ENGINEERING TOMORROW

VACON® NXP Grid Converter for Smart Grids

Intelligent power conversion for smart grids

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Transformation of the power sector

The accelerating development of electrification, decentralization and digitalization is de-carbonizing the global energy system to achieve climate goals.

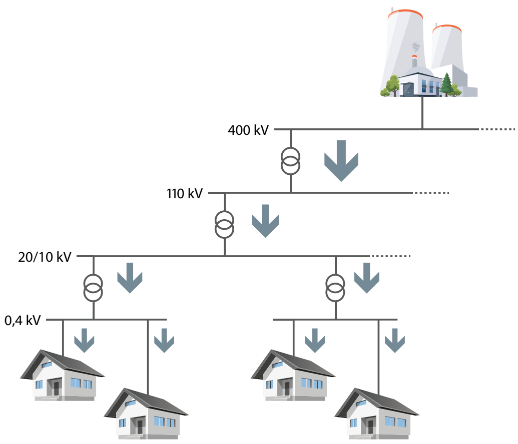
The energy landscape is evolving to embrace renewables and energy storage.

Grid evolution

Traditionally, grids have been powered by centralized fossil fuel power plants.
The modern grid incorporates diverse power sources including renewables and energy storage.

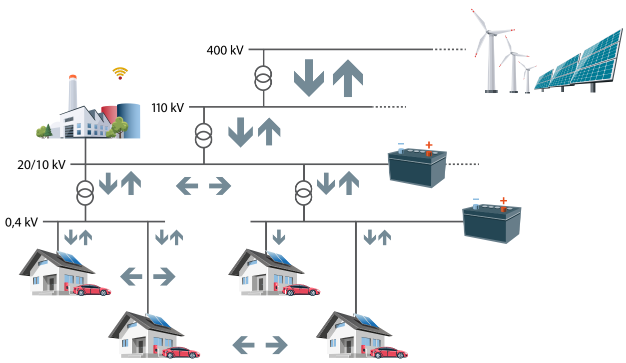
Traditional grid

- Few producers
- Large inertial masses
- Unidirectional energy flow
- "Clean grid"
- Virtually no communication between actors



Smart grid

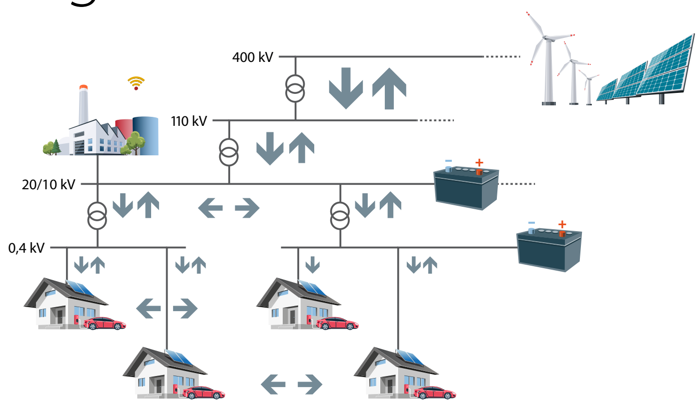
- Many producers
- Almost no inertia
- Bidirectional energy flow
- "Dirty grid"
- High degree of intercommunication



Grid evolution challenges

In order to achieve our climate goals, the proportion of renewables in the energy mix is on the increase, placing demands on the management of the grid.

However the wind is not always blowing and the sun is not always shining. Therefore we use energy storage to help ensure resilience and flexible demand response in the grid.



Energy storage is the enabler of renewable power sources. It helps in overcoming the challenges of unpredictability in renewable power, by facilitating peak shaving, time delay and backup power. These days, battery prices are falling and the technology is maturing.

Smart grids support distributed energy resources in bidirectional diversified networks, to optimize efficiency and to minimize losses.

