12th International Workshop on Application of Field Programmable Gate Arrays in Nuclear Power Plants

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### CNEA-I&C architecture design of FPGAbased Reactor Protection System for new Argentine reactors and other FPGA development experiences

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**I&C Department** 



Comisión Nacional de Energía Atómica

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- RPS Overview
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- Diverse FPGA Implementation
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## **CNEA-I&C Department**

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#### Introduction

- Placed in Ezeiza Atomic Center
- More than 40 years of developments
- Currently: 30 professionals, 9 technicians, 6 administrative
- ISO 9001:2015 Certification





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## **CNEA-I&C Department**



#### **Current RPS Projects**

- Primary RPS for CAREM25 (Prototype of Small Modular Reactor)
- RPS for RA10 (New Multipurpose Research Reactor)



### RPS

#### **Shared Requirements**

- Safety Functions Category A (IEC 61226)
- System Class 1 (IEC 61513)
- Simple design
- Proven technology
- Independence
- Single Failure Criterion
- Self-check
- Fail Safe Design
- Testability
- Online Monitoring
- Manual and Automatic Trips
- Maintenance and Test features
- Demands several actuation systems

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### RPS



**CNEA-I&C RPS main characteristics** 

- Digital Processing
- Diverse FPGA Implementation
- 2003 or 2004 Voting at two levels
- IEC 62566 life-cycle and V&V process

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Modular Eurocard System



### **RPS** 2004 Architecture for CAREM 25 NPP



### **RPS** 2003 Architecture for RA10 MRR

![](_page_7_Figure_1.jpeg)

### **Diverse FPGA Implementation**

![](_page_8_Picture_1.jpeg)

#### **Common Cause Failure Issue**

The Common Cause Failure (CCF) is an important issue in safety systems based on software and FPGA technology.

It is known that the *implementation of diversity reduces the probability of CCF occurrences* (IEC 61508 Part 7 Section B.1.4 and many other references).

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### **Diverse FPGA Implementation**

![](_page_9_Picture_1.jpeg)

#### **Diversification styles in CNEA-I&C RPS**

![](_page_9_Picture_3.jpeg)

- Developers team
- FPGA Manufacturer
- FPGA Technology
- FPGA software tools

![](_page_9_Picture_8.jpeg)

![](_page_9_Picture_9.jpeg)

![](_page_9_Picture_10.jpeg)

### **Diverse FPGA Implementation Diversification styles in CNEA I&C RPS**

![](_page_10_Picture_1.jpeg)

- Diversification styles in CNEA I&C RPS
  - Each pair of modules works in parallel in the same train
  - There is no priority between diversities
  - Real-time cross-verification between diverse modules

![](_page_10_Figure_6.jpeg)

### **Diverse FPGA Implementation**

**RPS Train** 

![](_page_11_Picture_1.jpeg)

#### Analog To/From other trains Signal Digitalization **Conditioning** Module Trips Comparator Voting & **Diversity A** Optical Optical ASC 111 11 to **Trigger Logic** Module Drivers Fiber Fiber ...... FALs **Diversity A Diversity A** Transmitter Receiver Digitalization 11 11 1 to 6 ASC Module ..... Safetv **Diversity B** Signals ASC Set-points Verification **Digital Signal** Verification **Digital Signal** Conditioning ..... Trips Hub E Optical Voting & Comparator Optical **Diversity A** to DSC 7 **Drivers** Trigger Logic Module Fiber Fiber FALs **Diversity B** Transmitter Receiver **Diversity B Digital Signal** 1 to 6 DSC Com-Hub **Diversity B** mands DSC Train Information Data Hub NI Digitalization Optical Train **Nuclear Diversity A** Fiber Full-state Instrumentation Transmitter datalink NI **System** Digitalization **Diversity B To Visualization Panels on** To Visualization Panels on **To Reactor Control Auxiliary Control Room** Main Control Room System ()()

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### **Diverse FPGA Implementation**

#### **RPS Train**

![](_page_12_Figure_2.jpeg)

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### **Diverse FAL Implementation**

#### **Diversity resolve**

![](_page_13_Picture_2.jpeg)

![](_page_13_Figure_3.jpeg)

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#### **Full Redundant Train**

#### Built on 3 Eurocard Sub-racks 19" Simple Height (3U)

![](_page_14_Figure_3.jpeg)

TRANSPORT FOR FAILURE

![](_page_14_Picture_5.jpeg)

#### **Full Redundant Train**

![](_page_15_Picture_2.jpeg)

Capability	Maximum w/3 Sub-racks	For CAREM25	For RA10 MRR
Nuclear Instrumentation Chains Inputs	2	2	2
24V Digital Inputs	64	26	36
4-20mA Analog Inputs	30	18	11
24V @ 1A Digital Outputs	16	14	12
Rx/Tx Optical fibers for other trains interconnections	4	4	3
Tx Optical fibers with full train information	8	3	5

Expandable using more Sub-racks

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![](_page_15_Picture_5.jpeg)

![](_page_16_Picture_1.jpeg)

#### **Visualization Unit for Hard Panels**

One Eurocard Sub-racks 19" Simple Height (3U)

![](_page_16_Figure_4.jpeg)

![](_page_17_Picture_1.jpeg)

#### **RPS to Control System Interface**

#### 1/3 Eurocard Sub-racks 19" Simple Height (3U) (Safety Category B)

![](_page_17_Picture_4.jpeg)

