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Article

# DC grids and selectivity using **VACON® NXP DCGuard™**

Current cut off in

**<5 µs**

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# Contents

## Summary

Utilizing DC grids instead of AC grids can improve system efficiency and system footprint by up to 20%. And there is a significant potential for energy saving especially when combining DC grids, energy storage and/or variable speed generators.

Utilizing DC grids rather than AC grids also enables power distribution with lower power losses. However, ensuring selectivity and limited short circuit energy requires more sophisticated protection devices.

Danfoss Drives has therefore developed the VACON® NXP DCGuard™, a semiconductor protection device that detects and cuts off any DC short-circuit current, to isolate the faulty part of the system in microseconds.

## 1. Introduction

The world is steadily, and quite quickly, diversifying its primary sources of energy. As we transition from fossil fuels, such as oil and coal, through natural gases and nuclear power and further towards solar, wind, and hydro, there is an increasing need to overcome the gaps occurring when the scales of energy supply and demand are out of balance. Electricity as an energy carrier is incredibly flexible and versatile, and at the moment our society is "electrifying".

AC grid system efficiency and system footprint have been optimized through decades, whereas DC grids have been somewhat overlooked. In this paper we will cover how there may be a potential for significant improvement in a system by changing to DC.

Traditionally, we have used DC for transporting high powers over long distances, point to point. We subsequently convert into AC for distribution, then back and forth AC to DC for various applications. In our modern society DC is increasingly becoming more common, though LED lighting, phones, computers (datacenters), energy storage mediums such as batteries, production lines and even entire factories are DC-based.

Having a more balanced approach to AC and DC grids, applying either where it makes commercial sense, is increasingly gaining traction.

AC drives represent a well proven technology that has been in use for many years. In essence, drives can be used to manage electricity in whatever form, making it easier and manageable to diversify our energy sources. Drives from Danfoss can be software-modified to manage DC grids, equipping the system with the proven reliability of hardware that has been in the market for decades. They enable use of storage technologies that have previously been out of commercial scope.

In this paper we will cover DC grids and selectivity.

[1] http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx

## 2. DC grids

The so-called 'War of the currents' was fought over a century ago. Thomas Edison was a devoted supporter of direct current (DC) power transmission while Nikola Tesla believed alternating current (AC) was the way to go. At that time, it seemed like AC had won the battle. However, today it's apparent that utilizing DC instead of AC might improve system efficiency and system footprint by 10–20%.

There is a significant potential for energy saving especially when combining DC grids, energy storage and/or variable speed generators.

The main benefits of using DC grids are:

- Less AC-to-DC and DC-to-AC conversion
- Fewer filters and transformers
- No reactive current
- No synchronization is needed
- In a drives system, regenerative braking energy (energy coming back from the motor) can be reused without any need for conversion

### 2.1 However, there is a but…

As with any grid, at any point in a DC grid, you have an inherent risk of a faulty circuit
One of the major challenges facing the DC grid is how to ensure selectivity and protection in case of such a short circuit.

The current in an AC system will pass though 0A twice per period (zero crossing). Hence, basically, inside an AC circuit breaker the short circuit is cut off when it passes through 0A.

However, a short circuit in a DC system will never pass through 0A. It will within microseconds become very high and stay high as long as there is energy available to feed the short circuit.

If a traditional circuit breaker is used to cut off a DC short circuit current, the result is a potentially lethal arc arising inside the circuit breaker. Especially in marine systems a common requirement for systems is that "a failure in one part of the system shall not affect the whole system". Therefore, a fast DC-current cutter device is needed to isolate the healthy part from the faulty part of the system.

### 2.2 VACON® NXP DCGuard™

To prevent accidents or injuries, sophisticated short-circuit protection devices are needed. Danfoss Drives has therefore developed the new VACON® NXP CGuard™, a short-circuit current suppressor based on current interruption through the switching of IGBT transistors. VACON® NXP DCGuard™ detects and cuts off any faulty DC short circuit current and isolates the defective part of the system in microseconds, leaving the healthy part unaffected by the fault. Hence full selectivity between DC grids is achievable.

## 3. Selectivity

As explained previously, the main challenge in a common DC system is selectivity, and it becomes even more challenging to maintain selectivity when several inverters are connected to the same DC-bus.

### 3.1 Selectivity by fuses

As a short circuit in a DC-bus system occurs the nearest fuses to the fault should burn to protect the system. However, often fuses feeding other vital equipment in the same system will also burn even if these fuses are not connected directly (nearest) to the short circuit.

