Improved energy efficiency of air cooled chillers

In these last 10 years awareness in energy saving has continuously increased in both industrial and HVAC applications, we strive to regulate the electrical consumption of cooling equipment using the most effective efficient techniques. In the refrigeration and heat pump sectors increasingly European standard and directives are now applied to the appropriate and proper use of materials, innovation and in the application of new technologies to improve refrigeration system efficiencies.

Maurizio Burba
Hitema
Managing Director
burbam@hitema.it

HVAC designs for Data Centre – Total Load 2.6 MW

In the refrigeration and air conditioning sector continuous attempts are made to reduce the energy consumption of all systems by improving the management of cooling power, optimizing the use of water-glycol flow and providing greater temperature accuracy. Recent research has developed the use of environmentally friendly refrigerants with lower ambient impact and excellent thermal performances. However, large refrigerant equipment still has very high power requirements, especially those demanded from very large air or water cooled chillers with screw compressors. The utilization of screw compressors is very high amongst large capacity chillers (>300 kW) and therefore the optimization of partial load performance, which is a condition present in almost all refrigeration plants at various stages throughout the year, is the goal prefixed by Hitema. A modern and intelligent technology is to control the large power demands of screw compressors with the frequency control network, using inverter electronic devices.

Advantages offered with the Inverter Technology

An inverter (VDF) is an electrical device acting on the variation of voltage and frequency. The inverter uses the line alternate voltage (a.c.) to produce a direct voltage (Diode Bridge - d.c.). From this direct voltage an alternate voltage is regenerated (PWM technique) with a frequency f between 0 and f_{max} (maximum frequency) and voltage $V<V_{net}$ (electric net voltage).

Inverters are widely used in film-polyester capacitor configuration, which is similar technique used on photovoltaic plants. The absence of electrolytic materials avoids the early aging due to the temperature, currents and stocking periods. The current distortion THDI is much lower than is electrolytic capacitors since the equivalent electrical capacity is lower. Moreover the compactness and longevity of inverters above film capacitors is also a consequence of superior effectiveness of cooling directly with liquid refrigerant line. When the frequency increases the number of compressor revolution increases linearly. As frequency increases compressors r.p.m. increases and as frequency decreases compressor r.p.m decreases. The application frequency range was widened between 30 Hz to 130 Hz.

Main advantages are:

- The starting current is effectively equal to 0, as current is directly proportional to frequency, the inverter starts the screw compressor with void frequency and it causes an absorption equal to 0.
- Cooling power can increase up to 20% above the optimal cooling power referred at 50 Hz, this is because the screw compressor can rotate with higher gears reaching higher frequencies up to 130 Hz.
- Higher operating flexibility due to large range of control (from 16% to 100%, widest modulation range on the market) and higher power density.
- Reduced electrical consumption at partial load between 30 Hz and 50 Hz compared to a standard screw compressor with a slide valve capacity control. This results in a measured absorbed power being reduced by up to 15%.
- Superior control of water outlet temperature exhibiting less fluctuation around the set point temperature. Typically tolerances of around +/- 0.5°C are possible.

- Reduced mechanical compressors wear, as the screw will rotate for most of year with reduced r.p.m. (higher MTBF).
- Inverter technology with screw compressor variable Vi, using automatic control of Vi the performances of chiller increase.

Performance of a Hitema chiller with compressors driven by inverter

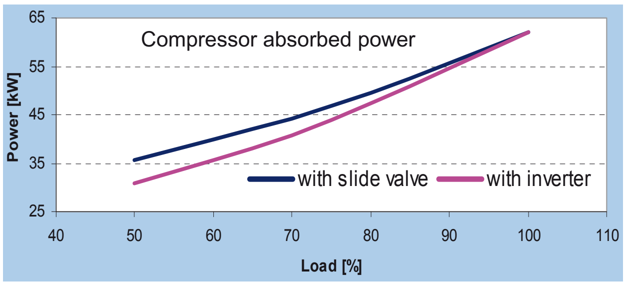

Figure 1. Comparison of performance of chillers.

