ENGINEERING TOMORROW

FIIF event “Reliability and Testing” w/ KOTEL 14.05.2020

Remote Monitoring as a tool for Product Reliability problem solving (use case)

Pasi Välimäki (pasi.valimaki@danfoss.com)
Product Engineering Center Finland
Danfoss Drives


Danfoss at a glance
ENGINEERING
TOMORROW
Danfoss

We engineer tomorrow and build a better future

27,795
Employees

Worldwide sales
in more than **100** countries

71 factories
in more than **20** countries

Privately held
Ownership

Nordborg, Denmark
Headquarters

Group financial highlights 2018

Net sales, EURbn
6.1

Growth in local currency
7%

EBIT margin
10.6%

NIBD to EBITDA ratio
1.0%

EBIT EURm
648

Net profit EURm
463

Please note. Figures from 2018

Four business segments geared for growth

Danfoss Power Solutions
#2 Market position

35%
of Group net sales

Danfoss Cooling
#1 Market position

27%
of Group net sales

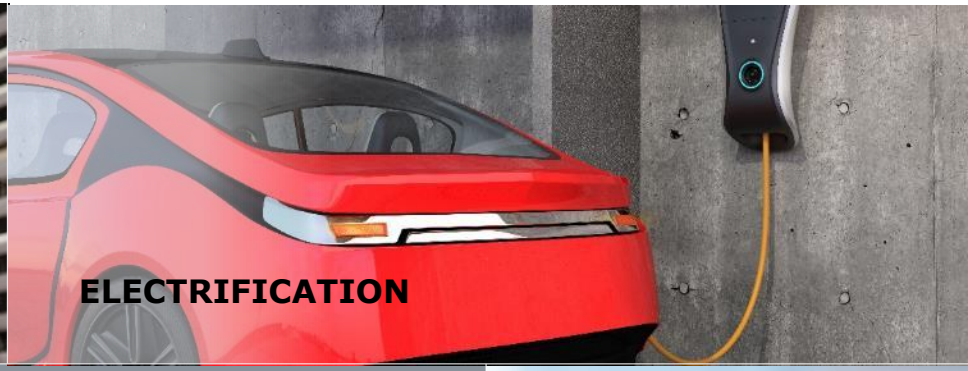
Danfoss Drives
#2 Market position

23%
of Group net sales

Danfoss Heating
#1 Market position

15%
of Group net sales

Please note. Figures from 2018



GLOBAL MEGA-TRENDS

transforming our world

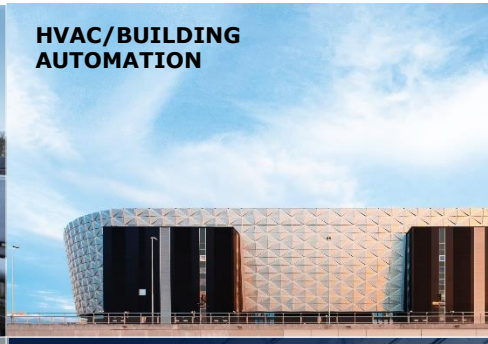
ENGINEERING TOMORROW

A better tomorrow is driven by drives

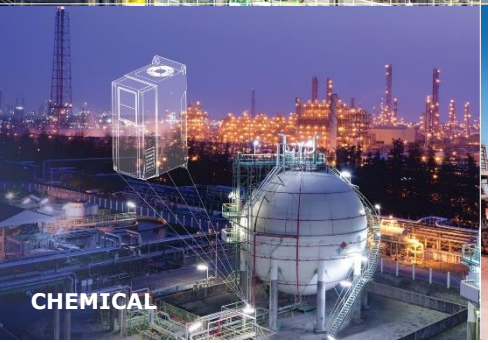
A variable-frequency drive (VFDs, also AC drives, inverters, …) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage. VFDs are used in applications ranging from small appliances (e.g. HVAC) to large systems in industry, marine/ooshore, …

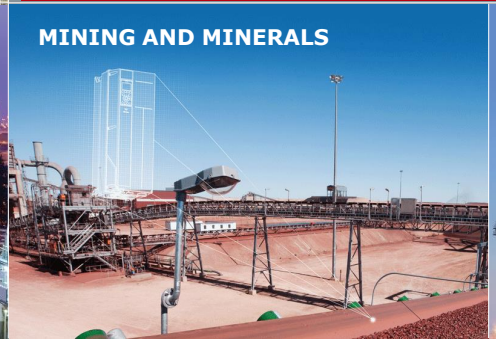
TODAY: 20% of the world's energy consumption is electrical energy. 50% of electrical energy is used by electrical motors. AC drives control power supply to electric motors and typically save 15-40% of energy consumed.