One of the biggest challenges by using fuses to disconnect the faulty part from the healthy part is the voltage drop on the healthy part. When a short circuit happens the voltage on the faulty side is close to 0V. Because of the low resistance inside the fuses the voltage on the healthy side will be 'pulled' down. Because the fuses take some time to clear the fault, the voltage on the healthy side will decrease below the under-voltage trip of the inverters on the healthy side. The result is a total blackout.

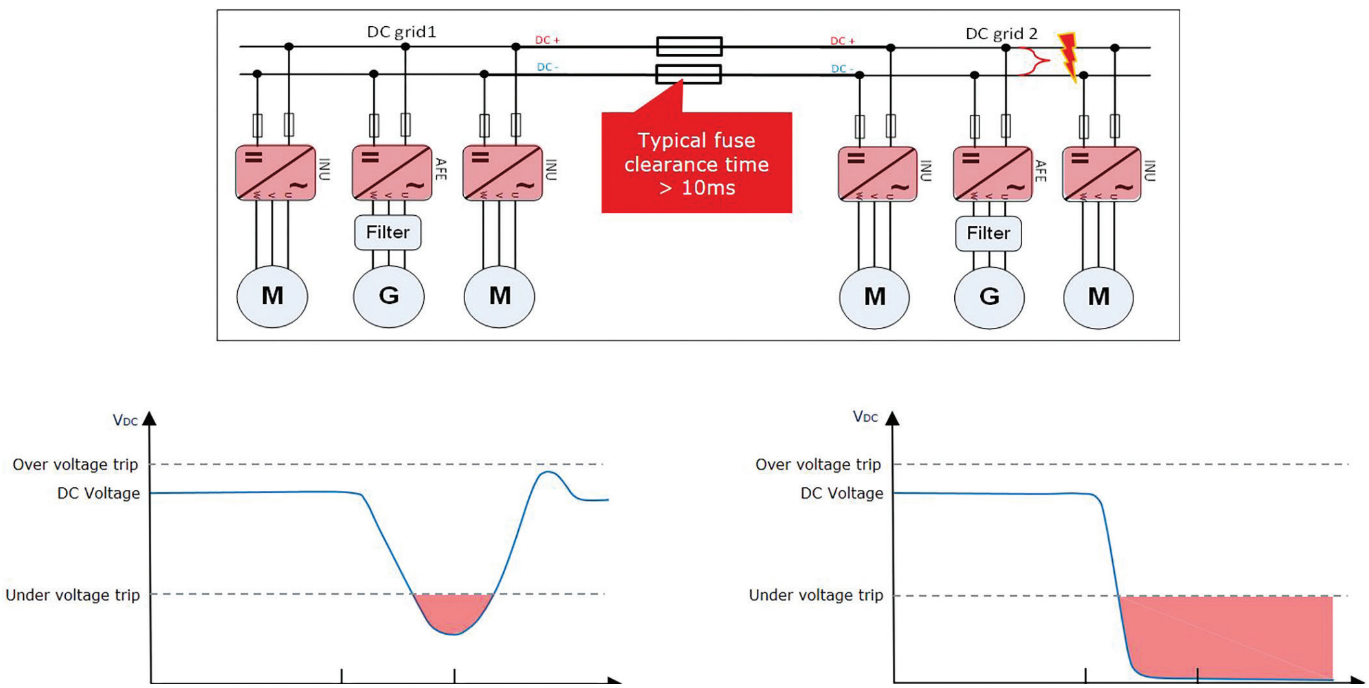


***Figure 1*** *Long fuse clearance time in a DC grid results in a blackout.*

## 3.2 Fast-current cutter/DC-bus tie devices needed

Total selectivity in a common DC-bus system can be achieved by splitting the system into separate DC-buses. This can be realized by using a fast-current cutter/DC-bus tie device such as the VACON® NXP DCGuard™, provided the separate DC-buses can operate at the same DC voltage level.

Power is then seamlessly transferred between the two DC-buses, while ensuring each system can be isolated in case of a fault. This method of connecting different DC-buses has been named: VACON® NXP DCGuard™, peer to peer topology.

## 3.3 Components

VACON® NXP DCGuard™ consists of a VACON® NXP inverter and the application software ADFIF102. Together they will enable any NXP inverter to be used as a VACON® NXP DCGuard™ unit.

