Environmental challenges in variable speed drive system (VSDs) applications: design and construction of a water cooling unit facing extreme temperatures and continuous critical duty

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A Background

Electric drives have lower environmental impact and greater flexibility than gas turbines in compressor applications. Although electric drives require a higher initial investment than conventional gas turbines, they have lower maintenance costs and improved efficiency. This leads to savings, especially when the electric drives are designed at an early stage of the industrial plant. Solutions based on adjustable speed drives are gaining momentum in oil and gas applications. Because many pump and compressor systems often run at partial load, the use of variable speed drives offers attractive benefits for the gas value chain.

The heart of the variable speed drive system (VSDs) is the frequency converter. Solutions vary from air-cooled to water-cooled converters depending on power and voltage requirements, and are sometimes subject to site availability. The cooling system design is crucial to ensuring long lifetime and high reliability of the whole system, particularly when installations encounter the harsh environmental conditions of chemical, oil and gas applications.

In 2009, our company was awarded a contract that included two VSDs rated 17MW to drive two centrifugal compressors for gas depletion plant facilities in Oman. The plant, located in a desert environment, required a system capable of withstanding severe environmental conditions. Following is a behind-the-scenes look at our design and testing of the raw water cooling system of a large adjustable speed drive for gas compression.

A.1 VSDs configuration

The variable speed drive system design included the following main equipment:

- Three-phase oil immersed four-windings transformer
- 12-pulse load commutated inverter (LCI)
- 17MW brushless synchronous motor
- Harmonic and power factor compensation filter

The drive system is controlled by the MEGADRIVE-LCI, the medium voltage load commutated frequency converter for synchronous motors. The LCI converter is one of the most reliable drives available on the market. It is a current-source drive based on thyristor technology and consists of an input rectifier, a direct current (DC)-link reactor and a load commutated inverter. The DC reactor serves to smooth the DC current and to reduce fault currents in the DC link. The rectifier and the inverter consist of two 6-pulse thyristor bridges series connected to form a 12-pulse system configuration both on the line side and the motor side.

Alternating current (AC) line voltage is supplied to the rectifier bridges through a four-windings transformer that has one primary and three secondary windings. The two secondary converter windings are phase-shifted by 30° (one secondary is wye-connected and the other winding is delta-connected) to ensure the 12-pulse rectification.

The harmonic filter connected to the fourth winding of the transformer reduces the reactive power consumption and the harmonics generated by the drive.

The 4-pole synchronous motor has been developed for heavy-duty applications.
In particular, this applies to the design and manufacturing of the rotor that makes the motor suitable for heavy start applications. The rotor body and the shaft ends are machined from a single forged alloy steel block. The synchronous motor is a totally enclosed machine designed for hazardous areas and equipped with an air-to-air heat exchanger. The motor and the exciter rotor have a common shaft that is supported by two stiff bearings. The motor exciter is fed via the excitation unit in the frequency converter.

