

MAKING MODERN LIVING POSSIBLE

Danfoss



Fundamentals of VFDs and Refrigeration Applications

VLT®
THE REAL DRIVE

Outline

- What is a VFD and how does it work
- Differences from across the line motor starting
- How a VFD is rated
- How to select a VFD

What is in a name?

- Adjustable Frequency Drive (AFD)
- Adjustable Speed Drive (ASD)
- Variable Frequency Drive (VFD)
- Variable Speed Drive (VSD)
- Drive
- Inverter

What is a VFD?

- An electronic controller that adjusts the speed of an electric motor by modulating the power being delivered.
- The key to successful operation is adjusting both the motor frequency and the motor voltage according to the requirements of the load.



What can a VFD do?

- Adjust the speed of a motor to match what is required by the system
- Provide a gentle ramp up and down in speed to eliminate surges mechanically, electrically, and hydraulically caused by starting a motor
- Monitor and protect the motor and the load



What can't a VFD do?



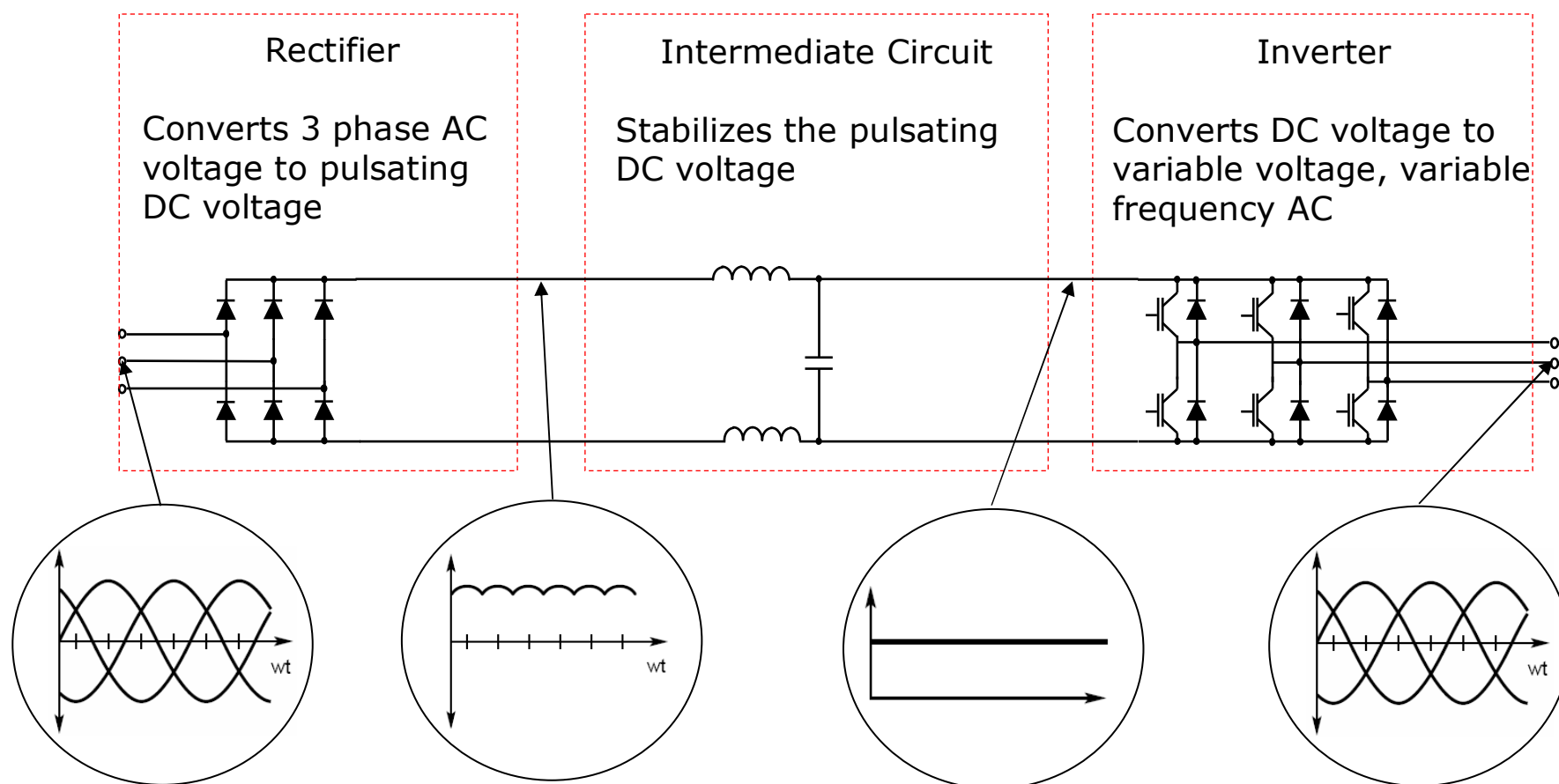
- Boost the output voltage significantly above the input voltage
- Increase the output power of the motor
- Magically solve all system problems

