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ASPECTS REGARDING THE USE OF VARIABLE SPEED DRIVES IN THE CASE OF EXPLOSION PROTECTED ELECTRIC MOTORS USED IN EXPLOSIVE ENVIRONMENTS

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Abstract: This paper presents some of the most important aspects that have to considered regarding the functioning of variable speed explosionproof electric motors designed for use in explosive mixtures of gases and vapors, highlighting some of the most important technical issues which can occur in practice, as well as some practical solutions in terms of designing these types of electrical drives in order to overcome some of the short comes which can arise while functioning in various technical installations of operators in the oil and gas industry.

Key words: variable speed drive, explosionproof electric motor, explosive atmosphere.

1. GENERAL CONSIDERATIONS REGARDING VARIABLE SPEED DRIVES

Explosion protected electric motors, designed to operate safely in hazardous areas, such as oil and gas as well as chemical industry play a crucial role in preventing accidents. Variable speed drives (VSDs) have been developed in order to enhance both the safety and efficiency of these motors.

The reasons for a rotor cage three phase asynchronous electric motor to be supplied by a static frequency converter, instead of a sinusoidal supply, is to reduce the energetic consumption and to optimize the technological processes, improving the reliability and safety in operation. Equipment consisting of rotor cage three phase asynchronous electric motor supplied by a static frequency converter are designed to enhance the performances in exploitation, in the sense of reducing the energetic consumption, optimization of the technological processes, enhancing the reliability and safety in operation, simplification of the installation and reducing of the costs for the maintenance and repair of the overall equipment.

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Explosion protected electric motors are designed to prevent the ignition of surrounding explosive gases, vapors or dust. These motors have to be manufactured according to explosion protection standards they and have to comply with certain rules of certification, such as ATEX in Europe [1, 2] and IECEx globally, ensuring they can operate safely in classified hazardous areas.

The combination of an electric motor supplied via a frequency converter can be used in a wide range of power drives systems in which the variation of speed ensures the regulating of certain technological parameters (pressure, flow, etc.).

1.1. The Power Drive System

The concept of a power drive system (PDS) is used to describe an electric motor drive system within an overall installation. The terminology is used throughout IEC and EN standards relating to electrical variable speed drives to describe a combination of components, including a power converter and motor. The conventional illustration of a PDS and its component parts is shown in Figure 1 [3], [9], [11].

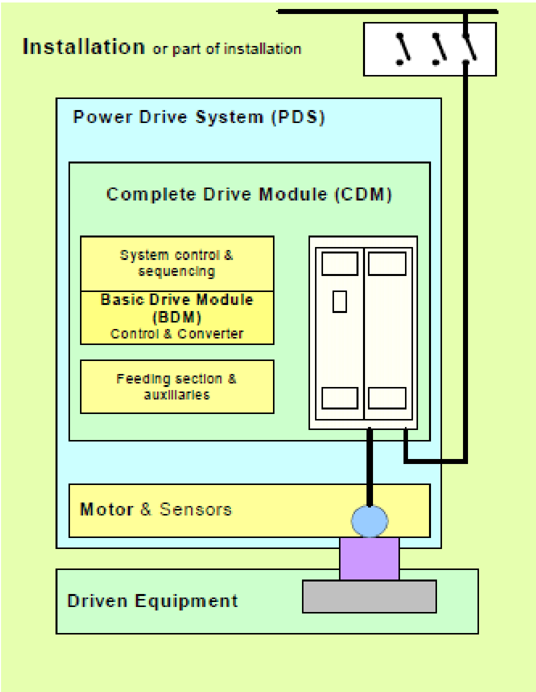

Fig.1. The Power Drive System

Where:

• BDM – Basic drive module consisting of power input, control and power output selections;

• CDM – Complete drive module consisting of BDM and auxiliary sections, but excluding the motor and motor – coupled sensors.

• PDS – Power Drive System, comprising CDM, motor and sensors.

2. POWER DRIVE SYSTEMS (PDS) USED IN POTENTIALLY EXPLOSIVE ATMOSPHERES

2.1. Operating conditions of the PDS

Usually only the motor and driven load will be installed in the potentially explosive atmosphere, with the converter supply operating in a safe area.

