Selecting the frequency conversion system for shore connection

S. Cissoko - D. Radu
March 2015

OVERVIEW

This document contains:

- A description of shore-side power supply systems for ships at berth, and their frequency conversion requirements
- A review of the frequency conversion technologies (rotary and static) available on the market
- A technical comparison of static and rotary frequency conversion solutions for shore connection applications
- An overview of static frequency conversion performance expected according to system topology

Schneider Electric

Shore connection applications
Main Challenges

Executive summary

Growing concern about air pollution from maritime shipping on the part of both citizens and elected officials has spurred the maritime shipping industry to respond. Shore connection systems, in use since the 1980s, have been identified as one of the solutions. By giving ships at port access to the grid, these systems cut emissions from ship generators. International standards for shore connection systems have emerged, and ports are beginning to offer ships at berth access to the on-shore grid.

To successfully implement shore connection systems, several design and operational issues must be carefully examined. Most notably, frequency conversion capabilities are required to cope with the different electrical frequencies used by ships worldwide and differences between the various national grids.

Naval fleets have relied on shore connection systems for decades. Today, naval fleet managers are facing challenges like changing technologies from old rotary systems to new static alternatives. This document will also address these issues, providing the necessary information to make the most appropriate choices in the ongoing replacement of existing power supply units.

This document provides maritime-industry decision makers seeking to implement shore connection systems with guidance on how to select between rotary and static frequency conversion technologies, depending on their technical specifications and performance requirements, and how to make the right choices at the engineering, installation, and operations phases of their shore connection projects.

Glossary

AVR	Automatic Voltage Regulator
CB	Circuit Breaker
GOV	(Governor) Speed Regulator
HV	High Voltage
HVSC	High Voltage Shore Connection
LV	Low Voltage
MARPOL	International Convention for the Prevention of Pollution from Ships
MTBF	Mean Time Between Failures
MV	Medium Voltage
PF	Power Factor
PLC	Programmable Logic Controller
PM	Particulate Matter
RMU	Ring Main Unit
SC	Shore Connection
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
VFD	Variable Frequency Drive
VLU	Voltage Limitation Unit

1 Curbing air pollution through tighter regulations on emissions from maritime shipping

It is now well-established that maritime shipping contributes significantly to air pollution, particularly in coastal areas. The effects of this pollution on the environment and on human health are well-documented.

Annually, oceangoing ships are estimated to emit 1.2–1.6 million tons of PM 10; 4.7–6.5 million tons of sulfur oxides; and 5–6.9 million tons of nitrogen oxides. Furthermore, studies have estimated that around 15% of global NO_x and between 5% and 8% of global SO_x emissions are attributable to oceangoing vessels. The cardiopulmonary and lung cancer mortalities attributable to particulate matter (PM) and other pollution from oceangoing vessels were estimated at more than 27,000 per year in 2012.

Despite mounting evidence of the devastating environmental and health impacts of this pollution, traditionally there has been little international regulation of emissions from shipping. However, the regulatory landscape is now changing. Revisions to MARPOL Annex VI on the prevention of air pollution from ships came into force in 2010, tightening emissions requirements.

DIRECTIVE 2014/94/EU: “Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and sea-going ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.”

More recently, the 2014 EU Directive on the Deployment of Alternative Fuel Infrastructure requires EU Member States to ensure that national policy frameworks address vessels’ need for shore-side electricity. Under the Directive, national policies must ensure that shore-side electricity supplies are installed as a priority in ports of the TEN-T Core Network, and in other ports, by December 31, 2025.

By providing ships at port with safe, reliable access to clean electricity from the local grid, shore connection systems can effectively control the amount of air pollution and reduce the associated environmental and health impacts.

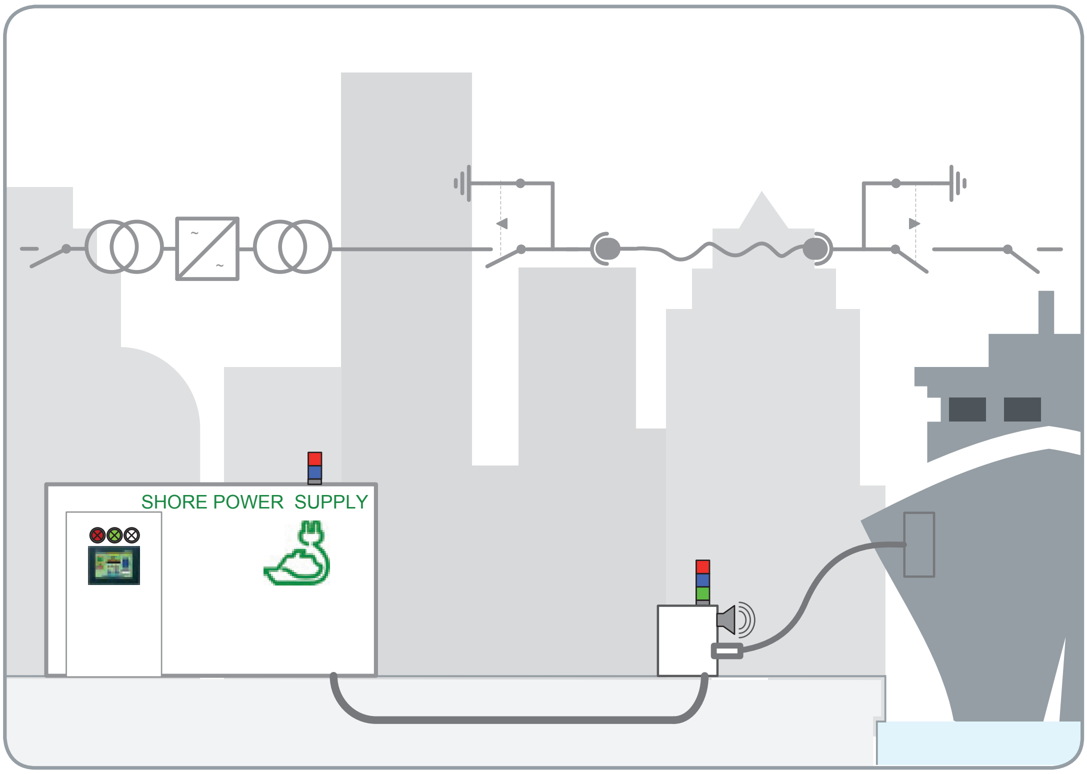
2 Providing ships at berth with access to clean power via shore connection systems

2.1 Shore connection systems: the basics

Shore connection systems encompass the equipment and procedures needed to power ships’ onboard equipment. They also provide a number of benefits, including:

- Eliminating all ship engine emissions (SO_x, NO_x, PM, CO_2) in the port area
- Eliminating ship noise and vibrations
- Improving working conditions in ports
- Facilitating maintenance and repairs on auxiliary engines while not in operation
- Ensuring compliance with MARPOL Annex VI requirements
- Generating savings, as ships at port can shut down their engines, when electricity is less costly than fuel.