TOMORROW: AC drives have the potential to save 8% of global electricity consumption by 2040



For 50 years, Danfoss Drives has been a global leader in the variable speed control of electric motors.
We have the world's largest installed base of variable speed drives comprising VLT® and VACON® AC drives, and can draw on decades of passion and experience within a wide range of industries.





Breadth and depth in **expert products**

VLT®

VLT® drives position you at the forefront of the energy-efficiency race.

Outmaneuvering other precision drives, they excel, with remarkable fit, functionality and diverse connectivity.

VLT® drives play a key role in rapid urbanization through an uninterrupted cold chain, fresh food supply, building comfort, clean water and environmental protection.

- AC drives (0.18 – 1,400 kW)
- Decentral drives
- Integrated servo drives
- Soft starters
- Power options (filters)
- Software tools

Breadth and depth in **expert products**

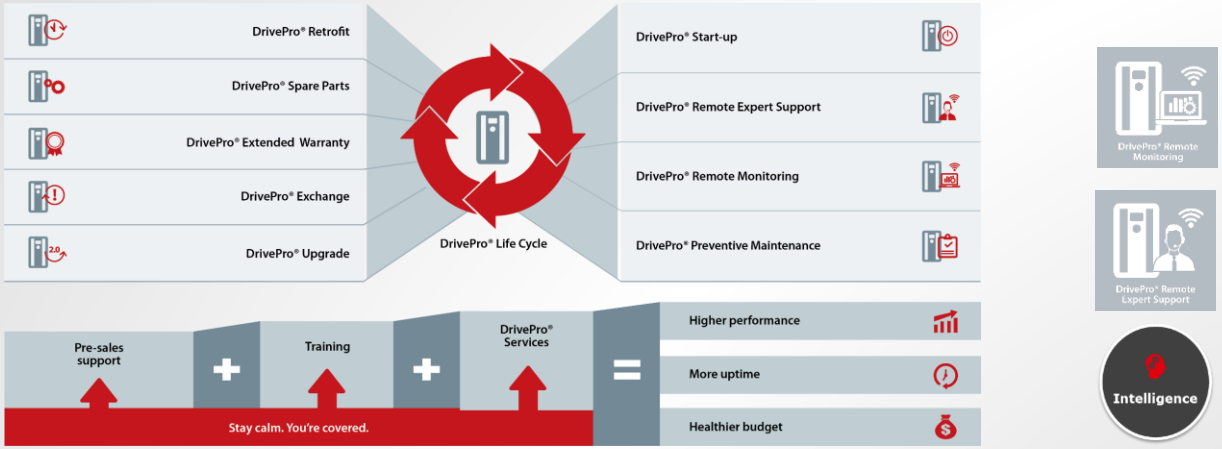
VACON®

Combine innovation and high durability for the sustainable industries of tomorrow.

For long lifetime, top performance, and full-throttle process throughput, equip your demanding process industries and marine applications with VACON® single or system drives.

- Air and liquid cooled drives (0.25 – 6,000 kW)
- Decentral drives
- Active Front-End drives
- Industrial system drives
- Grid converters
- DC/DC converters
- Hybrid and energy storage solutions
- Customer-specific solutions
- Software tools