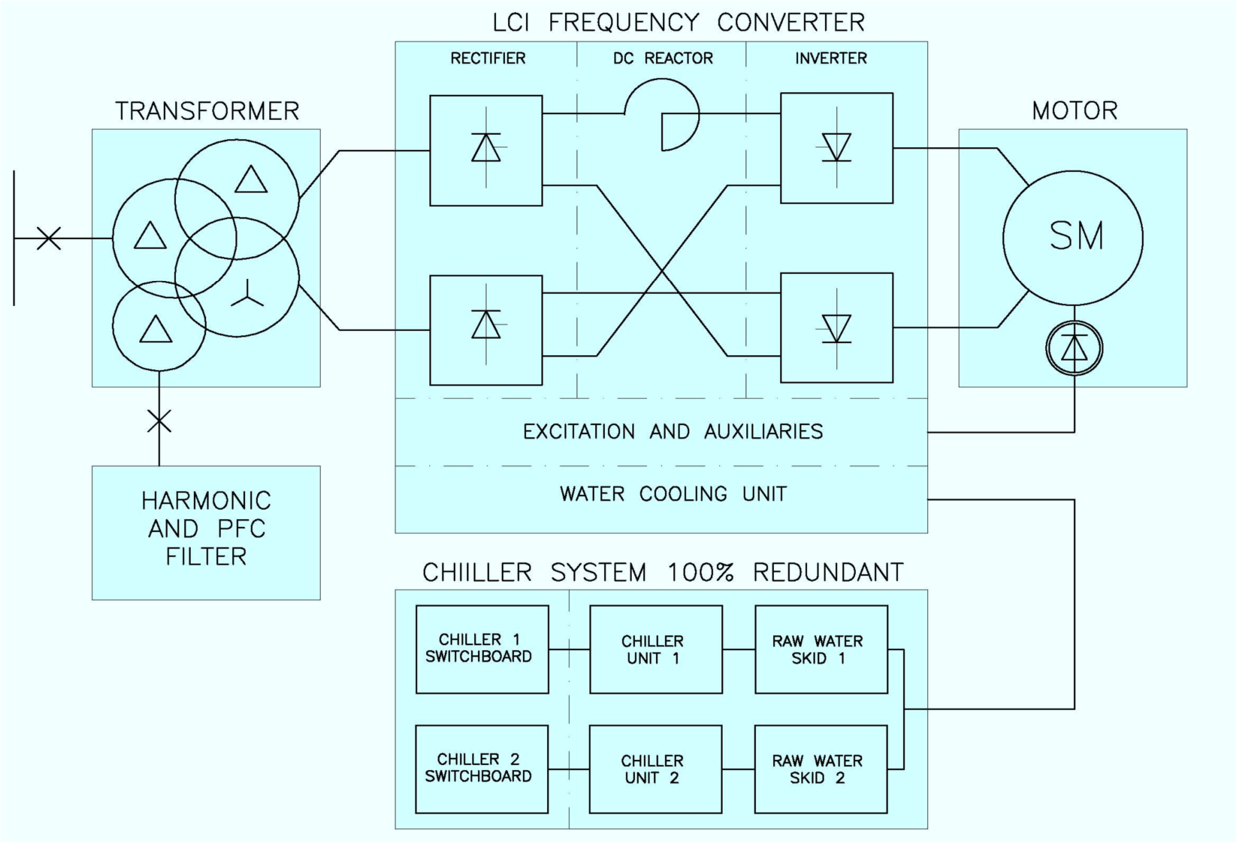

Figure 1: Variable speed drive system configuration

A.2 Critical design constraints

Due to power losses in semiconductors and other components, cooling of the LCI is one of the crucial points to be dealt with in the design, because an excessive temperature increase will force shut-down for thermal protection, with consequent loss of production. For high power applications, the cooling medium selected is water.

The LCI unit is cooled via an external water-to-water plate heat exchanger, with de-ionized water in the primary circuit and raw water in the secondary circuit. De-ionized water with low conductivity is necessary inside the frequency converter in order to avoid corrosion due to electrical potential differences. The primary circuit is a closed circuit where de-ionized water is pumped through the thyristor heat sinks, the resistors of the snubber equipment and the DC link reactor. Plate heat exchangers are fully redundant and circulation pumps are provided with automatic changeover upon failure.

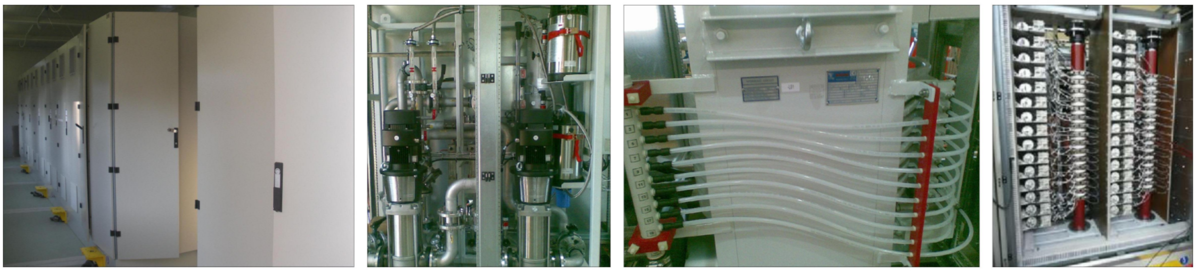

Figure 2: LCI frequency converter: overall, water cooling unit, DC link reactor, thyristor stacks

The raw water is cooled by a dedicated chilling system located outside the LCI electrical room. Due to the extreme environmental conditions and the need for continuous duty, the design of the chilling system was one of the most critical project activities. The raw water chilling system is 100% redundant in order to provide continuous cooling duty and provide highly reliable operation. The system features 2 chilling units and 2 water tank skids connected to each other, with the potential for immediate changeover to avoid temperature increase in the LCI primary circuit.