Why use a VFD

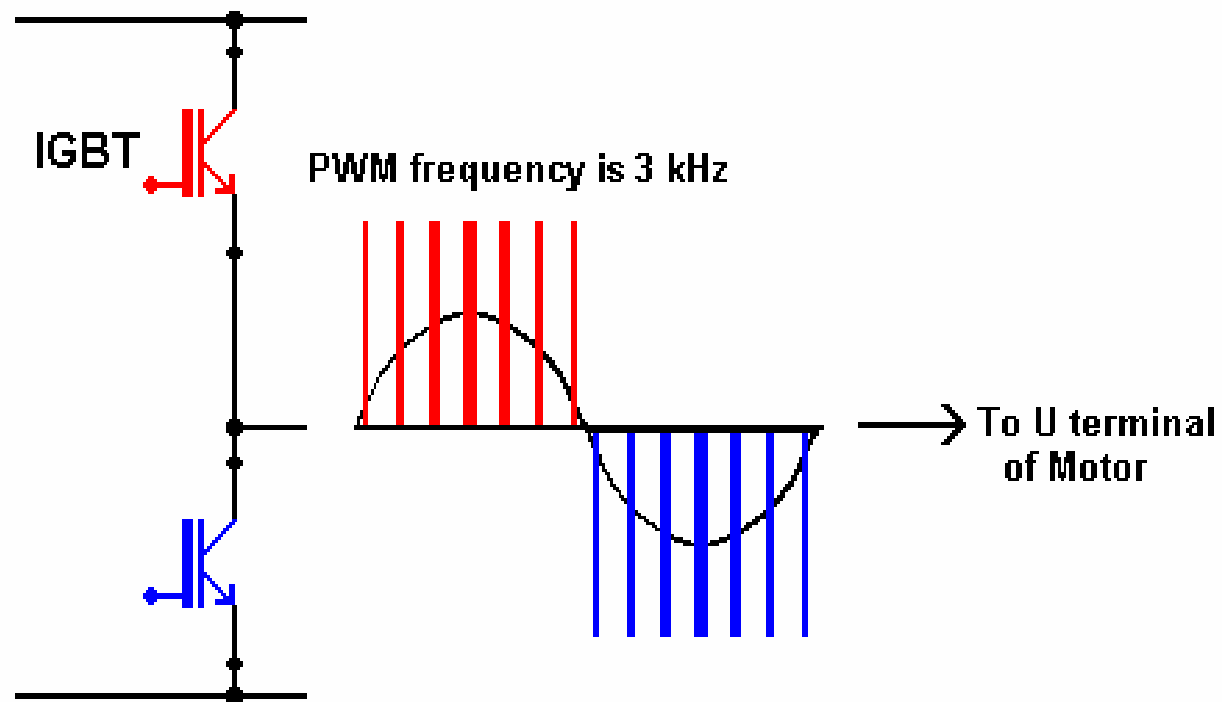
- Better regulation and control of the system
- Reduce system cycling
- Reduce maintenance cost
- Energy savings (almost all cases)



How does a VFD work



Pulse Width Modulation - PWM

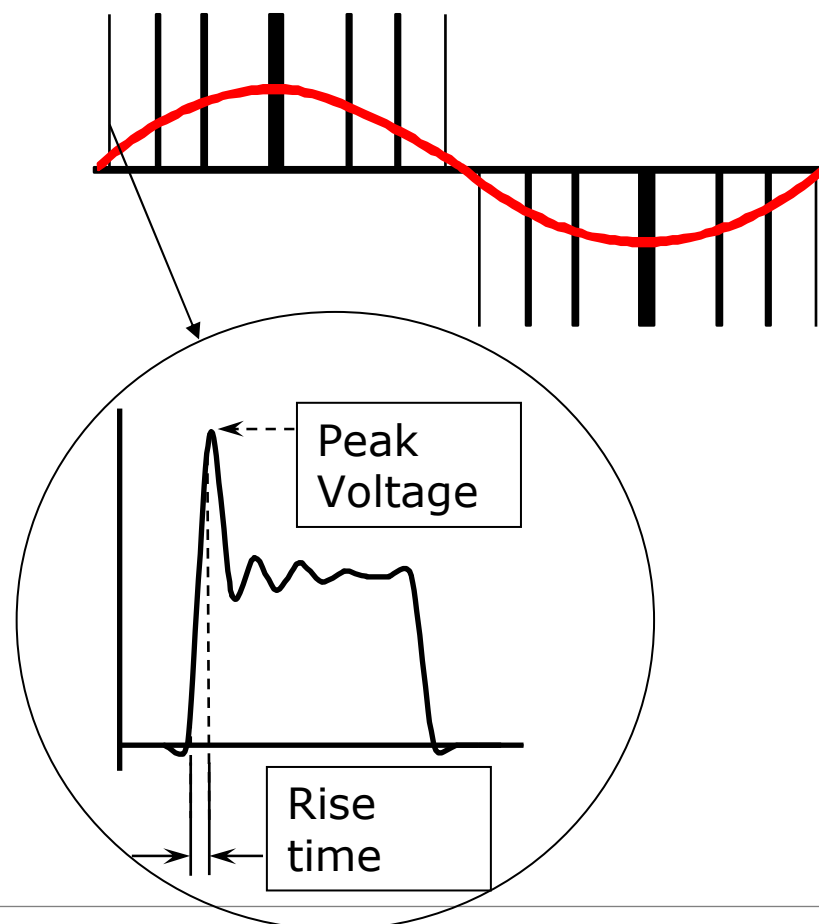


Differences from across the line starting

- Motor voltage waveform
- Motor current waveform
- Input current waveform

Motor Voltage Waveform

- The output voltage is not a smooth sine wave, but DC pulses
- The shape of the individual pulses in a function of VDF design and motor cable
- Waveform is described by
 - Peak Voltage
 - Voltage Rise Time
 - Rate of Rise (dV/dt)



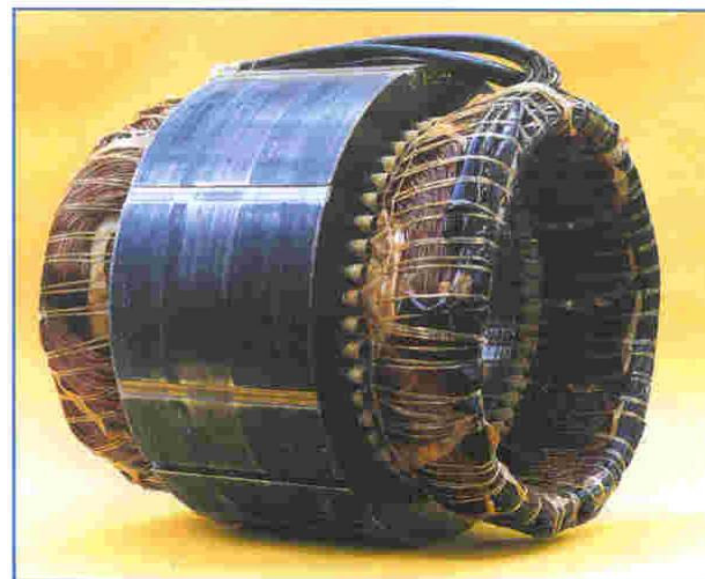
Effect on the Motor

- The voltage waveform is more stressful on the motor than across the line operation
- When using a VFD the options for the motor include
 - Use a motor designed for use on a VFD
 - Use an output filter on the VFD