Fig. 1 - Shore connection systems provide ships at berth with electricity from the grid.



2.2 A shore connection standard for international interoperability

The standard makes sure compliant ships can simply "plug in" to compliant ports wherever they are located around the globe.

Shore connection systems have been in use for commercial vessels since the 1980s. In their earliest form, these systems provided ships with low-voltage power. However, as ships' demand for electricity increased, high-voltage shore connection (HVSC) systems began to emerge. Based on successful pilot programs, these systems are currently being rolled out around the world, and today many ports can provide HVSC capabilities to connect different types of commercial ships—cruise, container, cargo, Ro-Pax, and Ro-Ro—to the grid.

Thanks to the concerted efforts of major standards organizations IEC/TC 18, ISO, and IEEE, a single worldwide standard was developed to ensure interoperability between ships and ports around the globe. Whatever HVSC system you choose, it must comply with standard IEC/IEEE 80005-1 Ed.1: *Utility connections in port - Part 1: High Voltage Shore Connection (HVSC) Systems.*

The standard sets forth:

- Requirements for shore connection design and construction
- Requirements to guarantee the safety of high-voltage shore connection systems
- Requirements for compatibility between onboard and on-shore equipment

The purpose of the standard is to enable compliant ships to simply "plug in" to compliant ports wherever they are located. And ships that do not comply with the standard may find it impossible to connect to compliant shore supplies. This standard is rounded out by IEC 62613-1 & 2, which cover the high-voltage plugs, socket-outlets, and ship couplers for high-voltage shore connection systems.

3 Determining your shore connection system requirements

3.1 Electrical dimensioning criteria

Shore connection systems are suitable for all types of ships, from medium-sized cargos and container vessels up to even the largest cruise ships (Fig. 2). However, the shore connection system must be sized according to:

- Vessel type and power required on board when at berth
- Number and frequency of calls at port
- Average duration of calls at port

Currently 70% of ships are designed for 60Hz, while only 30% of ports' electrical power supplies are 60Hz. In addition, the majority of on-shore grids are 50Hz. So, whatever the size and type of ship, electricity must be provided in 50Hz and/or 60Hz and for two standardized voltages: 6.6 kV and/or 11kV (IEC/IEEE 80005-1).

Fig. 2 - Power requirements for the various types of ships.

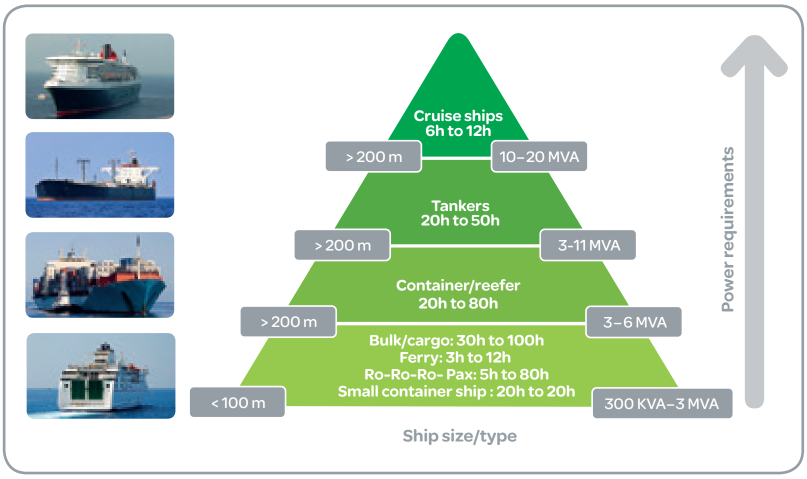


Fig. 3 - Different types of ships require different voltages and frequencies.

	LV	HV	50Hz	60Hz
Container<140m	100%	0%	63%	37%
Container>140m	88%	12%	6%	94%
Ro-Ro	100%	0%	30%	70%
Oil tankers	100%	0%	20%	80%
Cruise ships<200m	100%	0%	36%	64%
Cruise ships>200m	12%	88%	0%	100%

3.2 General electrical architecture

The shore connection electrical architecture should ensure three main functions (Fig. 4 and Fig. 5): connection to the port's electrical supply, shore-to-ship connection, and frequency conversion.

A connection to the port's electrical supply:

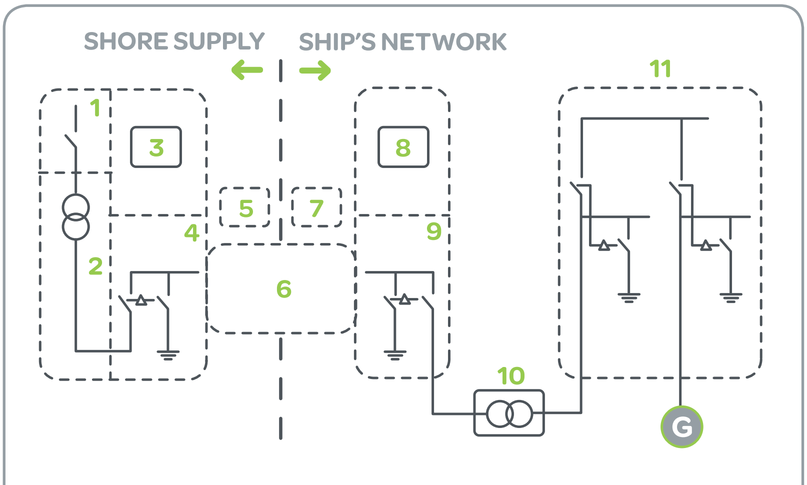
- Standard voltages from 4.76kV up to 36 kV as well as the two frequencies 50Hz and 60Hz should be covered.
- The required functions include the HV cubicles for the shore side connection either to the port's MV network or to the local grid.

A shore-to-ship connection system including:

- Isolation transformer for voltage adaptation.
- Main HV circuit breaker cubicle with associated protective relays needed for fault clearing.
- Disconnectors and earthing switches required for safety.
- System for connection to ships including motorized HV cable reels and HV plugs and sockets with their handling facilities.

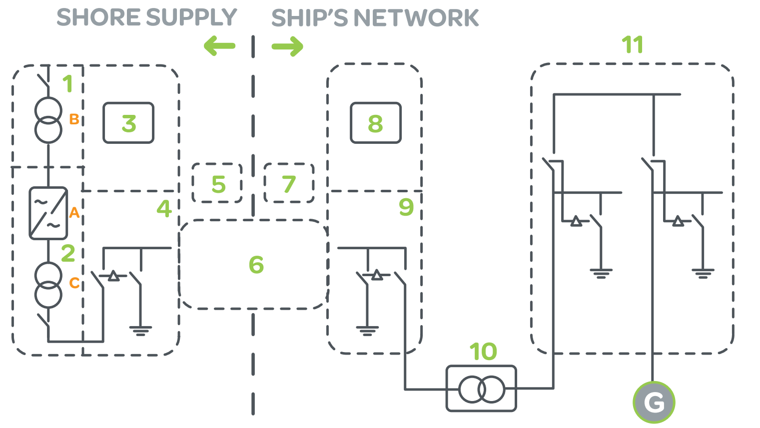
A frequency conversion system to deliver 50Hz and 60 Hz power.
Depending on the frequency of ships to be connected, the shore connection system may or may not need to include frequency conversion. When needed, frequency conversion systems consist of one or several parallel frequency converter units, depending of the required power. Generally, two power transformers are dedicated to each frequency converter unit: one step-down transformer upstream and one step-up transformer downstream.

