Utilization of Soft-Starter VFD in Compressor Applications

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Abstract:

Polyethylene production requires high power multiple pole machines for ethylene gas compression. In most cases the machines are started DOL implying in high starting currents, additional mechanical stresses, influence on other loads, limitation of the number of consecutive starts and reduction of equipment's lifetime.

This paper introduces and compares the conventional DOL start with soft-starting alternatives, including the variable frequency drive. Advantages and disadvantages of using a drive are investigated. The importance of the design coordination between machinery and drive are addressed. Key points to specify a soft-starter, aspects to consider and pre-conditions of the installation are summarized. The possibility to start multiple machines is outlined and evaluated. Concluding the work, application case study results are presented and discussed.

1 Introduction

The modern petrochemical industry requires large compressors in the high power range. Specifically the polyethylene production is moving towards bigger rated machines that are often large enough to take advantage from soft starting or even impose the utilization of a soft starting solution. The commonly used Direct on Line (DOL) starting method implies in high transients in the power system and the machine. The high current drawn from the grid can cause problems such as voltage drop and in some cases uncontrolled shutdown, reducing process reliability and eventually resulting in production and financial losses. Towards the machine, the high starting current causes additional mechanical stress that may also affect the driven equipment, limiting the number of consecutive starts and reducing equipment's lifetime. These disadvantages can be overcome by using a soft start method. One or more of the large drives in a process plant can take advantage of the soft starting providing a more reliable, flexible and safe electrical installation.

This paper presents and compares DOL start with soft-starting alternatives, including the variable frequency drive (VFD). The requirements for specifying a soft starting system based on VFD and the importance of the design coordination between machinery and drive are addressed. Application case study results are presented and discussed in the final chapter.

2 Overview of Starting Methods

This section reviews most common soft-starting methods that will assist in building the case for the proposed solution for large motors.

There is a wide range of starting methods to select from [1]. The selection criteria are mainly guided by: short circuit capacity of the network, acceptable voltage drop (maximum starting current at minimum starting voltage), load torque, load inertia, starting time, starting duty category and temperature limitations of the machine due to its location in classified areas. The number of possible consecutive starts depends on the selected starting method.

Some starting methods are presented in Figure 1.

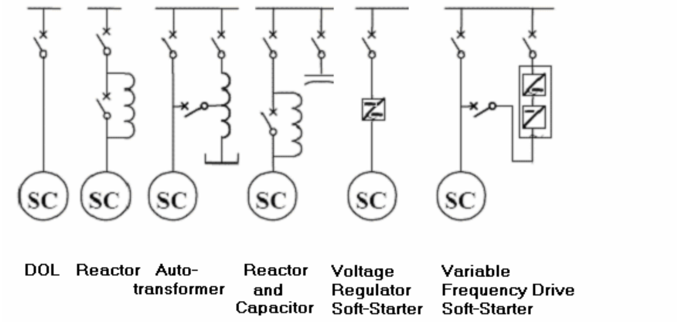

Figure 1: Starting methods alternatives.

2.1 DOL Start

The DOL start is the most common, simple and economical starting method. It gives high starting torque but requires a stable supply. The biggest disadvantages are the high starting currents that cause voltage drop on weak networks. Additionally it imposes large mechanical and thermal stresses on the machine.

2.2 Reactor Start

By connecting a reactor in series with the motor during start, the starting current is decreased proportional to motor voltage. However, this also means a substantial (quadratic) reduction in the available starting torque. The advantage of this method is its low cost in comparison with other methods. Attention should be paid to ensure sufficient acceleration torque.

2.3 Auto-transformer Start

The effect of auto-transformer start is similar to that of reactor start. Using a transformer to limit the voltage reduces the starting current and the torque, but less so than the reactor start. The method is more expensive than reactor start. Autotransformer motor starters consist of a transformer with voltage taps that allow operating from reduced voltage to full voltage. The starting torque is reduced only in proportion to line current while in reactor starting the starting torque is decreased as the square of the line current. The taps can be changed during run up to give high synchronizing torque.