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#### **Previous experience**

Diverse Trip Instrumentation for Atucha II NPP Boron Injection Safety System (2012)

- Similar diverse architecture for 2 analog and 6 digital input signals
- Each train was solved in one sub-rack
- Finally, it was not installed, so it only served as a proof of concept

![](_page_18_Picture_6.jpeg)

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![](_page_18_Picture_7.jpeg)

![](_page_18_Picture_8.jpeg)

FAT Platform

### Conclusions

#### **CNEA-I&C RPS**

![](_page_19_Picture_2.jpeg)

- The use of FPGA technology, as the main component of RPS design, has proven to be very effective
- The goal of a simple design was achieved by using FPGAs, finite states machines and one-way communication channels.
- CCF issue is addressed using diverse FPGA implementation running in parallel in each train
- The requirements for independence, isolation and wiring complexity reduction are fulfilled using serial transceivers over optical fiber.

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![](_page_19_Picture_7.jpeg)

![](_page_20_Picture_1.jpeg)

#### For Nuclear Instrumentation System

- Count-rate meter and flux-change-rate meter with automatic adjust of counting time for pulse-mode flux [SPL2019, IAEA-TECDOC-1765]
- Random Pulse Generator For Emulation of a Neutron
   Detector System In A Nuclear Reactor [SPL2011]
- Wide Range Neutron Flux Monitoring System using Campbell Mode [SPL2019]
- Wide Range Neutron Detector Emulator and Current
  Mode Neutron Detector Emulator

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![](_page_20_Picture_7.jpeg)

![](_page_21_Picture_1.jpeg)

#### **Count-rate meter for pulse mode**

![](_page_21_Figure_3.jpeg)

#### Count-change-rate meter for pulse mode

- Automatic adjust of counting time
- Stable output (no spurious trip)
- Extended range 0.1 to 10^6 cps
- Digital Output from -3 to 7%/sec

 $\times 10^5$ 10

cbs

Full Paper: "Digital count-rate meter and flux-change-rate meter with automatic adjust of counting time based on FPGA for pulse-mode flux measurements in nuclear reactors" Ríos, Estryk, Verrastro. IEEE SPL2019

#### (s/%) -3 to 7 %/s Count-rate at 90% of F.V.: 625 cps Delay in decades: 0.8 $\varphi_{(t)} = \varphi_0 \ e^{\theta t}$ \* Measured -Actual 100 200 300 400 500 0 0.1 to 10<sup>6</sup> cps Time (sec) Count-change-rate step from 0 to 50

4 and 6 %/sec, starting from 100cps

#### 

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Time

![](_page_22_Picture_11.jpeg)

![](_page_22_Picture_12.jpeg)

![](_page_23_Picture_1.jpeg)

## Random Pulse Generator For Emulation of a Neutron Detector

![](_page_23_Figure_3.jpeg)

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![](_page_24_Picture_1.jpeg)

#### Random Pulse Generator For Emulation of a Neutron Detector

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Exponential sweeps can be configured and commanded from the PC

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![](_page_24_Picture_5.jpeg)

### Other FPGA Developments Wide Range Neutron Flux Monitoring System using Campbell Mode

- Based on the Campbell Meansquare theorem
- The variance of the signal is proportional to the neutron flux
- Used with Fission Counters

![](_page_25_Figure_4.jpeg)

![](_page_25_Picture_5.jpeg)

![](_page_26_Picture_1.jpeg)

#### Wide Range Neutron Flux Monitoring System using Campbell Mode

![](_page_26_Figure_3.jpeg)

*Full Paper: "FPGA Based Wide Range Neutron Flux Monitoring System using Campbell mode". Alarcón, Marzano, Verrastro, Thorp. IEEE SPL2019* 

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- Variance signal is filtered by a two pole low-pass IIR DEWMA filter.
- DEWMA filter was used to improve response to fast transients with a good filtering because its adaptive nature
- K constant was update each calculation cycle

#### 

![](_page_27_Picture_1.jpeg)

Wide Range Neutron Detector Emulator and Current Mode Neutron Detector Emulator

- Standalone module, modes and values configurable by the front panel
- Upward sweeps of 3%/sec and 6%/sec (on both outputs)
- Wide Range on a single output
  - Periodic and Random modes (1K/10K/100K/1M cps)
  - Pulse shaping in FPGA with pile up generation
  - Fast DAC
  - Analog output
- Current output range: 500pA / 5nA / 50nA / 500nA

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![](_page_27_Picture_11.jpeg)

![](_page_27_Picture_12.jpeg)

![](_page_28_Picture_1.jpeg)

Wide Range Neutron Detector **Emulator** and **Current** Mode Neutron Detector **Emulator** 

![](_page_28_Figure_3.jpeg)

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![](_page_29_Picture_1.jpeg)

#### **Replacement Modules for NPPs and RRs**

- FPGA-based Alarm Unit for Embalse NPP Area Radiation Monitoring System
- CPLD-based replacement of Simatic Z24 for Atucha I NPP
- CPLD-based Scram Logic replacement for Argentine RRs [IAEA-CN-100]

#### Nuclear medicine

 AR-PET: Argentine Positron Emission Tomography Scanner [SPL2010]

![](_page_29_Picture_8.jpeg)

![](_page_29_Picture_9.jpeg)

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#### Thank You !

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![](_page_30_Picture_4.jpeg)