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SCREW COMPRESSORS CAPACITY CONTROL IMPROVEMENT USING VARIABLE SPEED DRIVE (VSD) IN A REFRIGERATION SYSTEM – CASE STUDY

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Abstract. *The main objective of these work and study was reducing electricity consumption in a large industrial cooling system at a beverage industry. Anhydrous ammonia (NH3) was the refrigerant in this cooling system, which had four screw compressors (800 HP) installed in 4600 volts to supply all cooling capacity. The thermal load of this cooling system has reduced a lot due to a construction of a new cooling system.*
The methodology used in this case study was, firstly, to evaluate the operating and modulating of compressors after the new configuration. Because of evaluation it has identified an opportunity to improve the equipments modulation by installing a variable speed drive (VSD) for 4600 volts.
A main premise of this work was the modulation made through the slide valve is less efficient than VSD, mainly to supply low cooling capacities. Thus, it was installed a VSD in a screw compressor to improve the modulation.
Results show a significant power reducing and electricity savings in this cooling system about 1,400,000 kWh per year, more than 2% of total consumption.

Keywords: *modulation, screw compressor, VSD, slide valve, electricity*

1. INTRODUCTION

Energy is an essential factor for the growth and development of a company, society, and / or country, because there isn't substitute for it. This would be enough to become this topic interesting, but there are more factors like energy availability, impact on product cost and in the environment, which reinforces the importance of energy. Moreover when a company reduces its electricity consumption it can be used as marketing. (Marques *et al*., 2007; Mesquita, 2009; Tassini, 2012).

Nowadays it's necessary to use energy wisely and the energy efficiency is the main tool for this, because it reduces the consumption without losing the efficiency and quality of service. (Mesquita, 2009; PROCEL, 2012; Rocha and Monteiro, 2005).

The reduction of electricity consumption in refrigeration systems is a challenge in companies that use this kind of utility, and compressors are the biggest equipment in cooling systems, in relation to electricity. They represent about 70% of all electricity consumption in a refrigeration system (Venturini and Pirani, 2005).

One of the main types of compressors used in refrigeration systems is the screw, because it combines reduced external dimensions and high cooling capacity, due to operate at high speeds (Tassini, 2012).

The cooling system studied was in a large beverage industry, whose thermal load varies very much, depending on the demand of process. Through the compressor capacity control is possible to keep stable the controlled parameter, which was suction pressure, in this case. Thus, it's avoided that the product doesn't reach the wish temperature or the product freeze (Mendes and Sobrinho, 2012).

In screw compressors there are two ways to control the capacity. One is the slide valve that restricts the amount of gas passing through the compressor and the other is by controlling the frequency, using VSD.

The slide valve moves parallel to the rotors and is responsible for controlling the amount of gas entering the chamber. When it opens, it creates a recirculation of gas to return to the suction before being compressed, avoiding losses in the compressor work. The modulation using slide valve is shown in Fig. 1.

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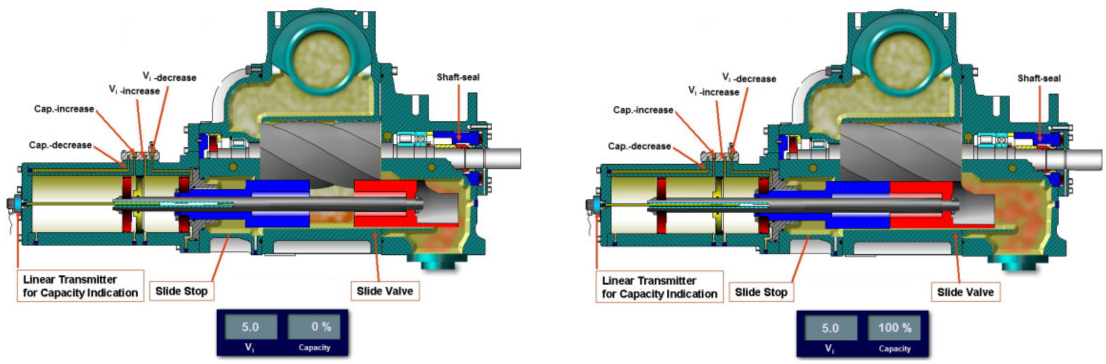