Fig. 4 - Typical shore connection system architecture without frequency conversion.



1. Connection to the MV port's internal network or to local grid
2. Shoreside isolation transformer: mandatory to prevent circulation of earth fault current between several ships
3. Shoreside protection relays and interlocking system
4. Shoreside CB and earthing switch
5. 6. 7. Shore-to-ship connection, including: HV cables and cable reels, HV plug/socket-outlets with handling facilities, communication and control wires, equipotential bonding cable, etc.
8. Shipside protection relays and interlocking system
9. Shipside CB and earthing switch
10. Where applicable (ship voltage different from shore connection voltage), an onboard transformer is needed to adapt the high voltage supply to the ship's main switchboard voltage; this transformer is preferably located near the main switchboard in a dedicated room
11. Onboard receiving switchboard

Fig. 5 - Typical shore connection system architecture with frequency conversion.



Power frequency conversion system:
Power converter (A) unit including
step down power transformer (B)
step-up power transformer (C)
The power frequency converter is either included in each shore connection system or centralized at port level for large power requirements.

1. Connection to the MV port's electrical network or to the local grid
2. Power frequency conversion system
3. Shoreside protection relays and interlocking system
4. Shoreside CB and earthing switch

5. 6. 7. Shore-to-ship connection, including: HV cables and cable reels, HV plug/socket-outlets with handling facilities, communication and control wires, equipotential bonding cable, etc.

8. Shipside protection relays and interlocking system
9. Shipside CB and earthing switch
10. Where applicable (ship voltage different from shore connection voltage), an onboard transformer is needed to adapt the high voltage supply to the ship's main switchboard voltage; this transformer is preferably located near the main switchboard in a dedicated room
11. Onboard receiving switchboard

4 Understanding power supply performance requirements for ships at berth

Using a power supply that runs off a public grid to power ships that have their own gensets and active loads creates a unique set of issues that must be addressed by the chosen shore connection system. These include:

- Grid regulations
- Customer acceptability issues
- Any additional requirements for frequency conversion

4.1 Mandatory requirements

Operation with regenerative loads

- The frequency converter must be able to feed one or more vessels, sharing the ship electrical load with its own generators during parallelization, for a transfer from ship to shore without causing a blackout on board the ship.
- Normally, the vessel is the master and its gensets are synchronized to the power supplied from the shore.
- During load transfers from ship generators to the shore frequency converter, the frequency converter must be able to transfer the transient power flow coming from the vessel generators to the upstream network (operation in a multi-source system). An appropriate frequency convertor topology should be installed for this purpose.

Fig. 6 - Ship gensets are synchronized with the shore connection power supply.

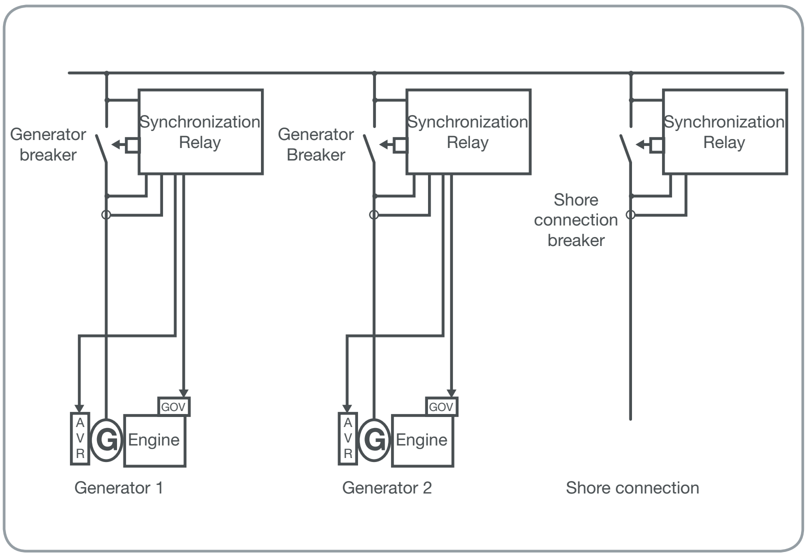
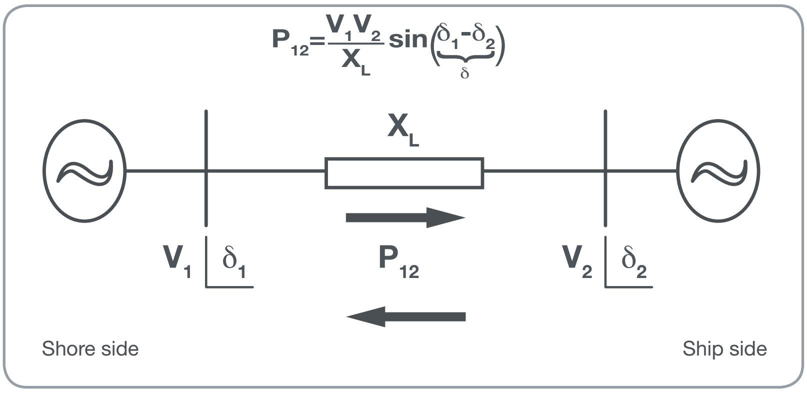


Fig. 7 - Power flow between ship gensets and shore supply.



The parallel configuration of two sources—an alternator and static converter—with very different dynamics results in a reverse power flow through the converters during transient power transfer. A similar phenomenon also occurs during load shedding (of loads initially fed by the generator).

Operation with emergency supply generators

To increase overall system reliability, mainly for naval applications, a genset power source can be used upstream from the converter, in order to mitigate the risk of a grid outage.

In this case, the frequency converter should also be able to be hooked up to an emergency supply generator in the event that the grid is unable to supply power for a prolonged period. The frequency converter should meet the following specifications for performance:

- Capacity to withstand large voltage and frequency variations at its input
- Ability to operate while being supplied by a low-short-circuit-capacity emergency generator without disrupting its operation (which implies compatibility in terms of harmonics and reactive power)

Downstream energy quality

- Sinusoidal output voltage (THD <5%) for compatibility with onboard equipment
- Regulated voltage to ±1%
- Capacity to feed non-linear loads with inductive power factor of 0.8
- Transient state variations limited as per IEC/IEEE 80005-1

4.2 Recommended requirements

Upstream energy quality

- Power factor close to 1
- Sinusoidal input current THD<5% (to ensure operation without disturbance to other loads connected to the utility and compliance with grid regulations)
- Immunity to downstream voltage dips:
- Immunity to voltage drops up to 0% residual voltage for durations of < 10ms
- Immunity to voltage drops up to 70% residual voltage for durations of < 500ms

Short-circuit and overload capacity

- Enough short-circuit capacity to ensure selective protection of the ships' equipment: up to 3xIn for durations of 0.8s

This requirement mainly applies to navy ship applications where several vessels are connected together to a 60Hz MV ring. The 60Hz MV ring protections will then be selective with the ships' protections.