Compared to a motor connected directly to a mains supply, the motor manufacturer must take account of a converter supply changing the operation conditions mostly due to:

- reduced cooling for self-ventilated motors at reduced speed, due to reduced airflow;
- increased loses due to non-sinusoidal supply at the motor's terminals leading to increased temperature rise, compared to sinusoidal supply;
- specific additional heat generation, particularly in the rotor cage and supporting structure as a result of harmonic currents;
- induced voltages in the rotor, which can lead to currents through the bearings (due to PWM technology and high switching frequency);
- dielectric heating due to high frequency / voltages.

For these reasons the application of the ATEx Directive calls for an extra attention to be paid when an Ex-motor is used with a frequency converter (CDM), and may require them to be tested together for certification [1, 3], [10], [12].

2.2. Selection of Ex-motor and BDM/CDM for PDS applications

2.2.1. General

The safety aspects include ensuring that:

- no additional risks exist of sparks due to premature insulation failure or to shaft voltages / bearing currents;
- no additional risks exist of exceeding the temperature class due to extra loses and possibly lower cooling.

2.2.2. Risk management of sparks

The motor and converter manufacturers will ensure that bearing currents are limited and sparks are prevented using techniques including:

- suitable stator insulation materials and techniques;
- reduction of voltage transients, by use of electrical filters.
- prevention of excessive bearing currents, by use of insulated bearings or bearing houses, usually at the non drive-end of the motor, reduced or optimized switching frequency, or by the use of electrical filters.

2.2.3. Risk management of excess temperature

The temperature class of the motor shall be checked by calculation or by testing as required by the appropriate standard concerning the type of protection of the motor [5, 8].

There are two main methods for diminishing the risks of excess surface temperature:

a) to have a physical feedback signal from the motor (thermal sensing element) and use this signal to initiate shut down in the case of excess temperature;

b) to control and limit the heat (temperature) which can be generated by the motor.

Temperature sensing technique uses thermostats, thermistors or RTD devices embedded in the stator windings, with the appropriate controls to ensure that the temperatures are within the permitted limits.

This does not always control any additional temperature rise within the rotating element, and for high power motors the manufacturer / Notified Body may stipulate the use of additional thermal detectors at the bearings.

It is also mandatory that the protection used in conjunction with the temperature detectors is suitable for the purpose (including any intrinsic safety barriers where appropriate). As the correct functioning of the protection is critical to the safety of the overall system, the functional safety of the protection should be assessed and approved in accordance with the appropriate standards [5, 8], [13].

Control of heating is achieved by limiting the current passing through the motor at a specific frequency. As the torque generated is directly related to current, a loadability curve may be established, which gives the maximum continuously available torque at a particular speed or frequency. The curve is dependent on the motor design, and can be advised by the manufacturer. The loadability curves must take into account the CDM technology, the surface temperature class of the motor and the type of Ex protection (flameproof enclosure, increased safety, etc.).

In many cases a manufacturer will publish the loadability curves for his products to allow users to check that the load characteristics fall within the PDS capability. Figure 2 shows an example of a loadability curve for a cage induction motor, fed by an inverter. This shows the reduction in torque capability at low speeds due mainly to the reduction in ventilation, a reduction in torque at base speed to allow a sufficient margin for safety, and a reduction above base speed due to the application of a constant voltage (field weakening) [3, 6, 7].

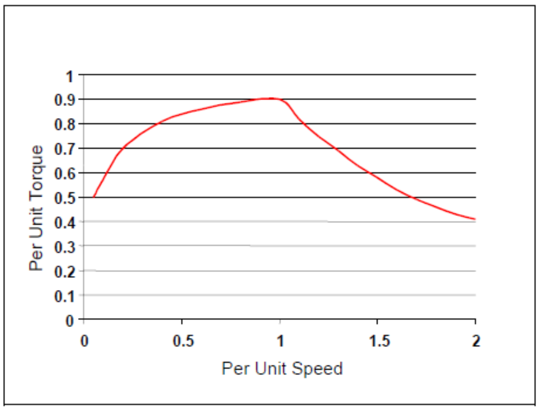

Fig.2. Example of loadability curve established by test for induction motor for PDS use