2.4 Reactor/Capacitor Start

Reactor/capacitor start is used on networks with very low short circuit capacity. In this method a capacitor bank is energized during motor start in order to provide necessary reactive current to the motor.

During motor acceleration to rated speed, the capacitors are disconnected. If a large capacitor bank would remain permanently connected, the voltage could rise above motor's maximum allowed level. For this reason the grid voltage or motor speed need to be monitored and controlled in such a way to connect/disconnect complete or part of the capacitors to avoid overcompensation and overvoltages. If the motor voltage reaches an intolerable level or if the motor has not accelerated to a suitable speed, the controller must open the mains. Synchronous machines can also be designed to provide reactive power neutralizing the advantages of this method.

2.5 Voltage Regulator Soft-Starters

Voltage regulator soft-starters are based on a thyristor bridge with two anti-parallel coupled semiconductors in each phase. During the starting process, the soft-starter progressively increases the motor voltage from zero enabling the motor to accelerate the load to rated speed without causing torque or current peaks. The reduction of starting voltage also reduces the available torque to the driven load by the square of the voltage. Voltage regulator soft-starters can also be used to control the stopping of the machines.

2.6 Variable Frequency Drive Start

Although a static frequency converter is designed to continuous feed the machines, it can also be used exclusively for start-up[2]. The variable frequency drive (VFD) enables low starting currents because the motor can produce exactly the required torque at rated current from zero to full speed. The VFD soft-start provides smooth, step-less acceleration of motor and load while controlling inrush current and starting torque. As the voltage regulator soft-starters they can be used to control the stopping of the process. One VFD can be used to start multiple machines.

This chapter presented various available starting methods. Not all starting methods are effective when starting large machines. The selection of one or another will depend on system topology, starting torque requirements, machine and supply network characteristics. Important aspects to take into account are the maximum allowed voltage drop in the supply network during start, start load torque and required starting time. Applications often require a less stressful and more controllable soft-start system. A commonly used method is with auto-transformer. The main disadvantage of this option is that with given network short circuit capacity it cannot be used. In this case a Static Frequency Converter turns into a very attractive solution, as will be outlined in the next chapter.

3 VFD Soft-Starting

Figure 2 illustrates a typical configuration and the main components of a VFD [3]. The synchronous machine (SM) with its main excitation and the running circuit breaker (RCB) are the components which are required to operate the load direct on line.

The task of the VFD is to accelerate the SM from zero up to nominal speed and synchronize it to the power supply system by closing the RCB, and optionally - after RCB has been opened - to decelerate the SM from nominal speed to standstill. Its main function is to control the energy exchange between the power system and the motor, which during acceleration and deceleration is operated at variable frequency and voltage

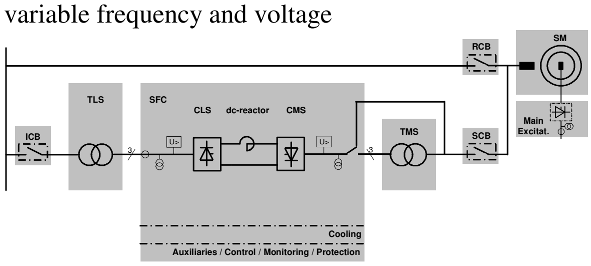

Figure 2: VFD soft- start with a 6/6 pulse converter.

The main components of the soft starting system are:

• Input circuit breaker (ICB) and starting circuit breaker (SCB)

• **I**nput transformer (TLS) and output **t**ransformer (TMS) which match the supply voltage and the machine terminal voltage to the converter design voltage. For economic reasons the VFD is designed with a voltage which is lower than the rated supply and machine voltages.

The transformers also limit the fault current in the converter. With the presented configuration the TLS and TMS have the same design, avoiding the saturation of the TMS at low frequencies.

• The VFD is based on the LCI (Load Commutated Inverter) principle. It comprises the following main units: line converter (CLS), dc-link reactor, machine converter (CMS) and control unit with auxiliaries that is responsible for the control, monitoring and protection. The transformer bypass is used at very low machine frequencies, from speed zero up to approximately 10% of speed.

A brief summary of the function of the VFD follows.

