SIL classification for Intelligent Motor Control Systems in accordance with the ATEX directive

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Abstract
While the motor management system and its hardware control devices is part of a low voltage assembly the Low Voltage directive applies. This directive refers to European standards that have their own requirements. But how to interpret other EU directives to classify and certify motor management systems including motor protection as part of low voltage switchgear?

This paper describes the “route of the process” based on experience obtained during the certification process of an electronic motor protection device as part of motor management system and its failsafe hardware control devices in a low voltage assembly and the effort of how to find the correct product and safety standards that apply for a complete system.

The requirements of the ATEX directive 94/9/EC Annex II (Essential Health and Safety Requirements) are covered by compliance with the European Safety standards, in which SIL is used as a method to define the (for the process) required safety level of a system consisting of safety related devices for equipment used in various zones within potentially explosive areas. Because there are no specific product standards available and they operate in a wide area where various directives are applicable, it is a challenge to find the right European standards to meet the relevant demands.

Process industries require a Safety Integrity Level (SIL) classification for a larger chain of control and protection equipment, from which the product certification in terms of MTBF, Safe Failure Fraction (SFF) and Diagnostic Coverage (DC) is a part of, in order to rate the safety level in hazardous areas.

Index Terms — ATEX, Safety Integrity Level (SIL), Intelligent Motor Control System (IMCS)

I. INTRODUCTION
For 20 years for motor overload protection a bi-metal based protection device only was used. In case of an Ex environment of the motor the device has to be certified according to EN 60079-7 Annex C. According to this standard only the thermal overload curve of the device needs to be proven save to be sure the motor cannot reach a dangerously high case temperature. After testing the setting of the bi-metal, the device was lacquered and marked as “Ex Safe”.

From the early nineties the thermal overload protection of the motor became part of motor management systems. The function is integrated in a microprocessor based embedded system. For this the motor current is measured with current sensors and used as input for a thermal model of the motor which is implemented in the safety device. The output of this model is used to protect the motor according the I-t-curve of EN 60079-7 annex C.

To prove the safety of a motor in an Ex environment not only the correct functional behavior is important. Also reliability of the complete motor management system has to be taken into account:
- is the design robust and without failure;
- does the device do what it should do under all possible circumstances? For instance during a short circuit of the system.

As already mentioned the primary circuit of the motor has changed. No longer is a bi-metal part of the primary circuit, it has been replaced by current sensors.

Middle nineties we followed the certification route for our first generation of a motor management system according to then available standards. However the Ex standard at that time only demands to prove the correct I-t curve of the thermal protection device. The Ex standard at that moment did not require demands for process control safety and reliability.

The notification body however decided, with justice, that these important items should be taken into account during the certification process.

Therefore a search was started to find the relevant standards which could be used. This was a difficult process, because no specific standards where available for intelligent motor management systems. But after a thorough survey by the certification party a complete set of standards was identified to which the system should comply.

Last year during the certification process of the newest generation of a motor management system we could make use of the ATEX directives which already take into account the use of electronics with software.

II. DEFINITIONS
ATEX
Atmosphères Explosive - Explosive Atmospheres

EUC (according to prEN 50495:2006)
Equipment under Control.

Ex Notified body
An independent body that has been notified by national authorities to the European Commission based on criteria in the ATEX 95 Directive.

Fault tolerance
Ability of functional unit to continue to perform a required function in the presence of faults or errors.
IMCS
Intelligent Motor Control System.

MCC
Motor Control Centre

SIL (according to prEN 50495:2006)
Discrete level (one out of a possible four) for specifying the safety integrity requirements of the safety function(s) to be performed by the safety device, where SIL 1 has the lowest level and SIL 4 the highest. If the safety device consists of several safety components the safety integrity level is defined for the complete safety instrumented system.

Temperature class
A classification indicating the maximum permitted surface temperature for an electrical motor relative to the minimum ignition temperature for the prospective gas/vapour.