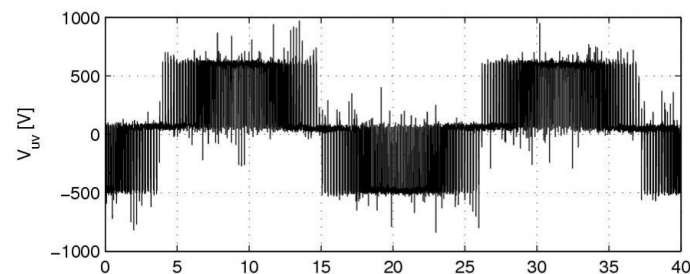
Motor for use with a VFD

Motor Type	Peak Voltage	Rise Time	dV/dt Volts/ μ sec
General Purpose	1000	>2 μ sec	500
Inverter Duty	1600	>0.1 μ sec	16,000

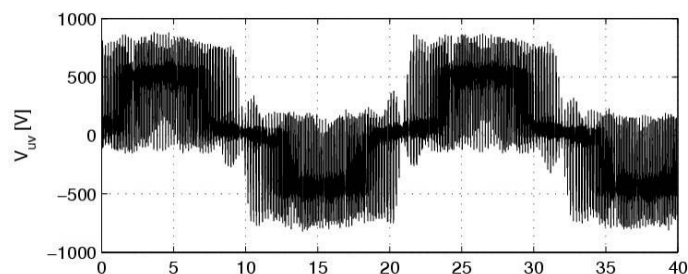
- NEMA MG-1 is the standard that defines motors
- Part 30 describes General Purpose Motors
- Part 31 describes Definite Purpose motors for use with a VFD



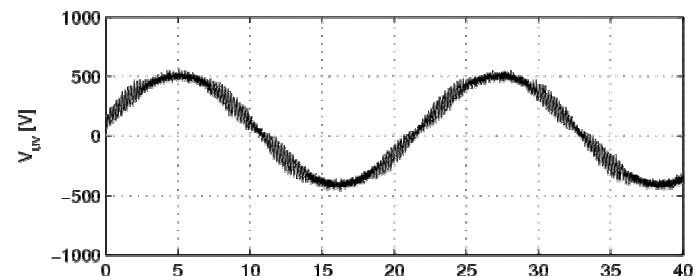
Output Filter Effects on Motor Voltage



■ VFD with no filtering



■ VFD with dV/dt filter



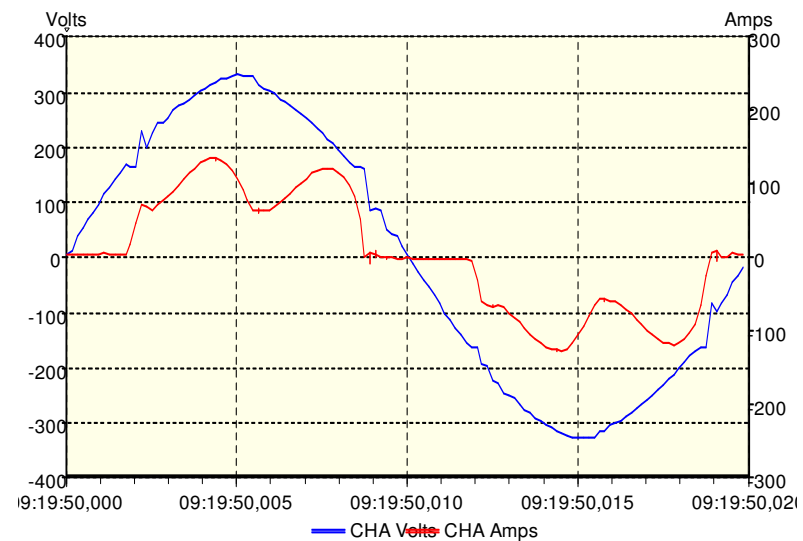
■ VFD with Sine filter

Motor Current Waveform

- The benefit of the PWM voltage switching is a smoother current waveform than previous technologies
- The closer the current is to sine wave the smoother the motor operates
- The closer the current is to sine wave the cooler the motor operates