• The line converter CLS is connected via the input transformer TLS to the power supply system. It is line commutated and operates at constant voltage and frequency. The machine converter CMS is connected to the machine. It is "load commutated" and is operated with variable voltage and frequency. Both converters are interconnected through the dc-reactor, which decouples the different frequencies of the converters.

• When the machine is operated as a motor (energy flow from power supply system to machine), the line converter acts as a rectifier providing current control and the machine converter acts as an inverter commutating the currents between the machine phases. Optionally the machine can also be operated in generator mode (energy flow from the machine to the power supply system; used for fast deceleration) without adding any extra equipment in the VFD, by simply controlling the machine converter as a rectifier and the line converter as an inverter.

• Speed and torque (equal current) can be controlled independently.

• The machine is self-controlled and hunting or loss of synchronization is not possible since the firing pulses of the machine converter are derived from the machine voltages and are therefore in phase relation with the angular position of the rotor.

4 Specifying the Soft-Starter VFD

Not always all parameters of the network, the compressor and the motor are known in an early phase of the project but the knowledge of the key data allows the adequate selection and design of the soft-starter equipment.

The power of the VFD is defined by the required starting torque of the compressor. Starting with an unloaded or partly-loaded compressor allows reducing the size of the frequency converter and the VFD transformers.

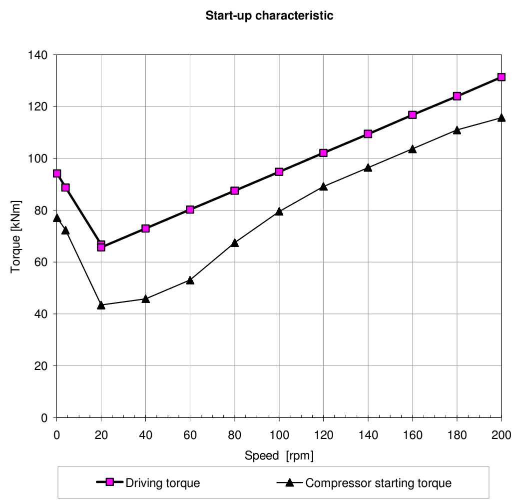

Figure 3: Typical starting characteristic curve

The driving torque of the motor is typically designed with a 10-15% margin above the required compressor torque over the entire speed range.

The starting torque – speed curve provided by the compressor vendor allows the VFD supplier to calculate the required VFD power. Together with the inertia of the rotating system (compressor, gearbox, motor) the expected starting time can be calculated. Any requirements for short starting time need to be specified since they can lead to an increased power requirement for the frequency converter and the VFD transformers.

In case the booster and hyper compressor are both synchronous machines one single soft-starter VFD can be used. Due to the rating of the smaller machine not always it's practical to invest on a synchronous machine and a DOL start could be more convenient. The proper selection depends on each case and should be evaluated.

4.1 Frequency converter

Frequency converters are available in different configurations and the selection is based on various parameters

• Required VFD power / starting power

• Short circuit capacity of the network (system fault level)

• Compliance with harmonic standards

• Availability of cooling medium

For smaller VFD powers (below 4000 – 5000kW) the selected configuration is a 06 / 06 pulse converter whereas for higher powers 12-06 or 12-12 pulse configurations are preferred. Higher pulse numbers allow reducing the harmonic impact the converter has on the feeding network (current and voltage harmonics) as well as on the mechanical system (pulsating torques).

Soft-starters are normally air cooled due to their short operation time. For high powers or in case of reduced availability of cooling air, water cooled converters might be preferred.

The control system of the frequency converter is designed for reliable protection of the motor during the starting of the compressor. It also communicates with the motor excitation system to adjust and monitor the motor voltage.

4.2 Transformers

The transformers at the in- and output of the frequency converter are required to match the network voltage and motor voltage to the permitted converter voltages. They reduce the harmonics injected into the network, limit the fault current inside the frequency converter and provide the required phase shifting in case of 12-pulse configurations. The design of these transformers is adapted to the parameters and requirements of the entire starting system.