2.3. Specific requirements for flameproof "Ex d" and increased safety "Ex e" electric motors

In the case of flameproof Ex d electric motors, the following requirements apply [8]:

Flameproof electric motors Ex d supplied at variable frequencies and voltages require either:

a) means (or equipment) for direct temperature control with the help of imbeded sensors, which are specified in the technical documentation of the motor, or other effective means for the limiting of maxium surface temperature of the motor enclosure. The action of the protective device must lead to the disconnection of the motor supply. In this case, it is not mandatory to test the combination between the motor and the converter together; or

b) the motor to have been submitted to a type test, for this kind of service, as an assembly together with the converter, specified according to the provisins of the standard CEI 60079-0 and with the protective device provided.

The user must also observe that in some cases, the highest temperature occurs on the motor shaft and for motors with type of protection increased safety Ex e terminal boxes, when using converters with high frequency pulses in the output, care should be taken to ensure that any overvoltage spikes and higher temperatures which may be produced in the terminal box are taken into consideration.

As regards the type of protection increased safety Ex e, electric motors which use this type of protection and which are supplied at varying frequency and voltage by a converter, have to be type tested for this duty in association with the converter and the protective device. The motors should be used within their electrical rating and the converter configuration should be set to match the motor rating information with respect to frequency range and any other specified parameters such as minimum carrier frequency. The converter configuration shall enable to adjust the parameter [8].

The user shall also take into account that permanent magnet motors operate as a generator while coasting after the power is removed. In the case of Level of protection "eb" where the voltage can be greater than the rated voltage, the motor-converter system wil need to be suitable for the voltages that wil result [8].

3. PARTICULAR REQUIREMENTS IN THE CASE OF EXPLOSION PROTECTED ELECTRIC MOTORS SUPPLIED BY STATIC FREQUENCY CONVERTERS IN HAZARDOUS AREAS

3.1. Constructive characteristics

The electric motor has to be designed in such a way that the maximum surface temperature of the enclosure of the motor is less (with a certain safety margin) than the minimum ignition temperature of the gases and vapors which are specific to the application in which it will be used.

In order to check and measure the external temperature of the motor running at rated load, heating tests have to be carried out [5, 6].

Most electric motors which are normally rated in T4 temperature class are being tested by supplying via static frequency converter using a load characteristic according to Figure 3.

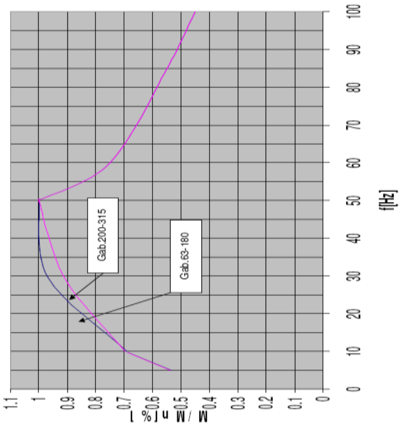

Fig.3. Loading characteristics [4]

3.2. Life expectancy of winding insulation

When the motor is supplied via a static frequency converter, the winding insulation system will be submitted to higher dielectric stresses, as compared to supplying the motor with sinusoidal voltages. When a current source converter is used, voltage peaks are likely to occur in the motor, especially during the commuting phase, voltage peaks which can lead to high stresses in the winding insulation system.

The dielectric stress of the winding insulation is caused by the peak voltage, the rise time and the frequency of the impulses produced by the converter, the characteristics and the length of the connections between the converter and the motor, the winding construction, as well as other parameters of the entire system.

In order to deal with this issue, filters are sometimes required to be used at the output of the converters [6, 7].

Due to the complex inter conditionings, it is necessary to have a careful design of the entire electric power drive. This requires sometimes the use of filters at the output of the converter [6, 7].