Input current waveform

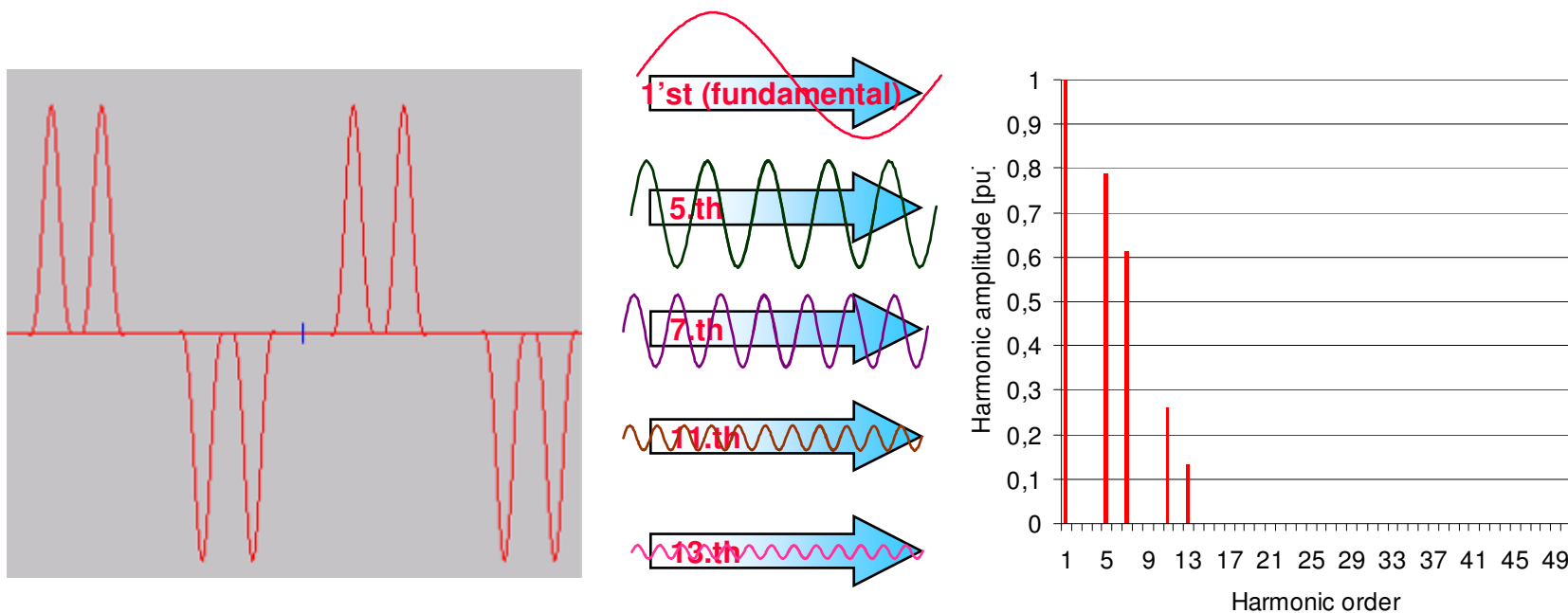
- The diodes in the rectifier section of the VFD only conduct current when the line voltage is greater than the DC bus voltage
- As a result current only flows at the peak of each voltage waveform
- Because the current is not sine wave the VFD is considered a “non linear” load
- This non linear current draw creates harmonics in the electrical system



Snapshot event at 1998-09-08 09:19:50,000

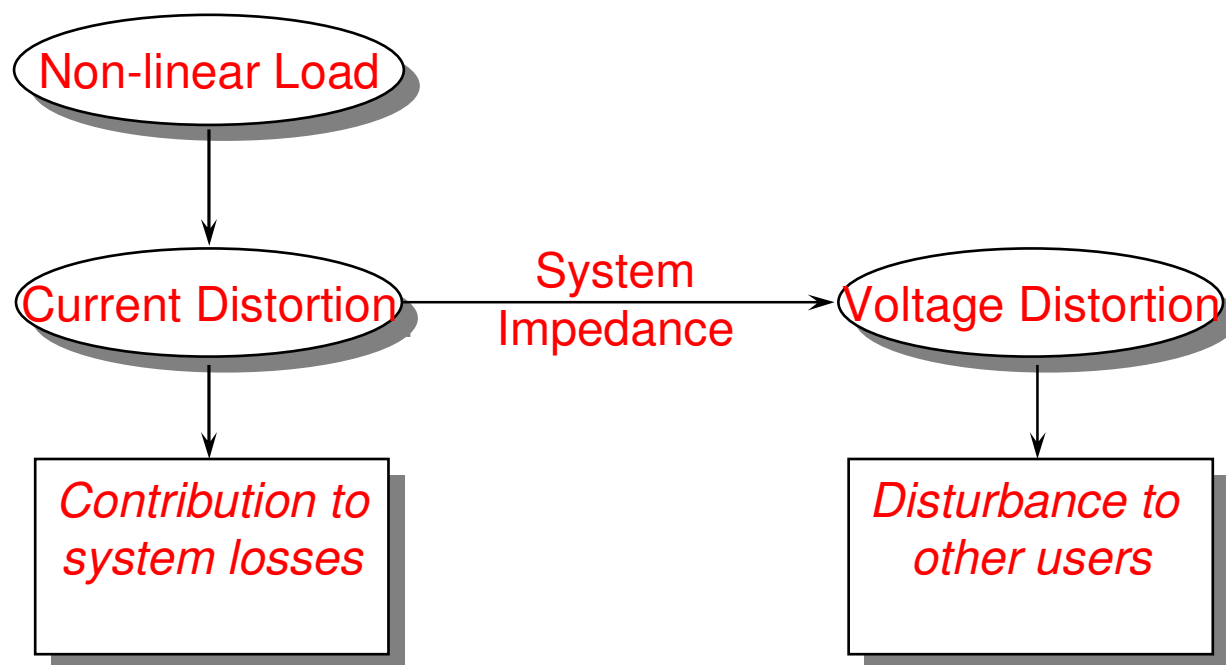
What are harmonics

- Harmonics is decomposition of a signal into different (integer multiples of fundamental) frequencies



Harmonic distortion by nonlinear loads

- Current distortion is device level performance
- Voltage distortion is system level performance