Reliability and availability

A very reliable power supply is a critical concern for applications in the tens of MVA or more (i.e., naval and cruise ships). To ensure maximum reliability and uptime:

- The frequency conversion system should be able to deal with the failure of a component or a control card ("single failure" tolerance). A blackout on board the ship caused by the failure of a single frequency-conversion component is not acceptable. The chosen frequency conversion system must ensure that single failure, even if it results in the partial degradation of conversion capability, still lets the ship shed loads in order to avoid a blackout.
- Maintenance: The system must be able to restore minimal operations within 24 hours without the need for special tools or major maintenance work.

4.3 Nice-to-have requirements

Operational autonomy

Additional capabilities to facilitate shore connection system operation should also be considered. These include stand-alone operation features (without the need for supplementary auxiliary sources), which would require:

- Premagnetisation capability for highpower input transformers
- Converter DC bus preload independently managed by the converters
- A converter with integrated overvoltage and overcurrent protections

5 Assessing frequency conversion technologies

5.1 General overview

Shore connection systems can have either rotary or static frequency conversion systems. The basic requirements for both systems are:

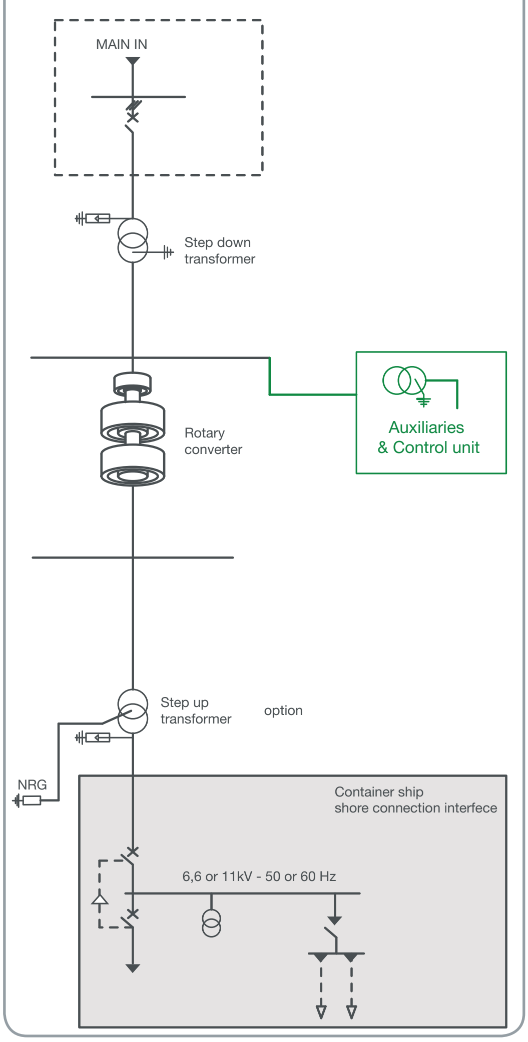
- MV protections
- Voltage adaptation transformers
- Ship-to-shore interfaces
- Control and monitoring units

The two options differ mainly in how the installations are configured and erected:

Fig. 8 - Rotary and static frequency conversion architectures.

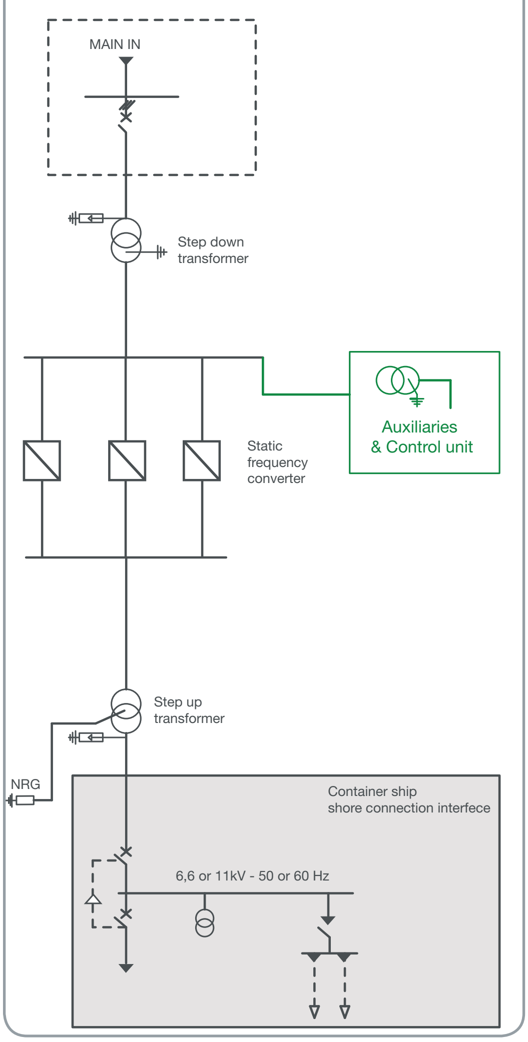
Rotary Conversion
A synchronous (or asynchronous) electrical motor is supplied by the grid via a transformer. The motor shaft is connected via a gear box to an alternator providing the converted frequency supply to the ship. Additional MV cubicles, protections and connection devices are used in the system.

Rotary solution



Static Conversion
A rectifier/inverter unit (static frequency converter) is supplied by the grid via a transformer and its output side, providing the converted frequency supply to the ship. Additional MV cubicles, protections and connection devices are used in the system.

Static solution



5.2 Rotary frequency converters

Rotary frequency converters are based on a synchronous motor supplied by the utility grid at 50Hz or 60Hz to run a synchronous generator that produces 60Hz or 50Hz power.

Rotary frequency converters can also serve as rotating filters, protecting critical loads from grid transient faults and brownouts. They are also 100% effective for outages lasting less than half a second.

These systems can be set up with either:

- A synchronous motor, for no deviation in output frequency
- A low slip induction motor, a more economical solution, but which allows the output frequency to deviate (0.60 Hz)

A pony motor can be used to get the main machines up to nominal speed.

5.3 Static frequency converters

Static 50/60Hz frequency conversion is generally carried out in two stages:

- Stage1: Conversion from 50Hz to DC
- Stage 2: Conversion from DC to 60HZ

The technologies used in this two-stage static frequency conversion process —MV DFE, MF AFE, and LV AFE—are described below.