What defines a **smart grid?**

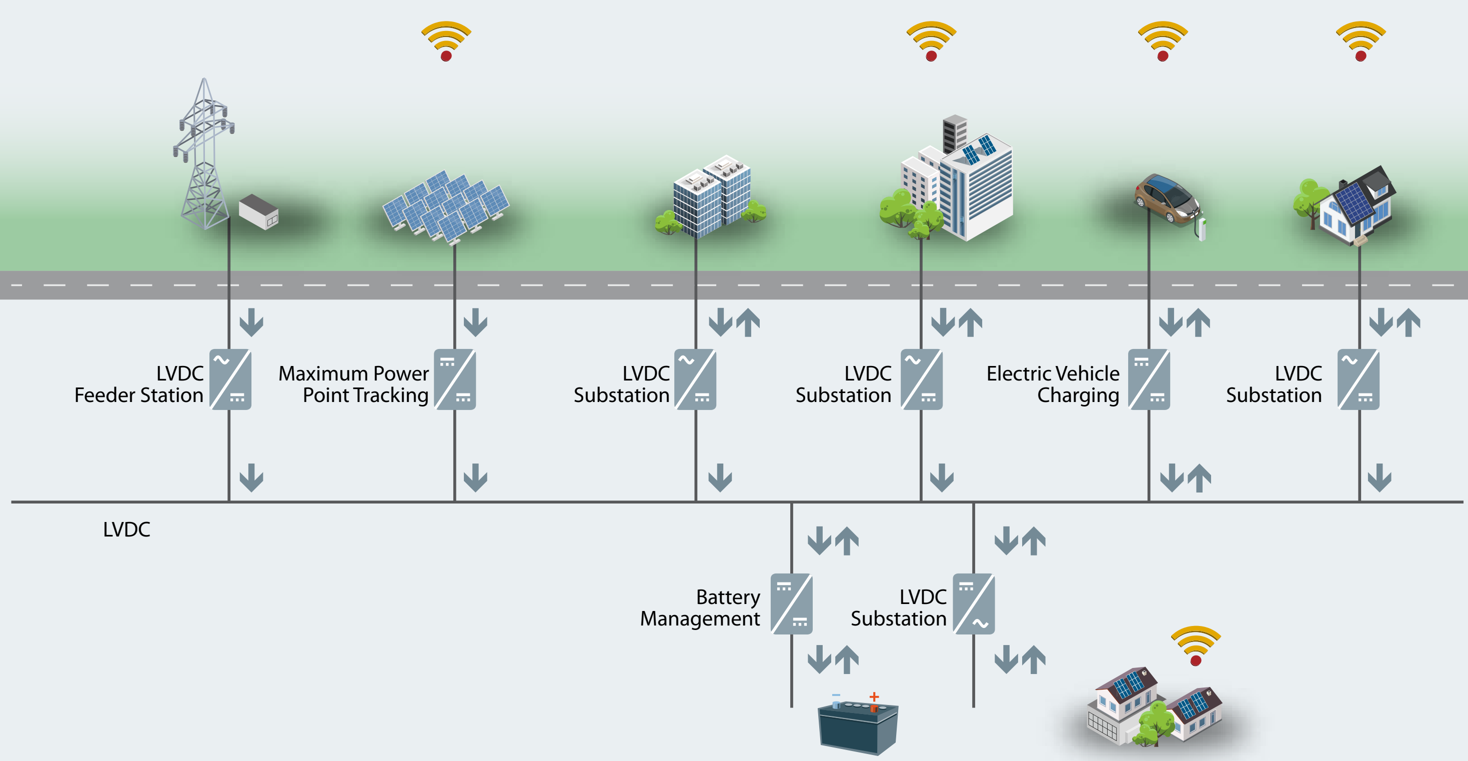
Smart grids support climate goals via renewable energy, electrification and digitalization.

A smart grid is characterized by distributed power generation with diverse energy sources feeding the grid. These energy sources include fossil based generators but also storage and renewables: for example, wind, solar, hydro, tidal, and geothermal. The energy sources must comply with grid standards and regulations: safety, EMC, and grid codes.

Energy storage adds resilience and flexibility to the smart grid. Energy storage takes many forms, for example battery energy storage systems (BESS), fuel cells, or compressed air energy storage (CAES).

Energy flow is bi-directional.

Advanced systems ensure a high level of compatibility and communication to maintain a stable power supply.



Grid code compliance demands **advanced power conversion**

Smart grids support distributed power generation in the grid with the help of grid codes, advanced systems and bidirectional communication.

Grid codes force distributed generators to take responsibility for maintaining power quality and availability of the grid. Therefore, they ask for different technical features to support them. For instance, the DGs are normally required to remain coupled to the grid in case some voltage dip affects the grid, and also, they may be required to supply reactive current to support the voltage.

