

USE OF INVERTERS WITH DWM COPELAND™ COMPRESSORS

1 Introduction

Inverters are used to vary the speed of motors and in this way can be used to control the capacity of a compressor. For refrigeration users they can be an effective method of accurately matching compressor capacity to load requirement. A way of reducing compressor output is needed in almost every application. With the emphasis today on saving energy by reducing head pressures, an effective capacity control method can bring enormous benefits. Without the means to run efficiently at low capacity, compressor cycling by switching on/off is most commonly used. This method introduces large fluctuations and high power consumption due to heavily loaded heat exchangers. Multiple compressor solutions overcome this problem to some extent and stepping by means of cylinder unloading is used with piston compressors.

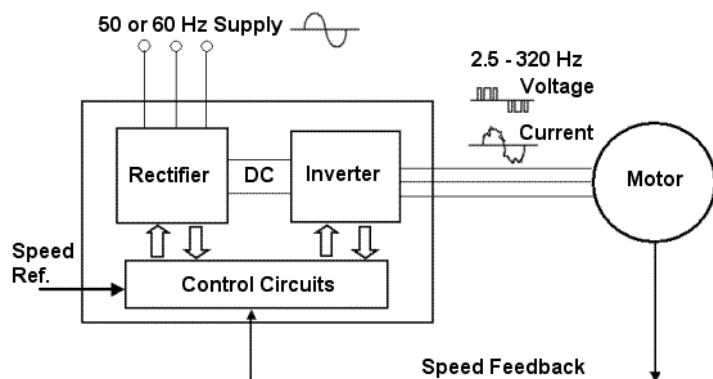
The advantages of varying compressor speed are:

- The load is more closely matched with minimal variation in evaporating pressure and fluctuations in load temperature are minimised
- Over-speed capability can allow use of a smaller compressor, eg, it could be sized for the nominal load, not the peak load
- Better system efficiency at part load
- Extended lifetime of equipment due to continuous operation instead of cycling
- Low starting current obviates the need for assisted start devices
- With gradual speed increase from standstill there is less risk of sudden liquid or oil return to the compressor on start up

The objective of this bulletin is to provide technical guidelines to developers, designers or installers that intend to use inverters in refrigeration equipment with DWM Copeland™ semi hermetic and 4 to 8 cylinder open compressors. The operation of an inverter, the effect on compressor application range, performance and power, precautions and some implications on system design are discussed.

2 Operation of an Inverter

An Inverter works by converting the input mains alternating current to direct current and, from this, regenerating a simulated A.C. signal at the required frequency. A compressor driven by a squirrel cage motor will run at a speed corresponding to the frequency. The speed will be in direct proportion to the frequency.



3 Evaluation and Important Considerations

Investigations carried out by Emerson Climate Technologies have included computer simulations, variable speed compressor performance testing, reliability testing, and refrigeration system field data comparisons. Most inverters are capable of generating frequencies from 2.5 Hz to over 300 Hz. This is well outside the range of any refrigeration compressor, therefore part of the investigation has been focused on assessing practical limits.

Limits arise due to the capability of the oil pump to maintain lubrication at low speed and motor cooling. Excessive losses at high speeds can result in inefficient operation and overheating (high discharge temperatures).

The power absorbed by a compressor operating with an inverter will always be more than for a direct connected compressor running at the same speed. It is important to choose a high quality inverter because the inverter absorbs a certain amount of power and also the nature of the electrical waveform at the motor is disjointed, resulting in increased motor losses.

When considering an inverter drive the following points should be taken into account:

- Loss of efficiency unless care is taken with system design and control
- Reduced compressor operating range
- Conventional capacity control methods may not be used with inverter drive
- Reliability of the inverter may be less than that of the compressor
- Vibration resonance may occur at certain speeds and these are very difficult to predict
- Restrictions on operating envelope may be necessary
- Risk of electrical disturbance to control signals

4 Limits of Use with Copeland® Brand Compressors

With many inverters it is very easy to alter the maximum and minimum output frequencies and the frequency range, so care must be taken to ensure the frequencies are correctly adjusted to prevent serious damage to the compressor.