Figure 1. Operation of the slide valve (York Training and Developing DK, 2011)

In this type of compressor, the position of the discharge is a characteristic of the machine design and it controls the compression, because it defines the internal volume ratio (V_i) and the maximum pressure reached before the opening of the discharge chamber, which depends on Vi and suction pressure (Pillis, 2005; Roriz, 2012).

The internal volume ratio (V_i) is calculated by Equation (1):

$$V_i = \frac{V_S}{V_D} \quad (1)$$

where:
V_i is the internal volume ratio;
V_S is the volume of suction;
V_D is the volume of discharge;

Normally in a screw compressors, the discharge valve opens just for a design pressure ratio, which is fixed and directly proportional to V_i. During compressor modulation by slide valve, the volume ratio increases and the efficiency of the machine decreases.

The discharge valve opens when the internal gas pressure in the compressor is the same as the piping of discharge only if the design pressure ratio is the same as the compressor in that exact moment, which is very hard to occur because discharge pressure usually fluctuates.

If because of adjustment of the compressor the discharge pressure is higher than the piping discharge of system, V_i will be high and it will occur over compression. When the discharge valve in the compressor opens, the gas will leave the compressor and will expand in piping discharge, i.e., in this case, the compressor could operate with a lower discharge pressure, which would also decrease the required power. If because of adjustment of the compressor the discharge pressure is lower than the piping discharge of system, V_i will be low and it will occur sub compression. When the discharge valve opens, the gas of piping discharge will invade the compression chamber, which will force the compressor increases the discharge pressure, i.e., the compressor will also increase the required power.

In all cases, the compressor operation isn’t injured, but in both cases the required power is bigger than necessary. There are some projects that adjust V_i according on the modulation of the compressor by slide valve, but not in this case.

Good efficiencies for high capacities (85% to 100%) in the compressor are achieved using the slide valve, because it maintains practically the same volume ratio. However, for low capacities the power required doesn’t reduce significantly and the compressor efficiency is low, although it is possible to reduce the capacity to near zero. (College UNICEN, 2012; Martinelli Jr, 2003; Salvador, 1999; Tassini, 2012; Venturini and Pirani, 2005).

Figure 2 shows the variation of the power required and capacity of a compressor according to variation of the slide valve.

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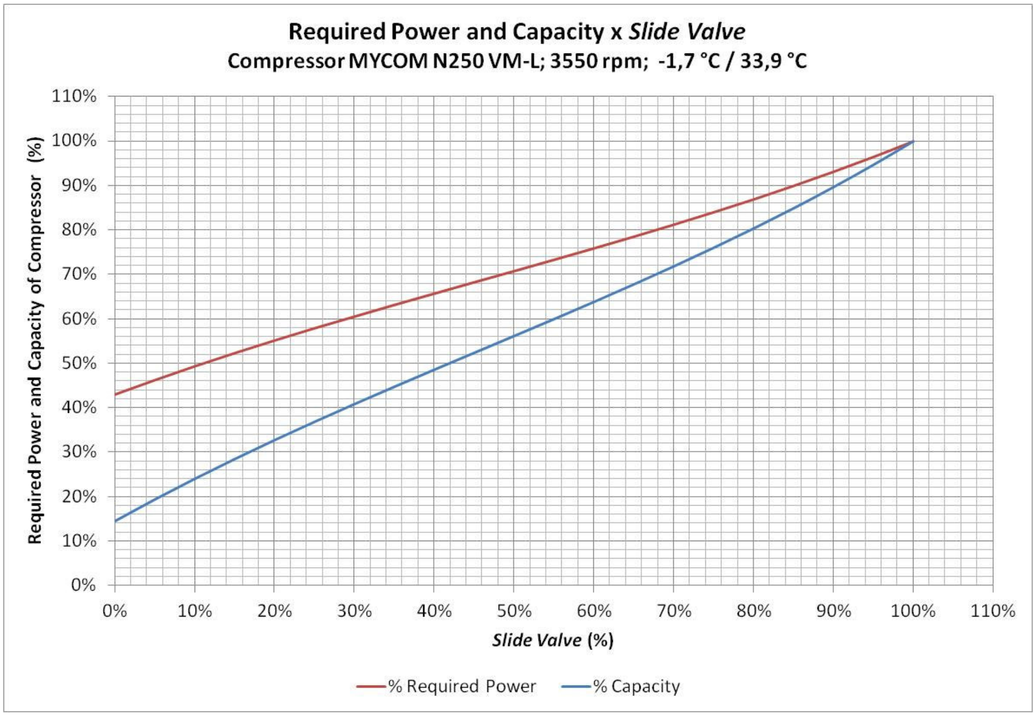