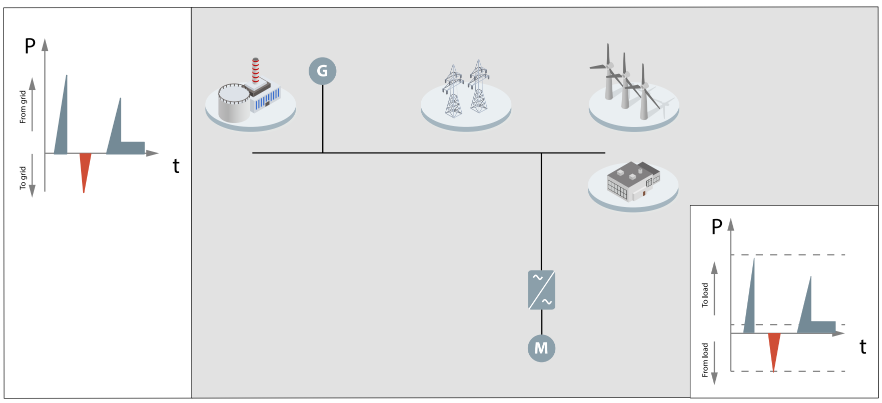
Advanced power conversion systems and other features are required

- For performance optimization:
  - To remain coupled to the grid during voltage dip
  - To supply reactive current to support the voltage

- For safety:
  - Anti-islanding protection disconnects the system during grid blackouts

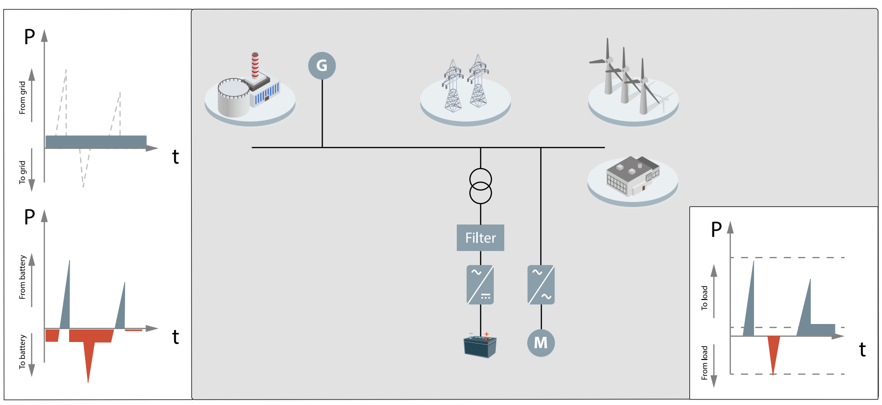
Peak shaving gives **more quality and less infrastructure**

Traditional grid with no energy storage
The consumer load creates peaks on the supply network



Smart grid with energy storage
Battery storage removes the power peaks on the supply network so the consumer load causes virtually no disturbance to the grid. The benefits:

- Good power quality
- Reduced scale and cost of infrastructure

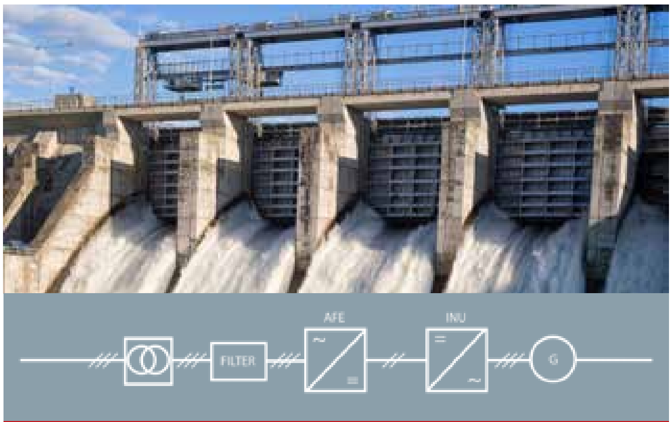


Power conversion
applications in smart grid context

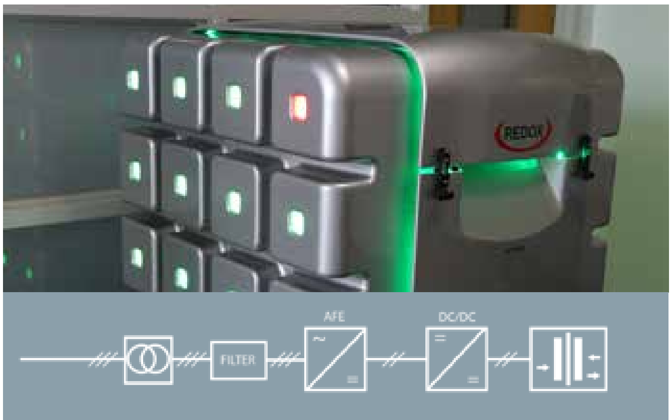
Wind

Solar (PV, thermo)