Figure 1 illustrates the first important point showing lower absorbed power of the screw compressor when installed with an inverter, compared against a standard screw compressor with a slide valve. Chiller with inverter screw compressors are more versatile and highly efficient specialists used in chillers for air conditioning systems and industrial process cooling.

With a slide valve the gas flow control is less accurate than the inverter controlled counterpart. With a standard compressor the capacity steps are static and prefixed (eg, 100%, 75%, 50% and 25%). With the inverter solution, the screw revolution decreases proportionally and the gas flow is modulated linearly.

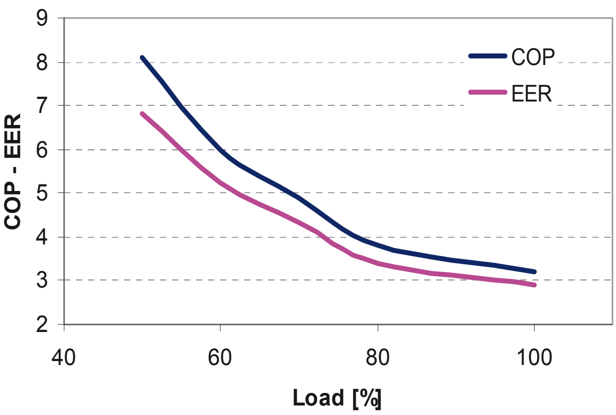

Figure 2. Performance for air cooled chiller.

Figure 2 illustrates the real data performance for air cooled chiller. The COP is the ratio between cooling capacity and the compressor absorbed power input. The EER is the relationship between the cooling capacity of chiller and the total power consumption of the refrigeration unit (compressors + fans). If the cooling load decreases whilst the ambient temperature decreases, then the absorbed power of chiller decreases much more rapidly than the reduction in cooling capacity in a non-linear relationship.

These COP and EER values are very competitive with other available technologies (eg, centrifugal compressors) and COP values with inverter screw compressors can attain >8 and EER >7. This chart above refers to an air cooled chiller with R-134A refrigerant, with inlet water temperature of 12°C and outlet water temperature of 7°C. The graph illustrates the massively beneficial effect on the efficiency of the chiller unit as the ambient air temperature and the load on the chiller reduce from 100% load in a 35°C ambient (worse case), to a situation whereby the load on the chiller is 50% and the ambient temperature is 15°C. As can be clearly observed, the EER for the unit at 50% load in a 15°C ambient is over double (~7) the value compared to when at 100% load in a 35°C ambient temperature (~3). The thermal performances indicated demonstrate that this unit easily qualifies for Class A efficiency categorisation.

It is clearly important to know the ambient temperature, the water temperature and the maximum load during the year (month by month) in order to assess the real operating efficiency of chiller unit.

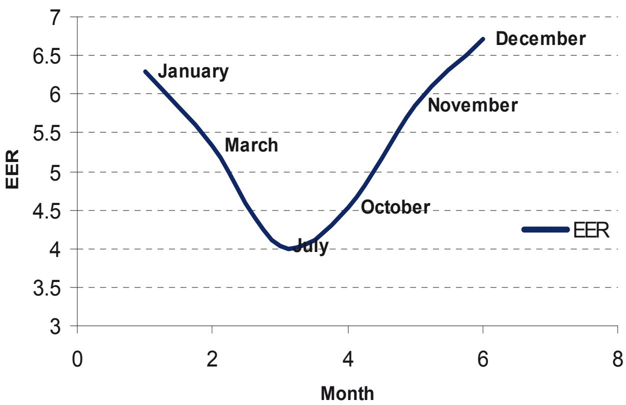

Figure 3. EER value of a chiller without free cooling.

Figure 3 shows the EER value trend of a chiller without free cooling when operating with a water outlet temperature of 5°C.