Fig.9 - **Static frequency converter performance at a glance**

	Operation with regenerative loads	Operation with upstream supply genset	Upstream energy quality	Downstream energy quality	Downstream short-circuit capacity	Operational autonomy	Efficiency at low load factor	"Single-failure" tolerance
MV DFE	OK if equipped with braking resistance. Risk of tripping during load transient response.	Risk of subharmonics oscillation: generator must be oversized.	PF <0.9 THDI 12% with 12 pulses. Harmonic filter required.*	OK	Semiconductor technology doesn't allow overcurrent capability. Converter requires oversizing of 3 x Pn.	Requires preload LV power supply. Protections to be provided.	Operation from 20% to 30% Pn with reduced efficiency.	Failure of certain individual components can lead to a total system breakdown.
MV AFE	OK: regenerative energy is evacuated to upstream network.	Compatible with operation supplied by a genset with rated power at the same level as converter.	PF>0.9 THDI <5%	OK	Semiconductor technology doesn't allow overcurrent capability. Converter requires oversizing of 3 x Pn.	Preload supply managed independently. Protection to be provided.	Operation from 20% to 30% Pn with reduced efficiency.	Failure of certain individual components can lead to a total system breakdown.
LV AFE	OK: regenerative energy is evacuated to upstream network.	Compatible with operation of power group equivalent to converter's.	PF>0.9 THDI <5%	OK	Semiconductors technology allows overload capability. Converter requires oversizing of only 1.7 x Pn.	Preload supply managed independently. Integrated protection.	Modular architecture: operation always at 70% Pn with optimal efficiency.	The failure of any single component in modular architecture does not impact overall system performance.

*24-pulse configuration requires two redundant converters

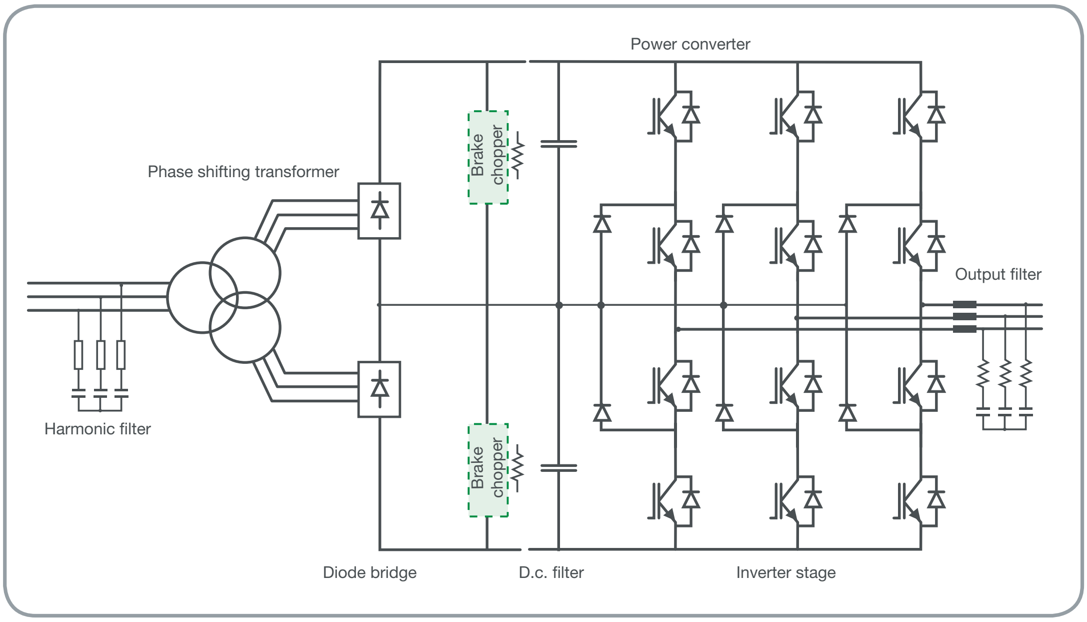
5.4 MV DFE (Diode Front End) systems

Generally, the input stage of this type of converter is comprised of diode bridges combined with a multiple winding transformer (12, 18 or 24 pulses). The base solution is made up of a secondary triangle-star-triangle double winding transformer to obtain a 12-pulse system.

However, to meet the specific needs of feeding on-shore power to a ship at berth, the following configuration is required:

- multi-pulse converter
- phase-shifting transformer
- input filter for harmonics
- PFC units
- output filter for sinus wave
- VLU (Voltage Limitation Unit) or braking resistor for reverse power

Fig.10 - Typical MV DFE static frequency convertor system configuration.



Scope of application

MV DFE technology is suitable for high power applications with low uptime requirements (e.g. motor speed drives). While it offers the advantage of being cost-effective, it is non-power reversible and ensures only mediocre upstream energy quality.

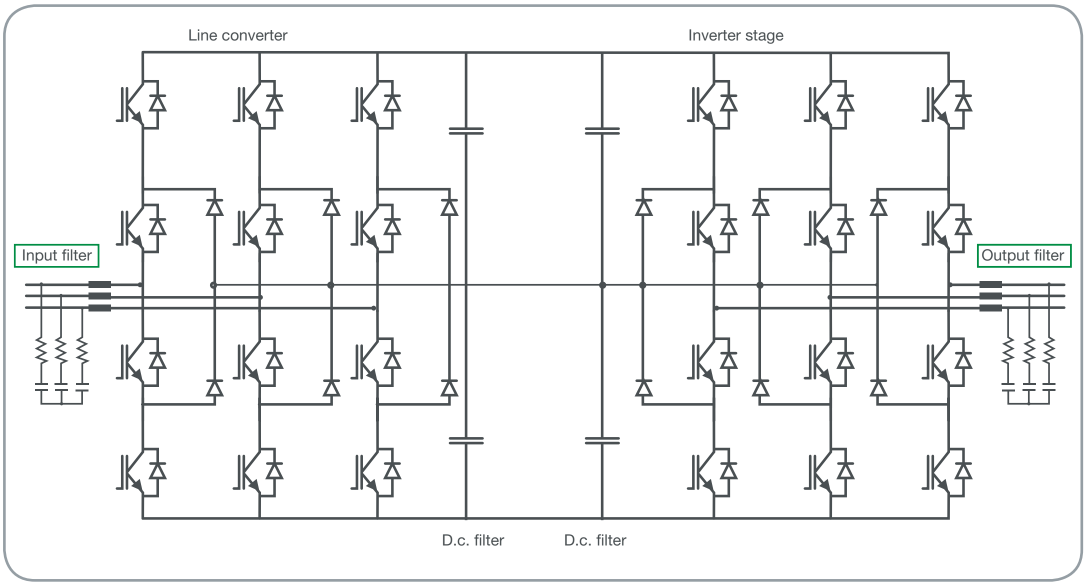
5.5 MV AFE (Active Front End) systems

The input step is made via a PWM (Pulse Width Modulation) rectifier with sinus wave input current based on controllable semiconductors (IGBT, IGCT, etc.). This configuration reduces harmonic feedback to the grid with a power factor of close to 1.

