can have their rectifier overloaded even though the DC-link does not show a high level of voltage ripple. Therefore the mains supply must be equipped with missing phase and overcurrent protection

NOTE: Load sharing can cause unintended warnings or reduced performance

In a load sharing application, the AC-brake function does not work as expected. The function checks for regenerative power, but in a load sharing application the regenerative power can come from another frequency converter.

- Turn off the AC-brake function in load share applications (Par 2-10 *Brake Function*).

Example: A frequency converter without a brake is combined with a frequency converter with a brake. When the frequency converter with a brake is braked, the other frequency converter receives an overcurrent warning. Performance is not affected.

NOTE: Risk of increased start-up time of the frequency converters.

3. Frame Size Combinations

The concept for limiting inrush current in the DC-link capacitors is not the same for all frame sizes. Therefore options for combining different frame sizes in load sharing applications are limited.

CAUTION: Risk of frequency converter failure through incompatible inrush control principles

Ensure that the applied inrush control principles are compatible before combining frequency converters in a load sharing application. The principles are listed in Table 1.

Frame size	Principle
A	DC inrush self limited
B	
C	AC inrush thyristor limited
D	AC inrush resistor limited
E	
F	

Table 1 Inrush control principles for individual frame sizes.

In the following, the different inrush control principles are discussed taking two use cases into consideration:

1. Frequency converter supplied from mains and supplying other frequency converters via load sharing terminals

2. Frequency converter supplied from load sharing terminals

3.1 Inrush Control for A and B Frame Sizes

The inrush control for frame sizes A and B is placed in series with the DC-link capacitors that control the current coming from mains and/or load sharing terminals.

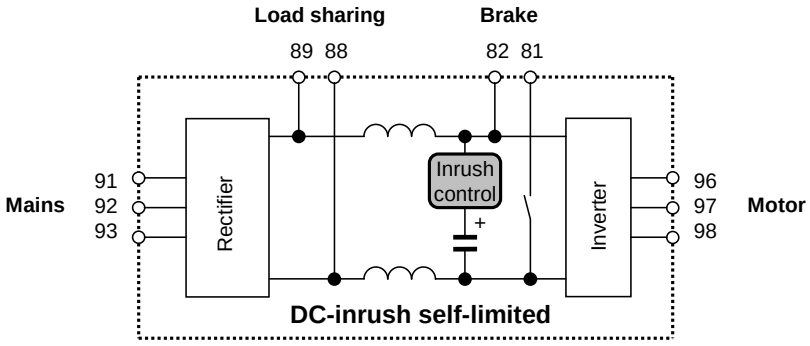

Figure 1 Inrush principle for A and B frame sizes.

- **Power via Mains**
  A and B frame sizes cannot control and limit the inrush to other frequency converters connected via the load sharing terminals

- **Power via Load Share Terminals**
  A and B frame sizes successfully limit inrush current when powered from the load sharing terminals.

3.2 Inrush Control for C Frame Sizes

The C frame size inrush circuit controls the phase-angle of the mains thyristor used for rectifying the AC-line voltage during power-up.

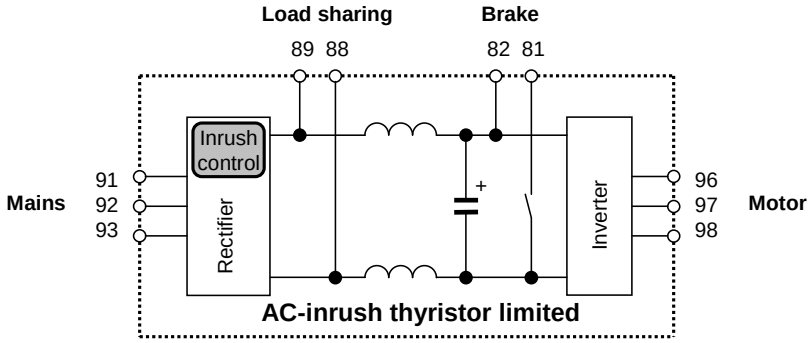

Figure 2 Inrush principle for C frame sizes.

- **Power via Mains**
  The C frame size frequency converter can control inrush for a limited number of frequency converters connected via their load sharing terminals.

- **Power via Load Share Terminals**
  The inrush control does not limit inrush current when power is coming from the load sharing terminals.

3.3 Inrush Control for D, E, and F Frame Sizes

D, E, and F frame size frequency converters limit the inrush current via a parallel path to the main SCR rectifiers. The parallel path contains series resistors to limit the inrush current while the main SCRs are held off. Upon inrush completion the main SCRs are gated to allow full power to the frequency converter

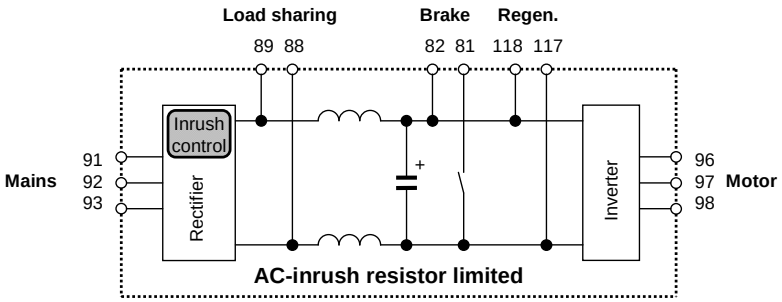

Figure 3 Inrush principle for D, E, and F frame sizes.

- **Power via Mains**
  The D, E, and F frame sizes are able to limit inrush for frequency converters connected to the load sharing terminals.

- **Power via Load Share Terminals**
  The inrush control for D, E, and F frame sizes does not limit inrush current when power is coming from the load sharing terminals.

3.4 Allowed Frame Size Combinations

CAUTION: Risk of frequency converter failure through incompatible inrush control principles

Ensure that the applied inrush control principles are compatible before combining frequency converters in a load sharing application.