Battery energy storage systems BESS

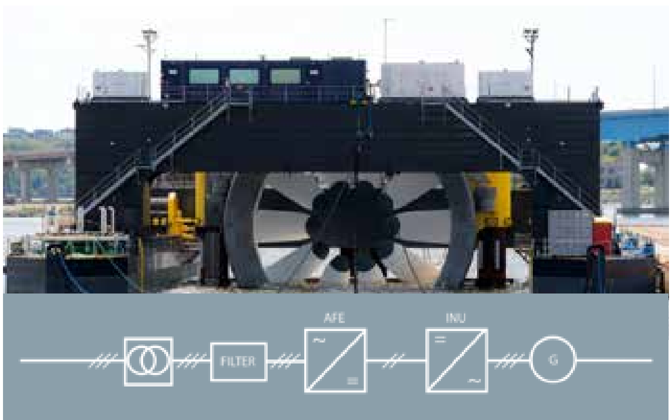


Hydro



Fuel Cells

Compressed air energy storage CAES



Tidal

Geothermal

VACON® NXP Grid Converter for Smart Grids

Smart grid converters are devices which couple some type of energy source to the electrical grid. As well as energy distribution, they facilitate a broad range of services to be offered to the grid operator.

Some examples of features that authorities may ask for are frequency or voltage control, inertia emulation, or low-voltage ride through

Typical applications could be energy storage, wind, solar, hydro, or fuel cells.

Benefits:

- Converts various energy sources to feed the power grid
- Complies with local grid codes and safety regulations
- Provides ancillary services

What Danfoss offers

- Full scale products
- Dedicated application software
- Wide range of certified grid code compliance
- Safety certifications
- Converter simulation model
- Comprehensive supporting documentation

Product	Air Cooled			Liquid Cooled				
Enclosure size	FI9	FI10	FI13	CH5	CH61	CH62	CH63	CH64

Grid code and **safety certifications**

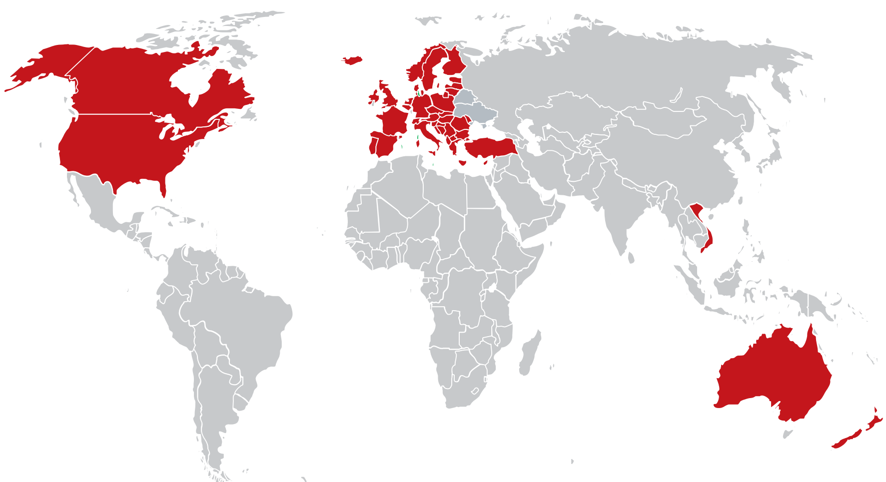
The increasing integration of non-conventional sources in power systems has forced the transmission and distribution system operators (TSOs and DSOs) to update and redesign their grid codes, in many countries. The grid codes are essentially sets of connection and behavior rules that generators in power systems must satisfy. The rules are different in each country and the corresponding operator is responsible for establishing those conditions and enforcing compliance. The grid codes take the electrical characteristics and the network design as reference, and their requirements are directly linked to the non-dispatchable power present and expected penetration rate.
With the new policy, the following goal is pursued: to equate the behavior of renewable generation to the conventional groups already in service. This ensures that the replacement of a generation units in the system by others means no additional risks in reliability. There is a close relationship between regulations, the consequences that these establish for manufacturers, and non-dispatchable energy penetration rate in the system.