The complete product range encompassing current and voltage ranges of 3–4140 A and 465–1100 VDC is already Type-approved by DNV-GL and ABS .

To ensure correct functionality and safety the following components are mandatory in a VACON® NXP DCGuard™ peer to peer system:

- Upstream mechanical disconnector to ensure safe disconnection of the VACON® NXP DCGuard™ unit from the feeding DC-bus.
  - VACON® NXP DCGuard™ functionality does not depend on a mechanical disconnector, neither in front nor after, to provide overcurrent and short circuit protection[2].
- aR supply fuses in each DC supply line, in accordance with the VACON® NXP drive manual[3].
- di/dt filter with ≈2% inductance.

## 3.4 Two-way systems

VACON® NXP DCGuard™ can only cut off an outgoing current (from DC+/- terminals to U, V & W terminals). To cut off current coming from both sides you therefore need two independent VACON® NXP DCGuard™ units.

As the two operate independently without any drive-to-drive communication, the final decision to open a VACON® NXP DCGuard™ should always be taken by the PMS/control system, since this action can affect the operation of the whole vessel. It is therefore imperative that the system integrator takes responsibility for implementing precautions to ensure the opening of both VACON® NXP DCGuard™ units in the event of a fault situation occurring.

[2] VACON® NXP DCGuard™ does not have any functionality to prevent incorrect operation of the mechanical disconnector.

[3] Disclaimer: In certain cases it might be required to make a system calculation to find a proper fuse configuration, which may differ from the default fuse configuration given in the manuals.

