Refrigeration Compressors | iSeries VFDs

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Figure 1 i550 protec IP66 / NEMA 4X

Figure 2 i550 cabinet IP20 / NEMA Open Type

1 Introduction

Refrigeration or heat-pump applications for commercial and industrial applications are used in a wide range of end-user applications. It is the most efficient technology to generate cold or hot fluids by utilizing the energy of the ambient air. The heart of this thermodynamic process is a refrigerant circuit driven by a compressor. The energy efficiency of such refrigeration / heat-pump equipment is defined by the COP (co-efficient of performance) or SSEPR (Seasonal Energy Performance Ratio). It is the ratio between the thermal energy and electrical consumed energy. Dependent on the product, use case and environment this is in the range of 4 to 7. A unit with a COP of 5 would achieve 225 kW thermal power by the usage of 45 kW electrical power on yearly average.

There is a huge range of different equipment that can be either characterized by the **end-user application** (e.g. building refrigeration, data centers,..), **compressor type** (e.g. scroll, piston, screw), **construction type** (e.g. compact unit, split unit), **refrigerant** (e.g. Propane R290), **thermal energy source** (e.g. air-cooled, water cooled) or by compressor **control** (e.g. VFD controlled, on-off controlled). Further they can be built-up with multiple compressors in parallel (volume increase) with one or two separate refrigeration circuits on one skid for different temperatures (e.g., fridge & freezing).

Lenze VFDs help to:

1. Biggest demand: Operate the **refrigeration compressor** in an energy efficient way in **commercial** or **industrial** applications. Our products particularly fit well for piston (reciprocating) and screw compressors.
2. **Fan-motors** used in fan-packs on top of condensing / evaporator units are typically controlled with built-in specific DC inverters called EC-Fans. However, in **demanding environmental** conditions a normal PM solution with separate VFDs like the i5x0 inverters are recommended.
3. **Circulation pumps** are also typically switched-on or off. For precise process control (e.g., for battery cooling) or better efficiency the usage of a VFD is recommended.

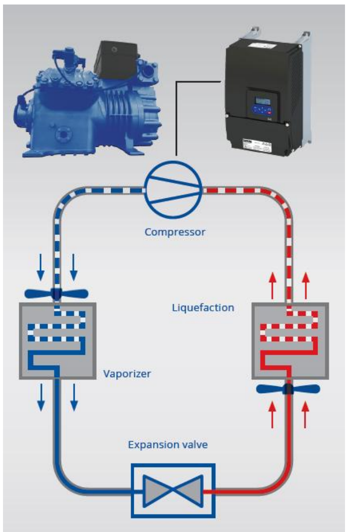


Figure 4 Refrigeration Circuit with Piston Compressor

Figure 3 Circulation Pump optionally with VFD i550 motec

2 Working principle of refrigeration machines

Overview of refrigeration process

The refrigeration cycle is the process by which heat is removed from one space and transferred to another. The chiller works by pumping a refrigerant through a compressor, compressing it and increasing its temperature. The heated refrigerant then flows to a condenser, where it cools and releases its heat via a heat-exchanger to water or air. The cold refrigerant is then fed to a condenser, where it absorbs the heat from the space and is returned to the compressor.

More details

Compression cooling

Compression refrigeration is an important part of the operation of a refrigeration system. This process uses the refrigeration compressor to pressure a refrigerant (usually a gas) and then liquefy it. This condensation releases heat, which is removed from the interior of the building or room.

Condensation

After the refrigerant is pressurized, it flows through a condenser, where it is brought to a lower temperature. Heat is released and the refrigerant liquefies.

Evaporation

After condensation, the cooled refrigerant is fed into the evaporator. In the evaporator, the refrigerant heats up and evaporates, releasing heat into the environment. This heat is absorbed by the refrigeration unit and dissipated to the outside by a fan.

During the evaporation process, the refrigerant absorbs energy from its surroundings. This energy is used to transform the refrigerant from its liquid state into a gaseous state.

Evaporation creates a negative pressure in the evaporator. This negative pressure forces the refrigerant back into the compressor, where it is recompressed and condensed. This cycle of compression, condensation, and evaporation is repeated over and over until the desired cooling capacity is achieved.