Grid Codes

- IEC 62116:2014
- ENTSO-e (2016/631/EU)
- BDEW
- VDE-4110/4120
- AS4777.2:2015 Air cooled units
- IEEE 1547 (600VAC)
- Hawaii rule 14H
- California rule 21
- Thailand PEA 2013

Safety Regulation

- UL1741 (600VAC)
- IEC 62109-1 & IEC 62109-2 Air cooled units



Dedicated smart grid application software

Integrated smart grid software provides

- Power quality
  - Harmonics / Interharmonics / Flicker
  - Switching operations
- Static grid support
  - Frequency and active power control
  - Voltage and reactive power control
- Dynamic grid support
  - Low-voltage ride through (LVRT)
  - High-voltage ride through (HVRT)
- Grid code compliance
- Immediate disconnection when unexpected islanding mode is detected
- Robustness against load unbalances and grid disturbances
- High configuration versatility

	AFE	Island	µGrid
Power Flow	Bidirectional power Flow	Generating the grid and feeding the loads	Sharing the required load power with other local units
Grid topology	Coupling to mains	Setting voltage and frequency	Drooping or isochronous modes
DC link control	Yes	No	No
Grid code support	Yes	N/A	N/A

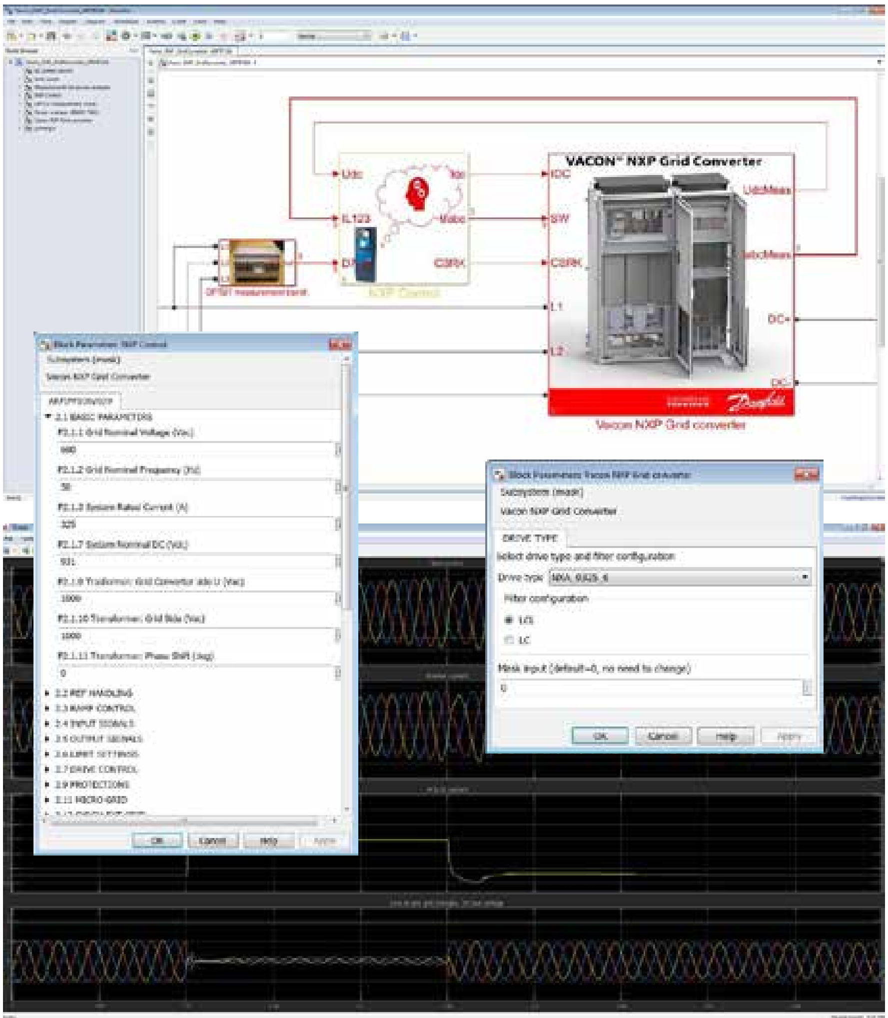
How to size VACON® NXP Grid Converter
for Smart Grids to the application

