ENVIRONMENTAL QUALIFICATION OF THE ITER SAFETY CONTROL SYSTEM – NUCLEAR (SCS-N)

In the design of the NPPs, the I&C systems have been in continuous evaluation. Requirements to comply with Common Mode Failure, to be qualified for extreme environmental conditions, to demonstrate that the software based I&C could be part of the Safety Systems, to introduce the digital information to the operators are part of the effort in the current I&C systems implemented in NPPs.
The IEC have issued standards to determine the requirements for different levels of protection called SIL Protection. Level 4 is the highest level of integrity and reliability of a system.
The activities performed by Empresarios Agrupados (EA) and presented in this paper are the qualification process of commercial components certified as SIL4 and SIL 3 for application in a nuclear installation, so that the Nuclear Safety requirements are mandatory and the commercial equipment must demonstrate the fulfillment with them. Additionally, an extensive environmental qualification campaign has been executed in dedicated samplers, specifically manufactured for this purpose. This qualification comprises the following tests:
- Electromagnetic compatibility
- Aging Seismic qualification

The qualification process followed as well as the use of test tools and simulation platforms designed by EA are described in the paper.

RICARDO PINDADO ANDRÉS
Project Manager
EMPRESARIOS AGRUPADOS
Telecommunication Engineer UPM
Nuclear Technology Diploma ICAI

Ricardo Pindado joined Empresarios Agrupados in 1977. He has 25 year experience in I&C engineering for nuclear projects, 4 of them as project manager and 15 in the airport telecommunication sector.

LUIS CERRADA DUQUE
I&C Department Manager
EMPRESARIOS AGRUPADOS
Industrial Engineer ETSIIM

Luis Cerrada joined Empresarios Agrupados in 2000. He has 17 year experience in I&C engineering for nuclear and thermal projects, 9 of them as I&C Department Manager.

INTRODUCTION

This paper presents the activities being performed by Empresarios Agrupados for the environmental qualification of the Safety Control System - Nuclear (SCS-N) of the International Thermonuclear Experimental Reactor (ITER).

For the ITER, several potential hazards to personnel and environment have been identified. The aim of the SCS-N is to implement the nuclear safety I&C functions that prevent or mitigate radiological hazards.

Qualification aims at providing that the SCS-N fulfils its mission in the environmental and usage conditions required for ITER.

QUALIFICATION APPROACH

The SCS-N design is based on Commercial Off-The-Shelf (COTS) products. In order to make qualification easier, third party certificated products (i.e. SIL certification) have been selected when available. The products chosen must be qualified according to international nuclear standards and their tolerance to the ITER environmental constraints must be proven. SCS-N qualification relies in both product and environmental qualification as described below.

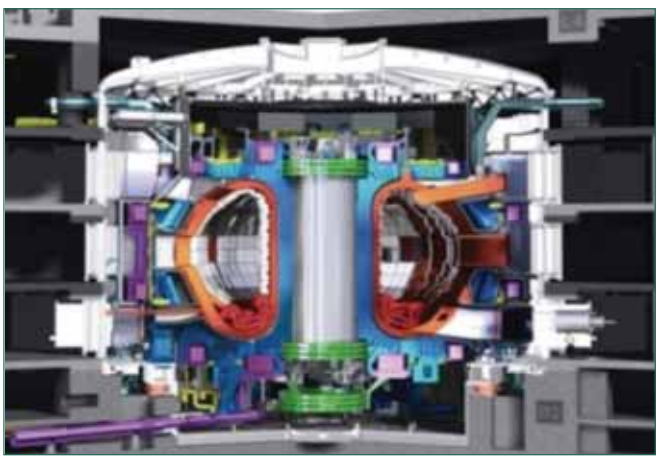

Figure 1. International Thermonuclear Experimental Reactor.

PRODUCT QUALIFICATION

The product qualification relies on:

- Third party certification.
- Verification of compliance with nuclear standards (compliance matrixes).
- Product Quality Assurance inspection.
- Operating experience analysis.
- Manufacturer environmental tests.

Main standard required for qualification is IEC 61513. Software design and life cycle processes of products is evaluated against IEC 62138, except for those cases of software-based devices of limited functionality, which are evaluated against IEC 62671.

Figure 2. Dummy cubicle inside the static magnetic field induction coil.

ENVIRONMENTAL QUALIFICATION

In order to qualify the system for its use under the ITER environmental operating conditions, various tests have been carried out. For this purpose, specific samplers have been manufactured as Equipment Under Test (EUT). For each test, the EUT is mounted in a manner and position to simulate its expected final installation and use. It is wired to a Test Tool as per dedicated schematic diagrams and the specific wiring procedure, and separation requirements are considered according to the safety classification of each cubicle. From this Test Tool different test scenarios are sent to the EUT, as input signals to the logic solvers, and the results, after processed in the logic solvers, are sent back to the Test Tool for checking.

The test results are classified in terms of the loss of function or degradation of performance of the EUT, relative to a performance level according to the established particular acceptance criteria and the applicable standards.

The results of the tests have to be registered and retained in the lifetime records of the ITER Organization. Any failures during the qualification tests are investigated, and the cause and rectification of the failure documented.

Environmental qualification for the SCS-N system is covered by the following tests:

- Electromagnetic compatibility (EMC) tests.
- Seismic tests.