The following frame size combinations are possible in load sharing applications:

- A and B frame sizes can be combined with other A or B frame sizes.
- C, D, E, and F frame sizes can be combined with other C,D, E, or F frame sizes. However, C-frame sizes can only be combined with F-frame sizes under the following circumstances:
    - All drives are connected to mains or only the F frame is connected to mains

    It is not possible to combine F and C frame sizes, if only the C frame size is connected to mains
- If the A/B frame size frequency converter is not connected to mains, A and B frame sizes can be combined with C, D, E, or F frame sizes. See Figure 4.

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A/B frame sizes are overloaded during both inrush and normal load condition.

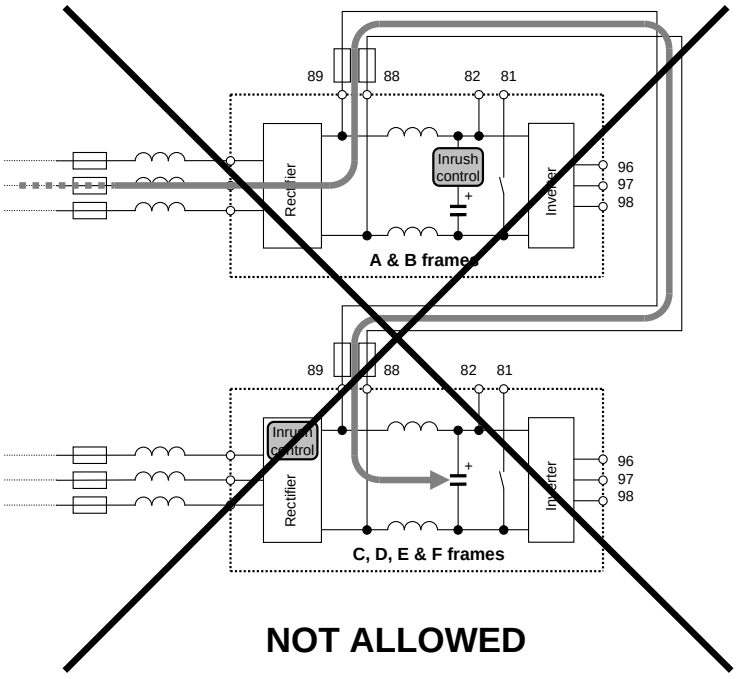

Figure 4 Risk of device failure if A / B frame sizes are combined with C, D, E, or F frame sizes and supplied from mains.

4. Load Sharing Configurations

This chapter discusses the following typical load sharing configurations:

1. All frequency converters supplied from an external DC supply
2. One large mains supplied frequency converter supplies all other frequency converters in the application
3. All frequency converters supplied individually from mains
4. Using a DC-link back-up
5. Using a brake resistor
6. Using a regenerative unit

CAUTION: It is the responsibility of the user or certified electrical installer that national and local regulations are followed.

4.1 All Frequency Converters Supplied from an External DC Supply

CAUTION: Use DC supply with inrush limitation.

When C, D, E and F frame sizes are supplied from DC, they do not have inrush control. Regardless of which frame sizes are used, always use DC supply with inrush limitation.

Requirements for the DC supply

- Contains inrush control/ soft charge
- Complies with EMC requirements for the entire application
- Can supply all connected frequency converters
- Is equipped with fuses, mains switch, and RFI filter as required
- Can withstand charge currents
  Charge currents depend on the input resistance of the common DC-link.
  - For C, D, E and F frame sizes the input impedance is almost zero and the DC-link must be overload protected (depending on the rise time of the supply).
  - For A and B frame sizes, the following values can be used in the dimensioning.

Frame size	Input resistance [Ω] @ 25°C	Type of resistance
A1, A2, A4, A5[1]	30	NTC
A3, A5[1]	60	NTC
B1, B3	50	PTC
B2, B4	75	PTC

[1]A5 is 30 Ω for powers similar to frame size A2 and 60 Ω for powers similar to frame size A3.

If required, input resistance can be calculated as follows:

$$I_{\text{charge}} = \frac{U_{DC}}{R_{total}}$$

R_{total} can be calculated as the total resistance of the DC links in parallel.

$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_N}}$$

R_X represents the resistance of each frequency converter on the DC-link.

NOTE: DC supply with battery back-up

If a DC supply with battery back-up is used, make sure that the motors are brought to a stop before battery runs down.

4.1.1 External DC supply with soft charge

If the external DC supply is equipped with inrush limitation, all frame sizes can be added on the load share terminals. The DC coils in the frequency converters limit the ripple current and minimize the harmonic current to the common DC supply. AC line reactors are not required as the intermediate voltage is the same for all connected frequency converters.

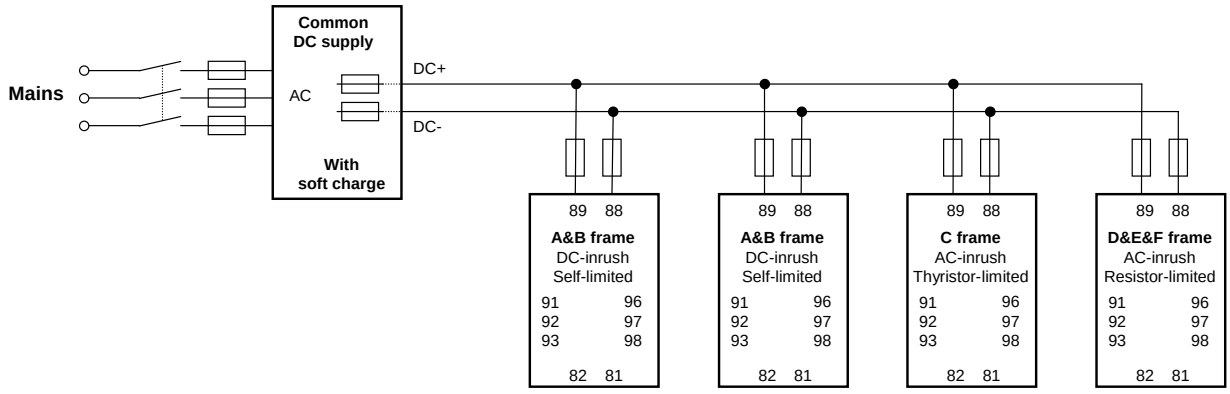

Figure 9 Frequency converters supplied from an external DC supply with soft charge via the load share terminals

CAUTION: Risk of short circuits
To comply with relevant regulations and prevent short circuiting of single frequency converters, load sharing terminals must be equipped with fuses. Without individual fuses on the load share terminals, there is a risk that a defect frequency converter will be charged by working frequency converters.

