Inverter Compressor Technology for Refrigeration

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Introduction

Many refrigeration systems require reliable processes that are more efficient, compact, environmentally friendly, easy to install, and easy to maintain. The cooling requirements vary over a wide range during the day, night, and year due to ambient conditions, product storage variation, occupancy and use, lighting, etc. Three different market trends are converging to create new opportunities for efficient, sustainable solutions:

- Energy efficiency
- Intelligent systems
- Environmental impact

Energy efficiency is no longer an option. Energy regulations are strengthening. Energy codes and standards are being developed globally and energy incentives are getting more attention. Another global issue is energy security. How can we make sure that we will not lack energy one day?

Refrigeration systems are usually designed for peak demand, which represents only a small percentage of the actual operation. Such oversizing leads to efficiency losses and extra costs for oversized equipment. Energy-efficient capacity modulation is a way to match cooling capacity to cooling demand, thereby, matching these application requirements.

Ways to Modulate Cooling Capacity

There are several ways to modulate the cooling capacity of refrigeration systems.

On-off Cycling

On-off cycling results in switching off the fixed-speed compressor under light load conditions and could lead to short cycling and a reduction in compressor lifetime. The efficiency of the unit is reduced by pressure cycling and transient losses. The turndown capacity is 100% or 0%.

Hot Gas Bypass

Hot gas bypass involves bypassing 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 is reduced, thus the cooling capacity. This naturally causes the compressor to run uselessly during the periods where the bypass is operating. The turndown capacity varies between 0 and 100%.

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 increase the cooling capacity of the unit. The turndown capacity is either 0/33/66 or 100% for an even trio configuration and either 0/50 or 100% for a tandem.

Mechanically Modulated Compressor

This internal mechanical capacity modulation is based on a 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 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 continuously runs.

Inverter Compressor

Inverter compressor uses a variable-frequency drive, also known as an 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 modulates from 10% (depending on the compressor model) up to 100% at full capacity with a single inverter.

Refrigeration applications use fixed-speed motors compressors, irrespective of the variable cooling requirements during day and night as well as during summer and winter. Fixed-speed compressors that run at 100% capacity at all times.

Ambient conditions are changing every twenty-four hours. But there is a wide difference between the day's peak and the midnight minimum temperature. Therefore, cooling requirements are not always the same, even in the summer during daytime and nighttime. These are significantly lower in the winter.

Therefore, a mechanism is required to tackle the changing cooling load requirement. As a rough estimate, 25% of the

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world's electrical energy is consumed by electric motors in various industries. The use of variable-frequency drive (VFD) will result in significant power savings by making the systems energy efficient at all loads. Continuous improvements are required to reduce the cost of VFDs and other controls and make inverter technology even more popular.

The inverter unit changes the input 220 or 440 AC voltages to 12 V DC with the help of a voltage step-down transformer and a rectifier. This DC power will again be changed to AC power of variable frequency with the help of another inverter called a power inverter.

Thus, there is the use of a dual inverter. It contains various control circuits and transformers such as pulse width modulation (PWM), to produce variable voltages using digital microcontrollers and VFDs. A PWM of the DC in the power inverter generates AC of the desired frequency.

This AC current of changing frequency drives the induction motor. Since the speed of the induction motor is directly proportional to the frequency of the alternating current, the compressor of the cooling unit operates at a variable speed (1100 to 4300 RPM) and continuously controls the rate of heat transfer as per cooling requirements.

The existing ambient air temperature is sensed by using a microcontroller and then the speed of the compressor is adjusted accordingly. Its function is similar to that of an accelerator in a car: to vary the speed. The initial cost of inverter units is much higher than that of constant-speed cooling units.

It is because of the complexity of the inverter technology. It has been estimated that the increased cost can easily be overcome over a period of two to three years in terms of power savings. Since the life of the refrigeration units is 15 years or more, this change over is necessary and requires immediate implementation.

Variable-speed operation requires a specially designed compressor and a special compressor lubrication system. Proper oil management for lubrication is a critical parameter to ensure a reasonable life for the compressor. Proper lubrication control is required at both low and high speeds. An inverter compressor can either be a scroll, rotary, or reciprocating, semi-hermetic, open compressor, including screw, centrifugal, and axial compressors.

Advantages

In contrast, inverters allow for continuous modulation of compressor speed, adjusting it according to the cooling demand in real-time. This fine-tuning capability offers several advantages:

- *Energy Efficiency*

In a variable-speed condensing unit, temperature is adjusted by changing compressor motor speed without turning the motor on or off. By operating at varying speeds rather than just on or off, inverter-driven compressors can match the cooling load more precisely. This results in significant energy savings compared to fixed-speed compressors as they consume less power during partial load conditions. In a non-inverter condensing unit remains constant and temperature is adjusted by turning the compressor on and off, which consumes more energy. Inverters control the speed of the compressor by adjusting the frequency of the supplied electrical power rather than using mechanical unloading devices to deliver improved low-load efficiency and better humidity control, all while using fewer watts while only partially loaded. It is estimated that standard systems draw 3–4 times as much power on start-up versus an inverter-driven system.