Time $t_E$
Time in seconds, taken for an a.c. rotor or stator winding, when carrying initial starting current $I_A$, to be heated up to the limiting temperature from the temperature reached in rated service at maximum ambient temperature.

III. THE ATEX DIRECTIVES

There are two ATEX directives 94/9/EC and 1999/92/EC:

Directive 94/9/EC, also known as ATEX 95: concentrates on the responsibility of the equipment manufacturer.

This directive involves rules for designing, verification, certification and manufacturing (process and product) for equipment intended for use in or control/protection of equipment in zones with potentially explosive atmospheres.

Directive 1999/92/EC, also known as ATEX137, is concerned specifically with worker protection, and concentrates on the responsibility of the end user.

IV. SAFETY INTEGRITY LEVEL

What does SIL mean for the end user of a safety related device? On the plant the end user has to classify the hazardous areas through zone ratings according ATEX directive 1999/92/CE. The directive defines for each zone the necessary category of (combined) equipment (1, 2 or 3) to be used. Through the right combination of fault tolerance of the equipment under control (EUC) and the safety device and the safety integrity level (SIL) of the safety device the category of combined equipment for the application in the hazardous area can be established. In zone 0 no electrical motors of any Ex classification are normally permitted. That leaves only zone 1 and zone 2 for applications of the IMCS that is subject of this paper.

V. EC TYPE EXAMINATION

The specific IMCS is reviewed according to annex III of the ATEX directive.

The application for this system is overload protection for electrical motors in hazardous areas of zone 1. In this case motors with the type of protection increased safety (Ex e). As this system is mainly for use in (petro)chemical industries but definitely not in mines, equipment...
Although the ATEX directive prescribes to follow the requirements of annex VI and VII along with the CE type examination of annex III, the notified body that approved the type examination, followed annex IV and VII as part of the examination based on EN 13980. Annex IV covers production quality assurance and annex VII covers product quality assurance.

The assessment for product quality assurance consists of two parts:
- Functional behavior
- Safety of the device

**Functional behavior**
The application of the equipment brings us to advise EN 60079 series: Electrical apparatus for explosive gas atmospheres. For this part tests has to be carried out to prove the functionality according EN 60079-0 (general requirements) and EN 60079-7 (Equipment protection by increased safety “e”) Annex C. This specific annex specifies the required safety margins for current/time curves for the motors to protect to ensure that the maximum surface temperature is not exceeded (for example temperature class T4 refers to a maximum surface temperature of 135°C).

Figure 3 shows the thermal characteristics of a motor in normal operation and when blocked together with the possible temperature limits according to temperature class T3, T4 and T5. In the same graph shows the Ex “e” protection curve (\( t_E = f(I_A/I_N) \)) according to EN 60079-7, and the \( t_E \) of a motor.

**Safety of the device**
This part is more complicated. For safety devices the ATEX directive distinguishes three aspects. To assess all aspects regarding the safety in general of this complex system in its application the prEN 50495 is used as reference standard. This standard has following objective: Requirements for archiving functional safety (5.4) …minimize the probability of statistical and systematic faults;

Each aspect that shall be assessed following this standard related standards are defined.
The aspects the ATEX directive mention are:
- functional safety
- electrical safety (hardware requirements)
- ambient and operational conditions

**Functional safety:**
Important aspect of the equipment involved apart from the hardware is the functionality realized in the software. This makes it essential to assess this software thoroughly. For the specific area of application a SIL classification of the equipment is done. Standard prEN 50495 refers to the EN 61508-series: Functional safety of electrical/electronic/programmable electronic safety-related systems, EN 62061: safety of machinery – functional safety of safety related electrical/electronic and programmable electronic control systems and EN 61511: Functional safety – Safety instrumented systems for the process industry sector – Part 1: Framework, definitions, system, hardware and software requirements.