4.2 One Large Mains Supplied Frequency Converter Supplies other Frequency Converters

In this configuration only the frequency converter with the highest power range is connected to mains.

The frequency converter connected to mains can supply up to 130% of its own nominal current and use this to charge itself as well as frequency converters connected via the load share terminals. The total power of the installation is the sum of the nominal powers of the frequency converters connected to mains.

CAUTION: The frequency converter connected to mains shares capacity with frequency converters connected via load share terminals and cannot be used at full capacity.

NOTE: The power-up time of the application is increased as the small frequency converters supplied from load share terminals are slowly charged through the bigger frequency converters supplied from mains.

The following requirements apply:

- The large frequency converter can be of any frame size as long as it is the largest frequency converter in the load sharing configuration.
- The large frequency converter must be dimensioned to supply the remaining frequency converters. Dimension the frequency converter to supply the total motor power.

  Example: The large frequency converter runs a flywheel and only provides power enough to overcome friction after start-up. In case of short-term mains failure, the mechanical inertia can be used to supply power via a common DC bus to smaller frequency converters. Possible application area is the textile industry.
- Additional components such as mains fuses and line reactors are not required for frequency converters not connected to mains.
- Fuses in the DC link must comply with relevant legislation.

NOTE: Only A and B frame sizes can be supplied from the large frequency converter. Due to the inrush control principle, C, D, E, and F frame size frequency converters cannot be supplied from a large frequency converter, see section 3.

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A/B frame sizes are overloaded during both inrush and normal load condition.

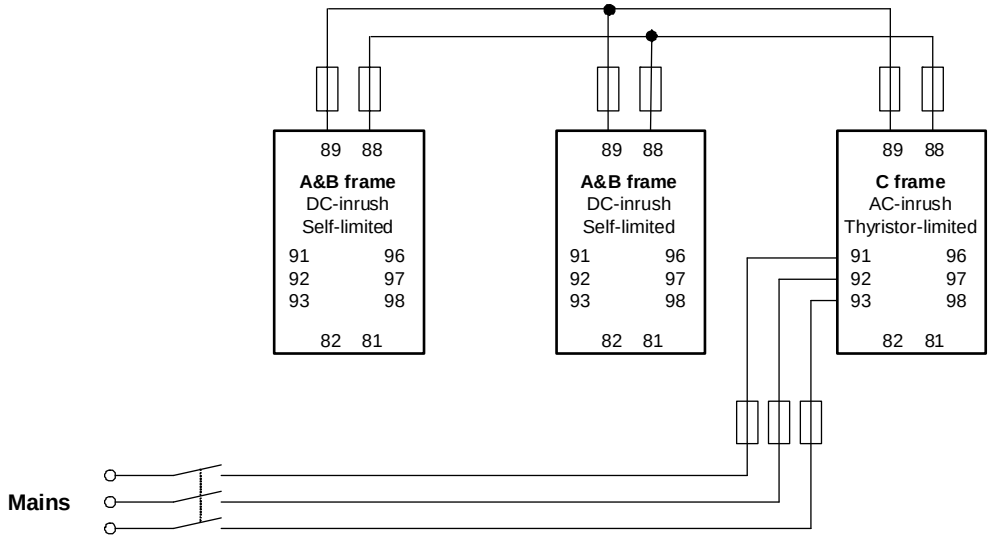

Figure 5 One large frequency converter supplies others via load share terminals.

4.3 All Frequency Converters Supplied Individually from Mains

This configuration is typical for load sharing applications. When motors run in regenerative mode, they supply power to other frequency converters in the load sharing application via the common DC link. In some

cases, this configuration does not require any brake resistor. The considerations necessary for the application depend on the combination of frame sizes.

4.3.1 Combinations of A and B Frame Sizes

A and B frame sizes can be combined without special considerations. If no other components are connected to the DC link, it is possible to install only one set of fuses between two frequency converters. The fuse must be dimensioned according to the smallest power size frequency converter to interrupt charging in case of frequency converter failure. To prevent any negative effect of a short circuit on the DC link, fuses can be installed in both ends.

CAUTION: Risk of frequency converter failure through overload caused by short circuits.
Ensure that mains fuses/circuit breakers enable a short circuit to blow the remaining fuses in case the load from the system is too high.

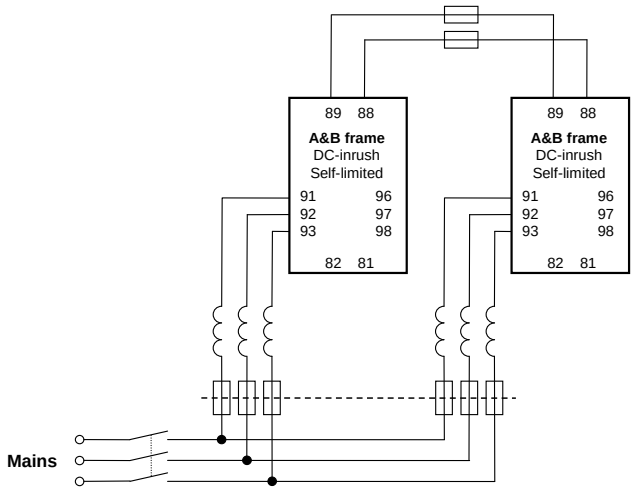

Figure 3 Load sharing with A and B frame sizes supplied from mains and connected via load share terminals.