For starting system, these transformers can be designed with a duty cycle (limited number of starts per hour) in order to reduce the size and investment costs for these components.

The transformers can either be dry type or oil immersed, depending on customers choice and environmental & installations conditions.

4.3 Motor

The electric motor design can theoretically be simplified when it is exclusively soft-started by a VFD and mechanical and thermal aspects of a DOL starts must not be considered in the motor design. However, such motors are frequently designed with DOL start capability as a back-up starting method.

The design of the VFD is adapted to match the given motor parameters; the motor parameters do not need to be changed to match the VFD design.

There is only one special requirement for motors started by a VFD and this is an excitation system that allows full excitation of the motor even at standstill. These are either DC excitation systems with brushes or brushless AC-AC excitation systems. For new projects, the AC-AC exciation is the preferred choice whereas DC exciation with brushes might be considered for installing a soft-starter VFD for an existing motor.

4.4 Harmonics

The operating time of the VFD soft-starter is small and the generated harmonics, even when higher than IEC and IEEE standards, are acceptable for the time duration. In case this is not accepted, a harmonic filter needs to be considered.

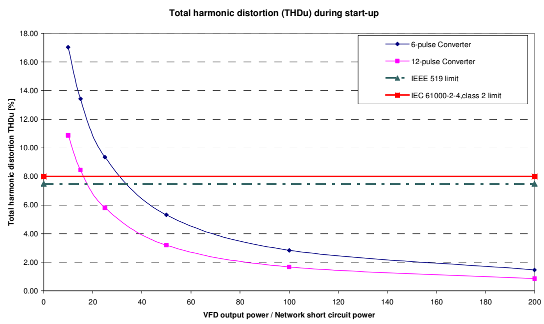

Figure 4: Harmonic distortion in the network.

Pulsating torques are not regarded as critical since the required starting torque is smaller than the nominal compressor torque and the starting is only a short and transient process. Mechanical resonances are not sufficiently excited by the generated pulsating torques to cause excessive mechanical stresses.

5 Case Studies: VFD starter for compressors

In the last 30 years several hundred starting systems in the power range of 1 – 20 MW converter power were installed in various applications (power, petrochemical, metals, research & testing) [3, 4]. Two case studies are presented in this chapter.

5.1 VFD soft-starter for a reciprocating compressor

In 2003 a Company required a soft starter for a 27 MVA / 28-pole / 214 rpm synchronous motor driving a reciprocating compressor. The power supply voltage and the rated motor voltage were both 10 kV, the rated motor current was 1'571 A_{AC}.

The load torque of the unloaded compressor during the start required a 5.6 MW starting converter. With this power the resulting acceleration time was approximately 27 s (Figure 5).

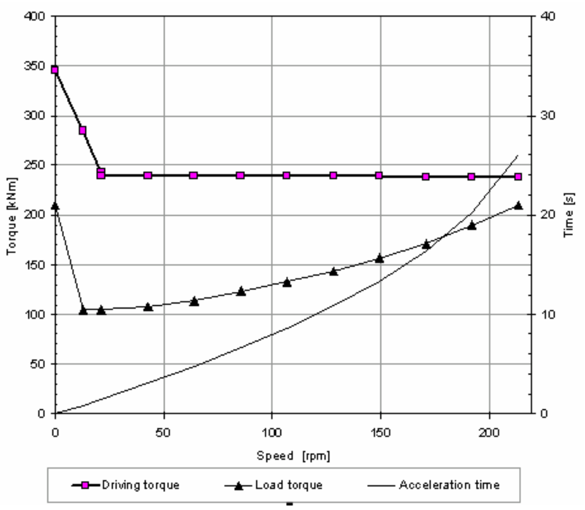

Figure 5: Design curves of 5.6MW starting system

An air cooled VFD with 12/12-pulse configuration was selected (Figures 6 and 7), with in- and output voltages of 2.1 kV and with a rated dc-current of 1'210 A_{DC}. Both 3-winding transformers are identical: 6.9 MVA rated power, Dd0y1 vector group and voltage ratio of 10 kV / 2x 2.1 kV.

