Inverter technology

APPLICATION
BULLETIN

WHAT IS THE “INVERTER” COMPONENT?

THE INVERTER IS AN ELECTRONIC POWER COMPONENT THAT CONTINUOUSLY VARIES THE ELECTRICITY SUPPLY FREQUENCY OF AN ELECTRIC MOTOR.

The continual variation of frequency in turn continuously varies the rotation speed of a motor, according to the equation below (valid for markets with a standard frequency of 50Hz):

EQUATION 1

$$RPM = \frac{Hz \text{ x } 120}{n° \text{ poles of the motor}} = \frac{50 \text{ x } 120}{n° \text{ poles of the motor}}$$

Equation (1) shows that the rotation speed of a motor depends on the frequency of the current (Hz) supplied and its number of poles. For example:

- A motor supplied by an alternating electrical current (AC) at 50Hz and with two poles has a rotation speed (unloaded) of 3,000rpm
- A motor with six poles (three pairs of poles) turns (unloaded) at 1,000 rpm.

Continuous modulation of the motor speed fine-tunes the power supplied by an electrical component and adjusts the power to meet an appliance’s requirement at any moment.

According to the laws of similarity applied to rotating operating machines, the power is proportional to the cube of its number of revolutions, as indicated in equation (2):

EQUATION 2

$$Power \propto RPM^3$$

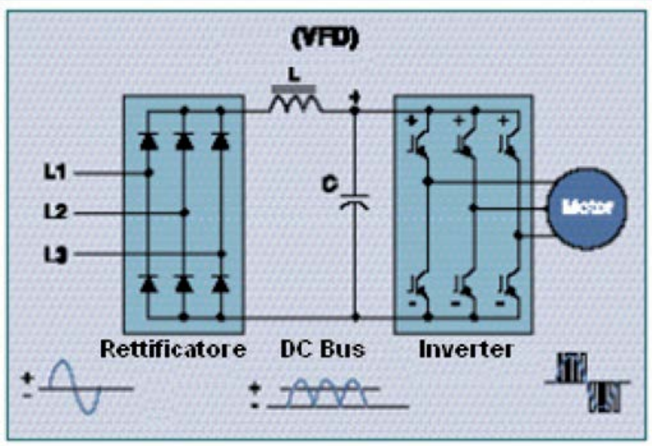
Modulating the power to meet the demands of an appliance optimises energy efficiency, delivering significant energy savings, thus reducing management costs and minimising the impact on the environment.

Any inverter is composed of 3 sections (Figure 1):
a) RECTIFIER transforms the alternating current (AC) into a direct current (DC)
b) DC BUS acts as a temporary energy reservoir
c) INVERTER generates a ‘new’ alternating current (AC) of suitable frequency to meet the power demands of an appliance.

The RECTIFIER is made of components that transform the current from 'alternating' to 'direct' and can be of different technologies: passive or active.

- Passive rectifiers are diodes
- Active rectifiers are Silicon Controlled Rectifiers (SCR) or transistors such as Insulated Gate Bipolar Transistors (IGBT), which allow the passage of current only if there is a control signal through an activation gate.