However, to meet the specific needs of feeding on-shore power to a ship at berth, the following configuration is required:

- Active Front End (IGBT, IGCT, rectifier)
- distribution transformer
- sinus filters

Fig.11 - Typical MV AFE static frequency convertor system configuration.



Scope of application

MV AFE technology is suitable for reversible high power applications with low uptime requirements (e.g. motor speed drives).

5.6 LV AFE systems

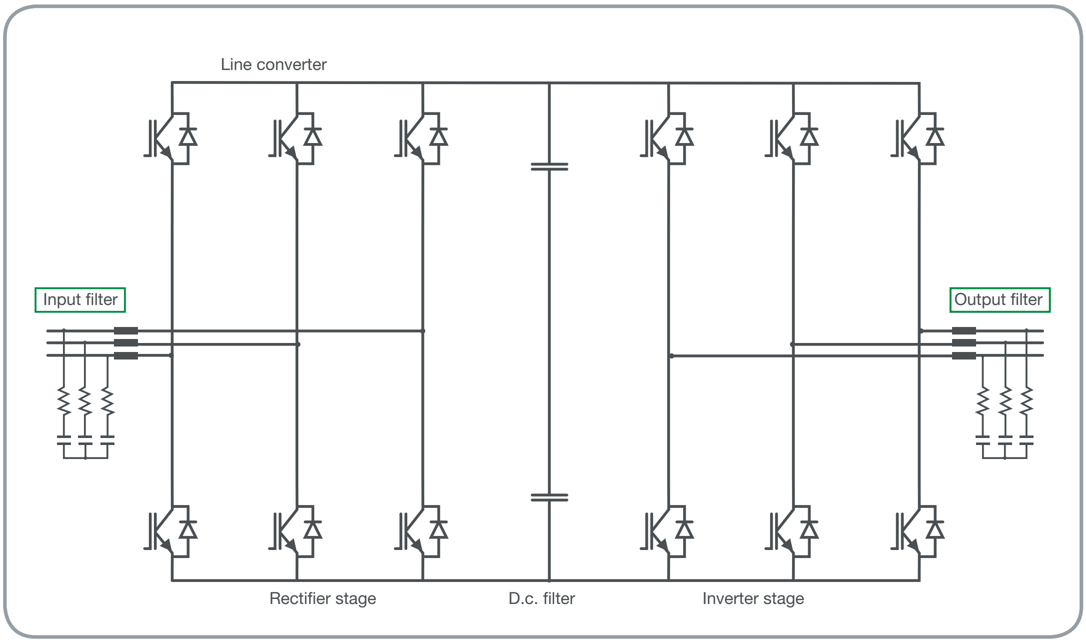
This is the low-voltage equivalent of MV AFE technology. Generally, LV AFE systems are built on several parallel converters to increase the power. It is the redundant converter setup that ensures high system uptime.

To meet the specific needs of feeding on-shore power to a ship at berth, the following configuration is required:

- Active Front End (IGBT rectifier)
- distribution transformer
- sinus filters

Scope of application
LV AFE technology is suitable for reversible medium power applications with high uptime requirements (E.g. navy applications).

Fig.12 - Typical LV AFE static frequency convertor system configuration.



6 Comparing static frequency converters and rotary frequency converters

The previous chapters described the configuration and scope of application of the different rotary and static frequency conversion systems. In this chapter, we will compare the performance of these two types of frequency conversion systems for shore connection applications. The purpose is to provide maritime-industry decision makers with the information they need to make the most appropriate frequency-conversion choice for their specific needs.

6.1 General criteria

Performance

- Response to short-circuit overload and motor start
- Immunity to load variations and grid variations
- Quality of the energy supplied to ship
- Energy efficiency

Reliability

- Output supply reliability and availability
- Curative maintenance
- Repair time

Maintenance and OpEx

- Life expectancy
- Preventive maintenance cost

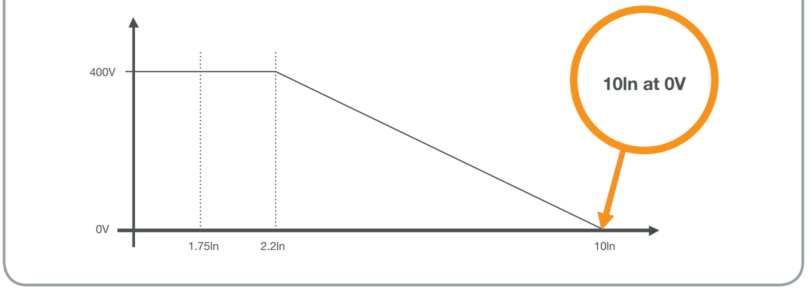
6.2 Point-by-point comparison of static and rotary frequency conversion systems

6.2.1 Short circuit and load transient response

	Rotary	Static
• Nominal short circuit current	3 In 2s	2 In 500ms
• Sub transient short circuit current	10 In	2 In
• Transformer magnetization	10 In	2 In
• Motor starting	10 In	2 In

Selectivity can be ensured with both systems. There are thermal constraints for motors powering rotating machines, which provide 10 In only with very close short-circuit conditions. With the rotary system, downstream transformers are subjected to high stress transient at start and ageing is accelerated.

Fig.13 - Real overcurrent capability of rotary systems.

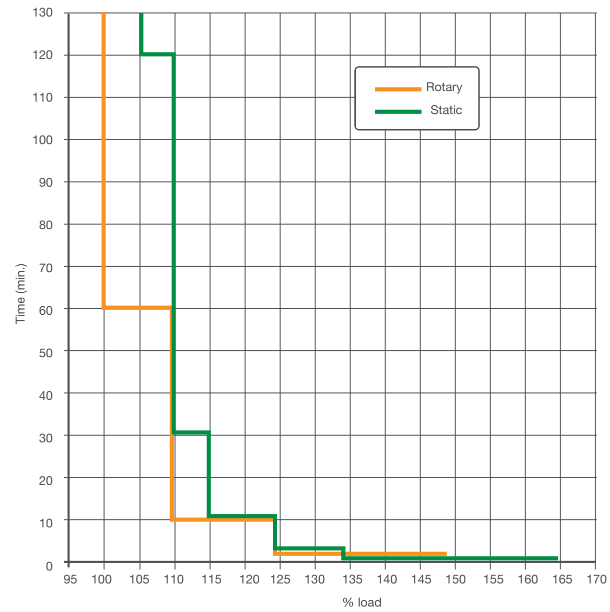


It is also important to point out that a direct 3-phase short circuit can have serious consequences on the motor side. A static system behaves as a current source and eliminates the short circuit.

6.2.2 Overload

	Rotary	Static
• Overload for unlimited period	0%	5%
• Overload for 2 minutes	50%	65%

Fig.14 - **Overload withstand capacity over time.**



6.2.3 Motor start

	Rotary	Static
• Motor start	Hard	Soft

For motor starts, a static converter behaves as starter drive providing a lower voltage during starting transient, whereas a rotary system interprets the motor as a short circuit and overloads.

