



*A collection of inverter scroll compressors*

# Inverter Technology in HVAC

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*Danfoss, in partnership with ISHRAE, has prepared this overview of the inverter technology from the basics to the advanced – working principle, applications, benefits and some more advanced information concerning implementation of inverter technology in HVAC systems – **Technical Editor***

## Introduction

An inverter compressor is one that operates on the inverter technology. In the hermetic type, it can either be a scroll or a reciprocating compressor. This type of compressor uses a special drive to control the compressor motor speed (measured in rounds per second – RPS). This leads to accurate capacity modulation and, as a result, to outstanding energy savings, precise temperature and humidity control, greater comfort, food and process safety as well as boosted power grid compared to other modulating technologies in cooling systems.

## Market Needs for Variable Capacity

Many refrigeration and air conditioning systems require reliable processes that are efficient, compact, environment-friendly, and easy to install and maintain. The cooling requirements vary over a wide range during the day and over the year due to ambient conditions, occupancy and use, lighting etc.

- *In comfort cooling*, there may also be the need for a stable and accurate temperature and humidity control in areas such as hospitals, IT and telecom, and process cooling. In applications like schools, restaurants and office buildings, it is important that the cooling system is able to adapt to wide daily shifts in load<sup>[1]</sup>.

- *In process applications* such as fermentation, growing tunnels and industrial processes, accurate temperature settings are required to secure production quality.

HVAC and refrigeration systems are usually designed for peak demand which represents only a small percentage of the actual operation (*Figure 1*). Such oversizing leads to efficiency losses and extra costs for oversized equipment. Capacity modulation is a way to match cooling capacity to cooling demand, thereby matching these application requirements.

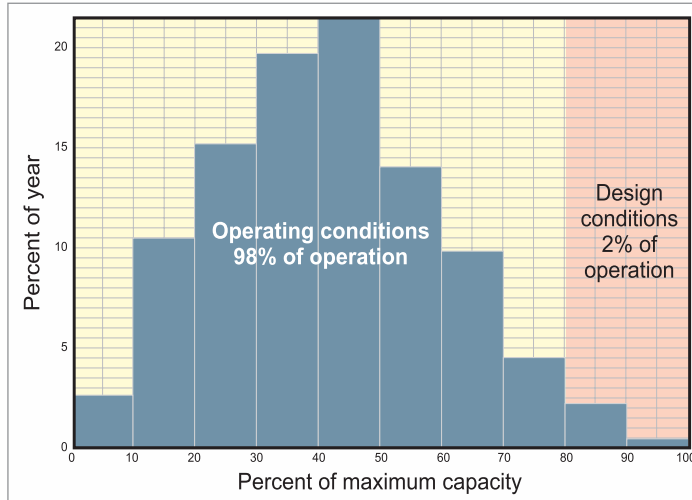
## About the Author

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### Typical load profile in a building

HVAC systems are designed for peak conditions (right side of the graph). These conditions are not the conditions in which the equipment will operate most of the time. The graph represents typical annual climate data and hours of run time (% of year) for each condition.

Source: Danfoss

the unit is reduced by pressure cycling and transient losses. The turndown capacity is 100% or 0%.

### Hot Gas Bypass

This involves injecting a quantity of gas from discharge to the suction side. The compressor will keep operating at the same speed but thanks to the bypass, the refrigerant mass flow circulating with the system, and thus the cooling capacity, is reduced. This naturally causes the compressor to run uselessly during the periods when the bypass is operating.

Figure 1: Only a small percentage of HVAC operation is at full load

## Different Modulating Technologies

There are several ways to modulate the cooling capacity in refrigeration or air conditioning and heating systems. The most common ways in air conditioning are: on-off cycling, hot gas bypass, use or not of liquid injection, manifold configurations of multiple compressors, mechanical modulation (also called digital) and inverter technology. Each has advantages and drawbacks (Table 1).

### On-off Cycling

This results in switching off the fixed-speed compressor under light load conditions and could lead to short cycling and the reduction in compressor lifetime (Figure 2). Efficiency of

The turndown capacity varies between 0 and 100%<sup>[2]</sup>.

### Manifold Configurations

Several compressors can be installed in the system to provide the peak cooling capacity. Each compressor can run or not in order to stage the cooling capacity of the unit. The turndown capacity is either 0/33/66% or 100% for a trio configuration and either 0/50% or 100% for a tandem<sup>[3]</sup>.