Figure 2. Required power and capacity of a compressor according to the opening of slide valve

The modulation speed of the compressor, through VSD, is currently the best alternative to reduce electricity consumption, because the geometry of the equipment is maintained and also because the reduction in speed decreases power consumption, but not linearly (Venturini and Pirani, 2005).

The capacity of a screw compressor operating with VSD can be calculated by Equation (2):

$$Capacity = \frac{\%\_Slide\_Valve}{100\%} \times \frac{frequency[Hz]}{no\min al\_frequency[Hz]} \times no\min al\_Capacity \tag{2}$$

If we compare energy consumption in the two types of control mentioned, for partial capacities near the nominal capacity, the investment with VSD is not justified because, although smaller, the difference in consumption is not enough to have a satisfactory payback, but for low capacities, the efficiency with VSD is better and the investment can be recovered quickly (College UNICEN, 2012).

Some details need to be checked before installation of VSD in compressors, such as speed limits, because the lubrication of bearings, and critical frequencies of vibration (College UNICEN, 2012).

Figures 3 and 4 compare the power consumption and the capacity of modulation using slide valve and VSD.

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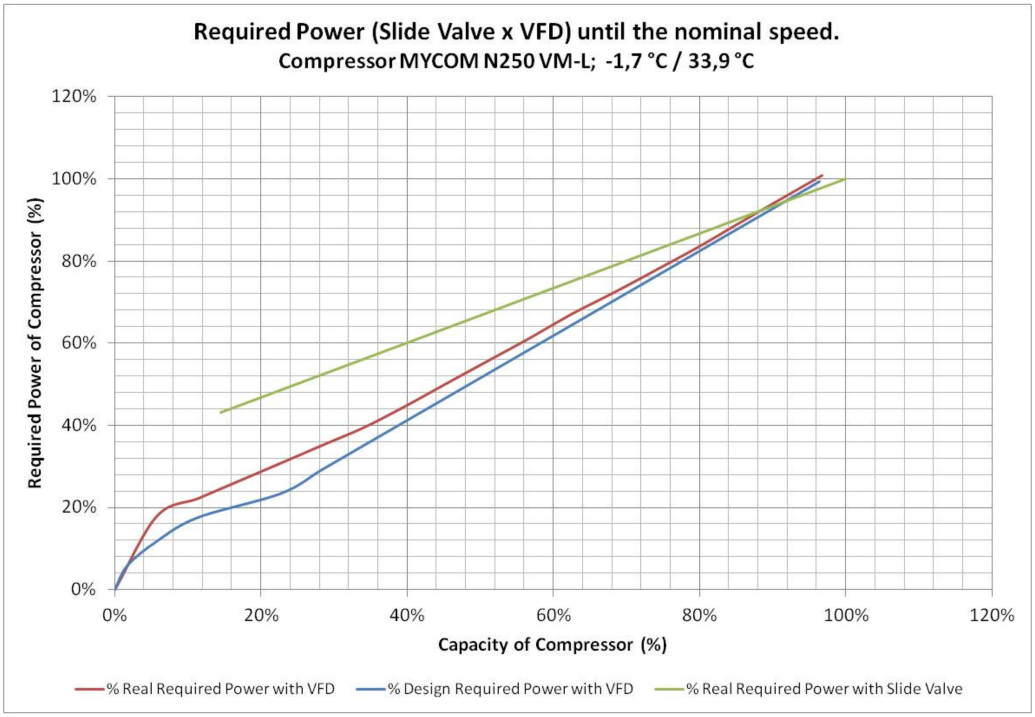