- *Temperature Stability*

Inverter technology enables more precise temperature control within the refrigerated space by adjusting compressor speed according to changing conditions. This helps maintain a consistent temperature, which is crucial for preserving perishable goods and maintaining product quality.

- *Quieter Operation*

Variable-speed compressors operating at lower speeds generate less noise compared to fixed-speed compressors that frequently cycle on and off. This contributes to a quieter environment, which can be beneficial in residential or commercial settings. There is automatic starting and stopping of fixed-speed compressors. These stop automatically on achieving the temperature set through a thermostat and also start automatically on the rise of temperature in the cooling unit. Both automatic starting and stopping are abrupt and are accompanied by a big noise. These fixed-speed compressors run at 2800 or 3600 RPM.

Because inverter-driven compressors operate more efficiently and experience fewer sudden starts and stops, they typically experience less wear and tear, potentially leading to a longer lifespan compared to traditional compressors. Unlike inverter-driven systems, fixed-speed compressors cannot ramp up gradually. While inverter systems are always on, running at a fraction of full speed is far more efficient in the long run.

- *Flexibility*

Inverter technology allows for more flexible design options, as the cooling capacity can be adjusted to suit different requirements. This flexibility is particularly useful in applications where the cooling load varies throughout the day or in environments with fluctuating ambient temperatures.

Inverter Condensing Units Product Range

The product range with R410a refrigerant is designed to operate up to ambient temperature of 48°C (typical).

Capacity

Medium Temperature Range: -1.3kW to 88kW at SST (-)10 and outside ambient temperature (OAT) 32°C.

Low Temperature Range: -2.1kW to 15kW at SST (-)30 and outside ambient temperature (OAT) 32°C.

Figure 1: Air-cooled R410 MT DC inverter condensing units

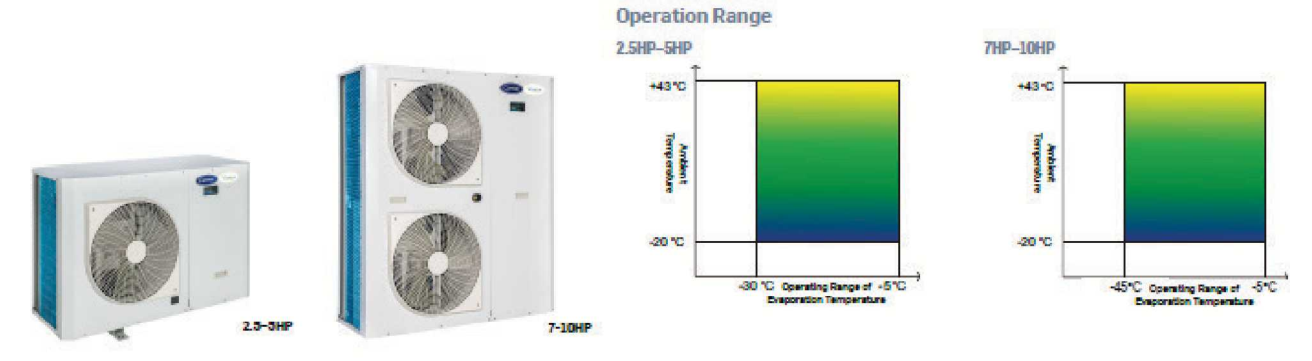

Figure 2: Air-cooled R410A LT DC inverter condensing units (Source: Carrier Commercial Refrigeration)

Figure 3: Case Study: MEI TUAN cold storage (Source: Carrier Commercial Refrigeration)

Customer Values

- DC Inverter Compressor: Frequency range: 30-100 rps, high efficiency, reliability, low noise, small size, light weight.
- Energy savings of up to 30%–40% when compared to fixed speeds depending on operating conditions.
- Small temperature fluctuations, which enhance the shelf life of the product.
- High-Efficiency Oil Separator: Better oil management during high and low operating conditions.
- Larger Condenser Coil Design: With subcooling to improve energy efficiency. DC inverter fan motor, adaptive control according to capacity and ambient requirements.
- SRDC R&D Control Logic-Self was developed with a remote monitoring system.
- Return gas separator design.

Power comparison between fixed speed and inverter CDU. Actual application results at one of the stores in Beijing.

Overall, the adoption of inverter technology in refrigeration systems offers improved energy efficiency, temperature control, and reliability, making it an increasingly popular choice for both commercial and industrial refrigeration applications.