FIGURE 1: DIAGRAM OF A "6 -PULSE" INVERTER TYPE



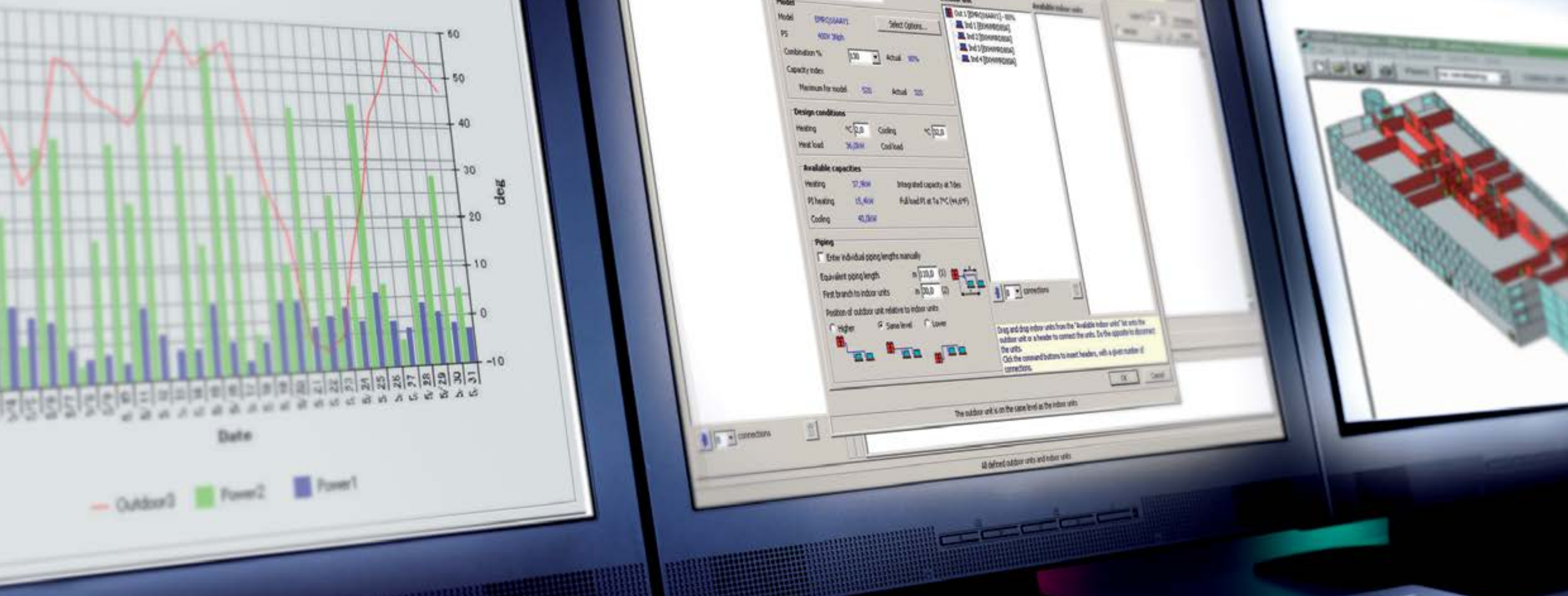
In view of the 'alternating' nature of the voltage supplied, at least two rectifiers are necessary for every supply phase: one allows the passage of current when the supply voltage is positive; the other "opens" when the voltage is negative. Therefore, in the case of 3-phase supply (L1, L2, L3 in a 50Hz network, 3 Ph. 400V), the Rectifier is composed of at least six rectifier elements, creating what is known as a "6-pulse inverter".

However, some inverters are fitted with a multitude of rectifiers, even as many as four, six or eight for every phase. These are known as '12 impulse' (4x3 phases) devices, '18 impulse' (6x3 phases) devices or '24 impulse' (8x3 phases) devices.

Providing more rectifiers per phase reduces the harmonic disturbances within a network, compared with those normally induced by an inverter component.

If the Rectifier is fitted with active components, such as IGBT transistors, then the inverter device is known as an Active Front End Inverter (AFE-inverter).

These devices meet the most stringent laws and standards regarding the maximum levels of harmonic disturbances that can be induced in a network by the VFD component.



THE MAIN BENEFITS OF USING AN INVERTER

A STARTER WITH AN INVERTER HAS THREE MAIN BENEFITS:
1) MECHANICAL BENEFITS
2) ELECTRICAL BENEFITS
3) ENERGY EFFICIENCY
4) END USER BENEFITS

All increase the quality, reliability and energy efficiency of the appliance but, depending on the particular appliance, some benefits may be more important than others.

1. MECHANICAL BENEFITS

It is known that any mechanical component is subjected to maximum stress in the "starting" and "stopping" phases, which, for that matter, often involve non-ideal conditions of lubrication of the moving components.