Figure 3. Comparison of required power and capacity in a screw compressor according type of control until 3550 rpm

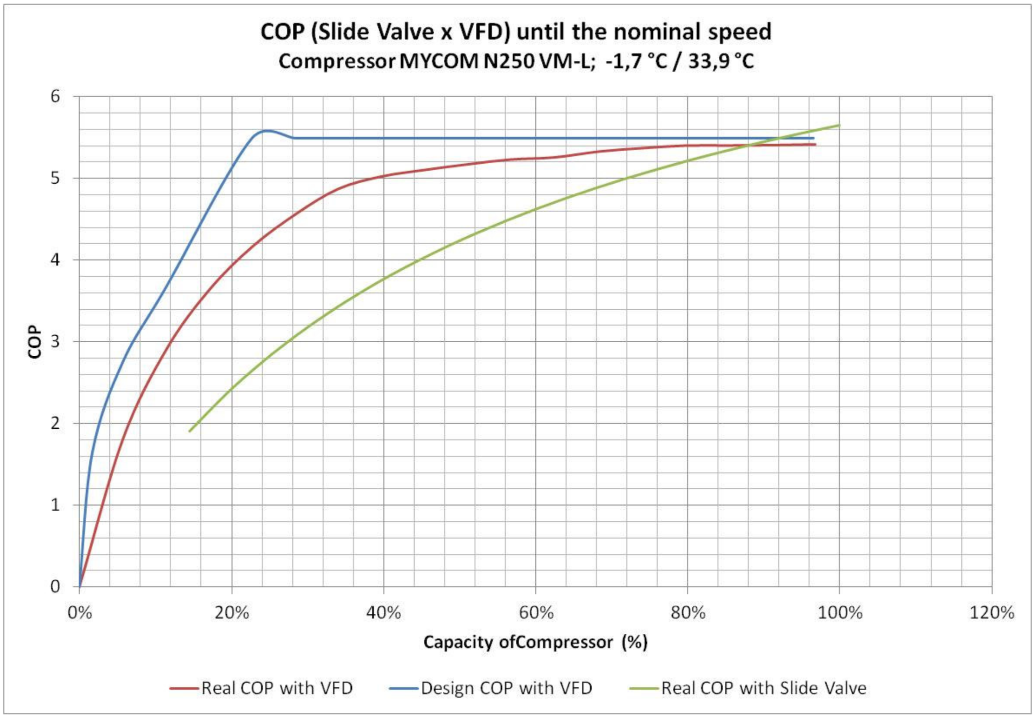

Figure 4. Comparison of COP and capacity in a screw compressor according type of control until 3550 rpm

ISSN 2176-5480

2. CASE STUDY

The cooling system improved has four compressors Mycom N250 VLD (800 HP; 4000 V; 3573 rpm; 1,709,200 kcal/h), ten evaporative condensers Allenge CEA 750 (638,000 kcal / h to Twb = 26 °C) with 1 pump of 5,0 HP and 4 fans of 4,0 HP each one. After the expansion project occurred in the factory, that created a new cooling system, most thermal load has been transferred to the new system and the existing system started to use just one compressor operating at low capacity, which modulated almost all time using the slide valve.