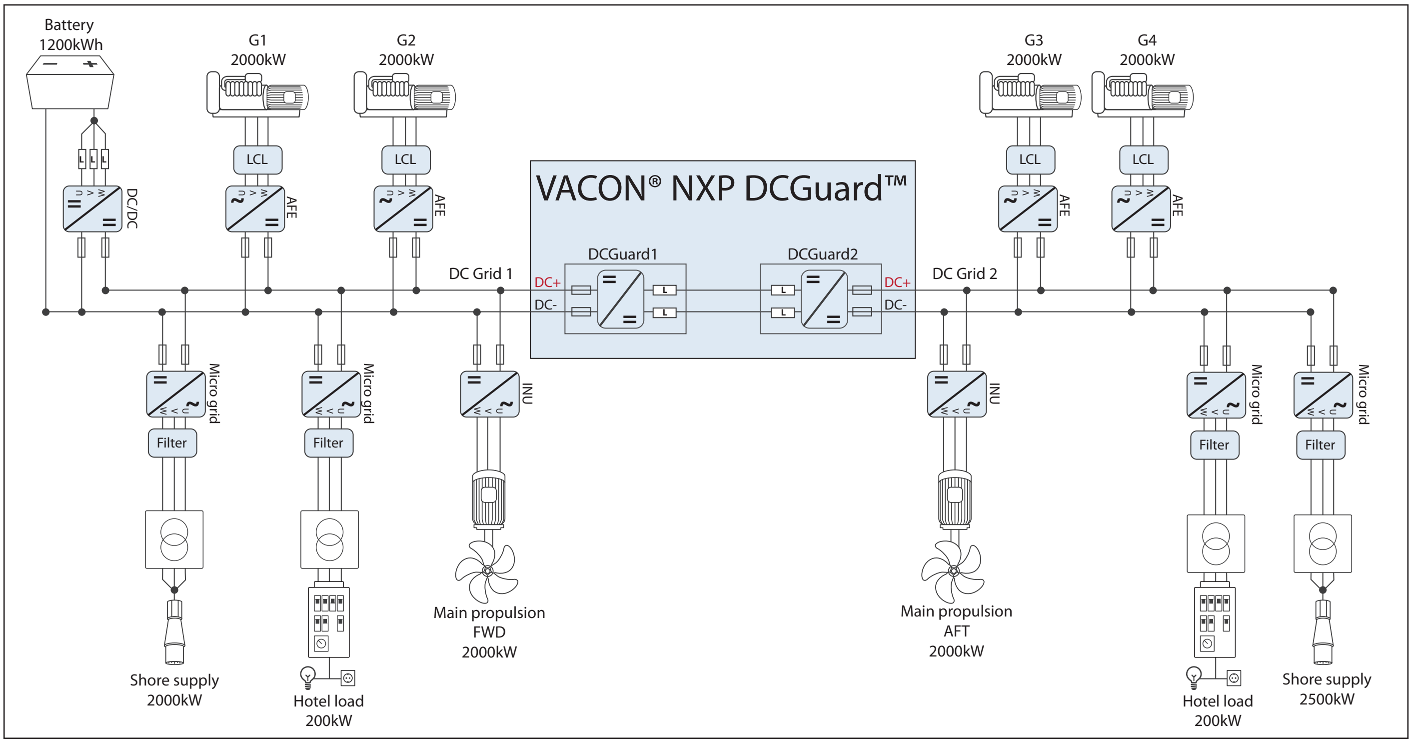


***Figure 2*** *Wiring diagram of a DC grid illustrating VACON® NXP DCGuard™.*

## 3.5 How does it work?

Traditionally a drive is used for rotating a motor at variable speeds. Inside the drive, IGBTs create the variable voltage and frequency required to adjust the speed, through DC voltage pulses. This way of producing a sinusoidal voltage is known as pulse width modulation (PWM), and involves switching the IGBTs on and off several thousand times every second. The typical switching frequency lies in the range 1.5-16 kHz.

To avoid damage when a voltage is applied the opposite way across the IGBT (emitter to collector), all VACON® NXP hardware is equipped with diodes connected in parallel to the IGBTs. The diode will protect the IGBT against damage and at the same time allow 'reverse' energy to return to the DC-link capacitors. This type of diode is often named a freewheeling diode.

Hence the VACON® NXP DCGuard™ IGBTs will connect the DC terminals to the output terminals, making a fixed path for the current passing through. All current passing through the VACON® NXP DCGuard™ will also pass through a serial connected inductance. The inductance will limit the current rise time (di/dt) to a level that makes it possible for the VACON® NXP DCGuard™ to measure it and act. Most importantly, the IGBTs are designed to cut off a DC current, and can do it without being worn out or damaged.

One challenge of cutting a current going through a coil is induction of voltage in the coil. In this configuration, after a current cut off the inducted voltage is discharged back to the DC-link capacitors inside the VACON® NXP DCGuard™ unit.

Let's look at system behavior throughout a fault situation.

## Normal operation

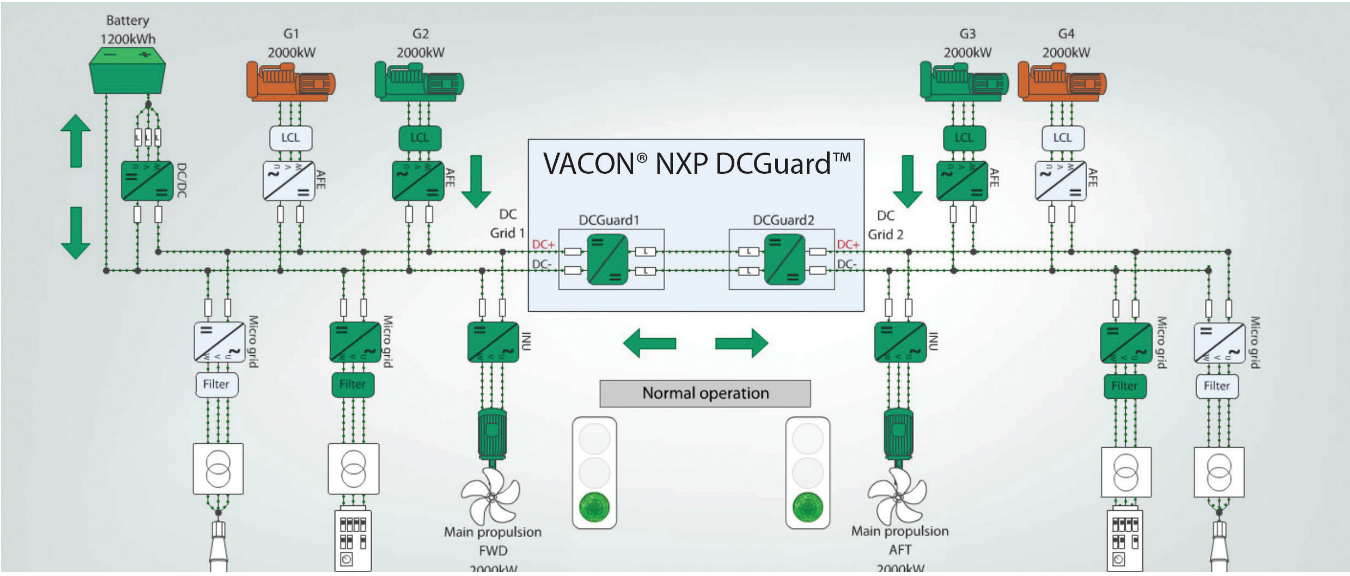


*Figure 3* Normal operation.