3 Compressor types

Scroll compressor

Typical power ranges from 1,5 to 11 kW. This compressor needs oil lubrication. If these compressors are used for variable speed operation it requires a specific design that supports correct lubrication throughout the speed range. Whereas a normal scroll compressor at 2,2 kW costs 300 €, a compressor suitable for VFD operation is at 1’000 € at the same power + the costs for the inverter. Due to this, most of these units still operate Direct-On-Line. In the VFD configuration they usually offer an efficient BLDC-Design. Lenze inverters can operate this well up to the nominal speed of e.g.,3’000 rpm in “U/f-mode”. However, the operation in the field-weakening range up to 6’000 rpm is difficult / not possible.

Possible compressor suppliers: Hitachi, Panasonic, Danfoss, Siam, Mitsubishi, Emerson Electric, Atlas Copco, Copeland (offer many times also a package of compressor and inverter) .

Usage:: Compact industrial chillers, heat-pumps.

Piston (Reciprocating) compressors

Typical power ranges from 5,5 to 90 kW. This is the working horse for most refrigeration equipment. The housing covers an asynchronous motor and the pistons. The lubrication in the speed range from 0 to 20 Hz is typically critical and requires a very quick start-up. The i550 offers therefore two different ramp times to master this application well.

These compressors have a piston and cylinder arrangement similar to that of an internal combustion motor. The refrigerant in the cylinder is compressed by the reciprocating motion of the piston. These compressors are capable of compressing gases to high pressures.

What is meant by open or hermetic construction?

In open compressors, the motor and compressor units are connected only by a shaft or belt. A seal ensures that no refrigerant leaks through the shaft. Hermetic compressors have a closed, usually welded shell around the motor and compressor unit. Semi-hermetic compressors represent an intermediate solution. Here, the motor and compressor unit are detachably connected by a flange.

Possible compressor suppliers: Bitzer, Dorin, Bock (part of Danfoss), Sabor

Usage: Building Refrigeration, Data Centers, Supermarkets, Industrial Processes

Screw compressors

Typical power ranges from 75 to 250 kW (few times even more). These compressors also require specific lubrication. Large units even have a separate VFD controlled lubrication pump.

Possible compressor suppliers: Sabor, GEA Refrigeration

Usage Large industrial processes, Heat Pumps with high temperatures (90˚C)

Construction types of compressors

Dependent on the separation of the fluid from mechanical / electrical components separate variants do exist:

- Fully hermetic compressors
- Semi-hermetic compressors (most typical design)
- Open-type compressors
- Suction-vapor-cooled compressors

4 Refrigerant

The refrigerant is the heat transport medium and essential lifeblood of any refrigeration system. It absorbs heat at the low temperature in the evaporator, is pressurized in the compressor, warms up, and releases the heat again in the condenser. From the planning to the operation of the refrigeration equipment, there are various aspects to consider when it comes to refrigerants: Refrigerants can affect energy efficiency, be flammable, toxic, or harmful to the climate! Each refrigerant is classified with a **GWP** value (Global Warming Impact) that is multiple of C02-Gas. In general OEMs have to reduce year by year these values according to their regional laws. There are less stringent laws in Asia than in Europe today. The so-called **F-Gas directive** is ruling this.

But the trend is globally the same and therefore the OEMs are constantly redesigning their equipment to meet the step-by-step more stringent laws. There are two types of refrigants:

Synthetic refrigerants

Synthetic, air-stable refrigerants (HFC1 and HFC2) are based on fluorocarbons. They are called stable because they degrade slowly in the air (average residence time of more than two years). If released (e.g., through a leak), they have a long-term, climate-damaging effect and **high GWP.**

The new not air-stable synthetic HFO refrigerants also share many of the positive properties of synthetic refrigerants. Unlike other synthetic refrigerants, however, they are not stable in the atmosphere. This means they remain in the atmosphere for only a few days (significantly less than two years) *and thus have a very low climate-damaging effect***.**