Figure 5 shows dates of compressor modulating by slide valve.

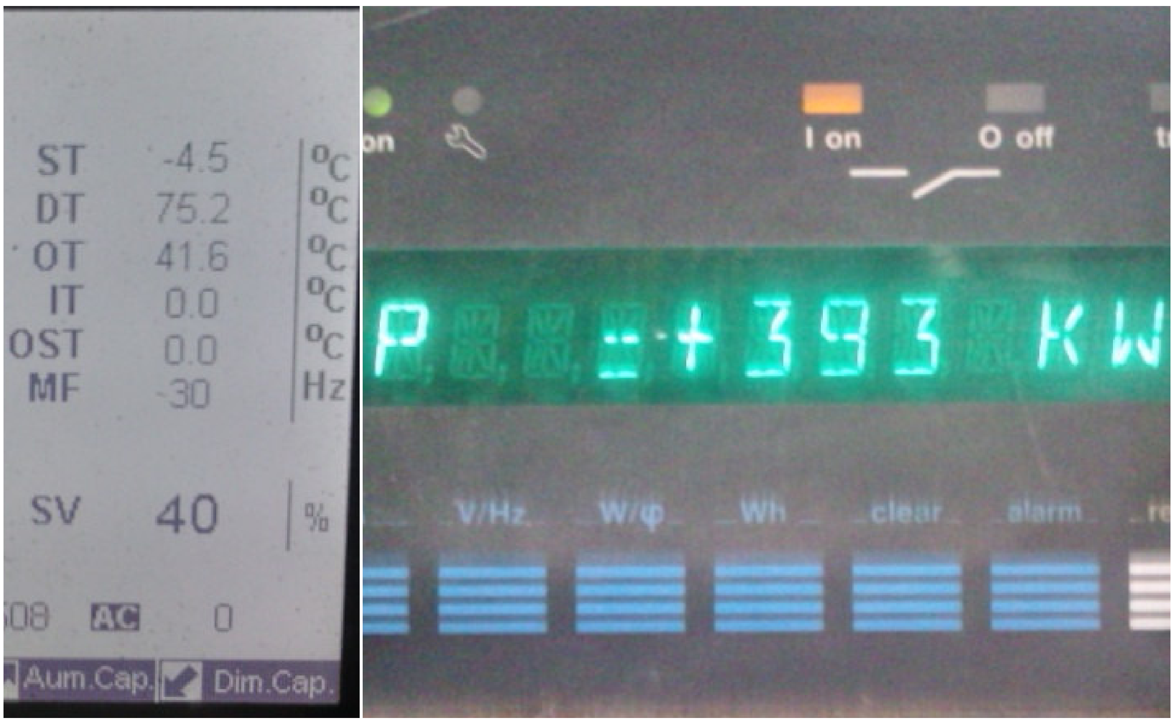

Figure 5. Dates of screw compressor modulating by slide valve

According to Fig. 5 the compressor with slide valve in 40% required an instantaneous power of 346 kW or 59% of the nominal power.

It was detected a great opportunity to save electricity improving the modulation of the compressor with installation of a VSD.

It had never benn installed any VSD in medium voltage in this factory and it was a big challenge to approve this project.

Firstly it was done a technical and economic study to get arguments to install this type of VSD.

It was visited three different suppliers of VSD in medium voltage. It was chosen the best option for this application and this project was approved, based on gains in electricity reduction.

In this case, the modulation of compressor with VSD would be more efficient because less energy would be consumed to produce the same cooling capacity, increasing the COP of machine. Additionally, the heat rejected by compressor also would be less. Thus, it would be possible to reduce the average thermal load in evaporative condensers too.

The VSD installed is showed in Fig. 6.

ISSN 2176-5480

Figure 6. The VSD installed

When VSD was installed the required power before and after was compared in the compressor to similar conditions. According to Eq. (2), it was possible to estimate the percentage of the capacity of the compressor with a frequency of 30 Hz and the slide valve in 77%, as shown in Fig. 7.