3.3. Thermal protection of the insulation

Usually, thermistors with positive temperature coefficient (PTC code), which are imbedded in the windings of the motor, are used for the temperature control of electric motors which are supplied by static frequency converters. These thermistors are connected to the protective device of the static converter, through the terminal box of the motor, thus ensuring that the motor can be disconnected safely from the electric power supply, in case of overloading conditions, so that the maximum temperature of the motor will not exceed the maximum admitted limits. The entire system comprising the electric motor and the frequency converter, for explosive atmospheres has to ATEX certified [1, 2, 8]. The motors are tested when supplied by the converter and the temperature of the motor is determined in order to predict the temperature evolution and to prevent the overheating of the motor [6, 7].

3.4. Bearing currents

Several situations can cause bearing currents and, in all cases, the bearing current will flow when the voltage is developed across the bearing sufficient to break down the insulating capacity of the lubricant.

The main sources for this voltage are:

- Asymmetry in the magnetic circuit of a motor creates a situation that causes slow frequency bearing currents (usually for motors with power greater than 400 kW);
- Electrostatic build up on the shaft of the motor due to the driven load such as an ionized filter fan;
- High frequency common mode voltage at the motor terminals generates common mode currents parts of which can flow through the bearings of the motor or of the driven equipment. The common mode currents may also generate a voltage across the bearings by transformer action. These effects result from the use of fast switching semiconductor devices and can cause bearing problems, due to different effects, in motors of all ratings.

In the case of generation of high frequency bearing currents, the most important factors that define which mechanism is prominent are the size of the motor and how the motor frame and the shaft are grounded. The electrical installation, meaning a suitable cable type and proper bonding of the earthing conductors and the electrical shield, also plays an important role, as well as the rated converter input voltage and the rate of rise of the converter output voltage. The source of bearing currents is the voltage across the bearing. There are three types of high frequency bearing currents: circulating, shaft earthing and capacitive discharge [7].

3.5. Supply cables and the distance motor – converter

Several parameters have to be considered for the determination of the cross section of the cable as well as the distance between the converter and the motor: the value of the current, the maximum diameter of the sealing gasket of the cable gland entry of the terminal box of the motor, the drop voltage across the cable, which can affect the motor parameters. By using frequency converters, it is possible to compensate the voltage drop across the supply conductors of motors which are located at great distances from the converter [6, 7].

3.6. Frequency/speed variation field and maximum safety speed in operation

Function of the design of the motor, operation at higher speeds can be allowed, but this possibility has to be checked by appropriate testing.

In the case of operation at speeds higher than the rated speed, the noise levels and the vibrations increase. It may be necessary to re-balance the rotor in order to operate at speeds higher than the rated speed.

Long term operation at speeds close to the maximum safety operation speed can lead to a considerable life shortening of the bearings.

This may also affect the sealing of the shaft and / or the lubrication intervals of the bearings [6].

4 CONSTRUCTIONAL AND FUNCTIONAL REQUIREMENTS IN THE CASE OF EXPLOSION PROTECTED (FOR EXAMPLE FLAMEPROOF ELECTRIC MOTORS „EX D", SUPPLIED BY STATIC FREQUENCY CONVERTERS

Electrical motors which endorse the type of protection "flameproof enclosure" have to be designed and manufactured according to the specific standards EN 60079 – 0 and EN 60079 – 1, and have to be certified by a Notified Body in the European Union. The Notified Body will issue an ATEX certificate for the electric motor. The static converter is normally located outside the Ex classified area (see also subchapter 2.3).

The most important subassemblies of flameproof enclosure motors that endorse this type of protection are: stator casing, shields, rotor, fan and fan hood, terminal box, terminal box cover, as shown in Fig.4.

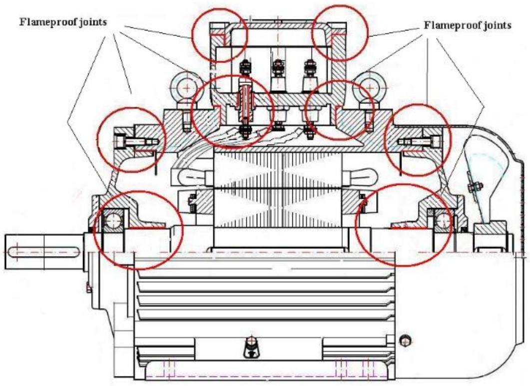

Fig.4. Flameproof enclosure motor assembly

In order to be ATEX certified, the electric motors designed with type of protection flameproof have to be submitted to certain tests and verification in explosive mixtures, according to the explosion group (or groups) for which the certification is seeked. The enclosure of the motor (as well as the terminal box enclosure) have to withstand the following type tests and verifications [5]:

- reference pressure determination and overpressure test;
- test for non-transmission of an internal ignition.