Figure 3: Chiller system: refrigerant unit and water tank skid

Below is a simple schematic of the raw water flow through the chilling system.

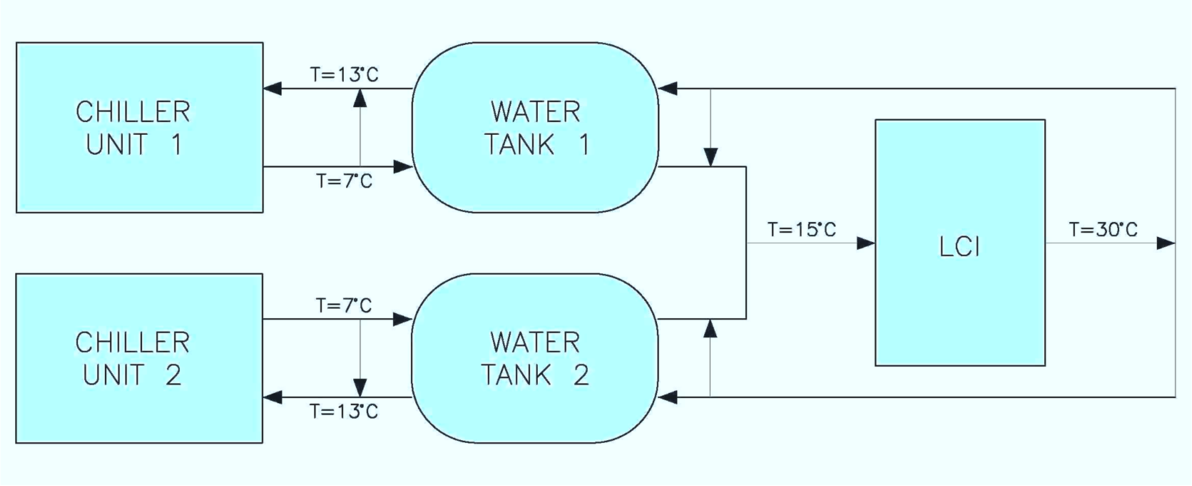

Figure 4: Chiller System: raw water flow

B Aims

B.1 Critical design constraints: ambient temperature

The first important constraint to be dealt with was extremely high environmental temperature.

The design basis of the project had to accommodate an ambient design temperature of 55°C and a maximum temperature (without system fault) of 60°C.

Moreover, the LCI was designed to withstand a temporary 10% overload demand from the compressor, and in these conditions the chilling system had to guarantee maximum cooling capacity of 250kW.

The following table highlights the main design data of the chiller system.

Data Description	**Design Value**
Chiller cooling capacity at 55°C ambient temperature	272 kW
Chiller cooling capacity at 60°C ambient temperature	250 kW
Flow rate through chiller unit	36,1 mc/h
Chilled water temperature from chiller unit to water tank (at 60°C ambient temperature)	7 °C
Water temperature inside buffer tank (at 60°C ambient temperature)	13 °C
Chilled water temperature to chiller unit from water tank (at 60°C ambient temperature)	13 °C
Flow rate through LCI cooling unit	14 mc/h
Chilled water temperature from water tank to LCI (at 60°C ambient temperature)	15 °C
Chilled water temperature from LCI to water tank (at 60°C ambient temperature)	30 °C

Table 1. Chiller system main design data

At such high ambient temperatures, the design of the air cooler (the condensing part of the chiller) is critical in terms of refrigerant fluid choice and compressor sizing. It meant that no standard solutions could be adopted and that the whole chiller system had to be tailored on specific requirements.

The refrigerant fluid considered was R 134A and each chiller featured 4 reciprocating compressors, each with a rated power of 160kW.

In the air-cooled condenser, the temperature scheme is as follows:

- Refrigerant condensing temperature: 72°C
- Max air inlet temperature: 60°C
- Max air outlet temperature: 68°C

In this kind of application, the design temperature and the environmental conditions are points to be carefully considered, even from the proposal phase of the project, because many of the primary brand vendors on the market are not always capable of developing highly customized solutions, and often “customized solutions” means longer delivery time and a more complex engineering phase.

B.2 Critical design constraints: continuous critical duty

As mentioned above, cooling system reliability is critical to the plant operation because a failure may cause shutdown of the compressor with subsequent loss of production.

For this reason, the system was designed to guarantee a full cooling capacity redundancy to the LCI.