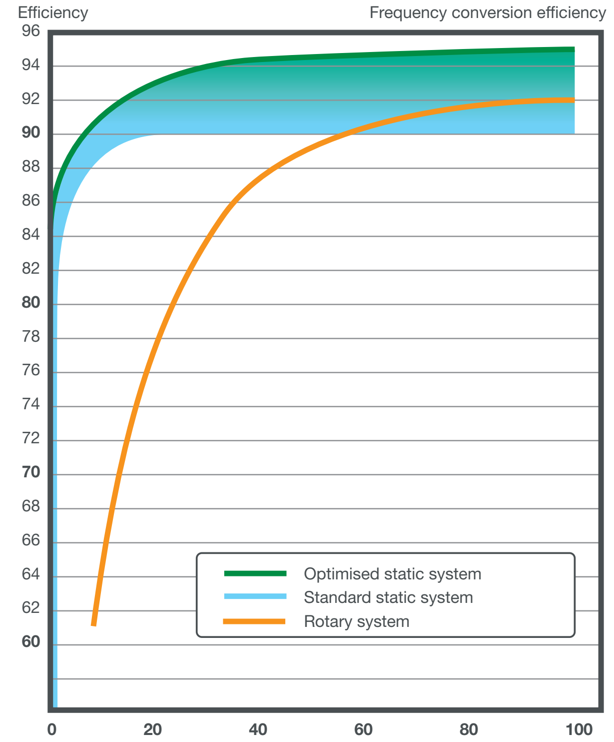
Asynchronous motors with constant torque or torque proportional to speed squared can be directly started by a static converter as long as the motor's nominal power in kW is equal to 30% of the converter's nominal power.

6.2.4 Efficiency

	Rotary	Static
• At full load	92%	94%
• At 20% load	75%	93%

In a modular configuration with several frequency converters, operation can be optimized to use only the necessary number of units for maximum efficiency, whatever the load.

Fig.15 - **Efficiency at full and partial loads.**



6.2.5 Output power quality

	Rotary	Static
• Power factor	0.95	0.99
• Harmonic distortion input current	sinewave	THD < 2%
• Harmonic distortion output voltage	THD may reach 10% with non-linear load and may generate operational disturbances	THD < 4% with non-linear loads due to low internal impedance at harmonic frequencies
• Voltage and frequency output regulation	large variations with 0-Pn impact load	± 1% with 0-Pn impact load ± 0.04%
• Non-linear loads	may disrupt operation	no impact

6.2.6 Immunity to grid performance

	Rotary	Static
• Grid voltage variations for long durations	Output power reduction and operating Disturbances if variation over 15%	From 70% Un to 120% Un with no impact on output performance
• Grid voltage variations for short durations	Up to 1 second	10 ms
• Grid frequency variation without impact	Under 15%	45Hz–66Hz
• Grid harmonic distortion	Overheating and operational disturbances (synchronization issues)	full immunity

6.2.7 Disturbances generated

	Rotary	Static
• Acoustic noise	86 dB	< 76 dB
• Electromagnetic disturbance	At pony motor inverter start, very limited at nominal power	i.e. compatible with data center requirements, so more than acceptable for shore connection applications

6.2.8 Reliability

	Rotary	Static
• Overall power supply availability (preventing unexpected events - blackout during connection)	99.33%	99.75%
• Equivalent power supply MTBF	44,242 hours	62,571 hours
• Failure rate for individual components	- 1x10-6 (M/G machine) - 2x10-6 (pony motor) - 3x10-6 (fans) - 5x10-6 (exciter circuit)	- 2.5x10-6 (rectifier charger) - 2.94x10-6 (inverter) - 1.39x10-6 (other elec.) - 3.13x10-7 (fans) - 1.54x10-6 (DC filtering)
• Failure risk	“single-component” failure risk; the failure of a single component or control card puts system operation at risk	Redundant architecture for guaranteed downgraded operation in the event of a single-component failure
• Time to repa	Complex and costly	Easy electronic parts replacement

In order to compare the reliability of rotary and static frequency conversion systems, the entire system has been taken into account (transformer, protections, control, and cooling systems). For comparison purposes, equivalent control and interface units were assumed for rotating and static systems.

The failure rate data, based on field experience, were used to compare the two types of systems’ core power conversion reliability rates.

In some circumstances, static frequency conversion systems may be more reliable than rotary systems. Static systems’ modular design ensures redundancy—something that is not possible for a single, large rotary machine. Auxiliary power supplies and control parts are also key contributors to overall system availability.

Rotary system failures are mainly caused by mechanical part failures, which means repairs and maintenance are complex and costly. Static systems mainly fail due to faulty electronics, and repairs are generally made quickly and easily on site.

6.2.9 Life expectancy and maintenance

	Rotary	Static
• Life expectancy	20 years	More than 25 years
• Ageing process	Continuous	Reset after maintenance
• Dismantling cost	Very high	Low
• Obsolescence	Non-standard control devices	Standard components
• Preventive maintenance	High cost (cooling fan motor and bearing replacement) Interruption of the operations needed	Low cost (auxiliaries, fan, PCB replacements) No interruption of the operations

With appropriate maintenance, static frequency converter units can be used for more than 25 years without major issues. For example, between 1975 and 1983, Alpes 100 and MG 30 UPSs were installed at several nuclear power plants. These systems have been operating in some cases for more than 30 years in a critical environment with strict specifications for shocks, vibrations, and temperatures.

This can be explained by the fact that preventive maintenance “resets” the ageing process for static systems, restoring them to optimal performance. This is not the case for rotary systems, which are mechanical, and which are subject to mechanical wear and tear.

Fig.16 - Mechanical component failure rate over time.

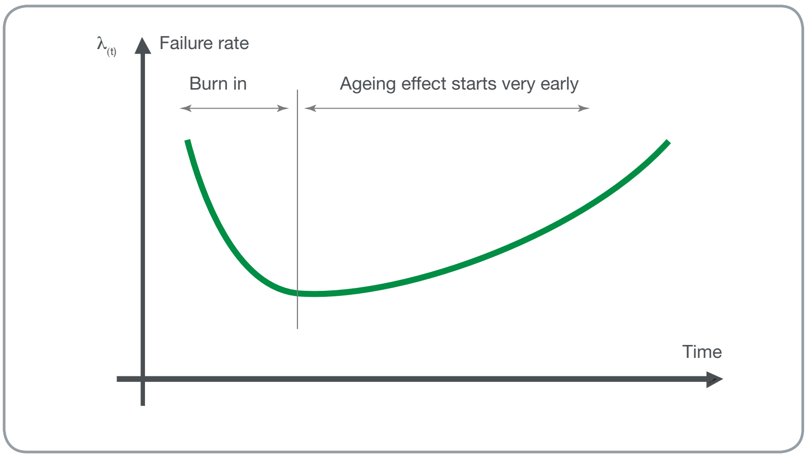
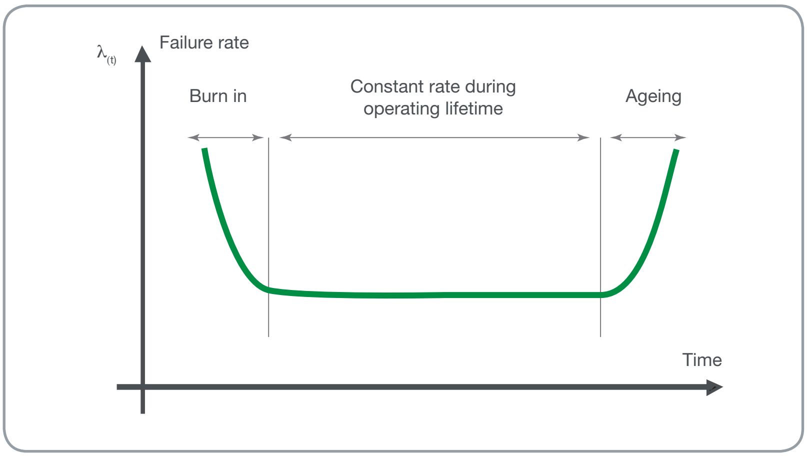