4.3.2 Combinations of all Frame Sizes

For load sharing with combinations of A, B, C, D, E and/or F frame sizes, note the following:

- Power-up frequency is limited to allow for necessary cooling of the frequency converters in the application (max. 1 power-up pr. 4 min).
- C, D, E, and F frame size frequency converters must be dimensioned to handle the maximum simultaneous power input to the load sharing application.
- The voltage of the DC capacitors (intermediate voltage) can vary due to differences in the mains rectifiers, different temperature, or similar. This variation of DC voltage requires installation of AC line reactors for each frequency converter. Furthermore, it is also requires fuses in the DC bus.
- When combining A and B frame sizes with C-F frame sizes in load sharing, it is only allowed to supply C, E, and F frame sizes from mains.

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A/B frame sizes are overloaded during both inrush and normal load condition.

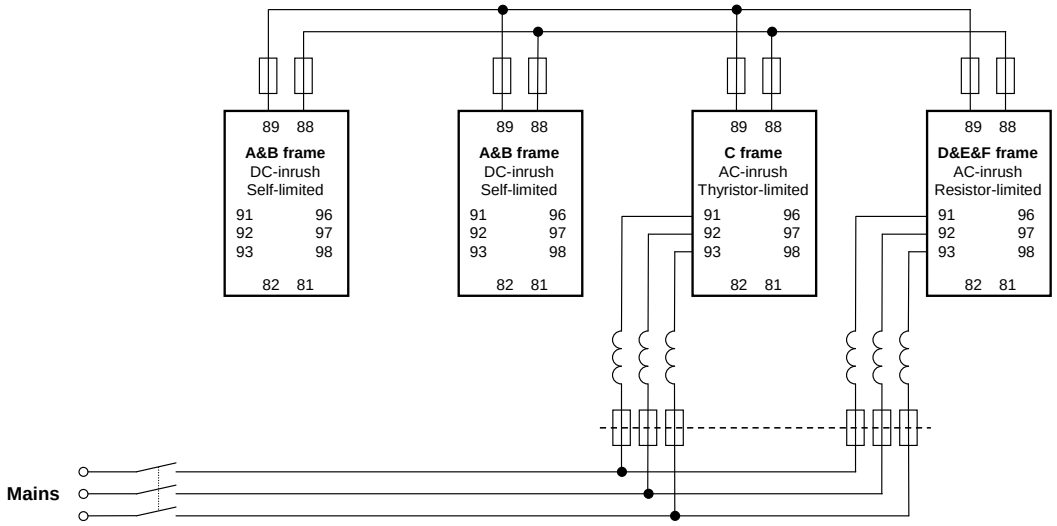

Figure 4. Load sharing with C-F frame sizes supplied from mains and connected to A and B frame sizes via load share terminals.

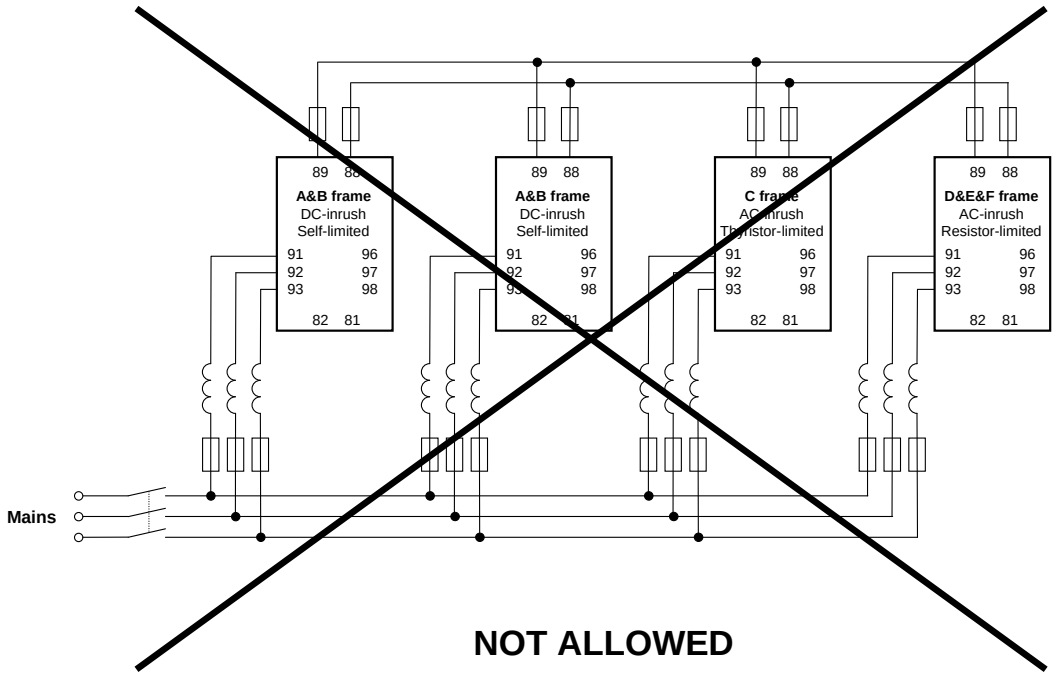

Figure 5. Load sharing with A to F frame sizes supplied from mains and connected via load share terminals is not allowed.

4.4 Using a DC Link Back-up

In a load sharing application with a DC link back-up, all frequency converters in the application can be supplied through the DC link from a back-up in case of mains failure. The application can thus continue running or go through a controlled shutdown. Note the following:

- Use a battery back-up with soft charge and isolation. Place an isolation diode in series with the battery supply to ensure that the frequency converters cannot charge the batteries.

- During a stand-by situation, the stand-by consumption of the frequency converters continues draining the battery in the battery back-up.

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A / B frame sizes are overloaded during both inrush and normal load condition.