4.1 Approved Frequency Ranges with Standard Motors

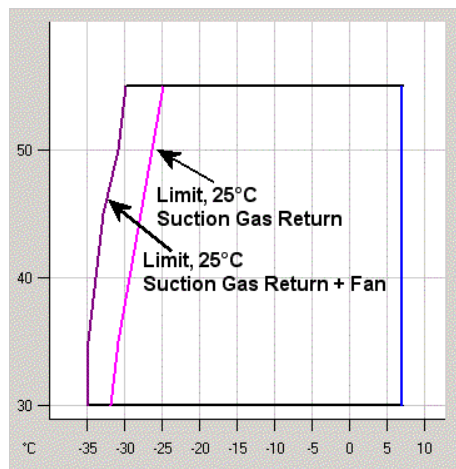
Model Family	Speed Range	Notes
DK, DL, D2S, D2D	25 – 60 Hz	Some models may operate over an extended range 20 – 65 Hz. Please check with Emerson Climate Technologies if this is required.
D3S, D4S, D6S, D8S,	25 – 60 Hz	
D3D, D4D, D6D, D8D	25 – 60 Hz	May be operated up to 70 Hz for limited periods.
6CC, 4CC, 8CC	35 – 60 Hz	Subject to drive motor limitations.

4.2 Operation at 25 – 50Hz with Standard Motors

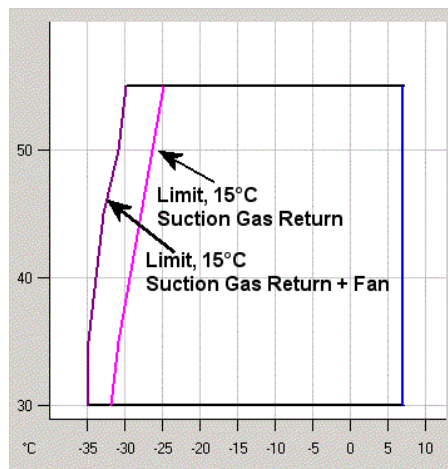
In the range 25 – 50 Hz the voltage supplied to the motor is reduced proportionately to the speed. However there will be a loss of motor efficiency. The magnitude of this loss will be dependent on the nature of the waveform generated by the inverter. Extra heat is generated in the motor windings and this gives rise to a discharge temperature increase. In order to ensure that safe working temperatures are not exceeded, users are advised to modify the discharge temperature limits shown in the Copeland® Brand Products Selection Software by reducing in each case the suction gas return temperature or superheat by 10K, as shown in the following examples:

Example 1

R404A, D4SA-200X, D4SH-250X, D4SJ-300X, D6SA-300X, D6SH-350X, D6SJ-400X, D8SH-500X, D8SJ-600X



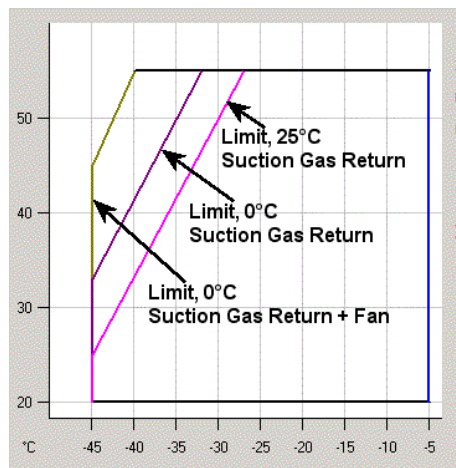
Envelope for direct on line supply



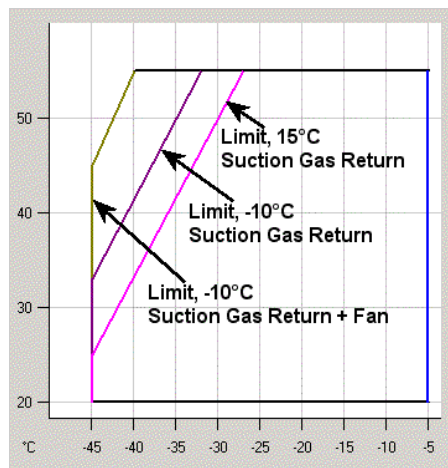
Envelope with inverter up to 50 Hz

Example 2

R404A, D2SK-65X, D3SC-75X, D3SS-100X



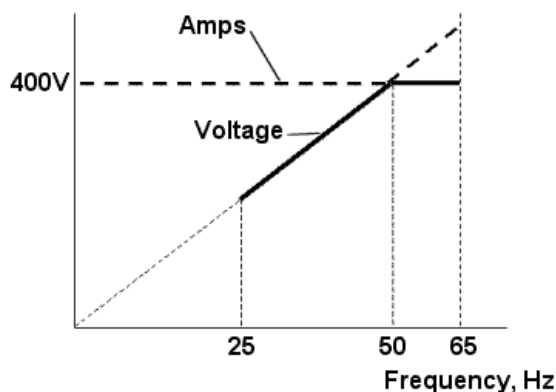
Envelope for direct on line supply



Envelope with inverter up to 50 Hz

4.3 Over-speed to 60Hz with Standard Motors

Most Copeland® brand compressors are designed to operate at 60 Hz speeds as they are marketed in areas where this is the mains supply frequency. Therefore they can safely and reliably operate at this frequency. However it must be noted that when connected to a 400V 50 Hz supply the inverter can only deliver a maximum voltage of 400V. The standard motor requires a higher voltage at 60 Hz otherwise the amps increase and this could cause overload. Therefore it is necessary to check that there is adequate reserve power in the motor at the maximum desired operating condition. For example, a motor drawing 20A at a desired operating condition will draw at least 24A (120%) at 60 Hz if the voltage is not increased, and must be capable of continuous running under these conditions.



A figure of 125% should be used to include a margin of safety and the additional waveform losses. To establish whether the operating envelope should be further limited for 60 Hz operation, compare the maximum operating amps with the values in the table when multiplied by 1.25 as shown below:

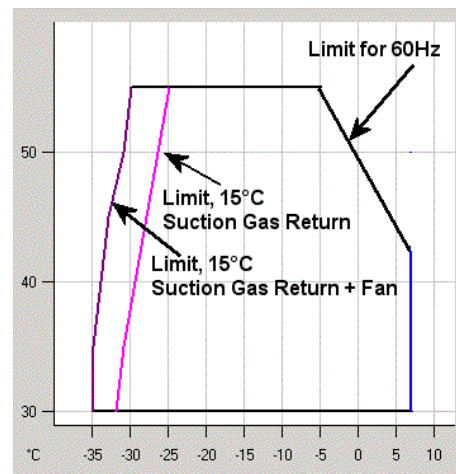
Example 3

R404A, D4SH-250X, Maximum Operating Amps = 50.9

Current at 380V, A

T _c \ T _e	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	-5.0	0.0	5.0	7.0
30.0	21.77	23.65	25.54	27.36	29.05	30.54	31.75	32.61	33.06	33.10
35.0	22.02	24.08	26.19	28.28	30.29	32.13	33.75	35.06	36.00	36.25
40.0		24.49	26.80	29.15	31.44	33.63	35.62	37.36	38.77	39.23
45.0		24.89	27.39	29.96	32.52	35.02	37.38	39.52	41.39	42.04
50.0		25.28	27.94	30.71	33.53	36.32	39.02	41.55	43.84	44.67
55.0		25.66	28.46	31.42	34.46	37.53	40.54	43.44	46.14	47.14

Amps x 1.25 > Max. Operating Amps
below this line



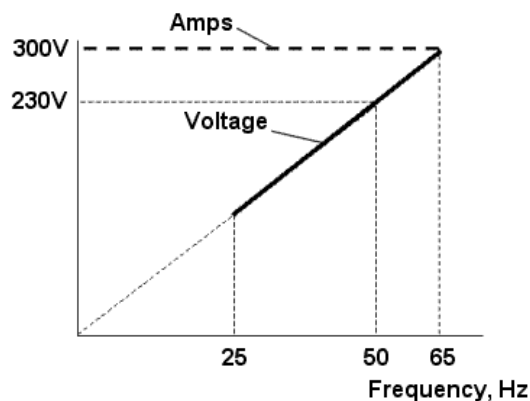
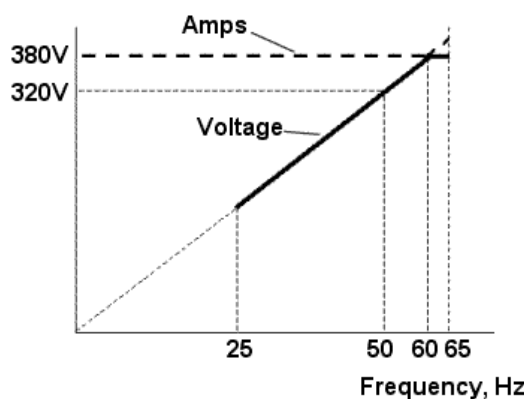
At frequencies greater than 65 Hz there is a possibility of reduced reliability because of increased stress on the valves. Many DWM Copeland™ displacements have two motor versions, and the larger motor option will in many cases provide sufficient reserve to allow inverter operation in regions of the envelope where the smaller motor has insufficient reserve.