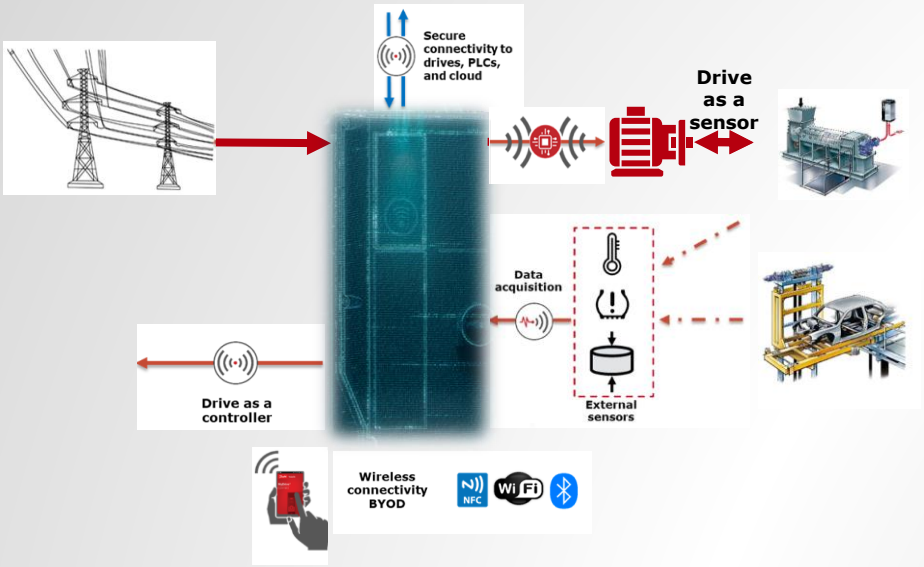
World-class expert services – DrivePro®

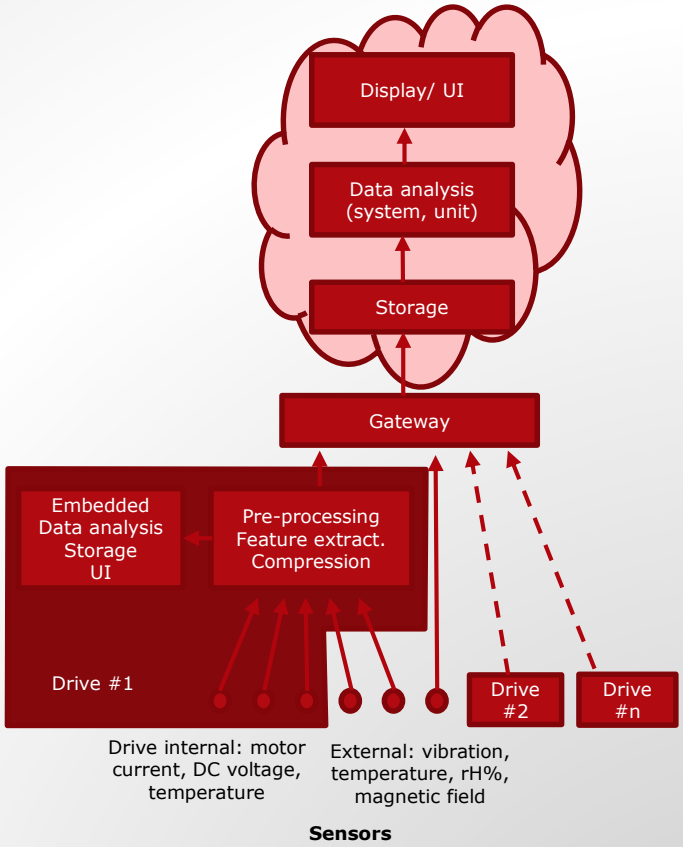


- Including Cloud based remote monitoring solution and intelligence
  - DrivePro® portfolio – DrivePro® Remote Monitoring with online connection to drive data, status and performance information, real-time measurements and cloud data storage
  - DrivePro® Intelligence: Drive as a sensor, Motor stator winding monitoring, Motor vibration monitoring, Motor load envelope

- Moving towards enhanced diagnostics and predictive capabilities

Drive as a sensor & IoT





- Data is collected from physical sensors, both drive internal and external sensors such as vibration, accelerometers, temperature, humidity, magnetic field…
- Derivative dimensions are calculated in the drive, for example power (U*I) and energy (U*I*time)
- Data often needs to be pre-processed and failure-mode specific feature extraction needs to be performed.

Use case – Remote Monitoring with DrivePro®

Typical challenge with industrial electronics…

- Drives are system components and slaves – upper systems maintain and dominate data assets
- Usually - no dataloggers, measurement or any application data available from the failure situation
- Failure analysis is often post mortem autopsy with extreme rush and high customer attention
- Return of the units takes weeks to months causing even more pressure on containment and analyses

Use Case - Problem Description

- A series of unexplained FC unit failures reported by end customer since vessel commissioned and launched in operation late 2016
- FCs built in Finland 2014-2016, vessel built and electrified during 2014-2016 and commissioned during 2016
- Operation since 2016 from Newfoundland/Canada as an Offshore supply chip at North Atlantic Sea
- Failure in two waves: 1st wave of failures occurred in very early phase of the operation; commissioning or soon after, 2nd wave of failures late 2018 and escalation early 2019

- A problems solving project established in collaboration with system integrator, vessel owner, vessel crew and Danfoss Drives Product team on spring 2019
- Installed base under the scope of this project drives in mission critical hybrid (diesel-electric) generator and steering thrusters applications

Liquid cooled, 900kW units, enclosed
$MTTF_{90\%}$ > 1Mhrs
FFR_{warr} < 1%
In production >10yrs
Widely used marine, offshore, heavy industry, hybridization applications system component.