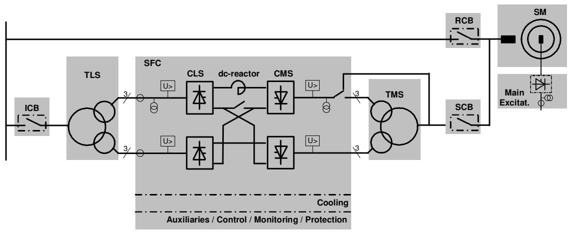

Figure 6: VFD soft starting with a 12/12-pulse LCI converter

Figure 7: 5.6 MW air-cooled LCI soft-starter

The electrical values of the motor during soft starting are shown in Figure 8. The motor voltage is controlled proportional to speed, from 0 V at standstill till 10 kV rated voltage at rated speed of 214 rpm, keeping nominal motor flux in whole speed range. The motor current during acceleration is controlled to a value equal or below 386 A, a value much lower than rated motor current of 1'571A.

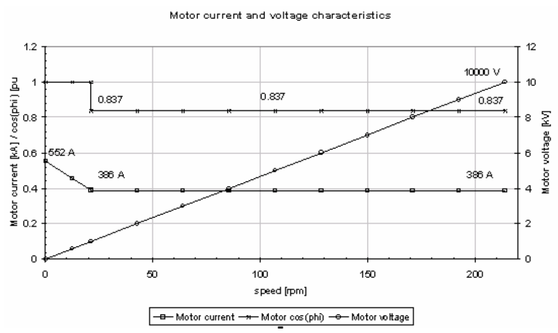

Figure 8: Motor electrical values during start.

5.2 VFD soft starter for two hydrogen compressors

In 1995 the owner of a refinery installed and commissioned two 5.4 MW synchronous motors aimed to operate two hydrogen compressors. Both motors were ordered and designed to start direct-on-line (DOL). At the beginning, each DOL-start produced troubles: loss of power supply in the whole refinery and, as a consequence, production stop. A palliative solution was then developed: every time one of the motors had to be started DOL, a team that included employees of the refinery and the power company was involved to stop production, in order to supply a power boost to be able to start and synchronize the motor DOL. This starting sequence was time consuming, inconvenient, expensive and did not satisfy the refinery owner.

The final solution was the installation of a 1.3 MW soft starting VFD. An air-cooled VFD with 6/6-pulse configuration was selected (Figure 9), that today starts the two motors sequentially, whenever required from the process.

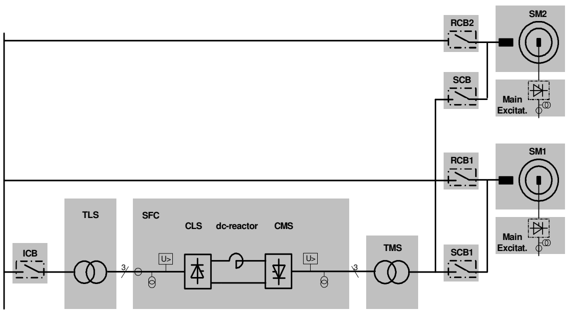

Figure 9: VFD soft starting of two motors with a 6/6-pulse LCI-converter.

After the installation of the soft-starter, an immediate benefit to the refinery was their profitability increase.

6 Conclusion

VFD starters can be used in new and existing MW applications. A pre-condition for using a VFD soft-starter is to have an AC type brushless excitation. A brief check will indicate if it's possible and what items eventually need to be modified. Depending upon the plant configuration the VFD can be used to soft-start one or more machines.

Compared to other staring methods, the VFD eliminates starting current peaks, reducing the stress on machines. This also results in reduced maintenance cost and increased lifetime of equipment. The number of starts can be selected as necessary. VFD for soft-starters has well proven design with documented reliability.

VFD soft-starters enables to accelerate the driven equipment safely to operation speed, limit the voltage drop in supply system and limit thermal and mechanical stresses in the equipment. A direct benefit of their utilization is the maximization of the distribution system capability. Taking all this aspects into consideration, VFD are an attractive solution for soft-starting compressors driven by electric machines in the petrochemical industry.

7 Acknowledgements

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