Fig.17 - Electronic component failure rate over time.



Both rotary and static systems require preventive maintenance, every 8 to 10 years, entailling the replacement of certain main parts that are defined by each converter manufacturer.

Fig.18 - Recommended parts replacement for static systems.

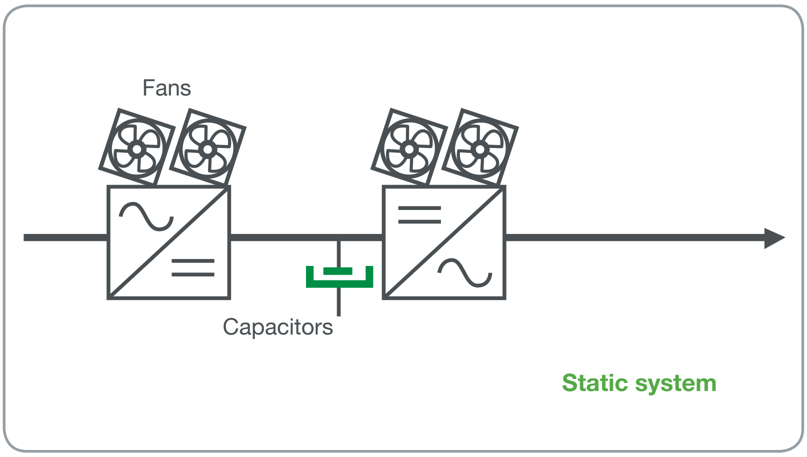
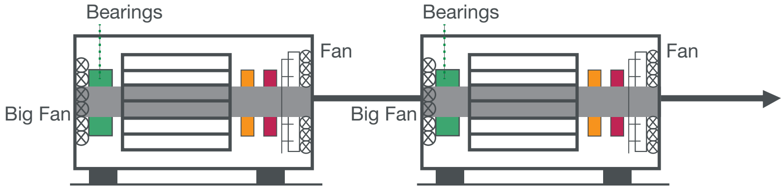


Fig.19 - Recommended parts replacement for rotary systems.



6.2.10 Features and flexibility

Rotary	Static
• Output frequency adaptation (50 Hz/60 Hz) not possible	• Output frequency adaptation (50 Hz/60 Hz) determined by PLC
• Permanent installation in a building, not moveable	• Can be shelter mounted, and transported anywhere
• Output paralleling difficult, not modular	• System is modular and easy to parallelize and expand
• Downgraded operation not possible in the event of a failure	• Downgraded (reduced power) is possible if unit converter fails

7 Conclusion

There are two relevant frequency conversion technologies used for shore connection application: static and rotary. Rotary frequency conversion is a proven technology that has been used successfully for decades. Static technology, which is more recent, leverages advances in power electronics, providing benefits in terms of reduced installation and maintenance costs and greater efficiency.

Both conversion technologies meet the basic requirements of shore connection projects if certain precautions are taken. However, based on shore power project key success factors like OpEx, CapEx, maintenance, and reliability, it is possible to compare the two and determine which overall system best aligns with the cost and performance objectives of your specific project.

8 Bibliography

1. Schneider Electric. Shore connection applications - Main challenges. 2013.

2. IEC/ISO/IEEE 80005-1 Ed.1: Utility connections in port. Part 1: High Voltage Shore Connection (HVSC) Systems. 2012.

3. Schneider Electric. Shore Connection Technology - Environmental Benefits and Best Practices. 2012.

4. Ion, M., M. Megdiche, D. Radu, S. Bacha, and D. Hadbi. Increasing the Short-circuit Current in a Shore Connection System. IEEE PowerTech Conference, Grenoble, France, 2013.

5. Mohan, N., T. M. Undeland, and W.P. Robbins. Power Electronics: Converters, Applications, and Design. John Wiley & Sons, 2002.

6. Schneider Electric. Comparison of Static and Rotary UPS. 2011.

About the authors

Seyba Cissoko received a engineer degree in electrotechnics and power electronics from the Ecole Nationale Supérieure d'Electrotechnique, d'Electronique, d'Informatique et d'Hydraulique, an engineering school in Toulouse, France, in 1990.
Early in his career was in charge of designing large power electronics systems at Jeumont Schneider Industries (1991). He later took up a position of project technical manager in UPS R&D at SAFT Power Systems (1995) before moving into design of multilevel inverters for embedded railway applications at Faiveley Transport (2003) as project technical leader.
He joined Schneider Electric in 2007 as a project manager for special power electronics applications, where the projects he worked on included high-current rectifiers (40 kA) for an aluminum plant, nuclear submarine power supply systems, and solar farms.
This variety of professional experiences has given him broad expertise across a range of technologies relevant to complex power system design, with applications encompassing MV device and power converters to digital control systems.
He now serves as technical manager of the shore connection competency center where he oversees the development of innovative solutions for shore connection systems and technical support for shore connection projects worldwide

Daniel Radu received his Ph.D. in Electrical Engineering in 2004 from Politehnica University of Bucharest, Romania.
From 1998 to 2002 he served as assistant professor of Electrical Engineering at the same university. He later joined the Power Engineering Laboratory of Grenoble, France, where he taught courses and conducted research.
He has been with Schneider Electric, France, since 2006. His interests include shore connection systems, transient analysis low-voltage power systems, power systems modelling, LV and MV equipment, and system design.
He is a technical consultant to TC18 & TC23 committees of the IEC and has been a member of the IEEE since 2006. Since 2012 he has chaired the IEC/ISO/IEEE JWG 28 utility connections in port committee, a group of 30 international experts tasked with developing shore connection standards.

Schneider Electric Industries SAS

Head Office
35 rue Joseph Monier
92506 Rueil-Malmaison Cedex- France
Tel.: +33 1 41 20 70 00
www.schneider-electric.com

03/2015