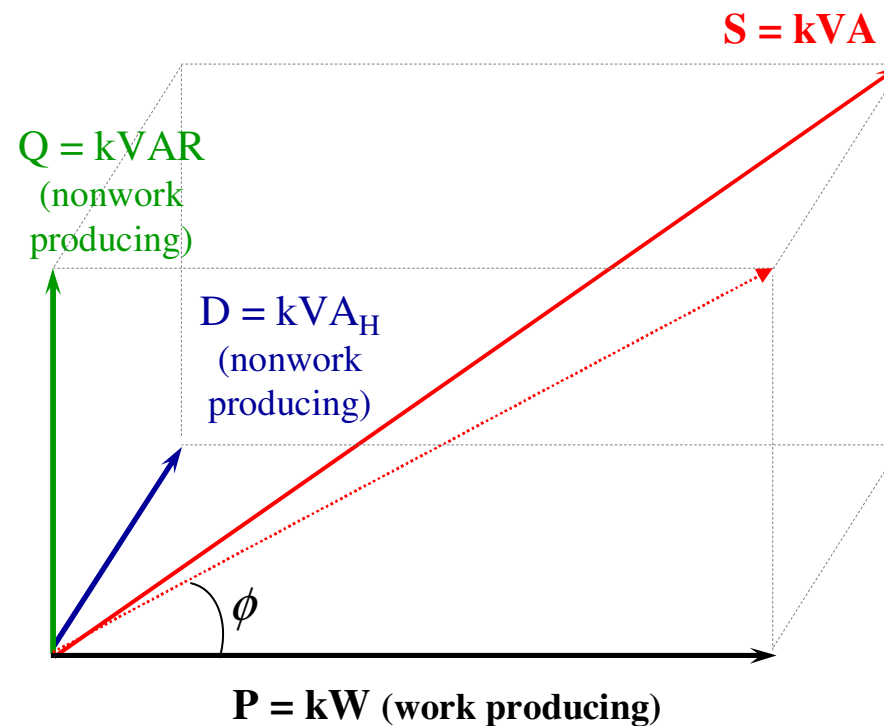


Effects of Harmonics

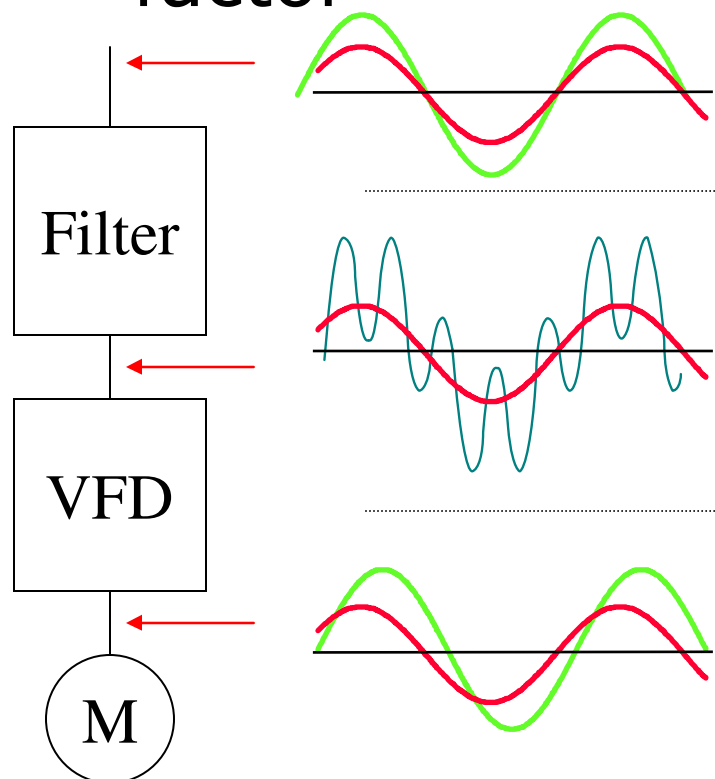
- Current Distortion
 - Adds to the total current flowing in the system
 - Cables and transformers must be sized for this
 - Current harmonics does NOT in itself generate interference with other equipment
 - Leads to Voltage Distortion
- Voltage Distortion
 - May lead to interference of other equipment
- Based on system information there are tools to predict system harmonics

Power Factor

- Without harmonics:
Power Factor is the cosine of the phase angle between voltage and current
- With harmonics:
harmonic current also decreases the power factor
- However:
The cosine of the phase angle between voltage and current is almost 1 into a VFD



Energy consumption and true power factor



THiD = 0%

$\cos(\phi) = 1$

PF=1

$P = \text{kW}$ (work producing)

THiD = 45%

$\cos(\phi) = 0,98$

$$PF \approx \frac{1}{\sqrt{1 + THD^2}}$$

$D = \text{kVA}_H$
(nonwork producing)

$P = \text{kW}$ (work producing)