Functionality Map

The VACON® NXP can be used in many functions, as shown in the functionality map. In this section we will explain how to size the drive for smart grid applications

Function	Functionality	Basis for sizing
AFE	Keeping grid clean while maintaining robust DC-link for motor drive(s)	Motor load with typical cos φ=1, meaning kVA~kW
Off-shore Grid	Creating and maintaining the AC-grid with other generators.	Grid apparent and active power, and fault current feeding capability
Smart Grid (On-shore Grid)	Keeping grid clean while maintaining robust DC-link for generation applications. Controlling energy flow between source and grid while ensuring grid compliance.	Active power of the energy source, and Grid code compliance. kVA≠kW
Generator	Controlling generator loading, speed and braking-torque, to ensure the necessary power take out while not overloading the generator.	Sized using the same method used for motor drives or an AFE. Power options are decided case by case. Rated according to electrical values in "DC-link".
DC/DC	Used for bi-directional power flow between DC-link and DC-source. Controls source voltage and/or current.	Sized using the tool. Dependent on $U_{source}/U_{dc\text{-}link}$ ratio.
DCGuard	Used to provide fast detection of short circuit situation in DC-grid and to separate the healthy part from the affected part.	DC power flow capability as per the nominal AC-current rating.

Simulation
model



The VACON® NXP Grid Converter simulation model is a Simulink model for Matlab/Simulink circuit simulator

The model comprises two parts:

Electrical main circuit model

- DC terminals and AC (3-phase) terminals
- LCL filter included in the model

Control unit

- Power conversion control
- Application software
- Line voltage (OPT-D7) measurement unit

Application functionality with relevant tunable parameters includes:

- AFE mode including grid code functionality
- MicroGrid mode

Grid compliance for on-shore grid applications

The VACON® NXP Grid Converter for Smart Grids
is a good and easy choice for most process applications requiring stable DC-bus for inverter modules and effortless interaction with grid. This drive ensures grid-friendly harmonic content. It also facilitates energy recovery back to grid when excess energy from process is available.

The VACON® NXP Grid Converter for smart grids offers these features to enhance smart grid performance

- Design for public grid functionality
- Grid code approvals
- Grid harmonics below or in accordance with grid standards
- Energy recovery back to grid when the process delivers regenerative energy
- Maintains DC-link at a stable level even under non-ideal grid conditions

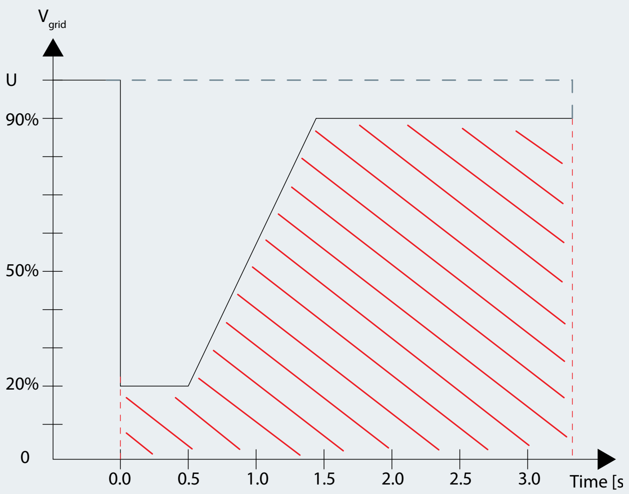
Technical information

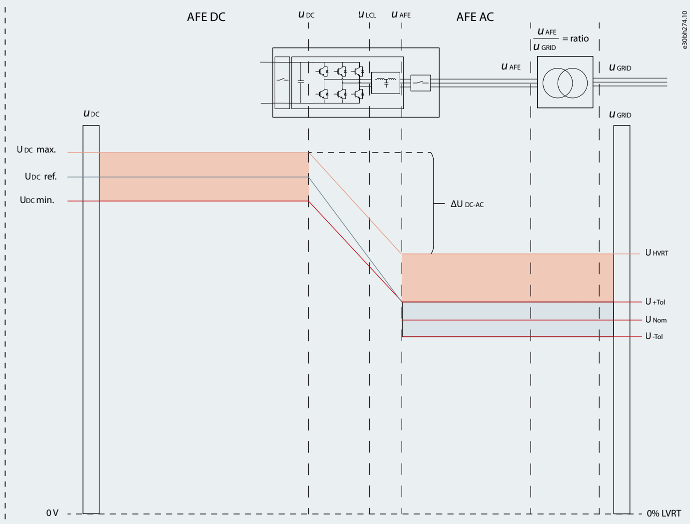
Basic functions
- Robust DC-link regulation
- Low harmonic AC grid current
- Unity power factor
- Support for grid voltage feedback option
- Power and current limitation
- Paralleling with out without drive-to-drive communication
- Automatic AC grid synchronization