Natural refrigerants

Natural refrigerants consist of substances that also occur naturally. They have little or no harmful impact on the environment and are more frequently used. However, they have other disadvantages. CO2 requires a very robust design (up to 100 bars) to allow somehow efficient operation. Propane transfers heat extremely efficiently, however it is flammable and therefore imposes a lot of regulations on the OEM and operators (e.g., max. amount, leakage detection, active fans, regular visits, etc. depending on amount of refrigerant in use)

Refrigeration examples

R134a & **R410A** –synthetic refrigerant stable in air, non-flammable, slightly toxic, GWP 1430, (A1)

R513a –new synthetic refrigerant stable in air, non-flammable, slightly toxic, GWP 573, (A1)

R1234ze & yf - synthetic refrigerant not stable in the air, slightly flammable & toxic, GWP 6 (A2L)

R290 (Propan) - natural refrigerant, flammable, slightly toxic, GWP 3 (A3)

R744 (CO_2) – natural refrigerant, non-flammable, slightly toxic, GWP 1 (A1)

R717 (Ammonia) – natural refrigerant, low flammability, highly toxic, GWP 0 (A2L)

A2L and A3 certification

For installations in flammable environments (propane, ammoniac) installed equipment must be certified accordingly. For the avoidance of any risk for VFD and other components, many OEMs put inverters in a “safe” cabinet and therefore there is no special VFD certification required.

Lenze is in the process of testing and certifying its i500 Frequency inverter family in accordance to A2L and A3 certification. This means that the surface temperature of these frequency inverters is examined and evaluated to ensure it is within the safety limits specified in the standard. Furthermore, arcing or sparking must not occur during normal operation. Therefore, according to the IEC/UL 60335-2-40 test standard, these frequency inverters are not considered a potential ignition source when used near refrigerants classified as A2L or A3.

5 Machine construction types / Thermal power sources

System overview

- Combined systems
- Hot gas combined systems
- Brine cooling
- CO2 refrigeration systems
- Glycol refrigeration systems
- Cascade refrigeration systems
- Air-cooled units
- Water-cooled units
- Split systems
- Compact systems
- Heat pumps

Refrigeration and air conditioning systems come in many different types and sizes, and each system has its own advantages and disadvantages.

Compact units

These units incorporate the complete cooling circuit from condenser, compressor to evaporator in one housing. DOAS (Dedicated Outdoor-Systems) / Roof-top climate systems integrate additional the building ventilation equipment that is cooling the fresh building air inside the same construction.

Split systems

Split systems are one of the most commonly used types of refrigeration and air conditioning systems. They consist of two units: an outdoor unit containing the compressor and condenser, and an indoor unit containing the evaporator. The two units are connected by piping and electrical wiring.

Split systems are well-suited for residential buildings, offices, and small businesses. They are relatively easy to install and come in a variety of sizes and performance ranges.

VRV/VRF systems

Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) systems are a type of multi-split system. They consist of an outdoor unit and several indoor units connected by piping. Each indoor unit has its own thermostat and can be individually controlled.

VRV/VRF systems are particularly suitable for larger buildings and businesses with multiple rooms or zones. They can achieve significant energy savings because they can adjust the amount of refrigerant to current demand. Furthermore, VRV/VRF systems can also operate with lower noise levels than conventional split systems.

Chilled water systems

Chilled water systems are another commonly used type of refrigeration and air conditioning system. They use a central chiller to generate cold water, which is then transported via piping to the cooling units throughout the building / process. Chilled water systems are well-suited for large buildings such as hotels, hospitals, office buildings or industrial processes. Chilled water systems can be energy-efficient and offer better temperature control than traditional split systems. However, they can also be more expensive to purchase and maintain because they are more complex and require more piping and pumps.

Geothermal systems

Geothermal systems use the constant temperature of the ground as both a heat source and a heat sink. They can operate as a heat pump to extract heat from the ground and use it for heating, or conversely, to extract heat from the building and transfer it back into the ground.

Geothermal systems can be highly energy-efficient and help reduce heating and cooling costs. They also have the advantage of providing consistent temperatures year-round, regardless of the outside temperature. However, geothermal systems are more expensive to purchase and require specialized knowledge and experience for installation and maintenance.

6 Heat pump

How does a heat pump work?