### Mechanically Modulated Compressor

This internal mechanical capacity modulation is based on periodic compression process with a control valve; the two scroll sets move apart stopping the compression for a given time period. This method varies refrigerant flow by changing the average time

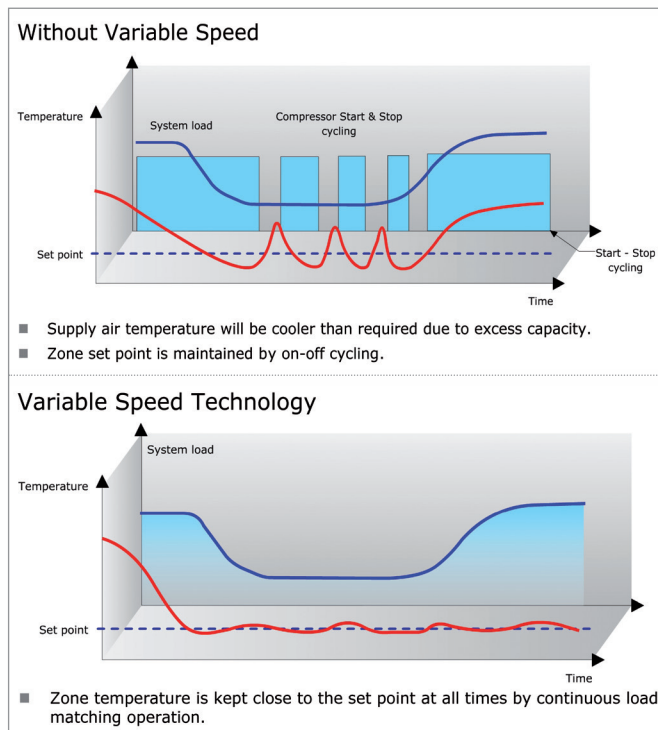


Figure 2: Compressor cycle over time: without and with inverter technology

Table 1: Comparison of different compressor modulation technologies

	Precise and smooth temperature control	Energy efficiency	Capacity modulation
On-off compressor			
Cooling with hot gas bypass	✓		✓
Manifold systems		✓	✓
Mechanical modulation	✓✓		✓✓
Inverter compressor	✓✓	✓✓	✓✓

of compression, but not the actual speed of the motor. Despite an excellent turndown ratio – from 10 to 100% of the cooling capacity, mechanically modulated scrolls have high energy consumption as the motor runs continuously<sup>[4]</sup>.

### Inverter Compressor

This uses an external variable frequency drive – also known as inverter drive – to slow down or speed up the motor that rotates the compressor. This method varies refrigerant flow by actually changing the speed of the compressor. The turndown ratio depends on the system configuration and manufacturer. It modulates from 15 or 25% up to 100% at full capacity with a single inverter, and from 12 to 100% with a hybrid tandem<sup>[5]</sup>.

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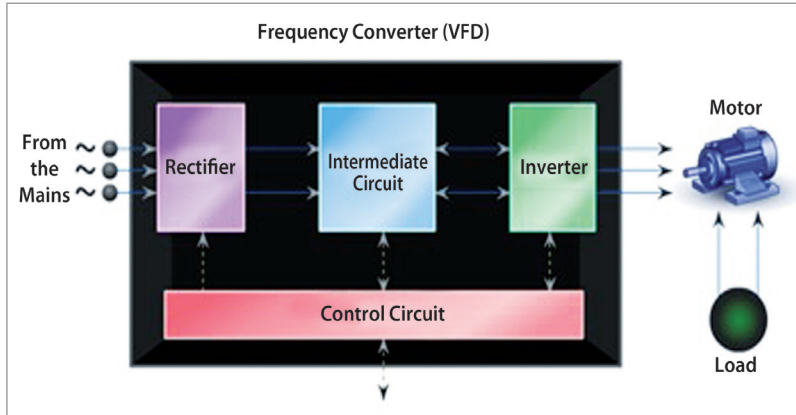


Figure 3: Simplified frequency converter

## Working Principle

Inverter compressors used in an air conditioning unit can operate at different speeds. The inverter compressor is specifically designed to run at different motor speeds, thereby generating a modulated refrigerant mass oil flow and cooling output. The variable frequency drive (VFD – Figure 3) indicates the cooling requirement to the compressor motor. The motor continuously adapts its speed to produce more or less cooling capacity to match the exact cooling need. The combination of the two devices – compressor and drive – gives a continuous cooling modulation. The variable speed principle requires a very sturdy compressor for full speed running and a special compressor lubrication system. *Excellent oil management is a critical requirement to secure compressor lifetime.* The oil management system (Figure 4) guarantees good lubrication of the scroll set at low speed and prevents excess oil from being injected into the circuit when operating at full speed to maintain a perfect Oil Circulation Ratio.