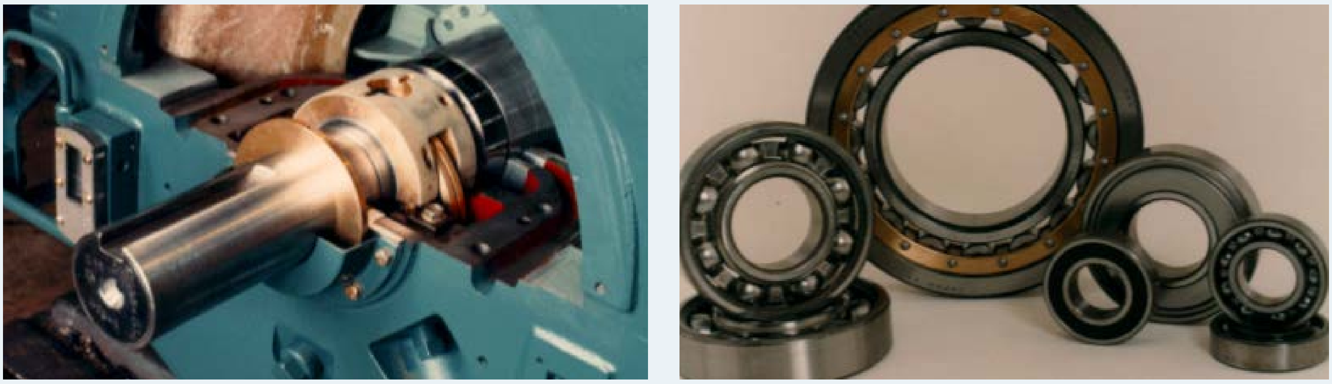


FIGURE 2: MECHANICAL COMPONENTS IN A MOTOR, AND/OR COMPRESSOR, AFFECTED BY LUBRICATION CONDITIONS

A mechanical component is subjected to maximum stress in the 'starting' and 'stopping' phases, especially in non-ideal conditions requiring lubrication of the moving components.

In such scenarios, repeated and frequent starting/stopping cycles of an electric motor - and specifically of a compressor - increases wear and can affect reliability over time (Figure 2). Mechanical wear in these phases of transition is in direct proportion to the acceleration of the moving parts.

An electrical starting system that maintains a constant frequency of electricity supply to the motor (D.O.L., Y-Δ, Solid State Soft Starter, Part Winding Starter) subjects the moving parts to maximum acceleration during the starting phase of the component.

In contrast, an inverter uses the continuous frequency change of the supply current as its main control variable, thus allowing the acceleration to be modulated gradually. This reduces the effect of poor lubrication during the transition stage, as well of the mechanical stresses induced by high starting torque.

2. ELECTRICAL BENEFITS

The electrical benefits of using an inverter are in three categories:

a) Starting current is minimised
b) High value of the motor power factor
c) Reduction of total power absorbed in kVA at full load.

a) STARTING CURRENT IS MINIMISED
High current absorption, even for only fractions of a second, can cause complications in an electrical network, including a drop in voltage and disturbance of sensitive electronic components. Sometimes an electrical panel's magnetic protection can even cause a motor to switch off immediately, because of the magnetic-thermal overload.

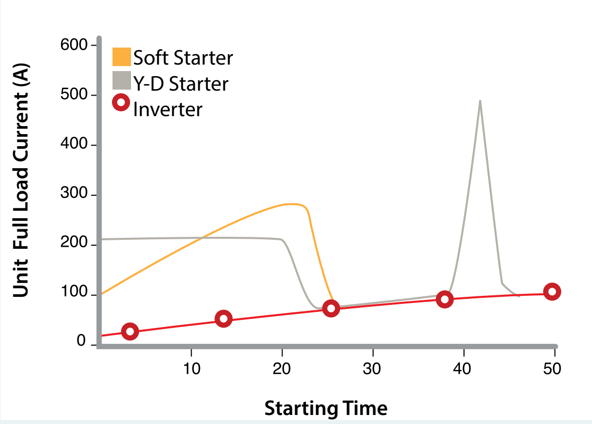
The value of the starting current of an electric motor is usually evaluated as a percentage of its Full Load Ampere (FLA) value.

The starting solutions for electric motors are mainly: D.O.L., Y-Δ, Soft Starter, Part Winding, Autotransformer and Inverter.

Of these, only an inverter can vary the input frequency of an electric motor, while all the others act exclusively on the value of the voltage. This is their main limitation in minimising the starting current. Table 1 compares the starting current values, as percentages of the FLA, guaranteed by the various starting solutions listed above.