User interface
- Changes to parameter naming (alarm, faults, warnings, info)
- Changes to the parameter structure
- Wizard support for startup and parametrization
- Change of start-up screen

Grid voltage behavior creates the need for voltage ratings. This requirement is due to varying low-voltage and high-voltage ride through (LVRT and HVRT) expectations in different grid codes.

Control margins and dynamic capabilities create the need for current ratings. Due to low-voltage ride through (LVRT) expectations, the drive needs to be able to catch the grid short-circuit situation.





Dimensioning example

Wind turbine application
In a wind turbine application, the grid converter controls the DC link to a specific voltage. The higher the voltage, the less current is needed for the same power. Therefore, the required hardware can be smaller. If HVRT is required, investigate whether the maximum AC voltage which can be reached in an HVRT translates to a DC level within the safe range.

Dimensioning data:
- 600 kW wind turbine
- Must comply with grid codes
- HVRT = 110%
- LVRT = 0%
- Grid voltage = 690 V AC ±10%
- Must be able to provide 0.95 cos phi

Calculation of safe range
For a 690 VAC grid voltage plus 10%, we can have 759 V AC at the secondary side.
This translates to 1.575 x 759 = 1195 V DC, which is far above the1100 V DC limit.
The value 1.575 comes from the ratio 1.5 (√2 + control margin) between the DC link and INU side, plus 5% filter losses.

Calculate maximum AC voltage
What is the highest possible AC voltage at the secondary side, which does not lead to exceeding the maximum DC voltage of the DC link?
Maximum V AC ≤ 1100/1.575 = 698 V AC.
This corresponds to an AC voltage level with +10% voltage tolerance and +10% if there is an HVRT episode, so the nominal AC voltage should correspond to:
Nominal V AC = 698/1.21 = 577 V AC.
Therefore a 690/577 V AC transformer must be installed.

Calculate current rating
The wind turbine must export the nominal power under all grid conditions, so to calculate the current rating, we must use the nominal AC voltage with -10% tolerance, that is,

V=520 V AC.
P = 600 kW
$= \sqrt{3} \times V \times I \times \cos \varphi$
$= \sqrt{3} \times 520\,V \times I \times 0.95$
Therefore, the current rating **I = 700 A**

Selection
The possible selections in the VACON® NXP Grid Converter rating tables are:
- Air-cooled NXA_0920 6
- Liquid-cooled NXA_0750 6

Due to the HVRT requirements and control margin, the 690 V AC Grid Converter for this Smart Grid application has been rated at 600 VAC nominal voltage.
The system is required to withstand 0% LVRT. Depending on system-level characteristics such as the type of generator, control, and pitch system, it may be necessary to install a brake chopper to control the turbine to ensure no overspeed.