4.4 Minimum Speed

The minimum allowable frequency of 25 Hz is governed by the lowest speed at which the lubrication system can operate effectively, and the frequency below which the inverter system efficiency significantly reduces.

4.5 Over-speed with Special Motors:

By using a motor designed for a voltage lower than 400V/50 Hz, in conjunction with a 400V supply, it is possible for the inverter to increase the voltage during over-speed. Normally the ratio of voltage/frequency (V/f) is kept constant, and it is only when the required voltage is above the supply voltage that the amps increase. For example, a 380V 60Hz motor will only require 320V at 50 Hz according to the constant V/f rule, and can therefore be safely operated at all conditions up to 60 Hz with a suitable inverter. By moving to 230V/50 Hz motor, the scope for increased voltage speed is even greater.



It is important to note that when using special motors in this way there is no option of running direct on line in the event of inverter failure.

5 Effect of the Inverter on Performance and Power Input

The capacity can be calculated as being in direct proportion to the speed. A compressor is designed to have optimum pumping efficiency at its nominal speed, usually 1450 rpm. When operating at speeds other than the nominal the efficiency will change because of the behaviour of the valve reeds and the change in pressure drop through the valve plate. However, as these tend to balance out, the change in volumetric efficiency is small.

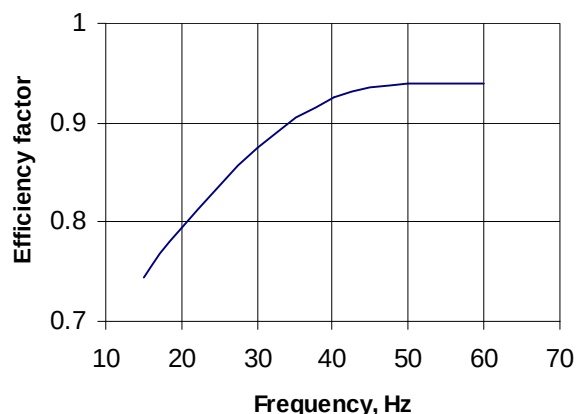
The electrical efficiency of an inverter/compressor combination decreases as the speed moves away from the nominal. Losses occur both in the motor and in the inverter itself. If the motor continues to receive a similar waveform at speeds below 50 Hz, the motor losses will tend to be constant. Data from inverter manufacturers indicates that the total reduction in efficiency could be of the order of 20% when considering a frequency range of 20 or 25 to 60 or 65 Hz. The graph shows the typical effect of frequency (and hence speed) on overall efficiency.

To calculate the power input to the inverter at the required frequency f , use the following equation:

$$\text{Power}_f = \text{power}_{50} \times f/50 \times 1/Y$$

where

- power_f = power Input at f
- power_{50} = power input at 50 Hz
- y = efficiency factor given in the figure



6 Control of Inverter Frequency

The signal necessary to control the inverter depends on the type of inverter used. They are normally controlled by a 4 to 20 mA or a voltage signal. This can be driven from the parameter which is used to control the refrigeration system, for example suction pressure or room temperature.

7 Power Measurement and Cable Sizing

The inverter can cause distortion of the sinusoidal current waveform, and between the inverter and the motor there is a stepped current approximating to a sine wave. High quality inverters will introduce less distortion and power losses. Power can be measured using the two wattmeter method on the input to the inverter.

Currents can exceed the amounts calculated from this power. Cables, fuses and contactors will need to be sized for the true RMS current flowing through them. General rules for this are:

- cable from motor to inverter - size for 10% more current than standard
- cable from inverter to mains - size for 20% more current than standard

8 Start Contactor Positioning

The inverter should not be allowed to operate with the output from the inverter to the motor open circuit. There should be a contactor each side of the inverter, ie, between the inverter and the mains and between the inverter and the compressor motor. They should be interlocked to break the mains side first. When switching on, the motor side contactor should be made first.

