Operation and Maintenance Experience of FPGA-based Applications

Vladimir Sklyar

8th International Workshop on the Application of FPGAs in NPPs
13-16 October 2015, Shanghai, China

Agenda

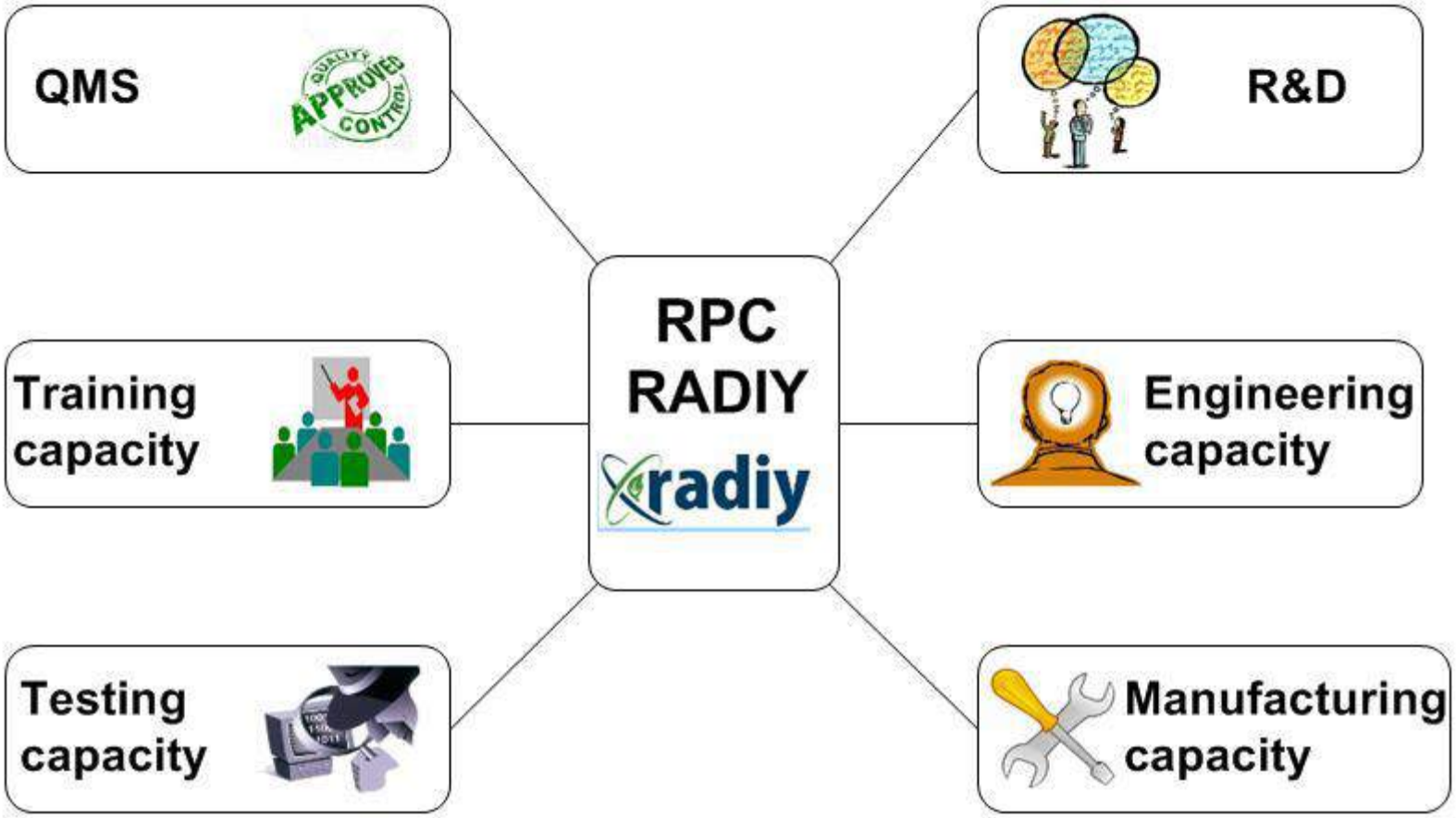
- RPC Radiy Company Profile
- NPPs I&C applications by RPC Radiy
- Challenges of FPGA technology using for NPPs I&C Systems