Ratings

Unit (NXI)						NXA Rated current for Grid connected AFE inverters	
Unit (NXI)	Unit (AFE/Grid Support)	Cooling type	Enclosure size	NXI High Overload I_H [A]	NXI Low Overload I_L [A]	NXA Rated current for Grid connected AFE inverters [A]	NXA Rated current for Grid support inverters [A]
NXI_0168 5	NXA_0168 5	Air	FI9	140	170	170	140
NXI_0205 5	NXA_0205 5	Air	FI9	170	205	205	170
NXI_0261 5	NXA_0261 5	Air	FI9	205	261	261	205
NXI_0385 5	NXA_0385 5	Air	FI10	300	385	385	300
NXI_0460 5	NXA_0460 5	Air	FI10	385	460	460	385
NXI_1150 5	NXA_1150 5	Air	FI13	1030	1150	1150	1030
NXI_1300 5	NXA_1300 5	Air	FI13	1150	1300	1300	1150
NXI_0125 6	NXA_0125 6	Air	FI9	100	125	125	100
NXI_0144 6	NXA_0144 6	Air	FI9	125	144	144	125
NXI_0170 6	NXA_0170 6	Air	FI9	144	170	170	144
NXI_0261 6	NXA_0261 6	Air	FI10	208	261	261	208
NXI_0325 6	NXA_0325 6	Air	FI10	261	325	325	261
NXI_0920 6	NXA_0920 6	Air	FI13	820	920	920	820
NXI_1030 6	NXA_1030 6	Air	FI13	920	1030	1030	920
NXI_0168 5	NXA_0168 5	Liquid	CH5	112	153	153	140
NXI_0205 5	NXA_0205 5	Liquid	CH5	137	186	186	168
NXI_0261 5	NXA_0261 5	Liquid	CH5	174	237	237	205
NXA_0300 5	NXA_0300 5	Liquid	CH61	200	273	273	261
NXA_0385 5	NXA_0385 5	Liquid	CH61	257	350	350	300
NXA_0460 5	NXA_0460 5	Liquid	CH62	307	418	418	385
NXA_0520 5	NXA_0520 5	Liquid	CH62	347	473	473	460
NXA_0590 5	NXA_0590 5	Liquid	CH62	393	536	536	520
NXA_0650 5	NXA_0650 5	Liquid	CH62	433	591	591	590
NXA_0730 5	NXA_0730 5	Liquid	CH62	487	664	664	650
NXA_0820 5	NXA_0820 5	Liquid	CH63	547	745	745	730
NXA_0920 5	NXA_0920 5	Liquid	CH63	613	836	836	820
NXA_1030 5	NXA_1030 5	Liquid	CH63	687	936	936	920
NXA_1150 5	NXA_1150 5	Liquid	CH63	766	1045	1045	1030
NXA_1370 5	NXA_1370 5	Liquid	CH64	913	1245	1245	1150
NXA_1640 5	NXA_1640 5	Liquid	CH64	1093	1491	1491	1370
NXA_2060 5	NXA_2060 5	Liquid	CH64	1373	1873	1873	1640
NXA_2300 5	NXA_2300 5	Liquid	CH64	1533	2091	2091	2060
NXA_0170 6	NXA_0170 6	Liquid	CH61	113	155	155	144
NXA_0208 6	NXA_0208 6	Liquid	CH61	139	189	189	170
NXA_0261 6	NXA_0261 6	Liquid	CH61	174	237	237	208
NXA_0325 6	NXA_0325 6	Liquid	CH62	217	295	295	261
NXA_0385 6	NXA_0385 6	Liquid	CH62	257	350	350	325
NXA_0416 6	NXA_0416 6	Liquid	CH62	277	378	378	385
NXA_0460 6	NXA_0460 6	Liquid	CH62	307	418	418	416
NXA_0502 6	NXA_0502 6	Liquid	CH62	335	456	456	460
NXA_0590 6	NXA_0590 6	Liquid	CH63	393	536	536	502
NXA_0650 6	NXA_0650 6	Liquid	CH63	433	591	591	590
NXA_0750 6	NXA_0750 6	Liquid	CH63	500	682	682	650
NXA_0820 6	NXA_0820 6	Liquid	CH64	547	745	745	750
NXA_0920 6	NXA_0920 6	Liquid	CH64	613	836	836	820
NXA_01030 6	NXA_01030 6	Liquid	CH64	687	936	936	920
NXA_01180 6	NXA_01180 6	Liquid	CH64	787	1073	1073	1030
NXA_01300 6	NXA_01300 6	Liquid	CH64	867	1182	1182	1180
NXA_01500 6	NXA_01500 6	Liquid	CH64	1000	1364	1364	1300
NXA_01700 6	NXA_01700 6	Liquid	CH64	1133	1545	1545	1500

A better tomorrow is **driven by drives**

Danfoss Drives is a world leader in electrification and variable speed control of electric motors.
We offer you unparalleled competitive edge through quality, application-optimized products and a comprehensive range of product lifecycle services.

You can rely on us to share your goals. Striving for the best possible performance in your applications is our focus. We achieve this by providing the innovative products and application know-how required to optimize efficiency, enhance usability, and reduce complexity.

From supplying individual drive components to planning and delivering complete drive systems; our experts are ready to support you all the way.

You will find it easy to do business with us. Online, and locally in more than 50 countries, our experts are never far away, reacting fast when you need them.

You gain the benefit of decades of experience, since 1968. Our low-voltage and medium-voltage AC drives are used in diverse facets of electrification, and with all major motor brands and technologies in power sizes from small to large.

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