This chiller is designed for 680 kW at full load. During the warmer months of the season (June-August) the required load is 100%, whilst during the colder period (November-March), when ambient temperature is much lower, the chiller load is estimated between 50% and 60%. It is interesting to observe that the EER in the hotter months, during the worst demanding ambient conditions, has a minimum value of 4, whilst when the chiller load is around 60%, the EER values are typically between 6 and 7, much higher than a standard chiller. All these values refer to the maximum ambient temperature for each month, so these EER are considered as a *minimum*.

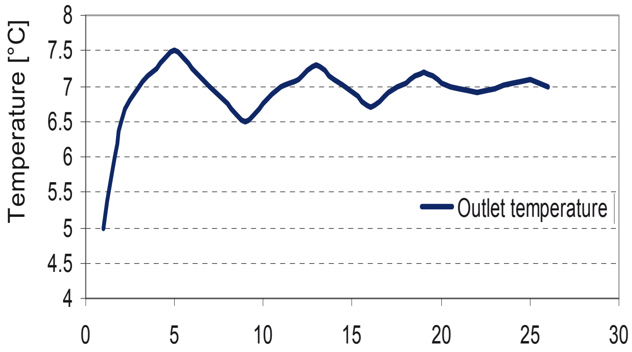

Figure 4. Outlet water temperature.

Figure 4 shows the outlet water temperature trend. Inverter control achieves much greater water temperature control than is possible with a standard screw compressor. It is evident that the water temperature fluctuation is only +/- 0.5°C deviation from the set point. Furthermore the set point value is established more rapidly than on standard a chiller.

In the European market the adopted index to classify chiller performance is E.S.E.E.R. (European Seasonal Energy Efficiency Ratio) and this is in accordance with E.E.C.C.A.C. proposal (Energy Efficiency and Certification of Central Air Conditioner). HITEMA inverter driven screw chillers has E.S.E.E.R. of over 5.

The formula used to calculated this is:

ESSER=
0.03 x EER(100%) + 0.33 x EER(75%) + 0.41 x EER(50%) + 0.23 x EER(25%)

The EER value (%) is the efficiency of chiller at 100%, 75%, 50%, 25% of load under various conditions in accordance with **Table1.**

For chillers with screw compressor installed with inverter control and variable Vi compressor, the increase achieved in the E.S.E.E.R. is around 15%.

Axial Fans for Condenser with inverter

Hitema also offer the use of inverters applicable to the standard axial fans. To control the volume of air circulated through the condenser in the air cooled chillers simple fan speed regulators to cut the phase applied to the fan motor are currently widely used. With this method, it is possible to decrease the rotation of the motor intervening directly on the supply voltage. However, with the use of inverters, which modulate the frequency from 20 to 50 Hz it is possible to reduce steadily the air flow and achieve improved condensing control.

Table 1. Weighting factors of part load efficiencies for calculating European Seasonal Energy Efficiency Ratio.

Water leaving temperature (°C)	7 (constant)			
Delta T full load (°C)	5			
Load (%)	100	75	50	25
Water Cooled Chiller				
Condenser water temperature (°C)	30	26	22	18
Air Cooled Chiller				
Condenser air temperature (°C)	35	30	25	20
Weight in ESEER (%)	3	33	41	23

Benefits obtained by the use of frequency variation with respect to voltage variation are the following:

- Reduced noise levels
  This is a key point when using axial fans for refrigeration in the air conditioning sector, as air cooled chillers are widely used in residential, external applications; when installed with fans operating from a variable frequency drive, significant noise reductions up to 6 dBA for the same chiller unit are possible (ISO3744).

- Lower energy consumption
  For low-medium speed (rpm) the frequency variation allows reduced power consumption. However the motor efficiency is completely utilized with all cooling load. A cut phase adjustable fan-motor has an efficiency ratio between 72–74% whereas the same motor with frequency driver has a performance ratio of 80%.

HITEMA uses another innovative application around the air fans, that it consists in the use of a special diffuser on top of the fans (**Figure 5**), that allows:

- Noise reduction of 6 dBA.
- Energy Saving of 22%.