RPC Radiy
Company Profile

Radiy Quick Facts

- 920 employees, 200 engineers, headquartered in Kirovograd, Ukraine
- Main profile: FPGA-based I&C systems for NPPs
- 20 years in servicing the NPP industry in the Ukraine
- 17 years in providing FPGA-based systems to the NPP industry in the Ukraine
- 7 years in providing FPGA-based systems to the NPP industry in Bulgaria
- All in-house processes (vertical structure): design, procurement, manufacturing, testing, installation

Radiy Profile



I&C modernization projects (continued)

Turn-key projects:

- Complete replacement of systems
- Long-term technical support and maintenance

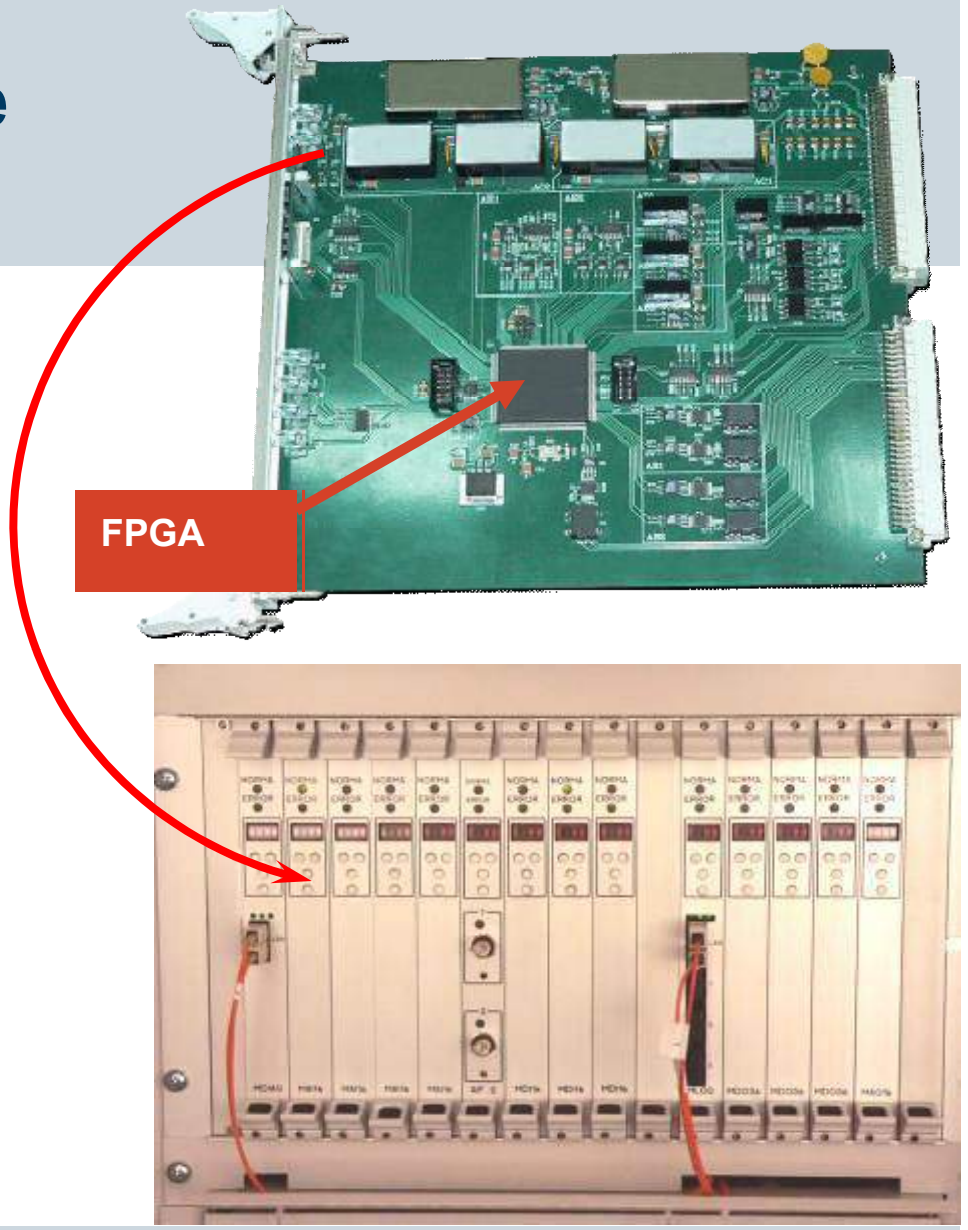
Small-scale stand-alone applications

- Reverse engineering or re-engineering
- “Like-for-like” solutions
- “Form, fit and function“ (FFF) solutions
- One-time development and applications