THiD = 0

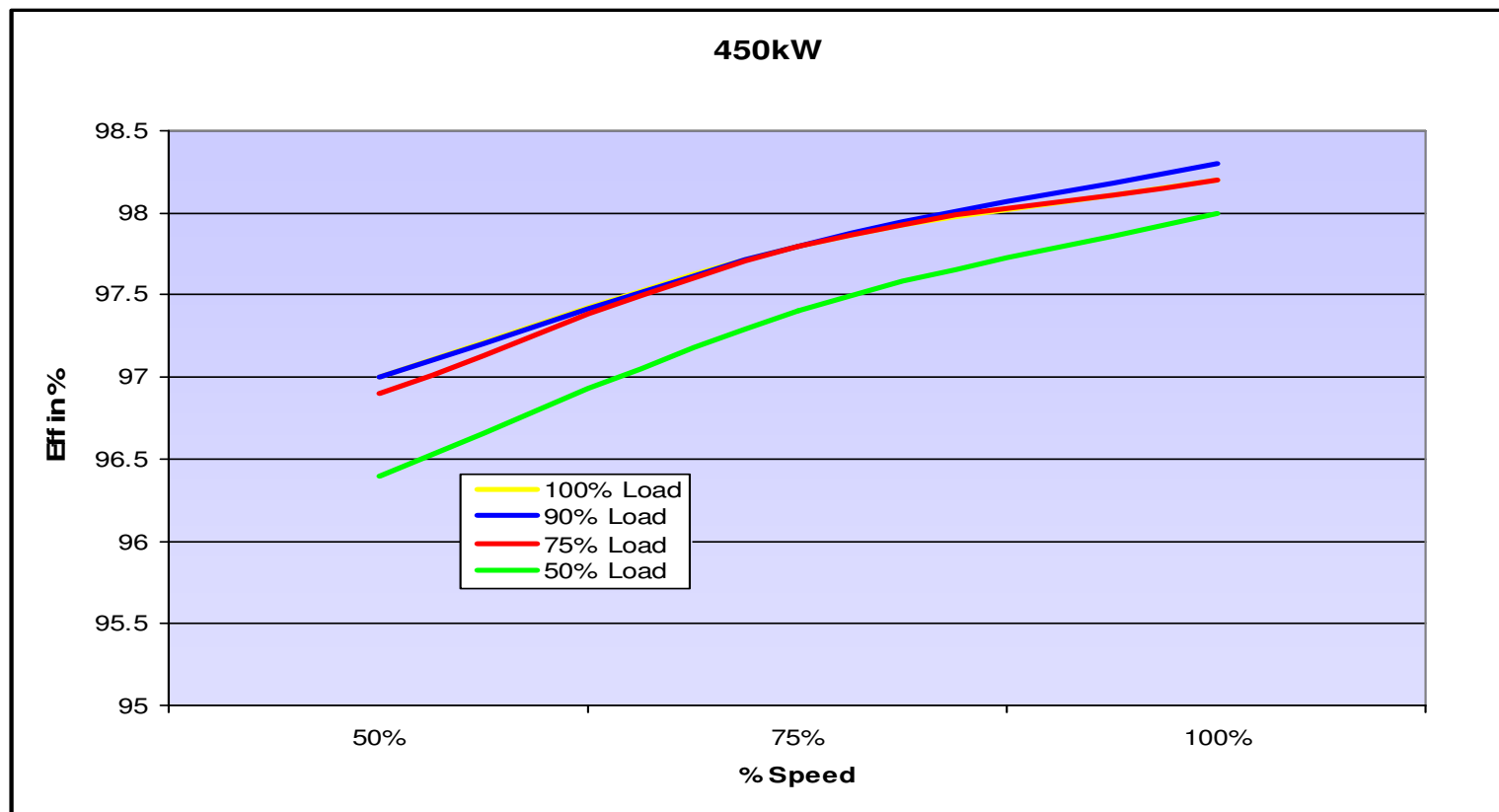
$\cos(\phi) = 0.85$

PF= $\cos(\phi)$

$Q = \text{kVAR}$
(nonwork producing)

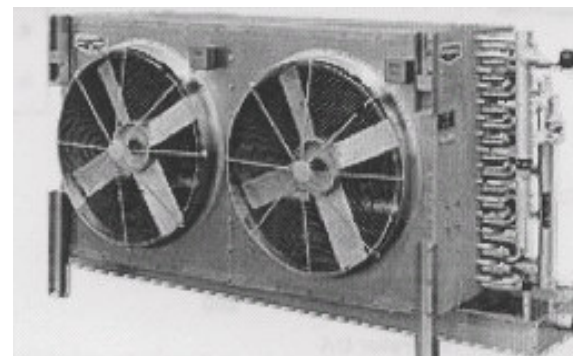
$P = \text{kW}$ (work producing)

VFD efficiency based on load and speed



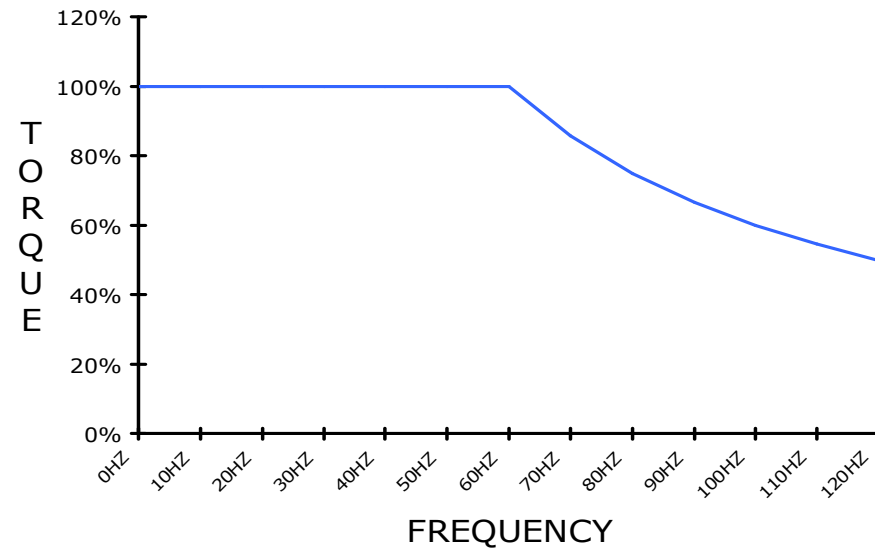
How a VFD is rated

- Required current to the motor
- Voltage rating
- Load Type
- Overload Requirements



Motor Basics

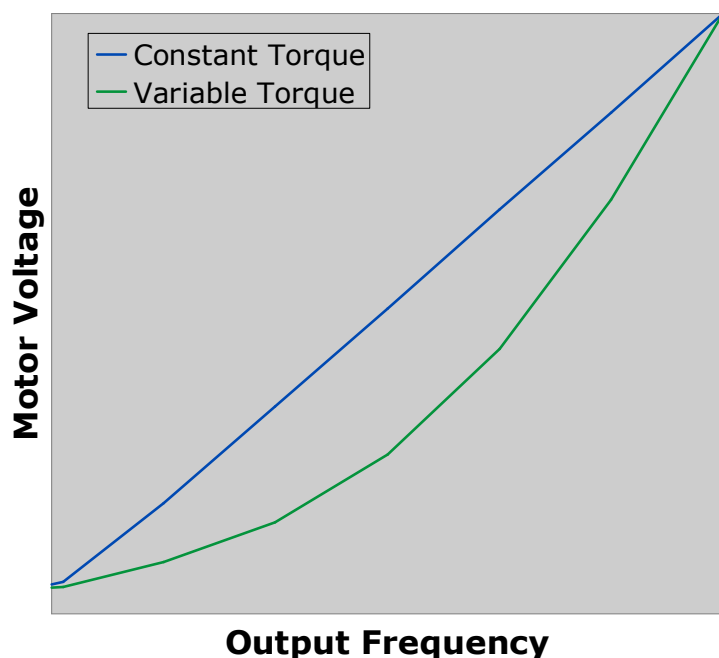
- $\text{Power} = \text{Torque} * \text{Speed}$
- Below base speed motors provide constant torque
- Above base speed motors provide constant horsepower



Load Types

- Variable Torque: The required torque increases as speed increases
 - Most pumps
 - Fans
- Constant Torque: The required torque is independent of the speed
 - Compressors
 - Some types of pumps
 - Some types of blowers
- Constant Power: The required torque decreases as speed increases
 - Cutting Tools