TABLE 1

Type of starting solution	Starting current as % of FLA
Direct on line (D.O.L.)	600-800 %
Part Winding	400-500 %
Auto-transformer	400-500 %
Y-Δ(Star-Triangle)	200-300 %
Solid State Soft Starter	200-300 %
Inverter	NO INRUSH CURRENT



When an inverter - sometime referred to as Variable Frequency Driver (VFD), controls a compressor motor, there is no current inrush during compressor starting.

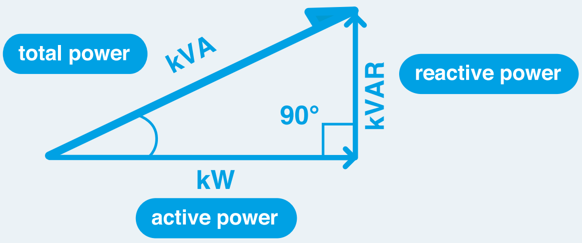
In the example of an inverter chiller equipped with more compressors: when the first compressor starts the unit, in-rush current is equal to only a few amperes. When another compressor starts, the unit in-rush current is never higher than the running amperage of the electrical motors already working. So for instance in a refrigerant compressor equipped with a 180 kW electrical motor, the Y-Δ in-rush current is more or less 700 A; but with an inverter it is equivalent to the stand-by current (which is basically zero).

b) HIGH VALUE OF THE POWER FACTOR (PF)
Any electric motor that creates and maintains a rotating magnetic field inside the motor absorbs two distinct powers:

- ACTIVE power, measured in kW and used to supply mechanical work
- REACTIVE power, measured in kVAR (kiloVolt-Ampere-Reactance) which creates the internal magnetic field.

The "vector sum" of these two powers is called Total Power and is measured in kVA (kiloVolt-Amperes), where A indicates the total and effective current absorbed by the motor. This is used to calculate the cross-section of the power conductors to be installed.

FIGURE 3: THE VECTOR TRIANGLE OF THE POWERS (ACTIVE, REACTIVE, TOTAL)



The ratio between the ACTIVE (kW) power and the TOTAL (kVA) power, as indicated in the equation (3), is called the Power Factor (PF).

EQUATION 3

$$Power\ Factor\ (PF) = \frac{kW}{kVA}$$

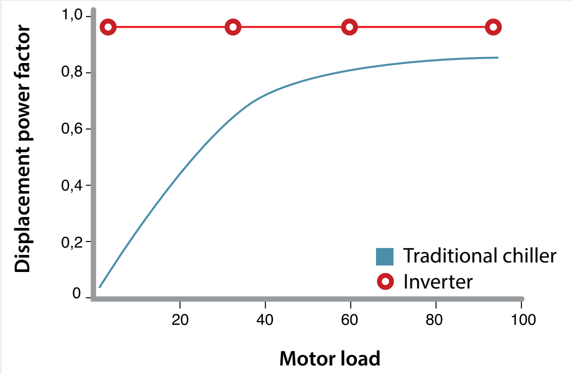
An electric motor necessarily absorbs REACTIVE power to sustain the magnetic field inside the motor. With reference to the ACTIVE quota absorbed (kW), the smaller the effective load of the motor, the more reactive power it tends to absorb.

In other words, the Power Factor of an electric motor decreases as its load level decreases, reaching values considerably lower than PF = 0.6 under minimum load conditions.

An increase in the reactive power absorbed is not advantageous in any case because:
- An increase in the effective current absorbed is associated with greater resistance losses (Joule effect)
- A larger cross-section of transformers and power wires is required
- There is a risk of incurring economic sanctions from electricity suppliers, which normally require power factor values of no less than 0.85-0.9 at the supply node.

On the other hand, the installation of an inverter - which contains a DC BUS section including the condensers (capacitive effect) in any load condition - ensures a Power Factor of 0.95-0.97 (Figure 4). An electric motor with an inverter always has a higher re-phasing value than one without an inverter but is equipped with an external battery of re-phasing condensers.