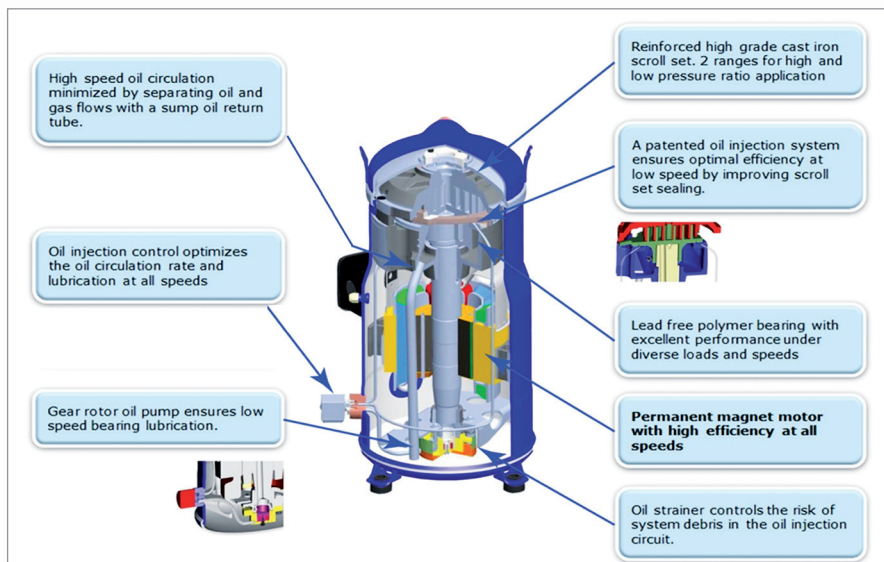


Figure 4: Key features of Danfoss inverter scroll VZH

## Applications

Variable speed technology can be implemented in HVACR, close control and process cooling applications and in equipment as diverse as packaged or split air-conditioning units, rooftops, chillers, precision cooling, VRF and condensing units (Figure 5).

### Rooftop

This is a very common unit type. The rising cost of energy means that air conditioning manufacturers must develop new generations of high-efficiency, cost-effective air conditioners for commercial buildings that meet or exceed a part-load efficiency standard of typically 18 IEER. The aim is to reduce energy use by 30% over current equipment. Inverter technology helps OEMs to build units which meet this demand.



Figure 5: Inverter compressor technology in HVACR applications.

### Air Handling Units

AHUs with integrated cooling are used in commercial applications for air conditioning and humidity control in diverse ranges of buildings such as small office buildings, fitness and medical centres. Inverter compressor solutions enable smooth modulation and huge energy savings.

### Modular Chillers

A typical modular chiller installation uses multiple fixed-speed units. These units share the same water system to supply the building with cooled or heated water. Hybrid tandem, associating one inverter and one fixed-speed compressor, can better match the capacity requirement compared to a modular chiller with fixed-speed tandem compressors, and increase efficiency.

### Close Control Units

These are used in the cooling of IT and electronic equipment in data centres, telecommunications and manufacturing industries. Power management, energy

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consumption and heat loads are major challenges. Maintenance of a stable temperature and humidity control, compactness of the system and overall efficiency are key design challenges in these applications for ensuring data safety and availability. This is where inverter technology makes the difference.

### Process Cooling

In many industries the machinery and processes generate a large amount of heat which requires cooling, to protect the equipment and/ or to ensure that the product being manufactured is of the required quality. Inverter technology helps to secure the process while providing greater efficiency.

### Variable Refrigerant Flow (VRF)

VRF units are very popular cooling or reversible (heating and cooling) systems. They combine flexibility for building owners and occupants alike, with energy efficiency, high comfort, and ease of installation, without compromising on reliability. VRF systems already extensively use inverter technology [6].

### Benefits [1]

Inverter compressor technology offers new opportunities for air conditioning systems, first of all in terms of reduced energy consumption (Figure 6) and lower running costs. Additionally, the technology improves the power factor leading to better power supply quality as well as better system diagnostics and open communication protocols which facilitate servicing. Continuous adaptation to cooling demand provides higher energy savings and accurate temperature control. The compressor matches power input with cooling capacity. The unit copes effectively with changes in temperature and runs at partial load which can represent over 30% reduction in the energy bill every year compared to a fixed speed or mechanically modulated compressor. The stable temperature control secures the processes in an optimum way and provides greater comfort.

The capacity modulation attenuates power demand peaks which also contribute to increasing the grid reliability and quality of power supplied. The soft start control leads to a near zero inrush current and improves EER:

- DOL (Direct-on-line) compressor start draws 5 to 6 times the nominal current until the compressor running speed is attained. The traditional fixed-speed compressor in a system can make 8-12 start/stop cycles and every start

will draw high current from the supply, which leads to high power consumption and stress on supply, and on compressor mechanical parts.

- Most inverter scroll compressors are soft starting which avoid torque surges. This prevents high mechanical stress on the machine, and leads to lower service costs and decreased wear. Low in-rush current also helps in saving fixed costs charged by utilities (peak current calculation) and reduces mains and power backup loads.

### Some additional benefits of inverter compressors are:

- Better humidity control makes the unit suitable even for spa installations thanks to adjustment of the capacity of the

unit and subsequent better control of the evaporating temperature.