RPC Radiy Company Profile

Radiy's product

- **FPGA-based I&C platform RadICS**
- Digital safety systems
- I&C systems of research reactors
- Electric power supply equipment
- Control room panels
- Fire alarm and suppression systems
- Seismic sensors and seismic monitoring systems



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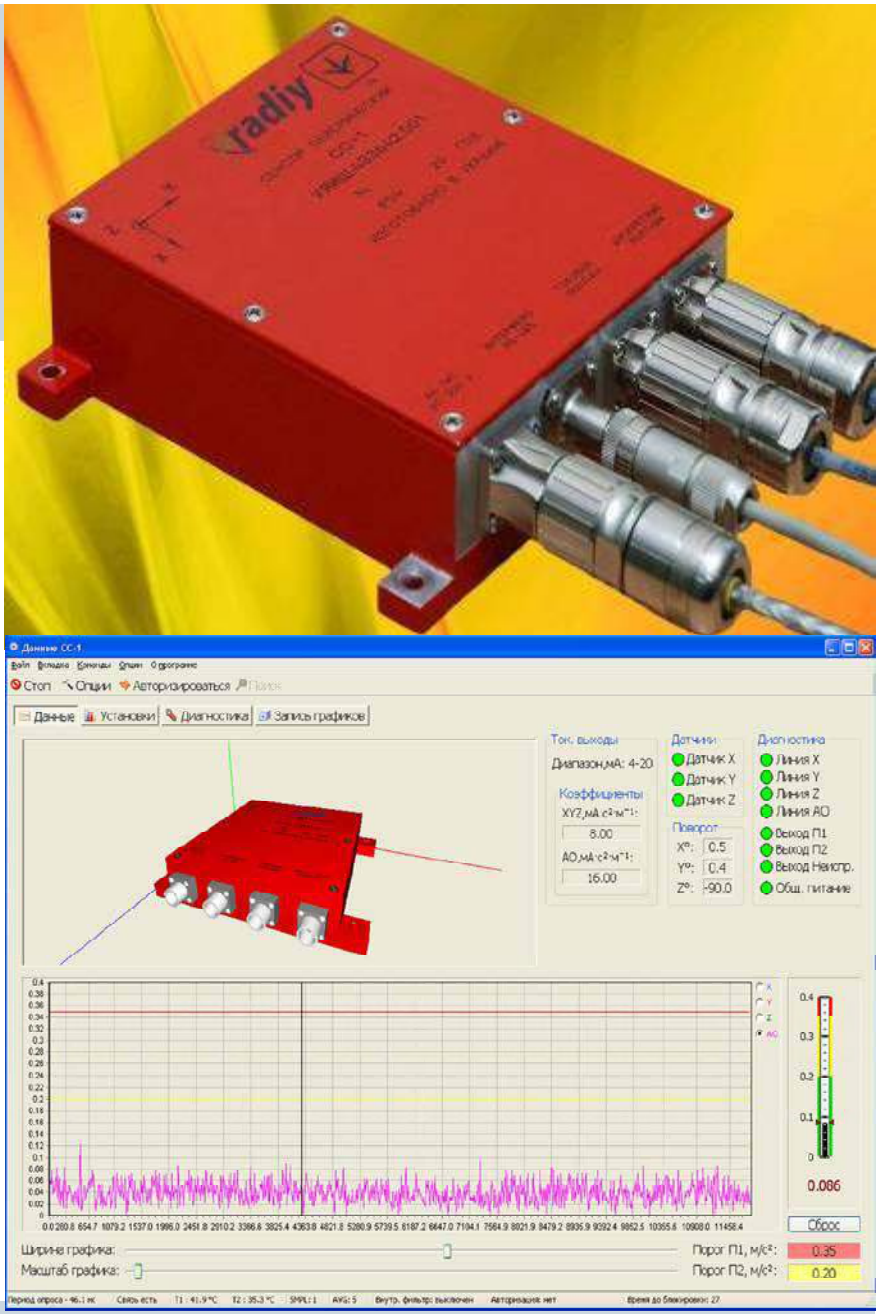
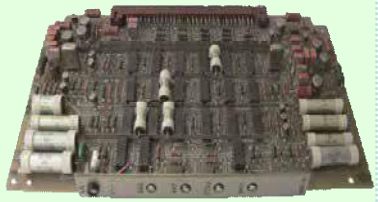