FIGURE 4: COMPARISON OF THE POWER FACTOR BETWEEN A MOTOR WITH AND A MOTOR WITHOUT AN INVERTER (400 V)



The reduced Power Factor of an electric motor and the decreased load issued (which tends to be opposite in the same motor equipped with an inverter) highlights the following:

1. The risk of incurring penalties from the electricity supplier because of non-compliance with re-phasing conditions at the supply point
2. The frequent need to install an external battery of load re-phasing condensers
3. The constantly higher absorption of electricity (A) by the motor, while providing the same output of active power (kW). This causes greater energy consumption and higher annual costs, due to resistance losses in the electrical conductors.

FIGURE 5: INVERTER COMPONENT IS A SUBSTITUTE OF "SOFT STARTER" AND "RE-PHASING CAPACITORS PANEL"

When comparing the technical and economic advantages of selecting a refrigerator either with or without an inverter, the need to install an external battery of load re-phasing conditioners and the mechanical benefits already mentioned should be taken into account.

If choosing a standard version without an inverter, the additional purchase of re-phasing condensers and soft-starter options will increase the overall price of the standard version. In fact the re-phasing condensers and soft-starter options cost around 7-8% of an entire standard unit without an inverter. This dramatically reduces the price differential between the two solutions, which each offer a comparable technical and commercial solution.

However, the observation in point 3 above can be economically quantified.

By comparing the electrical absorption of an EWAD-C-XS/XL/XR and of an EWAD-CZXS/XL/XR during a full cooling season - i.e. distributed over various loads according to the known Seasonal Energy Efficiency Ratio (ESEER) - it is easy to demonstrate the economic benefits of the EWAD-CZ with an inverter.

More than 40% energy savings can be made, thanks to dispersion of electric kWh from lower electrical resistance to transmission (the Joule effect). This delivers major savings in annual energy management costs of the refrigerator.

C) REDUCTION OF TOTAL POWER ABSORBED IN KVA AT FULL LOAD

Because the inverter always maintains a higher Power Factor in the electric motor compared with the effective active power absorbed, the current absorption is minimised, both at partial motor load and also at nominal load conditions (100%).

A direct comparison between the EWAD-CZ units and standard units without power factor correction, allows these advantages to be quantified.

TABLE 2

	EWAD760C-XS	EWADC10C-XS	EWADC13C-XS	EWADC16C-XS
Cooling Capacity - kW	756	1074	1349	1596
Unit Power Input - kW	233	338	410	503
Nominal Running Current - A	387	559	686	835
MAX Current for Wires Sizing	556	797	955	1196

	EWAD740CZXS	EWADC10CZXS	EWADC13CZXS	EWADC16CZXS
Cooling Capacity - kW	738	1037	1308	1622
Unit Power Input - kW	235	339	442	558
Nominal Running Current - A	381	505	659	829
MAX Current for Wires Sizing	533	725	869	1217
Increase in Electrical Power	0.9%	0.3%	7.8%	10.9%
Nominal Running Current - A	-1.6%	-9.7%	-3.9%	-0.7%
MAX Current for Wires Sizing	-4.1%	-9.0%	-9.0%	-1.8%

Table 2 shows:

- The higher absorption of active power (kW) at full load by the EWAD-CZ unit for the known loss of efficiency caused by the presence of the power component
- A reduction in the nominal current for the chiller equipped with an inverter
- A reduction in the value of current to be considered when deciding the cross-section of power wires for the electrical installation of the unit.

The decrease in the nominal current for normal functioning also reduces, by the same percentage, the Total Power absorbed by the refrigerator. This is quantified, in the case of three-phase load, by equation (4).

EQUATION 4

$$Total\ Power\ (kVA) = \sqrt{3} \cdot V \cdot I$$

This benefit is of even greater importance in installations where it is not possible to request increased power supply - perhaps because of the transmission saturation of the local electricity grid.