Prior to these tests, as required by the RCC-E, ageing test process has been performed:

A. EMC tests

- Static magnetic field test, as per IEC 61000-4-8 and ITER specific procedure.

  The test produces a controlled magnetic field of known field strength (13 mT/10,33 KA/m) in this particular case) by driving a large coil with a test generator. The EUT is placed in the centre of the coil, thus subjecting it to a magnetic field. In this project, an induction coil has been manufactured specially for this purpose.

  The test is performed on dummy cubicles with smaller dimensions than the actual ones. The EUT is tested in the three spatial planes and both magnetic field directions.

  The acceptance criterion for this test is that the EUT must work properly during and after the application of the magnetic field and without performance losses.

- Dynamic magnetic fields (lightning effects).

  The following tests have to be performed in order to check lightning effects on the components:

  - Radiated susceptibility: pulse magnetic field as per IEC 61000-4-9, Level 4 (300A/m).
  - Radiated susceptibility: damped oscillatory magnetic field as per IEC 61000-4-10, Level 4 (30A/m).

  Pulse magnetic field and damped oscillatory magnetic field tests are performed by means of the proximity method, that is, a small induction coil is moved along the side of the EUT in order to detect particularly sensitive areas.

  The tests are performed on actual size cubicles and safety desks.

  The acceptance criterion for these tests is that the EUT must work during and after application of the magnetic fields, although some degradation in performance is allowable during the tests.

- Emission tests:

  These tests evaluate the emissions of the EUT in relation to conducted and radiated disturbances as per the corresponding standards and specific procedures.

  The EUT is placed in an anechoic chamber. The following tests were performed:

  - Conducted emissions, as per the ITER EMC test methods document, and IEC 61000-6-4
  - Wire emissions (frequency and amplitude) are measured in a receiver, when the EUT is in normal operation
  - Radiated emissions, as per IEC 61000-6-4

  Emissions of the EUT itself are measured with an antenna, when the EUT is in normal operation

B. Ageing tests

The assessment of EUT behavior over time, to be developed prior to seismic tests, involves the performance of the test according the following sequence:

- Repeated operations test

  This test consists in plugging and unplugging equipment energized boards. The EUT is mounted powered in open frames.

- Fast temperature variations test, as per IEC 60068-2-14

  The EUT is exposed to quick temperature variations (alternately high and low temperatures). The EUT is mounted unpowered in open frames.

- Dry heat test, as per IEC 60068-2-2
  The EUT is exposed to high temperature conditions. The EUT is mounted unpowered in open frames.
- Cyclic damp heat test, as per IEC 60068-2-30
  The EUT is exposed to high humidity conditions, combined with cyclic temperature changes producing condensation on the surface of the specimen. The EUT is mounted unpowered in an open frame.
- Cold test, as per IEC 60068-2-1
  This test determines the suitability of the equipment for use under conditions of low temperature. The EUT is mounted unpowered in open frames.
- Mechanical vibration test, as per IEC 60068-2-6
  This test determines the suitability of the equipment to withstand specified severities of sinusoidal vibration. The EUT is mounted unpowered in metallic structures attached to vibrating tables.
- Prolonged operation test, as per RCC-E B 8340
  The EUT is mounted in a cubicle simulating the temperature conditions corresponding to the worst real configuration of heat generated/evacuated, when the external temperature is 40°C. For this purpose, it is powered simulating operation on site, with functional tests running for 1000 hours.

C. Seismic tests

Seismic tests are performed as per RCC-E B8400.

The chosen qualification method is "combined qualification", based on analysis and tests.

After the cubicles are designed, a Fine Element Model (FEM) is built. A full spectral modal analysis is performed on the cubicles and safety desks that are deemed susceptible to undergoing the more severe shaking conditions. This analysis will yield stress and displacement values (as well as acceleration levels) at every point of the structure, thus allowing the structural integrity of the equipment to be assessed. It will also provide the vibration levels that the mounted equipment are expected to withstand.

Next, seismic samplers are manufactured taking into account the most unfavourable case according to the analysis performed previously.

Finally, the seismic test specimen is submitted to a full dynamic test on a shaking table.

Figure 3. EUT cubicles mounted on the shaking table at the seismic qualification test.

For SCS-N equipment, SIC-1, SIC-2 cat B and SIC-2 Cat C equipment are qualified for structural stability. Functionality must be maintained during and after the corresponding earthquake level. For this purpose, functional tests scenarios have been designed to be run during and after the test.

CONCLUSIONS

The qualification of COTS equipment for subsequent use in ITER is a quite complex process that involves many actors including, among others, engineering, manufacturers, suppliers and testing laboratories.

To facilitate this qualification, the first step is to choose COTS equipment that is already third-party certified. This makes easier its compliance with nuclear standards (i.e. IEC 61513) and means that a quality system for both the design and manufacturing phases is already available. Manufacturer support in obtaining the corresponding documentation on the equipment life cycle phases is also absolutely essential for this step.

Additionally, detailed engineering work must be carried out in order to analyse the manufacturer type tests and determine the gaps between what these tests cover and the ITER environmental constraints. Once these gaps are determined, additional tests must be developed and performed. For this last step, it is very important that specialised testing laboratories are in the loop. These laboratories should be accredited by the corresponding regulatory bodies to perform the tests, in order to guarantee compliance with the applicable standards, bearing in mind that the corresponding test reports must be approved by the ITER Organization and questions/comments may be done by the ASN.■

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