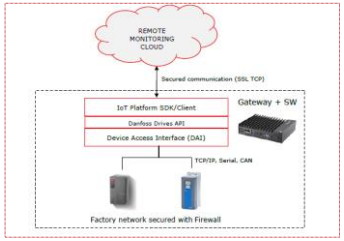
Problem Investigations – First iteration

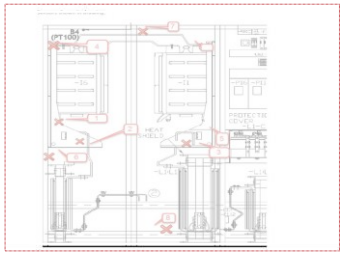
- Units were returned for Failure Analyses to Finland - but despite extensive analysis efforts, explicit root cause for failures remain unidentified – some suspections are raised concerning environmental impacts during early phase of life cycle (dirt, dust, high humidity)
- Available data loggers and fault history saturated with ”system noice” and ”external alarms”, system data is not available – no added value for further investigations
- Customer claimed failures occured during docking, but also in ”normal operation” - some initial suspection of vibration loads
- Analysis team visited the vessel during early summer 2019 to measure and inspect system and installations, some initial vibration measurements done but not enough accuracy with used data loggers

- After first iteration of investigations – root cause is still unrevealed and end customer raises the concern of loosing business and contract
- More accurate data is obviously needed, new plan is made...

Problem Investigations – Second iteration

- Plan for more advanced Remote Monitoring and measurement plan made together with system integrator and reviewed with vessel owner and captain/technical crew – finally two systems parallel:
  - System Integrator connects accurate vibration measurement system to most critical applications / enclosures through own system (used for thruster systems monitoring)
  - Danfoss Drives intalls DrivePro® Remote Monitor GW (IoT Ticket) directly into Drives in most critical propulsion systems/drives





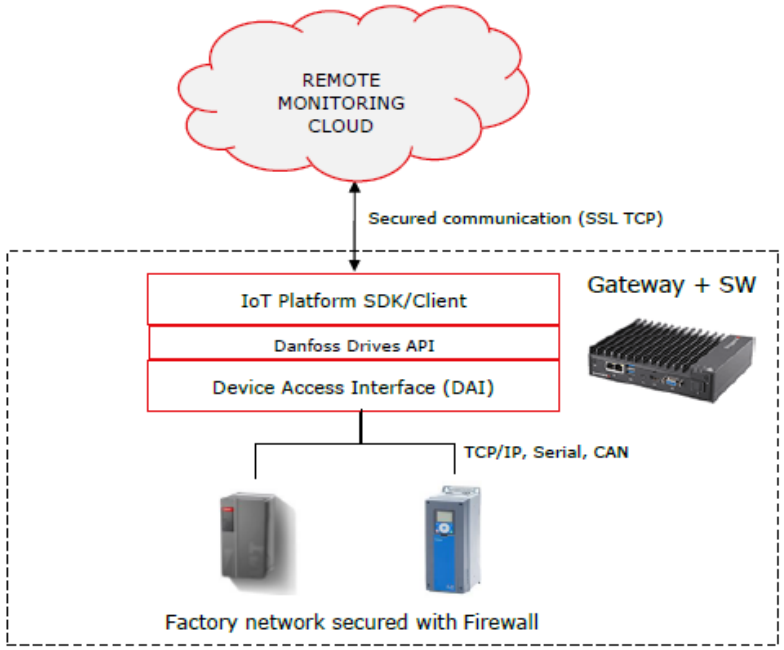
- Remote Monitoring systems are installed during autum 2019
- Vessel crew/captain grants access to local control/data network and permits the uplink connection (satellite link)

- Already first measurement period reveals alarming high vibration and displacement levels on certain drives during operations (nearly 10mm/s at <10Hz frequency range)
- Monitoring period is decided to continue following 6 months as vessel contractor provides continuation to contract...