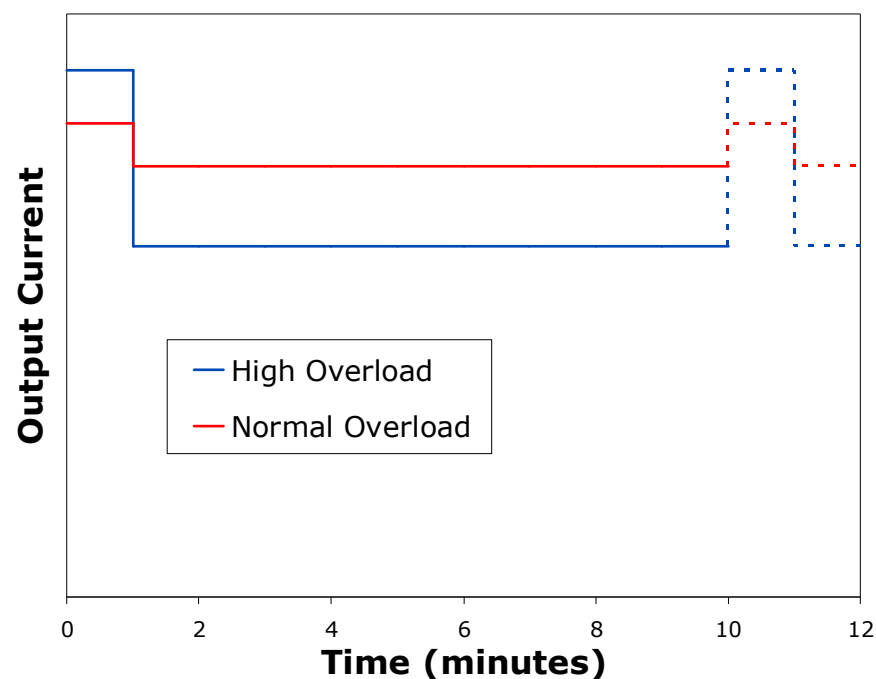
Constant Torque vs. Variable Torque



- For Constant Torque the ratio of motor voltage to motor current is constant
- For Variable Torque the motor voltage is reduced below what is required for constant torque
- By further reducing the motor voltage additional energy can be saved

Overload Characteristics

- The ratings are typical based on one minute at the overload rating every ten minutes of operation
- The other nine minutes of operation are assumed to be at rated output
- Required overload rating is a function of torque needed to start the load



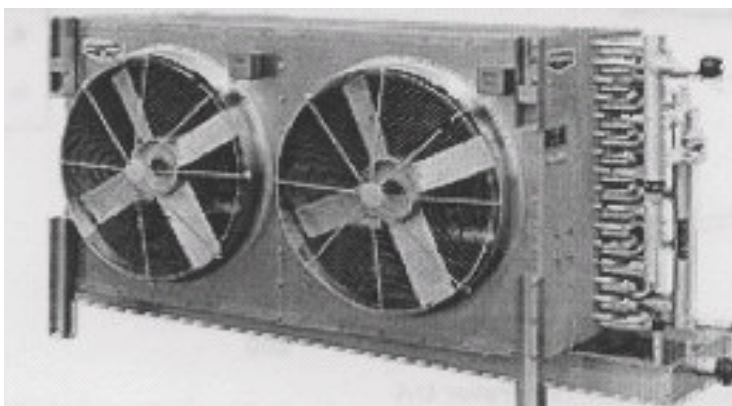
How to select a VFD



- Horsepower?
- Full Load Amps?
- CT vs. VT
- Temperature
- Altitude

- Current is what a VFD produces HP/kW is just a "guide"

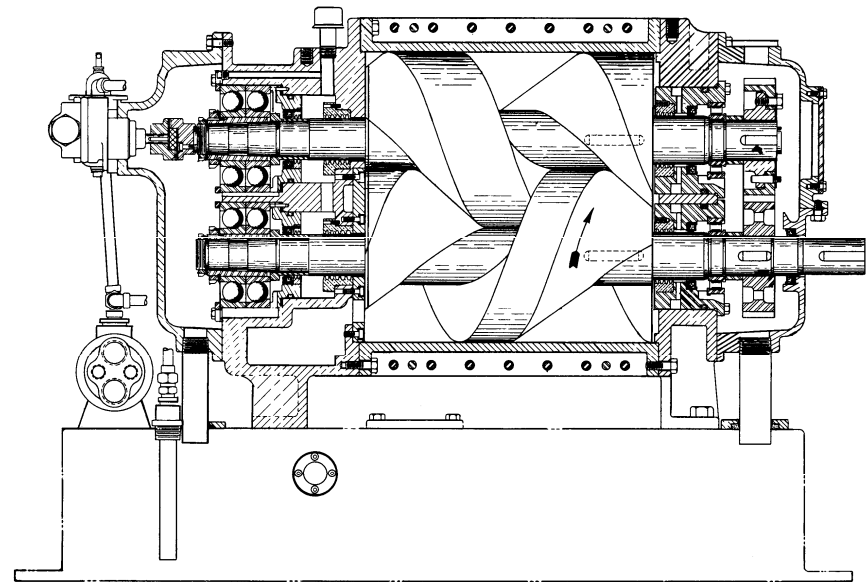
Fan Applications



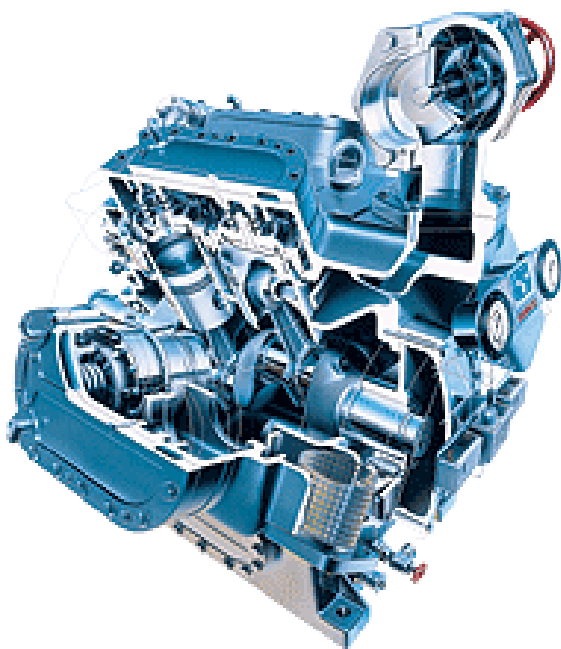
- Variable torque load type
- Low starting torque requirements
- Size based on normal overload current ratings
- Centrifugal pumps are sized the same as fans