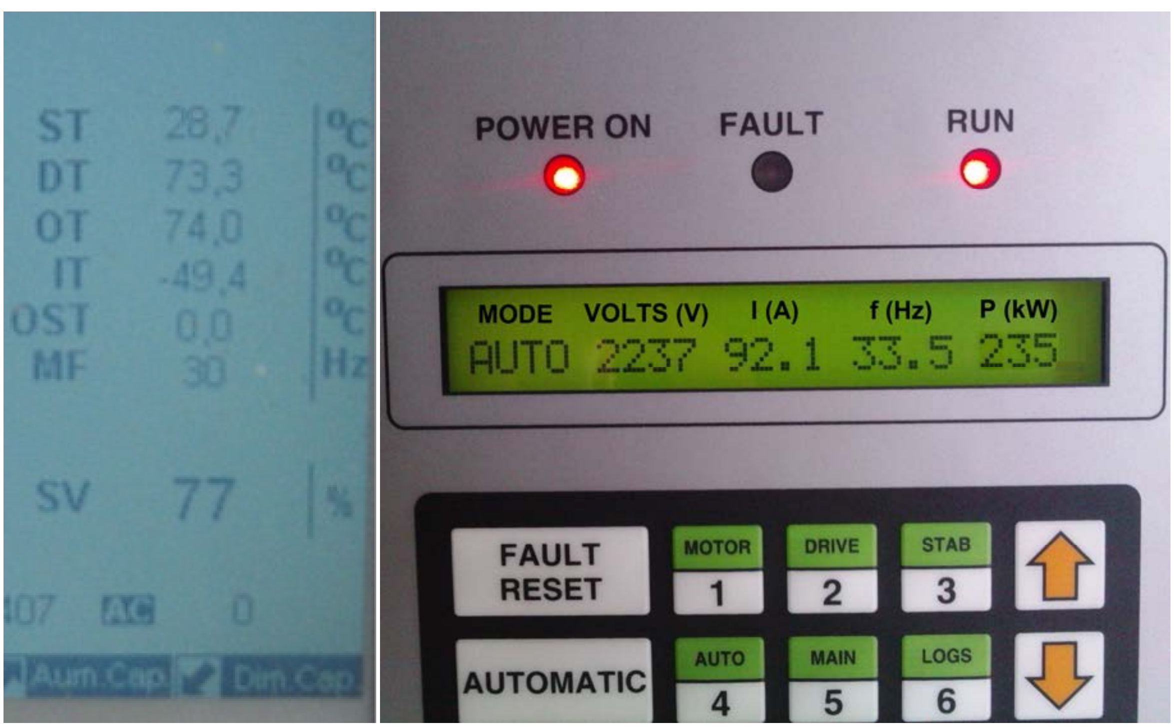

Figure 7. Dates of screw compressor modulating with VSD

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$$Capacity = \frac{77\%}{100\%} \times \frac{30[Hz]}{60[Hz]} = 40\%$$

The capacity in this case is approximately 40%. Considering that before VSD installation the percentage of slide valve position was the same of capacity in a screw compressor, as showed in Fig. 5, then in both cases the cooling capacity was the same, but the difference of instantaneous power was 158 kW.

3. CONCLUSION

The improvement project implemented in this factory was extremely interesting from electricity point of view, because with only one action, although with investment, there was reduction of power consumption, extremely significant.

Besides the energy saving, other improvements are expected with the installation of VSD, for example, increase the life of bearings and the motor.

VSD are an excellent tool for equipment that constantly modulate and / or operating at low capacity during a lot of time.

The investment of this project was significant, but the simple payback was one year and ten months, approximately, and implementation time was nearly eight months.

The reduction of power consumption with the implementation of this action was almost 1.4 million kWh per year, representing, approximately, US$ 115,000.00 per year. This economy was 2.2% of the total electricity consumption of the beverage factory.

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