CAUTION: Risk of frequency converter failure through overload caused by short circuits.
Ensure that mains fuses/circuit breakers enable a short circuit to blow the remaining fuses in case the load from the system is too high.

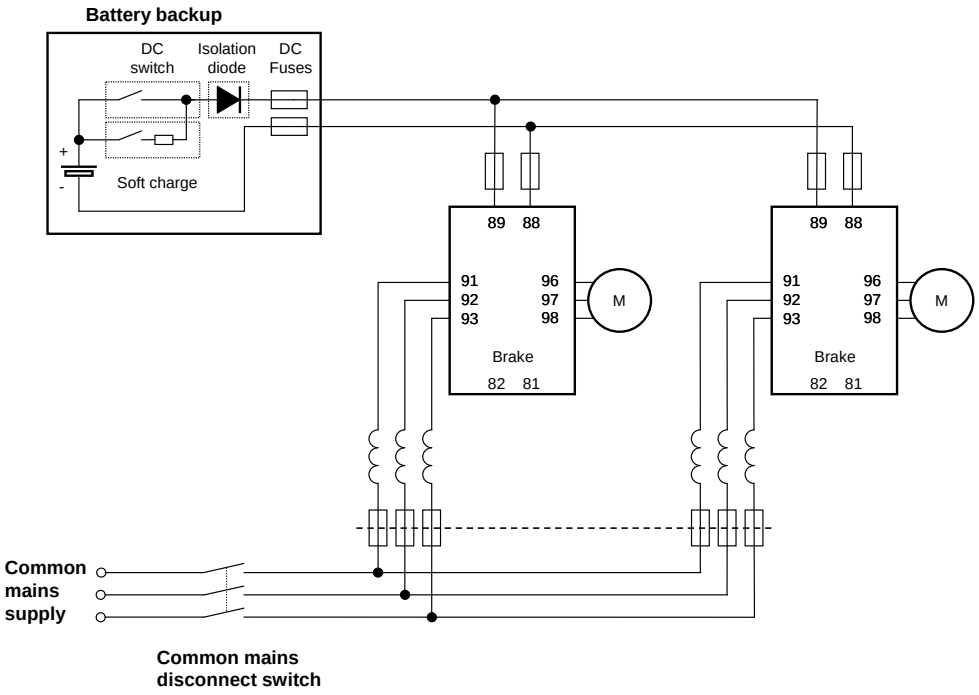

Figure 6 Load sharing application with battery back-up

4.5 Using a Brake Resistor

Using a brake resistor with the load sharing application ensure that energy from the DC link is dissipated. It is normally not necessary to equip all frequency converters in the application with resistor brakes. If only one frequency converter is equipped with a brake resistor, the following applies:

- The brake resistor must be dimensioned to dissipate the maximum energy from braking of the motors and must be connected to a frequency converter that can withstand the braking power.
- The brake resistor must be connected to the frequency converter with the highest power

CAUTION: Use of brake choppers required

All frequency converters in the load sharing must be equipped with a brake chopper

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A/B frame sizes are overloaded during both inrush and normal load condition.

NOTE: The brakes do not share loads proportionally to the resistor resistance value. Due to different tolerance intervals in the DC link voltage measurements of the single frequency converters, there is a risk that a brake is fully loaded, before the next brake starts braking.

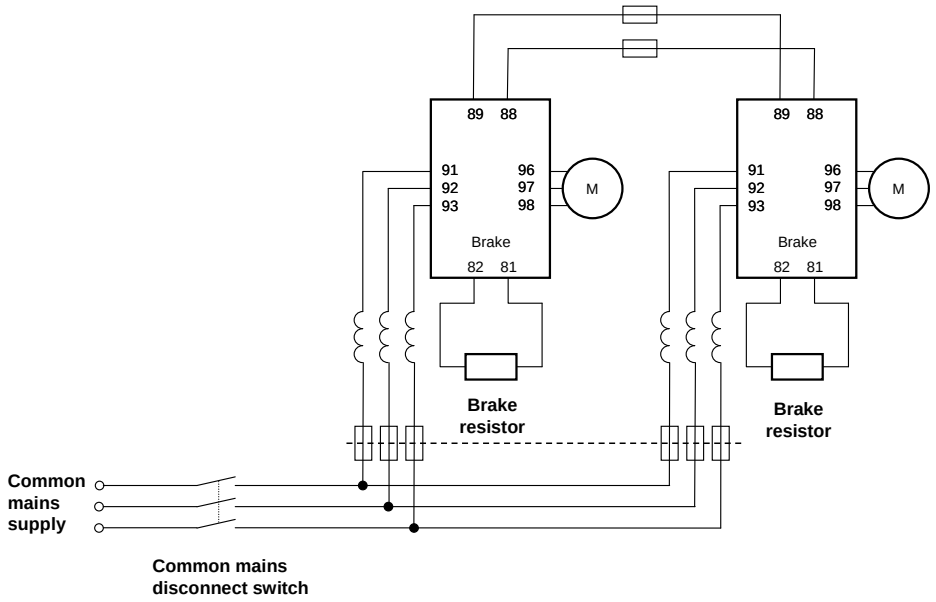

Figure 7 Load sharing with brake resistor. Energy flow from one unit to another

4.6 Using a Regenerative Unit

A regenerative unit can be connected to the common DC-link to transfer power back to mains. In general the same requirements apply as for section 4.1 (*All Frequency Converters Supplied from an External DC Supply*), but also note the following:

- The voltage working range of the DC-link must be taken into account.
- The regenerative unit must be able to keep the DC-link voltage below the nominal mains supply +13% multiplied by sqrt^2 and therefore below the actual value for braking.

Note: For further guidance and information on how to install a regenerative unit refer to vendor installation guidance.

CAUTION: Risk of frequency converter failure through rectifier overload

Ensure that A and B frame sizes are not connected to mains power when combined with C, D, E, or F frame sizes in a load share application. Otherwise the rectifier in the A/B frame sizes are overloaded during both inrush and normal load condition.