The equipment is verified to EN 61508-3 on following aspects:
- software architecture design
  - fault detection and diagnose
  - error detecting and correcting
o failure assertion programming
o redundancy in data processing
• support tools and programming language
• detailed design
  o structures methods
  o semi formal methods
  o modular approach
  o structured programming
  o use of verified software components
• software module testing and integration
  o dynamic analysis and testing
  o data recording and analysis
  o functional and black box testing
• programmable electronics integration
• software safety validation:
  o probabilistic testing
  o simulation modeling
  o functional and black box testing
• modification
• software verification
  o probabilistic testing
  o dynamic analysis and testing
  o functional safety assessment

Electrical safety:
For tests executed to verify electrical safety reference is made to EN61010-1. This covers an assessment of applied parts to comply with the intended application, voltage levels and dielectric properties.

Following tests are part of this verification:
• Single fault conditions
• Durability of markings
• Protection against electric shock
• Mechanical resistance to shock and impact
• Temperature rise test

Ambient and operational conditions:
This covers following aspects:
• Ambient temperature
• Humidity and atmospheric properties
• EMC

The verification for compliance to the EMC Directive 2004/108/EC was a separate certification process.

The product is tested in accordance with the standards:
• EN 60947-4-1 Low voltage switchgear and controlgear
• EN 61000-3-2 Limits for harmonic current emissions
• EN5011 Emission-Industrial, Scientific and Medical equipment (ISM).

The product is classified as Class A Equipment suitable in establishments other than domestic and those connected to a low voltage power supply network which supplies buildings used for domestic purposes. The product is also classified as ISM equipment in which radio frequency energy is internationally generated and/or used in the form of electromagnetic radiation for the treatment of material, and spark erosion equipment.

The outcome of the EC type examination for the particular IMCS confirms the required qualifications of:
• Equipment group II category 2 for environments with explosive gases, based on compliance with the protection curves in EN 60079-7 annex C and,
• SIL 1, based on the examination according prEN 50495.

Both the specific equipment group and SIL qualify the system for protection of electrical motors in zone 1.

VI. PRODUCTION QUALITY ASSURANCE

The standard EN 13980: 2002 specifies particular requirements and information for establishing and maintaining a quality system in accordance with the requirements of Annex IV and Annex VII of Directive 94/9/EC. In general the quality system shall ensure compliance of the product with the type described in the EC type-examination certificate. The EN 13980 is complementary to EN ISO 9001.

The verification focuses on:
• Control of documents, the documented procedures shall ensure that information contained within manufacturer’s documents are compatible with equipment documents.
• Control of quality records, the technical documentation on the approved type and copy of the EC-type-examination certificate and documentation on the quality system must be retained for at least 10 year after last piece of the equipment was manufactured.
• Responsibility, authority and communication, the ATEX authorized person shall co-ordinate activities with respect to the certified product, need to liaise with the notified body with respect to any proposed change to the design of the certified product and updating of the quality system and shall authorize technical documentation of the certified product.
• Management review, the management review shall include the overall effectiveness of the quality system.
with respect to the certified product and the ATEX authorized person shall participate in the review.

- Purchasing, suppliers providing a product, process or service that can affect the product’s compliance with the EC type-examination certificate must be capable to ensure compliance with all specified requirements. The purchasing documents shall describe the specific requirements. Purchased products must be verified to ensure compliance with the EC type examination certificate.
- Control of monitoring and measuring devices, the manufacturer shall use calibrated monitoring and measuring devices, calibrated by using an accredited calibration laboratory.
- Internal audits, the internal audit shall address the effectiveness of the quality system to ensure that the products are in conformity with the EC type-examination certificate.
- Identification and traceability, traceability is required with respect to the final product and its significant parts. In the case that an unsafe, non conforming product has been supplied to a customer, this customer can be identified.
- Production, the manufacturer shall have clear production process. This refers to: product assembly, quality control and test instructions to ensure that the product complies with the EC type examination.