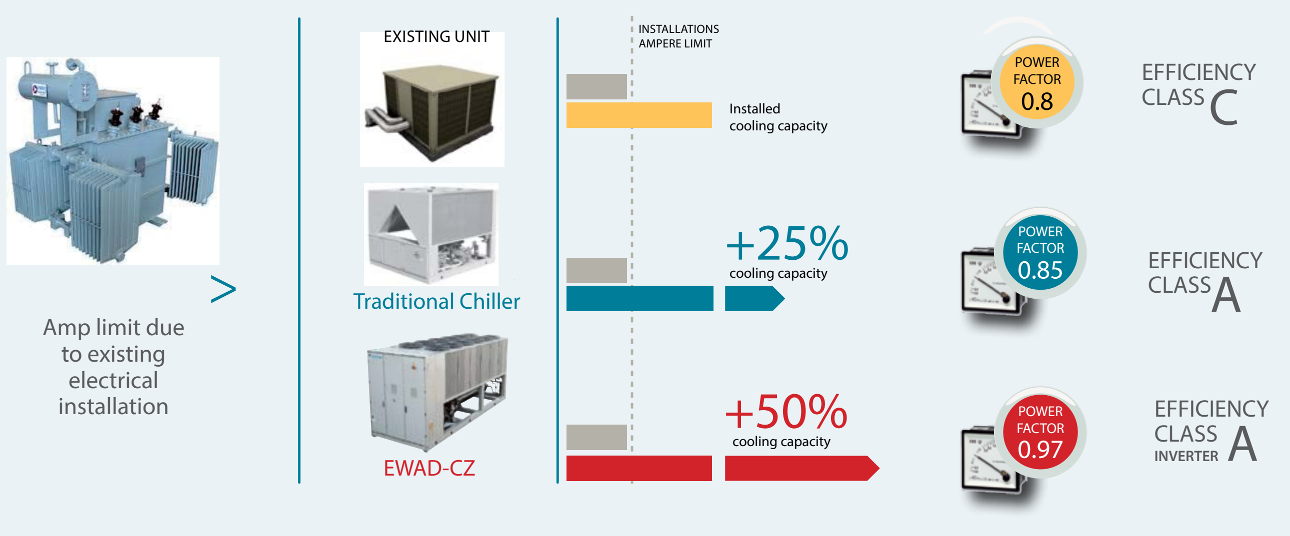
In renovation or retrofit projects where old installations have become obsolete, this makes it feasible to provide a refrigerator with the same cooling capacity as the previous unit, but which requires reduced total power demand. This may free up capacity to install additional appliances at the same supply node, yet without exceeding the fixed quota for maximum power usage. A very efficient chiller with high power factor (EWAD-CZ) may even allow the engineer to increase the cooling capacity available, while keeping the same current absorption.

Consider an existing installation of a chiller R-407C with EER 2.8 at full load (Eurovent condition, therefore with 'Class C' energy classification) with limited ampere absorption, due to the existing size of the main transformer located in the electrical substation. However, if the building needs at least 30% additional cooling capacity to fulfil increasing HVAC or process cooling requirements, a high efficiency inverter chiller can satisfy these, thanks both to its extremely high EER value and the Power Factor of electricity utilisation always being a little below one.

To replace an existing 'Class C' chiller, with a Power Factor of 0.8 at full load, while keeping the same ampere absorption (Fig 6):

- A typical modern chiller (R-134a and 'Class A' Eurovent) can increase the cooling capacity by only 25%
- An innovative EWAD-CZ (R-134a and 'Class A' Eurovent) can produce up to 50% more cooling capacity.

FIGURE 6: EXAMPLE OF A REVAMPING APPLICATION OF AN EXISTING PLANT THAT NEED MORE COOLING CAPACITY



When selecting the cross section of power lines to be installed, less total available current is required, so concrete savings can be made in the cabling installation costs of the refrigerator.

Example

For a refrigerator of approximately 1,310kW, assuming a maximum voltage loss of 5% compared with the nominal 400V and a distance of about 100m between the refrigerator's power panel and the Low Voltage cabin:

- The unit without an inverter would require three conductors, each with a section of 300 mm^2
- The unit with an inverter would require three conductors with a section of 240 mm^2

Choosing a unit with an inverter would deliver a saving of around 20% on the electrical installation costs of the refrigerator.