In the case of reference pressure determination, each test consists of igniting an explosive mixture inside the enclosure and measuring the pressure developed by the explosion.

The explosive mixture is ignited by one or more ignition sources. The location of the ignition sources, as well as of the pressure recording devices is left att the discretion of the testing laboratory, based on its experience to find the combination that produces the highest explosion pressure. After that, the enclousre will also be tested for the ability to withstand 1.5 times this highest explosion pressure during the so called overpressure test, so that the manufacturer of the motor will have to design the enclosure for this new increased pressure of 1.5 times the reference pressure.

For the test for non-transmission of an internal ignition, which is normally carried out in a so called explosion chamber, in which the enclosure of the motor is placed, both the enclosure of the motor, as well as the explosion chamber are filled with the same explosive mixture, at the concentration required by the specific standard (EN 60079-1).

The explosive mixture in the enclosure of the motor is then ignited using an ignition device and it is observed whether the explosion inside the enclosure is transmitted to the explosive mixture outside the enclosure (explosion chamber). This is a yes / no test (a qualitative test), the only result that matters is whether the internal ignition of the explosive mixture has been transmitted or not, to the external surrounding atmospehere.

The electric motors are normally designed for use in hazardous gases and vapors related to explosion groups IIB or IIC (which contains the most dangerous gases, in terms of their explosion potential). The temperature class of these motors (that is the maximum external surface temperature that can be obtained in normal operation, including any abnormal operation, such as overloads, which are admitted by the manufacturer) is normally rated T3, T4, T5, or in some cases even T6, depending on the maximum ambient temperature and rated power of the motor as well as the frame size of the motor involved.

The terminal box (or terminal boxes) of the motor is normally also designed with type of protection flameproof enclosure, but it can also endorse other types of protection, such as increased safety Ex e, which can easily be used in association with the flameproof type of protection of the stator frame of the electric motor.

As far as the environmental conditions are concerned, most electric motors are manufactured for operating and transport in areas with temperate climate, but of course, on request, they can be designed for use in other areas, as well.

5. LEGAL REQUIREMENTS REGARDING THE SAFETY IN OPERATION FOR EXPLOSION PROTECTED ELECTRIC MOTORS SUPPLIED BY STATIC FREQUENCY CONVERTERS

5.1. Classification of environment and equipment according to the ATEX Directives

The European Union has adopted two major Directives covering all equipment used in a potentially explosive atmosphere:

- the Product Directive ATEX (officially known as the product Directive 2014/34/EU,) concentrates on the responsibilities of the equipment manufacturer and It defines the Essential Health and Safety Requirements (EHSRs) of equipment;

- the Worker Protection Directive ATEX 137 (officially known as the Worker Protection Directive 1999/92/EC).

This Directive is concerned specifically with Worker Protection, and concentrates on the responsibilities of the end user. It classifies the environment into Zones and states which Category of equipment must be used in each Zone.

5.2. The product Directive 2014/34/EU

This "Product Directive" is required to be implemented by the product manufacturer before a product may be placed on the European market for use in a potentially explosive atmosphere. This Directive constitutes a real "new approach" compared to previous directives. According to this "new approach" the ATEX Directive introduces the EHSRs needed for all equipment installed in potentially explosive atmospheres instead of prescriptive solutions given in previous directives. Directive ATEX 2014/34/EU applies consistently throughout the EU and the EEA [1].

All equipment shall be delivered with instructions for safe:

· assembling, installation and taking into service;

· operation, adjustment and maintenance;

· dismantling.