VII. IMCS OVERLOAD PROTECTION FOR MOTORS IN A ZONE 1 AREA

According to the directive 1999/92/CE the employer is responsible for the safety of the workers. The employer in fact is responsible that safety devices are installed according the relevant standards, manufacturers instructions and are maintained in a proper way. First the decision shall be made to apply a MCC with an intelligent motor control system or a conventional overload protection. IEC 60079-14 chapter 7 allows three types of protection devices, from which a current monitoring protection is one and a PTC embedded in the motor is another. The third mentioned is “another equivalent device”, which allows an IMCS to be used. For Ex-e type motors, additional requirements according chapter 11 of the IEC 60079-14 are applicable. These additional requirements and the standard requirements can be met by an IMCS if the functionality and integrity have been certified by a notified body. In the tendering stage the certification of the motor protection device of system is only one part of the requirements that shall be met. In accordance with table 1 the protection system of the EUC in a zone 1 area shall have a SIL 1 or SIL 2 qualification. The selection for SIL 1 or SIL 2 is based on the fault tolerance of the EUC. Some motors i.e. shall be protected by a PTC connected to a certified PTC controlling device. This PTC controlling device can also be integrated in the IMCS, providing it is an independent protection.

To verify the reliability of the motor protection it shall be possible to test the system. In the IEC 60079-17 the requirements for testing thermal protection systems can be found. In table 1 item B9 can be read that it shall be checked that protection devices shall operate between acceptable limits (the standard IEC60079-14 requires that if 120% of the set current flows, the device shall trip the motor within 2 hours and the motor shall not trip within 2 hours if 105% of the set current flows). Item B10 requires checking, that the protection device has been set correctly in accordance with the motors specification. No automatic reset for zone 1 is allowed. The verifications shall be performed before first use and after every modification or revision of the equipment. Making the correct settings in an IMCS a one to one relation between the setting device and the EUC properties itself is very helpful to the commissioner. Retrieving the settings of a motor starter unit shall be possible by taking the drawer from its position and make a read out with a simple handheld connected on the RS232 or on a spare network number to which the starter unit temporarily is connected. Only by this way of checking, it is not possible to interchange two devices by addressing the wrong drawer from a central engineering station.

The EC directives and relevant standards have defined restrictions on the use of electrical motors in hazardous areas. An IMCS can be very helpful to check that the design criteria comply with the operating criteria or even prevent operation outside the limits given. One of the criteria on which an installation should be checked during periodic inspections is item B11 of IEC 60079-17: “special conditions of use (if applicable) are complied with”. As an example: a pump might be designed for S1 (continuous) operation. Without any mechanism of warning, in some operating periods the pump is started and stopped for more than 4 times within one hour. The motor can be overheated, without notice. A conventional low voltage thermal protection (not a PTC) will have a heating curve similar to the heating curve of a standard motor. But does it also have a cool down curve representative to the actual cool down time constant of the motor? This is where an IMCS also proves its advantage; giving an alarm if the number of starts exceeds the safe maximum number of starts in a time span given by the motor manufacturer or even better, preventing the thermal protection to be reset.

Additional advantage of an IMCS compared to conventional protections is the ability of producing an accurate report on the type of prospective danger on which it has switched off and the ability to monitor the performance of an application. For example some types of magnet pumps, are not allowed to run dry in an ATEX zoned area, because the magnets are cooled by the process medium. One way to protect is the use of thermocouples on the pump head. Another way is to use a minimum consumed power protection in the IMCS, or a combination of both to comply with a SIL 1 protection.

VIII. CONCLUSIONS

The ATEX certification of a complex protection system containing multiple parts and functional software that is manufactured by a third party is not an easy task.

The number of verifications that have to be fulfilled is not obvious from the ATEX directive(s) only, but requires a thorough risk analysis and research to define the applicable references.

While the complex system carries not only an equipment classification marking but also a SIL classification, it is part complete application suitable for particular hazardous areas. In this case Ex-e motors in zone 1 and zone 2 areas.

For the user it is important to understand the various equipment classifications relative to complex applications in ATEX zones.
IX. REFERENCES

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X. VITA

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