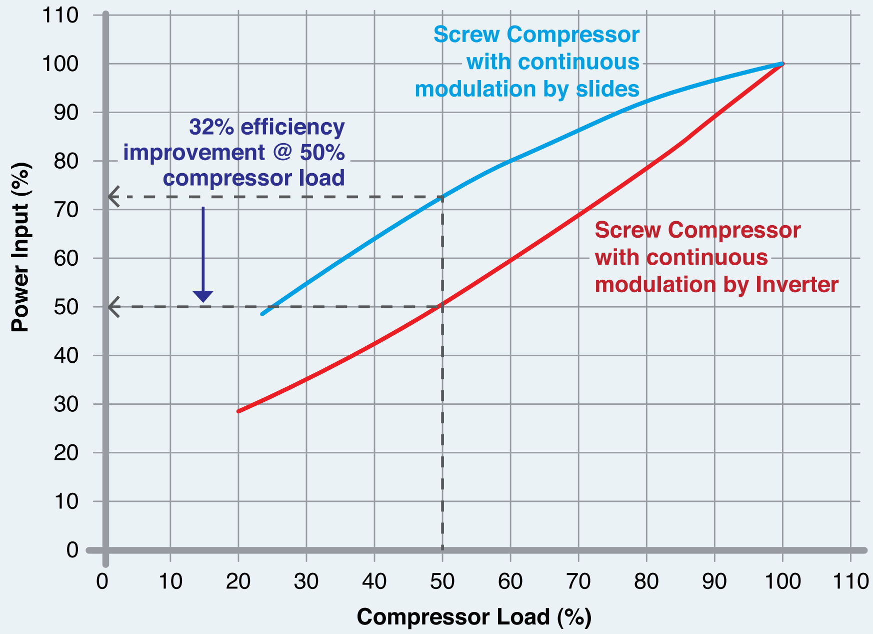
3. ENERGY EFFICIENCY

Undoubtedly, one of the main benefits of an inverter controlled device such as a fan, pump or compressor is the significant annual energy savings achieved.

Continuous variation in the rotation speed of the electric motor fine-tunes the power supplied by the component activated by the motor, adjusting it to the effective load demand.

The modulation of the electric motor speed reduces the capacity supplied by the activated mechanical component, such as the chiller's compressor, and delivers high energy efficiency throughout all load variations (0-100%), especially when compared with mechanical adjustment systems, such as slide control valves, or the fixed bypass orifices activated by solenoid valves.

FIGURE 7: COMPARISON COMPRESSOR EFFICIENCY



The annual energy savings that can be achieved when operating an inverter controlled appliance often quickly repay the additional investment.

However, it must be noted that the extent of the energy and cost savings depend on the specific price of the electricity per kWh and, above all, the average functioning rate of the mechanical device analysed.

For example, the continuous functioning of an inverter at almost full load for most of the year will not deliver the same economic savings that can be easily obtained in an appliance which functions at an average annual load considerably below the maximum.

For this reason, it is always advisable to carry out an energy analysis (even a simplified version) of the functioning of the appliance that could be fitted with an inverter, to check the benefits of using such a device in that particular appliance.

4. END USER BENEFITS

Comfort: Inverter-controlled air conditioning systems continuously adjust their cooling and heating output to suit the temperature in the room, thus improving comfort levels. The inverter reduces system start-up time, so the required room temperature is reached more quickly. As soon as the correct temperature is reached, the inverter ensures that it is constantly maintained.

Energy efficiency: Inverter-controlled products run most efficiently at partial loads, resulting in lower energy consumption than other systems as they only need the power necessary to match the load. This results in reduced annual energy consumption. An inverter controlled air conditioning system, for example, monitors and adjusts the ambient temperature whenever needed, so energy consumption drops by 30% compared with a traditional on/off system.

Cost savings: Lower energy consumption delivers cost savings and can also reduce the impact of rising energy prices on their bottom line.

Reduced carbon emissions: By improving efficiency, companies can benefit from significant carbon savings.

Intelligent controls maximise benefits: Daikin control units provide absolute control of a system and can be integrated easily with communication modules to provide end-users with a total management solution. These units offer a simple, user-friendly set of controls that allow programming and monitoring every aspect of a system’s operation, providing a long-term record for use by maintenance engineers. Intelligent controls reduce usage and improve energy efficiency.

In all of us, a green heart

Daikin's unique position as a manufacturer of air conditioning equipment, compressors and refrigerants has led to its close involvement in environmental issues. For several years Daikin has had the intention to become a leader in the provision of products that have limited impact on the environment. This challenge demands the eco design and development of a wide range of products and an energy management system, resulting in energy conservation and a reduction of waste.

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