The manufacturer shall, in most cases, use a quality management system for production quality or product quality assurance that has been assessed and approved by a Notified Body, chosen by the manufacturer.

5.3. The Working Protection Directive 1999/92

Among different articles, this Directive specifies:

· places where explosive atmospheres may occur (Zones);

· category of equipment according to the Zone.

The users of all equipment used in potentially explosive atmospheres (Ex – equipment) are responsible for the application of this Directive.

For the first time, the Directive contains requirements for equipment and for worker protection in locations having atmospheres with potentially combustible dust.

The safety of an installation in a potentially explosive atmosphere is the result of a cooperation between the equipment manufacturer, the installer and the end user. This directive concentrates on the duties of the end user, which are [2]:

· explosion protection measures should be taken and an Explosion Protection Document (EPD) must be established;

· zone 0 or zone 20 requires category 1 equipment;

· zone 1 or zone 21 requires category 1 or category 2 equipment;

· zone 2 or zone 22 requires category 1 or category 2 or category 3 equipment;

The most important PDS related responsibilities are:

- the employer should train workers on potentially explosive atmosphere issues;
- authorisation should be delivered to each employee who is working in a potentially explosive atmosphere;

- explosion protection measures shall be taken and an Explosion Protection Document (EPD) shall be established;
- the employer should initiate a co-ordination procedure in the case of maintenance of equipment from different 'origins' in potentially explosive atmospheres. When equipment has to be repaired, the end user has the responsibility to select a competent repair shop and, where spare parts are used, to ensure they comply with the legislation where relevant;
- the employer shall implement the following equipment selection principles:
    - zone 0 or zone 20 requires category 1 equipment;
    - zone 1 or zone 21 requires category 1 or category 2 equipment;
    - zone 2 or zone 22 requires category 1 or category 2 or category 3 equipment.

Compliance with the ATEX Directives provides improved safety aspects, first of all by simplicity, because there are only two fields of responsibility. Third parties are resposible either to the manufacturers or by default to the end users, and the duties of each party are clearly defined in the specific standards (Figure 5) [3].

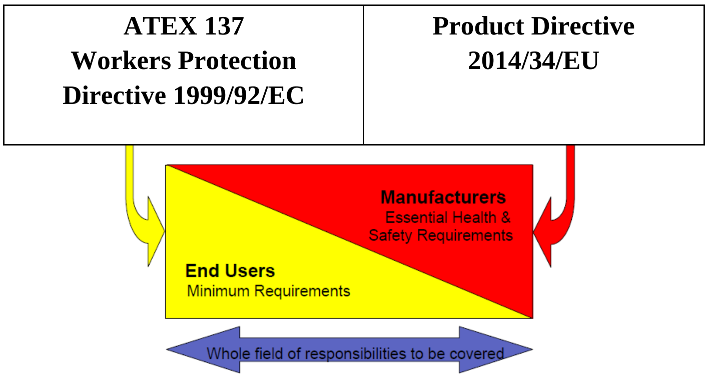

Fig.5. Resposibilities

6. CONCLUSIONS

Variable Speed Drives represent a significant advancement in the operation of explosion protected electric motors in hazardous environments. By enhancing safety, improving energy efficiency and offering greater operational flexibility, VSDs contribute to the reliable and efficient performance of critical industrial processes.

As industries continue to prioritize safety and efficiency, the adoption of VSDs in explosion protected motors is set to become increasingly prevalent, driving further innovations and improvements in this vital field.

The aim of this paper is to give the user of such a system, made up of a motor supplied by a converter designed for use in potentially explosive atmosphere an overview of what the implications are, when such a system is used in a hazardous location, specific to refineries, chemical and petrochemical industries. The most important aspects that have to be observed are the following:

- Particular requirements in the case of explosion protected electric motors supplied by static frequency converters in hazardous areas;

- Constructional and functional requirements in the case of explosion protected (for example flameproof electric motors Ex d, supplied by static frequency converters, as well as the requirements concerning the ability to function of variable speed explosion protected electric motors in potentially explosive atmospheres;
- Legal requirements regarding the safety in operation, of variable speed electric motors, used in hazardous locations, according to the European Directives which regulate this field of activity.

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