Each chilling system (one for each LCI) features two chilling units, each capable of covering 100% of cooling, and two water storage tank skids (6 m3 each), with tanks and water circulation pumps. Additionally, the power feeding, monitoring and control cabinets have been tailored and specified/designed above all manufacturer standards for specific off-skid installation.

“Cold standby” was the operative configuration chosen. While only one chilling unit was on duty, both water tanks were connected. Thus, the whole volume of water was kept at operating temperature in order to allow a quick switchover between the two units without any impact on the LCI temperature. The switchover between the two units was foreseen not only in case of failure of the unit on duty, but also for maintenance purposes.

B.3 Critical design constraints: materials and construction choices

Another design issue to be considered was the desert environment itself, with low water availability, and sand and dust containing chlorides and sulphides.

Low water availability forced the design toward a closed circuit for the raw water as well, thus keeping the water consumption to a minimum. However, water in a closed loop can cause problems. Accumulation of chlorides and sulphides from sand and dust entering the system can cause corrosion problems in the water circuit. To avoid this, the water tanks were kept under pressure with a nitrogen blanketing system. All piping materials were made of stainless steel (AISI 316L).

C Methods

C.1 System components

At this point, a closer analysis of chilling system technical features is beneficial.

Each system is composed of:

- n° 2 chilling units, each featuring:
  - n° 4 reciprocating compressors
  - n° 1 evaporating section: shell and tube water/cooling fluid heat exchanger
  - n° 1 condensing section: 4 condensing coils with 2 air fans each
  - control and safety instruments
- n° 2 water tanks and pumps skids, each featuring:
  - n°1 stainless steel water tank, volume 6 m3
  - n° 2 inlet water pumps (one working, one stand-by)
  - n° 2 outlet water pumps (one working, one stand-by)
  - blanketing nitrogen distribution
  - instrument air distribution
- n°2 electrical and control panels featuring:
  - power section, receiving one main power supply and feeds:
    - compressors and fan motors: withdrawable drawers with conventional relays
    - pump motors: withdrawable drawers with intelligent relays
  - control section, receiving n° 2 power supply (240 V - 50Hz) from 2 uninterruptable power supply (UPS), with changeover managed by the programmable logic controller (PLC)
  - redundant PLC, managing all control parameters of the cooling section and automatic changeover between units
  - direct digital control (DDC) to manage compressor start/stop with reference to outlet water temperature

C.2 Control and changeover philosophy

Along with the physical and technical characteristics described previously, careful design of the control system is fundamental to achieving safe and reliable operability of the system and maximum possible lifetime of its components.

Main parameters to be controlled are the following:

- water temperature to LCI
- water flow rate

- buffer tank water level
- pumps discharge pressure
  - primary water circuit (from chiller to tank)
  - secondary water circuit (from tank to LCI)
- differential pressure across strainers
  - primary water circuit (from chiller to tank)
  - secondary water circuit (from tank to chiller)

The refrigerant circuit is controlled by DDC that start/stop the compressor in order to achieve the full cooling capacity in 4 steps and have capacity reduction if required at 25%, 50%, 75% or 100% of overall cooling capacity.

Starting sequence as follows:

- ✓ start temperature of first compressor: water from LCI at 13,5°C
- ✓ start temperature of second compressor: water from LCI at 14°C
- ✓ start temperature of third compressor: water from LCI at 14,5°C
- ✓ start temperature of fourth compressor: water from LCI at 15°C

Actuated crossover valves between the tanks allow the temperature of the stand-by tank to be kept at the same range as the one on duty.

The changeover between the redundant equipment is managed by the PLC, and is activated either to cope with anomalous operating conditions (maintenance, failure of one component, etc.) or to distribute the working load between equipment (anti-ageing system), thus allowing a longer lifetime for the system and its components.

The anti-ageing changeover is mainly based upon the working hours of each component.

A counter implemented in the PLC will count the effective working hours of each chilling train, pump and compressor. When the counter reaches the value set by the operator, the PLC will command the relative changeover.