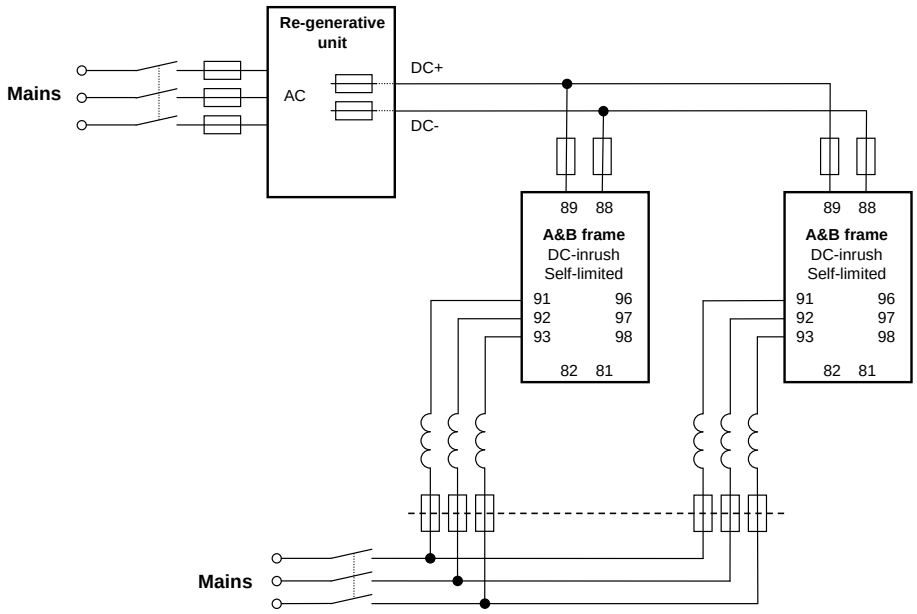

Figure 8 Load sharing using regenerative unit

5. Additional Components Needed for Load Sharing

In a load sharing application, some additional components are typically needed.

1. DC fuses
2. Mains fuses
3. Line reactors
4. Common mains disconnect switch

Figure 9 shows a typical set-up with the additional components.

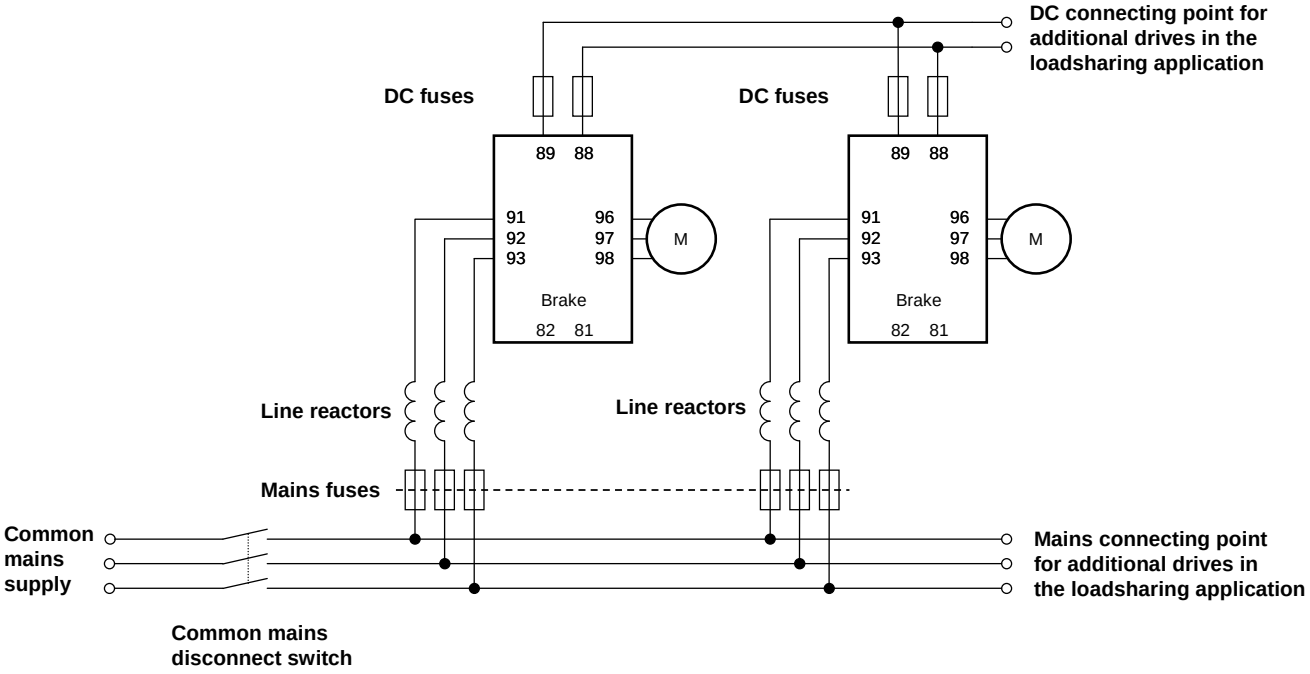

Figure 9 Typical load sharing application setup and the components needed.

5.1 DC Fuses

In order to protect the DC bus against short-circuits and the frequency converters from overload, install fuses in series with the load sharing terminals of all connected units. The following specifications apply:

- The voltage class of the fuse must be able to handle the maximum DC bus voltage ($1{,}35 \cdot U_{LL}$)
- The fuse must be a fast semiconductor type, for example, aR or gR. For fuse selection guidelines, refer to application note MN.90.T1.
- The maximum fuse current rating must not exceed the mains fuse current rating for the individual frequency converter ($I_{fuse,DC-link,\max} \leq I_{fuse,mains}$)

The fuse size is calculated as follows where the nominal voltage, U_{LL}, is reduced by 10% to allow for tolerances.

$$I_{DC} = \frac{P_{in}}{U_{DC}} = \frac{P_{in}}{1{,}35 \cdot U_{LL,n} \cdot 0{,}9}$$

Equation 1 Calculation of DC bus fuse size.