A heat pump works similarly to a refrigerator – only in reverse. While a refrigerator extracts heat energy from the inside and transfers it to the outside, a heat pump does the opposite: It extracts heat energy from the environment outside of the building and uses it for heating of water / air. In addition to the indoor or outdoor air, a heat pump can tap into heat energy from groundwater and the earth. And because the temperature of this extracted heat is usually not sufficient to heat a building or hot water, the thermodynamic process is used.

Refrigeration cycle process core of the heat pump principle

Regardless of which heat source is used to generate heat, the refrigeration cycle process, which takes place in four steps, is always part of the functioning of the heat pump.

1. **Evaporation**
2. **Compressing a gas**
3. **Condensation**
4. **Relaxation**

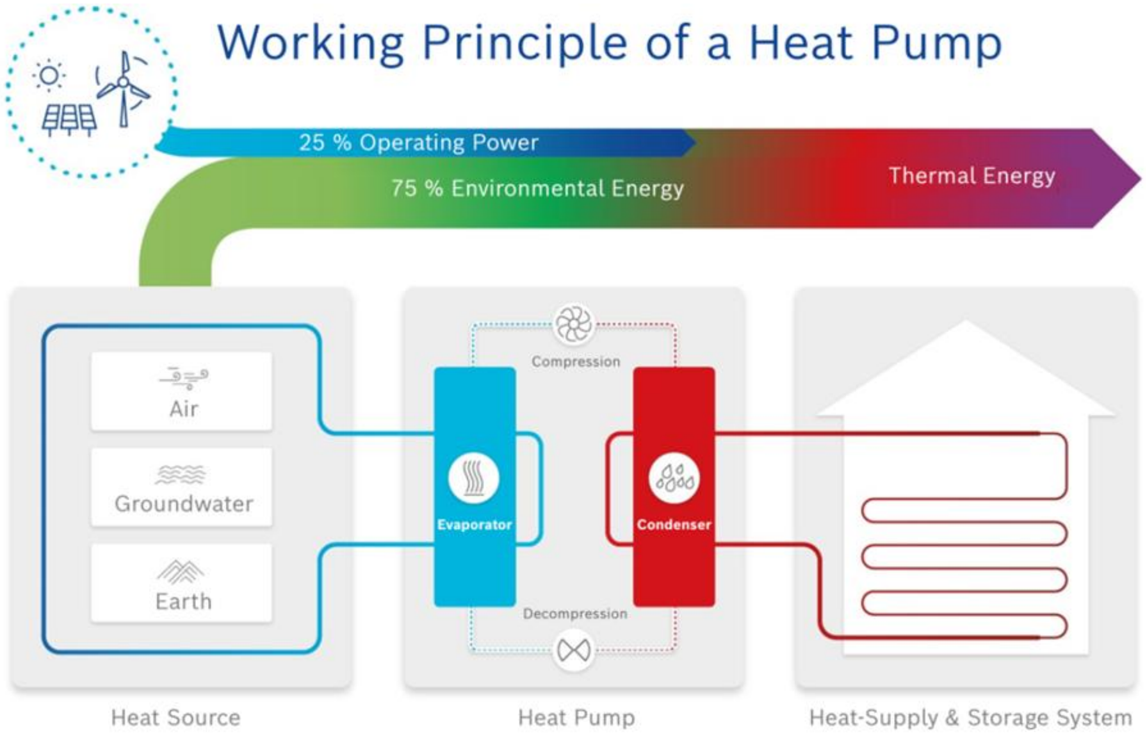
Constant repetition of the process

These processes take place within the heat pump in a closed circuit. A liquid (refrigerant) is used to transport heat, which evaporates even at very low temperatures. To evaporate this liquid, thermal energy is harnessed, for example, from the ground or outside air. Temperatures as low as minus 20 degrees Celsius are sufficient for this. The cold refrigerant vapor, for example -20 degrees Celsius, is then compressed to a very high degree. In the process, it heats up to a temperature of up to 100 degrees Celsius. This refrigerant vapor is condensed and releases the heat to the heating system. The pressure of the liquid refrigerant is then greatly reduced. This causes the temperature of the liquid to drop to its original level. The process can begin again.