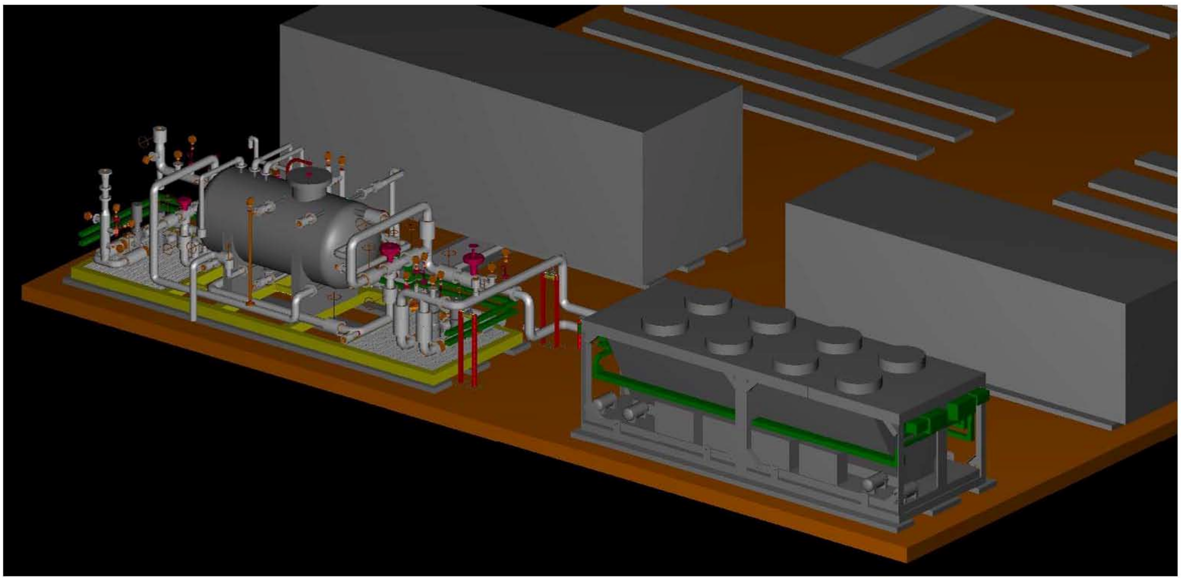

Figure 5. Overview of one chiller system taken from 3D model

C.3 Acceptance tests

Because the system's operating environment was so extreme, the chiller had to be tested in working conditions.

The performance test was carried out on one (1) chiller unit (25% of supply), in order to verify that the design was correct and the required performance parameters were met.

The test was performed in a certified third-party laboratory, according to standard EN 14511 (tolerances on measurement values and instruments accuracy according to standard EN 14511).

During the test, the chiller unit was operated with a temporary electrical control panel.

Test conditions were as follows:

- constant water flow at required temperature passing through the water chiller evaporator (10L/s – 13.5°C)
- two (2) hours constant ambient temperature inside climatic testing room +55°C with chiller unit running, starting from ambient temperature
- suitable calibrated instruments and certified devices for continuous monitoring of following parameters:
  - chiller unit inlet and outlet water temperature
  - climatic testing room ambient temperature
  - inlet/outlet water flow

D Results

The performance test was considered fully satisfactory in light of the following results: average outlet water temperature 7°C, during two hours of chiller running with constant 55°C ambient temperature and 10L/s water flow entering into chiller evaporator at 13.5°C (tolerances on measurement values and instruments accuracy according to standard EN 14511).

The startup sequence of the chiller unit compressors was done manually by means of no.1 manual selector (0-1 position) installed for each compressor and operated by a service engineer in order to reach and keep the operating test conditions (7/13.5°C water temperature across the evaporator).

An additional test at increased cooling load (inlet water temperature 14.2°C /300 kW outlet water temperature 7°C) at 50°C ambient temperature was successfully carried out.

E Summary

To avoid significant production losses resulting from unplanned shutdown, high availability and reliability requirements must be fulfilled in oil and gas production plants. This is especially important in unmanned plant scenarios.

High-power applications of large variable speed drives usually require a water cooling system capable of dissipating frequency converter heat losses.

The design of the water cooling system must consider the worst ambient and operation conditions and engineered solutions must ensure a fully redundant system capable of providing continuous cooling duty.

As we know, environmental conditions are always an important factor in the design of complex systems such as the VSDs, and the underestimation of their importance can drive the project into unforeseen management problems and huge delays.

In the present case, high ambient temperature forced the engineering phase to tackle the chilling service, which is normally considered as an “off-the-shelf” utility, as a wholly customized system. Our company responded with tailored solutions covering every aspect of the design, from refrigerant fluid to piping materials and control cabinets, and from process arrangements to control hardware configuration and philosophy.