After the calculation, round up to the next available fuse size and then select a fuse one size bigger

Example: $U_{LL} = 230\text{V}$ and $\text{P}_{\text{in}} = 3{,}7\text{kW}$ gives $I_{DC} = 13{,}2\text{A}$. The next available fuse size is aR-16, hence aR-20 is selected.

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Table 2 DC bus fuse selection recommendations.

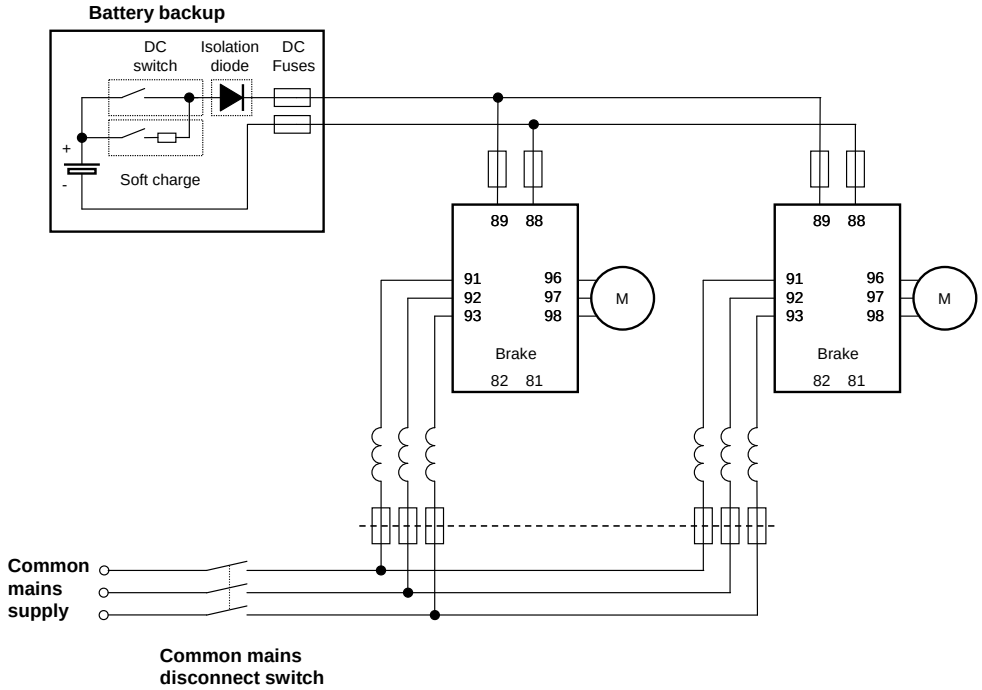
Note: The recommendations are valid for ambient temperatures of around 20 °C. At 40 °C gR/ aR fuses are rounded one size further up, that is, rounded up to the nearest fuse size AND TWO further sizes up. For high ambient temperatures, contact the fuse supplier.

5.2 Mains Fuses

A frequency converter that works correctly limits the current it can draw from the supply. In order to comply with IEC 60364 for CE or NEC 2009 for UL it is furthermore required to use fuses and/ or Circuit Breakers on the supply side as protection in case of component break-down inside the frequency converter (first fault).

For selection of fuses, refer to Application Note MN.90.T1.

CAUTION: Risk of frequency converter failure through overload caused by short circuits.
Ensure that mains fuses/circuit breakers enable a short circuit to blow the remaining fuses in case the load from the system is too high.



5.3 Line Reactors

Line reactors are only required if the frequency converters are powered from mains.

In load sharing applications, the rectifiers of the frequency converters are connected in parallel via the external DC bus connection. When frequency converters with different power size are connected in load sharing or when frequency converters of same power size are operated at different load conditions, the forward voltage drop of the rectifiers differs. This can result in unbalanced compensation within the load sharing network and must be balanced out via line reactors.

The line reactors are placed in series with the mains fuses. They ensure that the load is shared proportionally to the nominal power of each frequency converter and prevent damage to any rectifier.

NOTE: The line reactors add a load-dependent voltage drop. The voltage drop ($\Delta U_{\%}$) of the frequency converters must be the same for all frequency converters in the load sharing network.

Tables with order numbers are provided for 50 Hz 230V and 380V.

NOTE: The values in Table 3 and Table 4 are for Normal Overload. Example: If a 22 kW FC-302 is used in Normal Overload, use 175U1009. If it is used in High Overload, use 175U0047 (see Table 3).

The following formula can be used to calculate coils for 60Hz, for other voltage drops and for other mains voltages, not listed in Table 3 and Table 4.

$$L[H] = \frac{U_{phase-0}[V] \cdot \Delta U_{\%}}{I_{In,\max}[A] \cdot 2\pi \cdot f[Hz]} = \frac{U_{LL}[V] \cdot \Delta U_{\%}}{I_{In,\max}[A] \cdot 2\pi \cdot f[Hz] \cdot \sqrt{3}}$$

FC-102 1)/ FC-202 P [kW]	FC-300 P [kW]	Max I_{in}, continuous [A]	Line reactor current [A]	Voltage drop Uk [%]	AC coils L [mH]	AC coils code no
0,25	0,25	3)	2,3	1,7%	3,20	175U0015
0,37	0,37	2,2	2,3	1,7%	3,20	175U0015
0,55	0,55	3,2	2,6	2,1%	2,83	175U0017
0,75	0,75	4,1	3,8	1,9%	1,93	175U0021
1,1	1,1	5,9	5,3	1,9%	1,39	175U0024
1,5	1,5	6,8	7	1,7%	1,05	175U0025
2,2	2,2	9,5	9,1	1,8%	0,81	175U0026
3	3	11,3	12,2	1,6%	0,60	175U0028
3,7	3,7	15	15	1,7%	0,49	175U0029
5,5		22	22	1,7%	0,32	175U0132
7,5	5,5	28	32	1,5%	0,23	175U0030
11	7,5	42	44	1,7%	0,17	175U0032
15	11	54	60	1,6%	0,12	175U0034
18,5	15	68	72	1,6%	0,10	175U0036
22	18,5	80	90	1,6%	0,08	175U0047
30	22	104	104	1,7%	0,07	175U1009
37	30	130	144,6	1,6%	0,05	175U0070
45	37	154	174,1	1,5%	0,04	175U0071

Table 3 Line reactors for 50 Hz and 230 V. 1) FC-102 starts at 1.1 kW. 3) Due to the design of this frame, the AC coil recommended for 0,37 kW can be used.