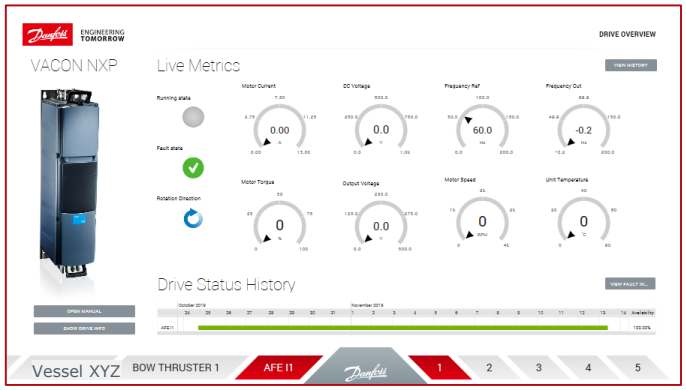
Installed DrivePro® Monitoring solution

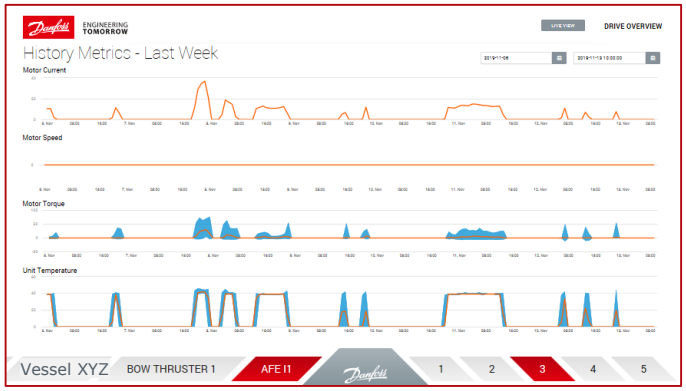
- Drives connected through NX serial bus IO to Danfoss DrivePro® Remote Monitoring Gateway (see spec)
- GWs connected through vessel's ethernet network to satellite link to Remote Monitoring cloud
- Data accessible through user access controlled, tailorable parameter set on DrivePro® Dashboard

RM_gateway_data sheet



Dashboard – Live metrics and data access

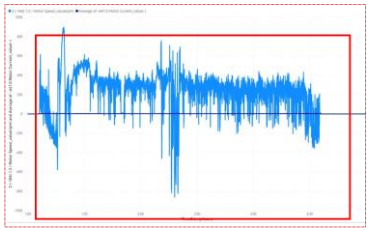


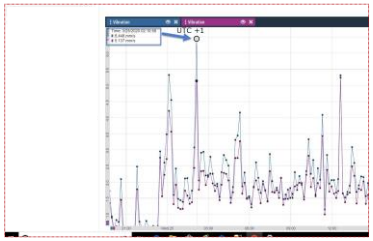


- *Vessel XYZ* Remote Monitoring Dashboard – basic operational views, tailorable
- Drive status, overview of key parameters, external links, history views, trends, …
- Fault history (events) and Data Loggers logs downloaded automatically on any incident
- All datatags downloaded once per day, selected measured and downloaded once per second
- Dashboard views can be modified, data combined and all data exported, …
- Basically any data tag available in/by application is accessible if so defined

Conclusions & Resolution

- Until early spring 2020 a massive data asset has been collected from two parallel monitoring systems (drive operation & measurement data and vibration measurement data)
- Comparable analyses of Drive measurement data (mission profile data) with vibration measurements confirm high vibration load during operation with high propulsion torque
  - ✓ Systems vibration / displacement levels are challenge during the certain operational points of propulsion (both docking and on sea) at very low frequencies and resonance <10Hz
  - ✓ One recent drive failure recorded in operation; main suspection of slow, latent degragation (ageing) of power semiconductors due to vibration





- ➢ Corrective action: Simple mechanical on-site improvement addressed - improvements of system enclosure (narrow-band) vibration dampers to prevent low frequency resonances and vibration stresses certain frequency range.
- ➢ Preventive action: Utilise data asset in system model (FEM) to find suitable structural improvements for enclosures (TBD). Feed the data asset to verification and maint/dev.

Lessons & future considerations

- Reliability engineering is much about understanding **Physics of Failures**
  - Based on (historical) knowledge of materials and components in assumed conditions
  - Components are utilised assuming use within specified and tested limits
- Reliability engineering is much about **using available data to predict the future**
  - Very often predictions are based on field data from products warranty window only
  - Products are built on requirements, models, assumptions and validated by laboratory tests
- **All this is done knowing that customers will push the spec limits in real use anyway…**
- **In practice**, Engineering also becomes **much about wondering what the hell went wrong**…

Field & Mission Data is the Super Power of Reliability Engineering and now we have better than ever chance to gain it

- Technically mature and effective solutions are here today - even for ”legacy” products data harvesting – remote monitoring, cloud services, big data, smart sensors, computing power, virtual twins, ... ?
- New skills may be required in reliability engineering – computing, programming, algorithm development, data management and manipulation (e.g. Python), connectivity (IP, IoT, 5G, satellite...) – or agility to utilise smartly those peers and people who already have these skills ...
- The big question is can we utilise all this available power for and add value for customers ...

ENGINEERING
TOMORROW