Principle of the heat pump using the example of an air-water heat pump

This process is easiest to explain using the example of an air-to-water heat pump: An air-to-water heat pump can consist of one or two units. In both cases, a built-in fan actively draws in ambient air and directs it to a heat exchanger. A refrigerant flows through the heat exchanger itself, which changes its state of aggregation even at very low temperatures. Upon contact with the ambient air, the refrigerant heats up and gradually turn into vapor. A compressor is used to increase the resulting heat to the desired temperature. This compresses the vapor and increases both the pressure and temperature of the refrigerant vapor.

Large heat-pumps for industrial / district heating with piston or screw compressors are very well suited for i550. Residential / commercial building heat pumps operate with cost-effective BLDC motors. This type of motor cannot yet be controlled with the i500 family, so this query should be asked of the customer at the beginning of the project



7 Refrigeration industries

There is a broad range of applications with a growing demand everywhere. OEMs or System Integrators may focus on one or several different applications.

Building refrigeration

Very large market: Refrigeration Units provide cool water to the air-water heat-exchanger to the building air-handling units that provide afterwards cold fresh air to the rooms. These systems can be installed as split or compact units. Lenze equipment with a broad ambient temperature operating range and flexible power sizes is ideally for commercial or industrial buildings.

Commercial food cooling (Supermarkets, Large kitchens)

Large market: Typical usage of central refrigeration equipment for the supply of fridge and freezing cooling furniture for groceries, meat or milk products. Typically used for medium and large supermarkets. The equipment consists typically of 2 cooling circuits (fridge & freezer) with 1 to 4 piston compressors for each process. Typically, the first one or two units are controlled with VFD and 2nd and 4th unit in cascade control switched on or dependent on actual demand.

Figure 5 CO2 booster package system, with semi-hermetic reciprocating compressor, oil separator, control cabinet, etc. for supermarket refrigeration

Data center cooling

Huge and very fast-growing market. Equipment to provide cooling at 18 ˚C. Very strong growing demand. Sometimes requiring low power-factor è i550 motec.

Refrigeration systems for food & beverage

Equipment can be used for: Freeze Drying of food (-60 ˚C), Cold Storage (-20 ˚C), Process cooling Beverage (-10 ˚C)

Industrial / Process cooling

Application examples are: Plastic injection, Machine Tooling, Chemical industry in general

Heat-pumps

Same equipment in opposite direction. Used for industrial processes (up to 90 ˚C), District Heating or Greenhouses (50 ˚C). Also, more commercial buildings have changed from gas / oil firing to heat-pumps that could be used both for heating in winter and cooling in summer.

Other

a) **Battery cooling:** Cooling equipment for static installed batteries to balance fluctuating demands. Growing and require typically also precise speed-controlled circulation pumps.
b) **Medical applications:** Laser cooling, Radio Technology, Organ storage
c) **Ice-Rink**, bob-sleighs, snow-making
d) **Wind-Tunnels** (automotive)

8 Compressor control variants

When there are large differences in the performance of individual cooling points in a system, a performance regulator is used. This ensures that the compressor operates within an optimal range and prevents unnecessary compressor switching on and off. Various performance regulators are used:

- Frequency inverter
- Cold gas bypass
- Hot gas bypass with post-injection
- Hot gas bypass without post-injection
- Cylinder head lifting
- Increased clearance space

Step control	With this control type, several compressors of the same or different capacities work together. Depending on the cooling demand, individual compressor stages can be switched on or off. The solution is relatively simple, but imprecise.
Speed control	The speed control works with a frequency inverter, among other things, and is considered particularly energy-efficient. This technology changes the power supply parameters, thus enabling continuous adjustment of the motor speed to the cooling demand.
Bypass control	If positive displacement compressors are used, the capacity can also be adjusted using an internal bypass. In this case, already compressed refrigerant flows back through a valve to the suction side to reduce the overall cooling capacity. The disadvantage is the higher energy consumption compared to variable speed control.

9 Sizing of VFDs for refrigeration compressors

The sizing of a frequency inverter for a refrigeration compressor can basically be done in two different ways. Below is an example to select the appropriate inverter for the Bitzer compressor 4TES-8Y in comparison.