## Short circuit

0-100 µs after short circuit.

The current will build up until it reaches the tripping limit of the VACON® NXP DCGuard™. In Figure 5, the fault is shown on the right. The red arrows indicate current contribution from all connected inverters.

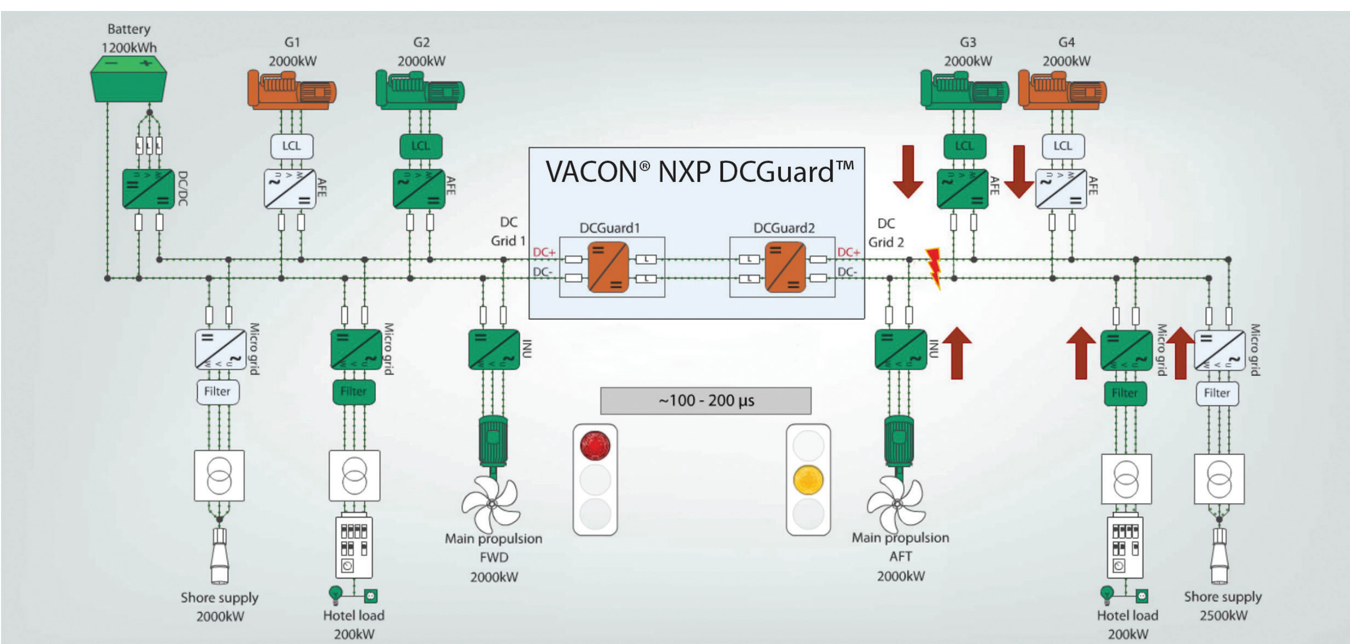


*Figure 4* Short circuit situation 0-100 µs.

Approximately 100 µs after a short circuit the VACON® NXP DCGuard™ clears the fault.

<u>250 µs after short circuit occurs</u>

250 µs after the short circuit occurs, the healthy side of the circuit is still in normal operation, disconnected from the faulty side.