Screw Compressors

- Constant torque load type
- Starting torque is similar to running torque
- Size based on Normal Overload current ratings
- Some manufactures size the motor based on the service factor, others do not

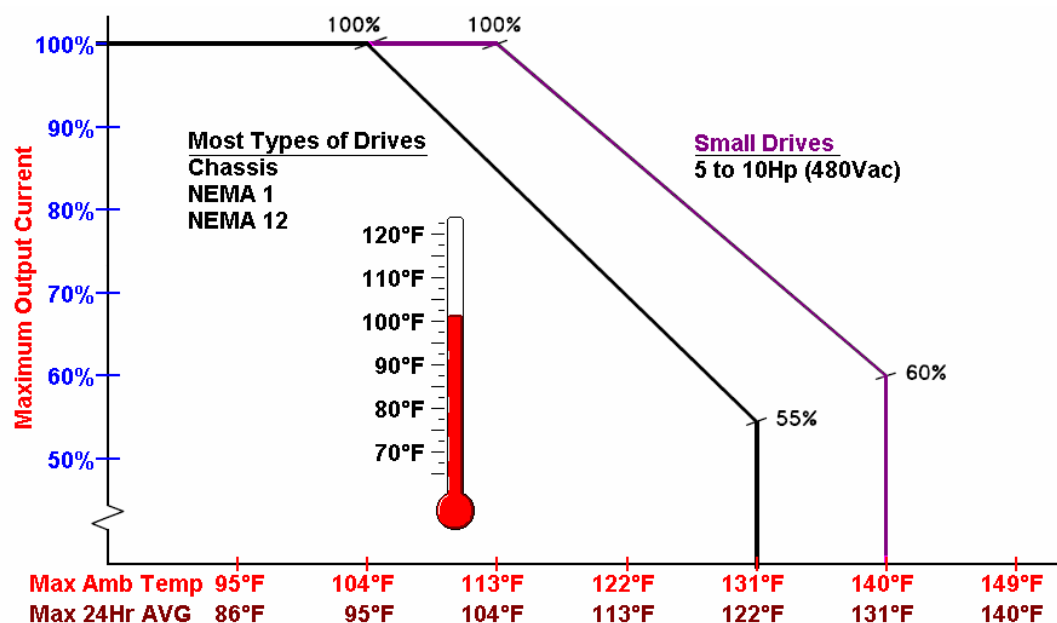


Piston Compressors



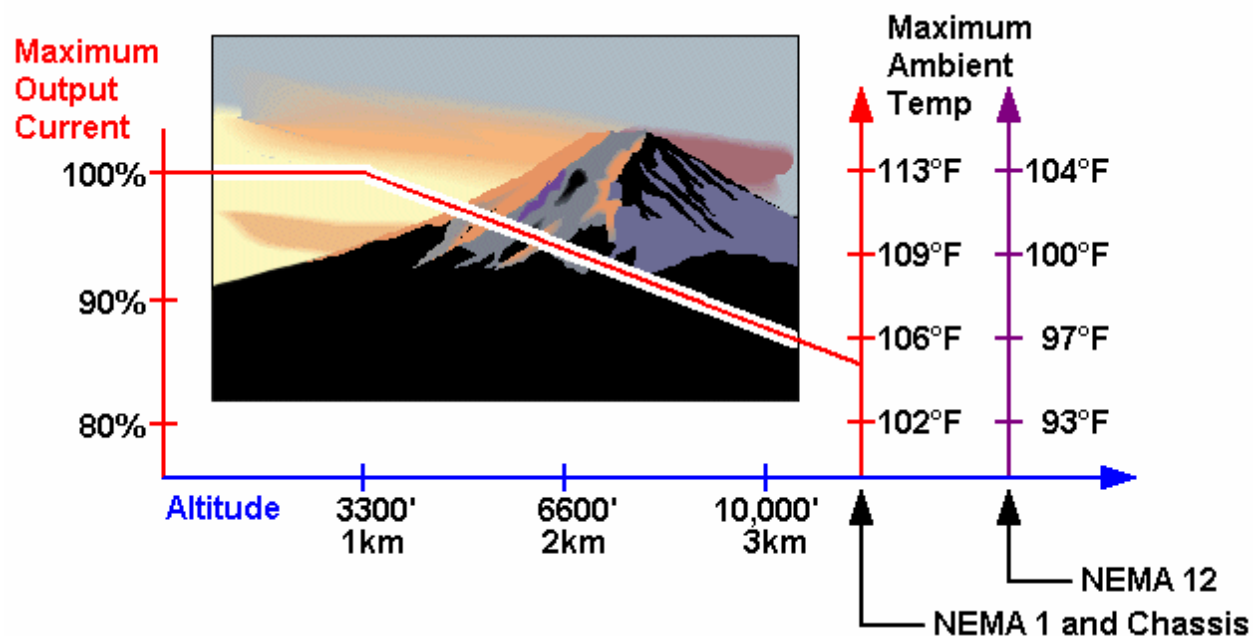
- Constant torque load type
- Starting torque depends on where in the stroke the piston stopped
- Size based on the high overload current ratings
- If running with three or fewer pistons talk to the VFD supplier

Ambient Temperature Effect



- The Hotter the environment, the lower the current output

Altitude Effect



- Higher elevation means less air, less cooling
- Reduce surrounding temperature or reduce heat generation



Thank you for your time.

Any Questions?

Contact Information

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Who is Danfoss?

- Danfoss was founded in 1933 in Denmark
- First company to mass produce VFDs starting in 1968
- From 0.25 to 1600 horsepower (up to 690 VAC)
 - Number 4 globally
 - Number 3 in Europe
- Up to 125 horsepower
 - Number 1 globally