- Manual Calculation: Designed for the maximum current of the refrigeration compressor.
- Sizing Tool: Design for the operating points (condensation and evaporation) if these are known; there are good calculation programs for this (e.g. from Bitzer) BITZER SOFTWARE

Manual calculation by maximum current

Compensation factor for reciprocating compressors (Designed for maximum current)
Consider the overload capacity for starting the compressor.

Additionally, a compensation factor Fc for the current during compressor start-up must be considered. Since the torque of reciprocating compressors is not constant with the rotation angle (the higher the number of cylinders, the more constant the torque), a higher starting torque is required for a smaller number of cylinders. The compensation factors are as follows:

- 2-cylinder reciprocating compressor for CO_2: FC = 3
- Other 2-cylinder reciprocating compressor: FC = 2
- 4-cylinder reciprocating compressor: FC = 1.6
- 6-cylinder reciprocating compressor: FC = 1.5
- 8-cylinder reciprocating compressor: FC = 1.4

This results in the design of the frequency inverter for a 4-cylinder reciprocating compressor:

Compressor specifications: 4TES-8Y
Number of cylinders x bore x stroke: 4 x 60 mm x 42 mm
Motor specifications: 3-phase, 380-420V / 50Hz, Max. operating current: 12.1 A

- I_{max} of the compressor motor (see nameplate) x compensation factor Fc x 1.10 (reserve) / 1.50 (overload current of the frequency inverter, during 60sec.) = nominal current that the frequency inverter must supply.

Example: 12.1A(I_{max}) x 1.60(Fc) x 1.10(Res.) / 1.50($_{\text{overload frequency inverter}}$) = 14.20A

i.e., frequency inverter selection I55AP275F0710K03S / 7.50kW / 400V / 16.5A, the 7.50kW frequency inverter has a continuous rated current of 16.5A

For inverters with e.g., only 110% overload for 1 minute the rated current needs to be higher

12.1A(I_{max}) x 1.60(Fc) x 1.10(Res.) / 1.10($_{\text{overload frequency inverter}}$) = 19.36 A è 11 kW VFD

Sizing by dimensioning tool

Example design based on the value calculated based on compressor OEM Sizing Software, e.g., Bitzer:

Input Values		Results	
Compressor model	4TES-8Y	Compressor	4TES-8Y-40P
Mode	Refrigeration and air conditioning	Compressor fre-quency	65,0 Hz
Refrigerant	R134a	Cooling capacity	15,97 kW
Reference tempera-ture	Dew point temp.	Cooling capacity *	15,97 kW
Evaporating SST	-10,00 °C	Evaporator capacity	15,97 kW
Condensing SDT	45,0 °C	Power input	6,40 kW
Liq. subc. (in conden-ser)	0 K	Current (400V)	10,41 A
Suction gas tempera-ture	20,00 °C	Condenser capacity	22,4 kW
Operating mode	Auto	COP/EER	2,50
Power supply	400V-3-50Hz	COP/EER *	2,50
Useful superheat	100%	Mass flow	374 kg/h
		min. cooling capacity	5,83 kW (25 Hz)
		max. cooling capacity	17,12 kW (70 Hz)
		Discharge gas temp. w/o cooling	97,0 °C

10 Parameterization of compressor VFDs

Controlling a reciprocating compressor is not feasible with every frequency inverter, as different torques occur during a 360° rotation of the crankshaft. This phenomenon only occurs with compressor control, not, for example, with pump or fan speed control, and can therefore lead to malfunctions in an unsuitable frequency inverter. In addition, incorrect parameterization of the acceleration ramp to the operating frequency could result in compressor failure within a very short time. Acceleration ramps that are set too long, in particular, can have devastating consequences for the compressor's **lubrication buildup**.

Therefore, for a reciprocating compressor with a reciprocating compressor operating at approx. 25 Hz, an **acceleration ramp 1** of 0.8 seconds should be selected. Depending on the application, an **acceleration ramp 2** of 5.0 to 10.0 seconds can be used to increase the speed from the minimum operating frequency to the maximum operating frequency (usually between 65 and 70 Hz).

For all the details, please refer to the Refrigeration Quick Start Guide.

11 Disclaimer

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