When using an inverter bypass, care should be taken to ensure there can be no voltage feedback to the inverter. Therefore when the bypass contactor is closed and the bypass is in operation, the contactors on either side of the inverter must be open.

9 Starting and Ramp Up

An inverter is capable of delivering a soft start, but at the same time care must be taken to ensure that stalling does not occur. The inverter must be able to deliver sufficient power at the lower frequencies to ensure that the compressor accelerates to nominal speed in approximately 3 seconds or less. Only general guidance can be given here, because the exact torque requirements will depend on system pressures at the time of start up. Longer ramp up times could result in inadequate lubrication. It may be necessary to set the inverter to deliver a slightly increased

voltage (compared to the normal V/f rule in Section 4.5) at the low frequency applicable during ramp up, but this should not result in deviation from the V/f rule during normal operation.

10 Electrical Screening and Voltage Rise

Wiring of the electrical enclosure and the installation must be carefully conducted in accordance with EMC recommendations. High quality, high reliable pressure sensors must be used and it is necessary to follow EMC measures to ensure that the inverter does not disturb the signals from pressure transducers. Suction and high pressure sensors signals must be noise-free to the controller input. The inverter itself should be fitted with suitable EMC filters, eg, EN55011 Class B.

Because the waveform generated by the inverter is built up from pulses, there is a danger that the rate of voltage rise on an individual pulse can be too fast. Generally this is measured in kV per microsecond, and limits at the motor terminals which should be adhered to during the first microsecond are given in EN 60034.

11 Vibration

A compressor running at fixed speed imposes vibrations on its associated framework at a set group of frequencies. The framework can of course be designed such that its natural frequencies differ from the imposed frequencies.

A compressor driven at variable speed will impose different frequencies at each speed, so the framework design to eliminate vibration throughout the speed range is more complex.

The framework structure should be stiff enough such that its resonant frequencies are above the maximum frequency, ie, 60 or 65 Hz. Designing with natural frequencies below the minimum speed 20 or 25 Hz, could lead to vibration problems during start up. Spring mounts should not be used as they have a natural frequency below 65 Hz.

12 Internally Compounded Compressors

The operation of internally compounded compressors at variable speed may require the selection of a different liquid injection interstage cooling expansion valve. Please consult Emerson Climate Technologies for further details.

13 Costs and Payback

Outlined below are the major factors to consider when calculating capital and operating costs and savings.

In addition to the capital cost of the inverter, there are costs associated with minimum off time controllers and special fast acting overloads. It is also advisable to fit a bypass around the inverter for 50 Hz operation which is necessary if the inverter fails.

The high capital cost of an inverter can be partly offset against savings made by:

- elimination of conventional method of capacity control and unloaded start devices where appropriate;
- elimination of need to oversize compressor to handle peak loads due to over-speed capability, although at reduced efficiency;
- reduction in number of contactors needed as direct-on-line start can be used in place of star-delta or part-wind start;
- reduction in running costs, although these may not be as high as some inverter manufacturers suggest due to the inherent inefficiency of the inverter. The major energy savings are due to the system running with suction pressures and case temperatures closer to the design condition, although higher case temperatures may be required to offset the inherent inefficiency of the inverter.

Many of these items cannot be quantified in general terms, an individual system analysis is necessary.

14 Summary

The following is a summary of the main considerations when using inverter drive as capacity control:

- The compressor must not operate outside the range 25 to 60 or 20 to 65 Hz
- The compressor application range should be reduced to allow for extra motor heat and for motor loading, if overspeed is used

- The capacity of the compressor will be in direct proportion to the speed
- The power input to the compressor will depend on the efficiency of the inverter and the frequency
- The framework should be designed such that resonance frequencies are above 65 Hz
- There are inherent inefficiencies associated with the operation of the inverter
- Care must be taken when setting up the inverter to ensure it does not operate outside the specified frequency range, and that it operates at maximum efficiency
- Cable sizing from the mains supply and to the compressor motor must be sized to account for higher currents than for a similar size system without inverter
- The control circuit should be designed such that the inverter cannot operate with the output from the inverter to the motor open circuit
- Reduced gas velocities at lower speed may necessitate re-design of discharge and suction pipe work