- Less noise than with conventional on-off systems during partial load operation.

In addition to the standard benefits for all inverter compressors and technology, inverter compressors and drives designed to work together have been prequalified. This adds to the

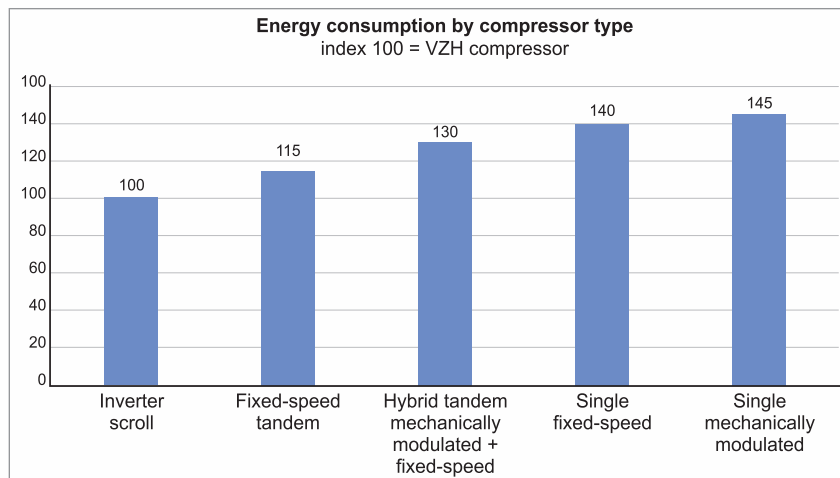


Figure 6: Energy consumption for cooling systems using different compressor configurations; average consumption index based on simulations for 10-30TR compressors used in applications with low pressure ratio (rooftop); index 100 = Danfoss inverter scroll VZH energy consumption

long list of benefits to manufacturers, consulting engineers and end-users in terms of:

- Reduced number of components in the system
- Higher reliability and continuous running
- Easier to implement technology
- Reduced applied costs
- Faster time to market.

### Challenges in Adopting Inverter Scrolls in HVAC Systems

#### Importance of the Inverter Drive

The compressor and drive need to be qualified to work together and for dedicated applications. The drive modulates the compressor speed and prevents it from operating out of the compressor operating limits. The inverter frequency drives use algorithms developed specifically for heating, ventilation and air conditioning (HVAC) or for refrigeration. They ensure that the system will run within the application constraints. The drive can also manage other devices such as oil injection valves or multiple compressors. As the compressor rotational speed changes, the amount of refrigerant — and oil — flowing through the compressor increases or decreases. The drive ensures that the compressor and bearings are optimally lubricated at all compressor speeds.

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### **OEM Manufacturer Skills in Inverter System Integration**

Not all OEMs are yet prepared to adopt inverter technology due to the following reasons:

1. Strong experience in the mechanical aspects of implementing inverter technology must be complemented by electrical engineering skills as well as controller development and programming.
2. Inverter compressors continuously keep changing speed to match the load, which makes oil management of the system more complex compared to traditional technology. Oil management mastering is a key issue where compressor manufacturer experience makes the difference.
3. Application support for OEMs by compressor and inverter drive manufacturer is critical in system integration.

### **Misconceptions About Variable Speed Technology**

#### ***Inverter Technology Reacts too Slowly to Load Changes***

Ramp up/down speed of some inverter scrolls is indeed up to 3600 seconds, whereas the new generations need as little as <0.1 seconds.

#### ***Full Load Inverter Losses are 5-10%***

At full speed the inverter can lose 3% of efficiency. As full

load is not the dominant profile, the loss will be minimal in the overall unit consumption.

#### ***Oil Circulation Increases at High Frequency Operation***

Oil circulation rate electronically controlled by some inverter scrolls can be less than 3% at full speed.

#### ***Oil Management is More Complex with Inverter Compressor Systems***

Some inverter scrolls control oil circulation at both low and high speed, requiring minimal design accommodations.

#### ***Inverters cannot be used where EMC (Electro Magnetic Compatibility) is a Concern***

Some inverter solutions offer two levels of EMC filtration, which meet the most stringent European standards related to electromagnetic interference.

### **References**

1. <http://www.invertercompressor.danfoss.com>
2. <http://www.pipelineandgasjournal.com/bypass-method- recip-compressor-capacity-control>, Pipeline and Gas Journal, March 2013, Vol. 240, No. 3
3. <http://www.ishrae.in/journals/2000apr/article02.html>
4. Scroll Compressor, Wikipedia
5. Air Conditioner Inverter, Wikipedia
6. [http://info.aia.org/aiarchitect/thisweek09/0410/0410p\\_vrf.cfm](http://info.aia.org/aiarchitect/thisweek09/0410/0410p_vrf.cfm) ♦