FC-102[1)]/ FC-202 P [kW]	FC-300[2)] P [kW]	Max I_{in}, continuous [A]	Line reactor current [A]	Voltage drop Uk [%]	AC coils L [mH]	AC coils code no
0,37	0,37	[3)]	2,3	1,0%	3,20	175U0015
0,55	0,55	[3)]	2,3	1,0%	3,20	175U0015
0,75	0,75	2,2	2,3	1,0%	3,20	175U0015
1,1	1,1	2,7	2,6	1,1%	2,83	175U0017
1,5	1,5	3,7	3,8	1,0%	1,93	175U0021
2,2	2,2	5	5,3	1,0%	1,39	175U0024
3	3	6,5	7	1,0%	1,05	175U0025
4	4	9	9,1	1,0%	0,81	175U0026
5,5	5,5	11,7	12,2	1,0%	0,60	175U0028
7,5	7,5	14,4	15	1,0%	0,49	175U0029
11		22	22	1,0%	0,32	175U0132
15	11	29	32	1,0%	0,23	175U0030
18,5	15	34	37,5	1,0%	0,20	175U0031
22	18,5	40	44	1,0%	0,17	175U0032
30	22	55	60	1,0%	0,12	175U0034
37	30	66	72	1,0%	0,10	175U0036
45	37	82	89	1,0%	0,08	175U0047
55	45	96	104	1,0%	0,07	175U1009
75	55	133	144,6	1,0%	0,05	175U0070
90	75	177	174,1	1,1%	0,04	175U0071

Table 4 Line reactors for 50 Hz and 380V. FC-102 starts at 1.1 kW. 2) FC-301 ends at 75kW. 3) Due to the design of this frame, the AC coil recommended for 0,75 kW can be used.

5.4 Common Mains Disconnect Switch

The mains supply must be from the same source for all units in the load sharing network. When power is applied or removed, it must be via a common disconnect switch.

If frequency converters are powered on/off individually, it can lead to blown fuses or in certain cases device damage unless interlock for proper power up- and down sequencing is in place.

6. Best-practice Load Sharing Example

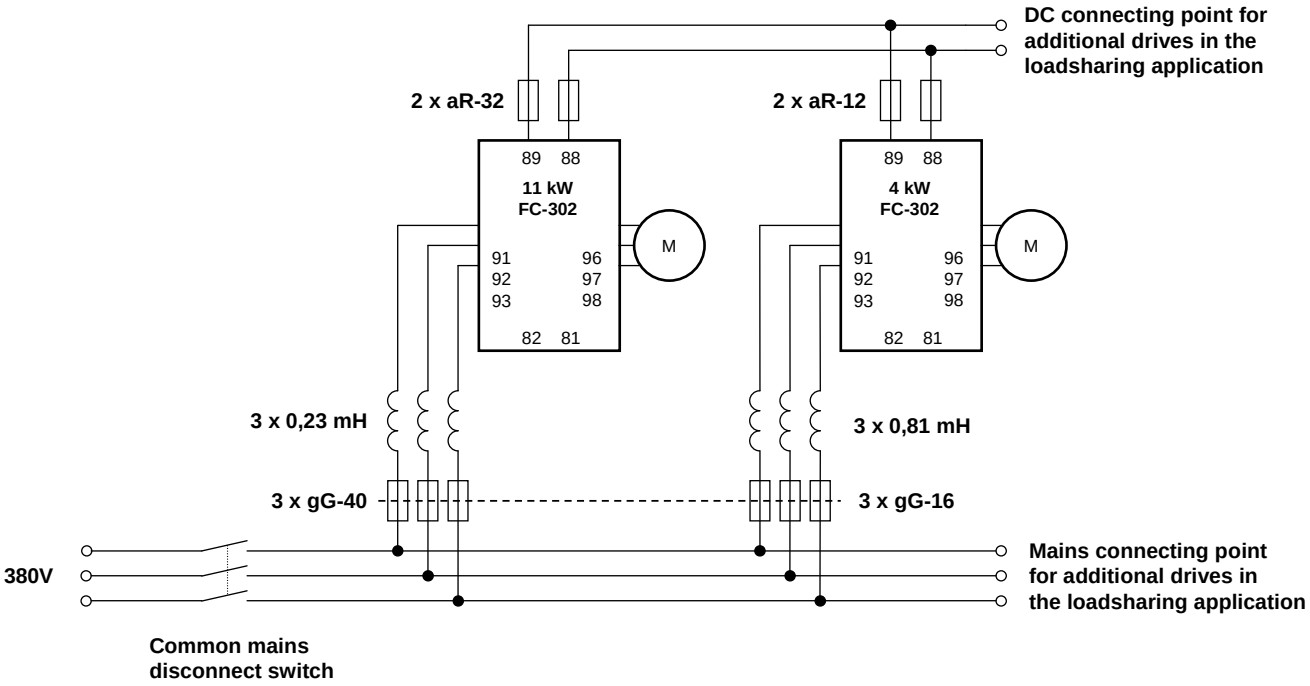


Figure 10 Example of load sharing with all frequency converters supplied individually from mains. DC fuse and line reactor values stem from the tables in this application note and the values for mains fuses are taken from the Design Guide (also found in application note MN.90.T1)