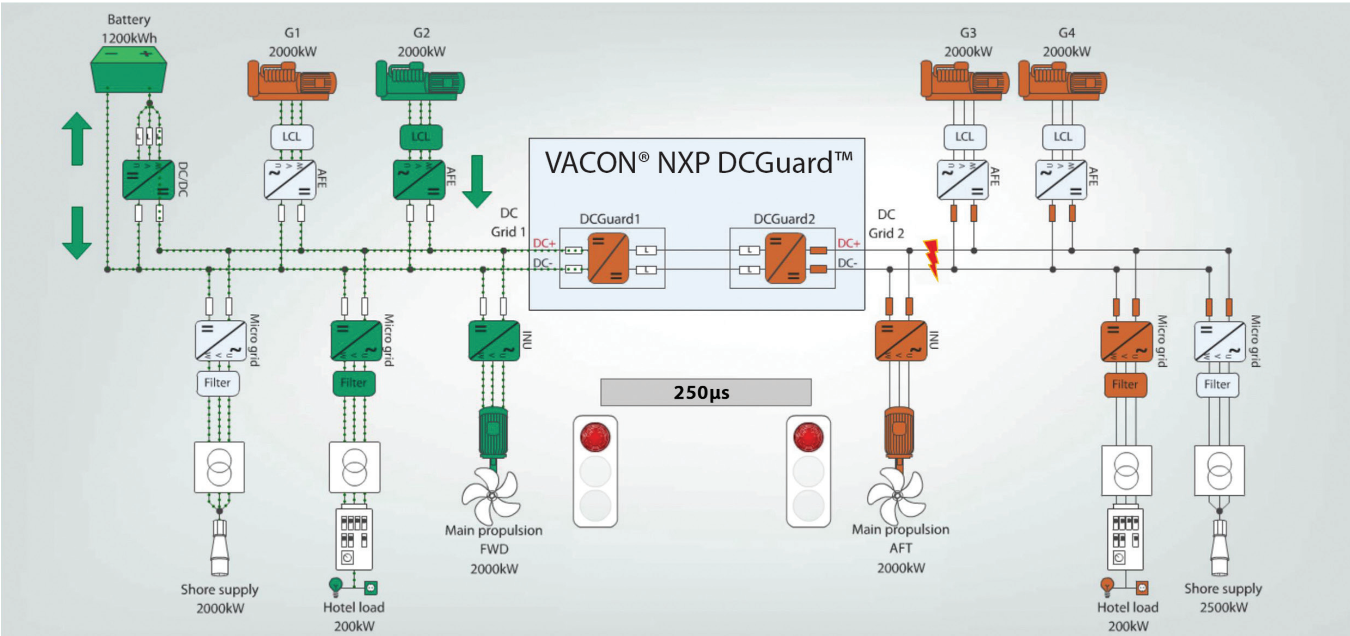


***Figure 5*** *Short circuit after 200 µs.*

The faulty system is isolated from the healthy system. However, power is still available for basic functionality.

During the fault the feeding DC grid will see only a small dip in DC voltage (typically less than 50V) on the healthy side.

It is important to note that VACON® NXP DCGuard™ cannot influence what happens inside the faulty DC-bus during a short circuit situation.

### Connecting

To prevent a high inrush current when a VACON® NXP DCGuard™ unit connects to the bus tie cables, a controlled voltage ramp-up of the bus tie cables voltage is always performed before closing of the VACON® NXP DCGuard™ unit. The voltage will be ramped up from the current level to full DC voltage. Typically, voltage rise time from 0 V to full DC voltage is 200-400 ms. Voltage rise time and switching frequency are programmable.

## 3.6 Easy dimensioning

The primary dimensioning factor for the VACON® NXP DCGuard™ is the required load current through it, hence energy transfer from one side to another

Rated VACON® NXP DCGuard™ DC current = Rated VACON® NXP AC current.

It is as easy as that.

### 3. 7 Approvals

Today there are no relevant standards for an application as such as the VACON® NXP DCGuard™. However, all VACON® NXP products are Type-approved by DNV-GL and ABS, which is very useful when applying for system approval.

## 4. Proven technology

As early as 2009, Danfoss delivered one of the first DC grid systems for a river cruiser. Today, more than 50 of these vessels are in operation. In 2016, the first VACON® NXP DCGuard™ units were piloted in two IJ River-crossing ferries in Amsterdam. By including all Danfoss Drives hybridization products in the same DC grid, energy efficiency and system selectivity were taken to a whole new level. And, in 2018, the first DNV-GL-approved VACON® NXP DCGuard™ units will be in operation in a sea-going vessel on one of Norway's busiest ferry routes.

## 5. Contact

Read the VACON® NXP DCGuard™ Fact Sheet:

http://danfoss.ipapercms.dk/Drives/DD/Global/SalesPromotion/Factsheets/ProductFactsheets/UK/vacon-dcguard/

Contact your local Danfoss office to learn more:

https://www.danfoss.com/en/contact-us/contacts-list/?filter=type%3Adanfoss-sales-service-center