Centrifugal process pump (2-4 poles) with Inverter

Hitema proposes the application of the inverter control on one or more centrifugal pumps, in order to obtain a non-dissipative regulation of power with the pump speed variation, depending on the heat load required. (**Figure 6 and Figure** 7)

Figure 5. Special diffuser for air fans.

Figure 6. Inverter driven double pump.

Figure 7. Electrical board with inverters for pumps.

Hence we obtain significant results in energy saving as you trace the real load energy requirements without any additional loss or consumption being incurred by the process.

To understand how the non-dissipative adjustment is able to act in this method, we can consider the operating curve of a centrifugal pump. (**Figure 8**)

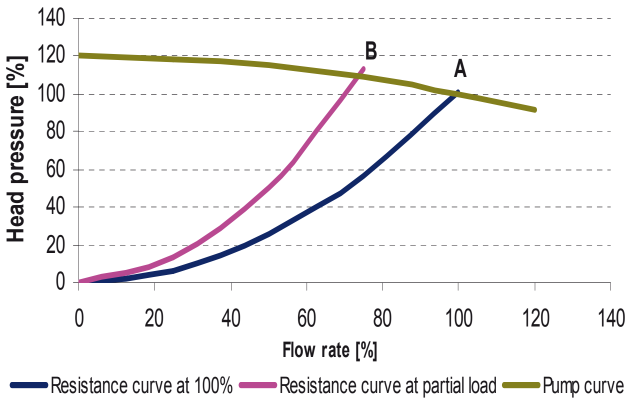

Figure 8. Operating curve of a centrifugal pump.

The intersection of the characteristic operating range for centrifugal pump with the typical flow-pressure curve can be used to identify the point of working regime (**point A** for 100% of load). If the load in the system requires a flow of 75% of the maximum by the regulation by the classic choke valve installed after the pump then an additional pressure drop is artificially introduces and the system must overcame a higher pressure drop (kPa or m.w.c.) than is actually required by load (**point B**). Furthermore by moving the operating flow point, the pump efficiency is also changed, which then introduces a further efficiency loss.

By adjusting inverter frequency instead, it follows the *real load demand* by altering the pump curve. (**Figure 9**). Varying the speed of the pump changes its actual operating curve, which will move vertically downwards and thus we reach into the new operating point (**point C**) without any adjustment valve introduction. This results in a real energy saving of 30%.

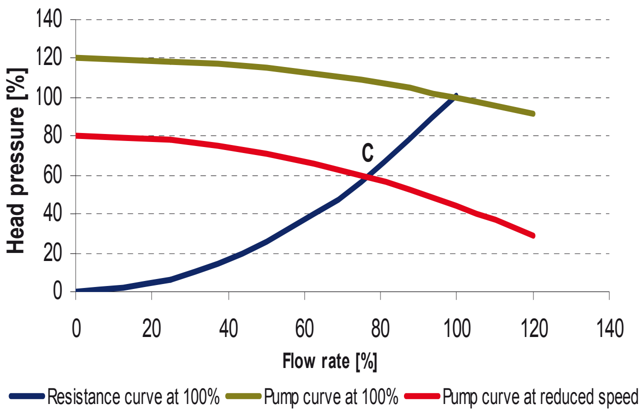

Figure 9. Operating curve with speed pump variation.

The process pumps when installed with an inverter can effectively have zero starting current if the water flow can be gradually increased up to the maximum flow, which again avoids potentially water hammer. The correct management of the inverter location completes the full system optimization.

Conclusion

Today there are many applications that require effective and innovative solutions to reduce the absorbed powers requirements of refrigeration hardware in process cooling industries, commercial air conditioning and data centres facilities. The optimum operation of refrigeration equipment at partial loads is especially significant in condition where the medium annual ambient air temperatures are between +5°C and +20°C, typical for the vast majority of European conditions. For even lower ambient temperatures the combination of inverter technology coupled with that of free-cooling, whereby chilled water can be produce using only fans energy, can be effectively used to produce chiller units with even greater efficiencies than previously considered possible. ∃€