Radiy products evolution

1995

Started development and supply of the equipment for NPP I&C systems



Replacement of obsolete NPP I&C modules

1998

First generation of equipment for NPP I&C systems

FPGA-based I&C systems for NPP

2002

Second generation of equipment for NPP I&C systems

FPGA-based I&C platform for NPP

2014

Third generation of equipment for NPP I&C systems

SIL3 certified FPGA-based I&C platform for NPP

FPGA-based safety controller: RadICS Platform

LM DIM AIM AIFM DOM AOM OCM

exida CERTIFICATION

The manufacturer may use the mark:

Valid until October 1, 2017
Revision 1.0 September 26, 2014

ANSI Accredited Program
PRODUCT CERTIFICATION
#1004

Certificate / Certificat
Zertifikat / 合格証

RAD 1406037 C001

exida hereby confirms that the:

FPGA-Based Safety Controller (FSC) RadICS
produced by **RPC Radiy**
29 Geroyiv Stalingrada Street
Kirovograd, Ukraine

Has been assessed per the relevant requirements of:

IEC 61508 : 2010 Parts 1-7

and meets requirements providing a level of integrity to:

Systematic Capability: SC 3 (SIL 3 Capable)

Random Capability: Type B Element

SIL 3 @ HFT = 0; Route 1_H

PFD_{AVG} and Architecture Constraints must be verified for each application

Safety Function:
The FSC will read input signals, perform user-defined application layer logic and write results to the output signals within the stated response time.

Application Restrictions:
The unit must be properly designed into a Safety Instrumented Function per the Safety Manual requirements.

Evaluating Assessor

Rudolf P. Chalupa
Certifying Assessor

Page 1 of 2

FPGA-Based Safety Controller (FSC) RadICS

exida CERTIFICATION

64 N Main St
Sellersville, PA 18960

T-002, V3R4-3

Certificate / Certificat / Zertifikat / 合格証

RAD 1406037 C001

Systematic Capability: SC 3 (SIL 3 Capable)

Random Capability: Type B Element

SIL 3 @ HFT=0; Route 1_H

PFD_{AVG} and Architecture Constraints must be verified for each application

Systematic Capability :

The product has met manufacturer design process requirements of Safety Integrity Level (SIL) 3. These are intended to achieve sufficient integrity against systematic errors of design by the manufacturer.
A Safety Instrumented Function (SIF) designed with this product must not be used at a SIL level higher than stated.

Random Capability:

The SIL limit imposed by the Architectural Constraints must be met for each element.

SIL Verification:

The Safety Integrity Level (SIL) of an entire Safety Instrumented Function (SIF) must be verified via a calculation of average Probability of Failure on Demand (PFD_{AVG}), or Probability of Failure per hour (PFH), considering redundant architectures, proof test interval, proof test effectiveness, any automatic diagnostics, average repair time and the specific failure rates of all products included in the SIF. Each subsystem must be checked to assure compliance with minimum hardware fault tolerance (HFT) requirements.

The following documents are a mandatory part of certification:

Assessment Report: RAD 14-06-037 R002 V1R0 61508 Assessment - FSC

Safety Manual: D11.1 - Radiy FSC Product Safety Manual V1R2

SIL3 in single channel configuration

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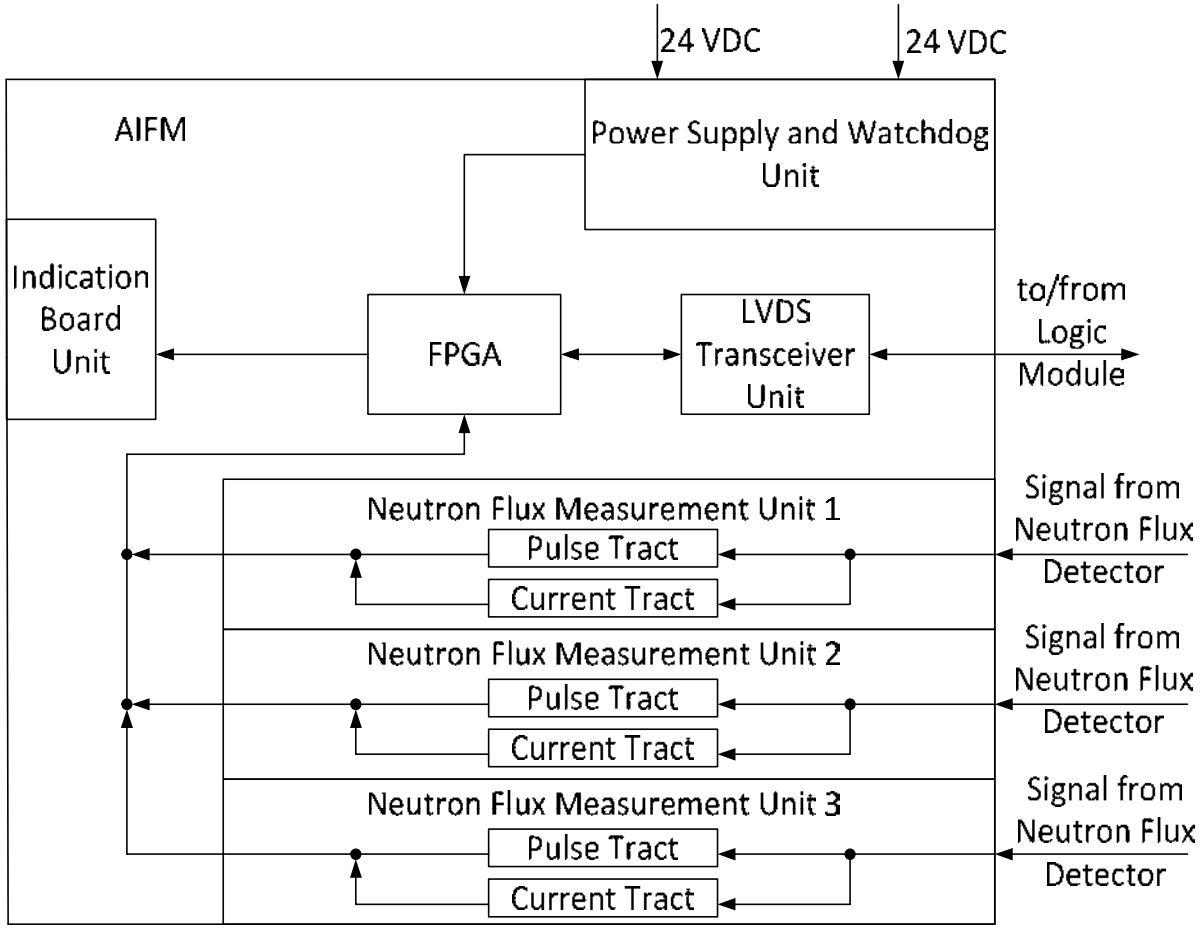
RadICS Platform: ANALOG INPUT FOR NEUTRON FLUX MEASUREMENT MODULE (AIFM)

Input analog signal range (current)	1.0 pA … 10 mA (10 decades) Pulse signal processing up to $2 \cdot 10^6$ cps Input impedance less than 1500 Ohm
Input channel isolation	all input channels are galvanic-isolated 2000 V AC/DC field-to-chassis or channel-to-channel
Information package exchange cycle	5 ms
Diagnostic package exchange cycle	up to 100 ms
LVDS line speed	100 Mbit/s
LVDS line protocol	proprietary protocol with integrity checking (CRC), galvanic-isolated Tx / Rx
Self-diagnostic functions	independent watchdog unit, I/O error detection, checksum analysis, active diagnostics with internal fault detection, continuous self-tests, power supply fault detection
Power supply / consumption	2 independent inputs – 24 (18-36) V DC / 0.75 A
Indications	2 status LED indicators (RUN/FAULT); 4-Character Dot Matrix symbol-indicator for current operational mode, service info and errors codes providing
Operating temperature	0 to 60°C
Operating humidity	5 ~ 95%RH, non-condensing

RadICS Platform: ANALOG INPUT FOR NEUTRON FLUX MEASUREMENT MODULE (AIFM)
Continued



AIFM references:

- I&C system of Research Reactor, Nuclear Research Institute (Kyiv, Ukraine) – in operation since 2006
- Prototype of NFMS for VVER-1000 – in trial operation since 2013
- Nuclear Channels of I&C system of IEA-R1 Research Reactor, IPEN-CNEN institute (Sao Paulo, Brazil) – installation is planned in 2016

NPPs I&C applications by RPC Radiy

Complete I&C systems installed in operating NPPs in Ukraine and Bulgaria

- Reactor Trip System (RTS),
- Engineered Safety Features Actuation System (ESFAS),
- Reactor Power Control and Limitation System (RPCLS),
- Rod Control System (RCS),
- Nuclear Island Control System and Turbine Island Control System,
- Switchgear and Electrical Distribution Systems.

About 100 applications installed at NPPs in time in budget
More than 100,000 FPGA chips in operation, no detected failures

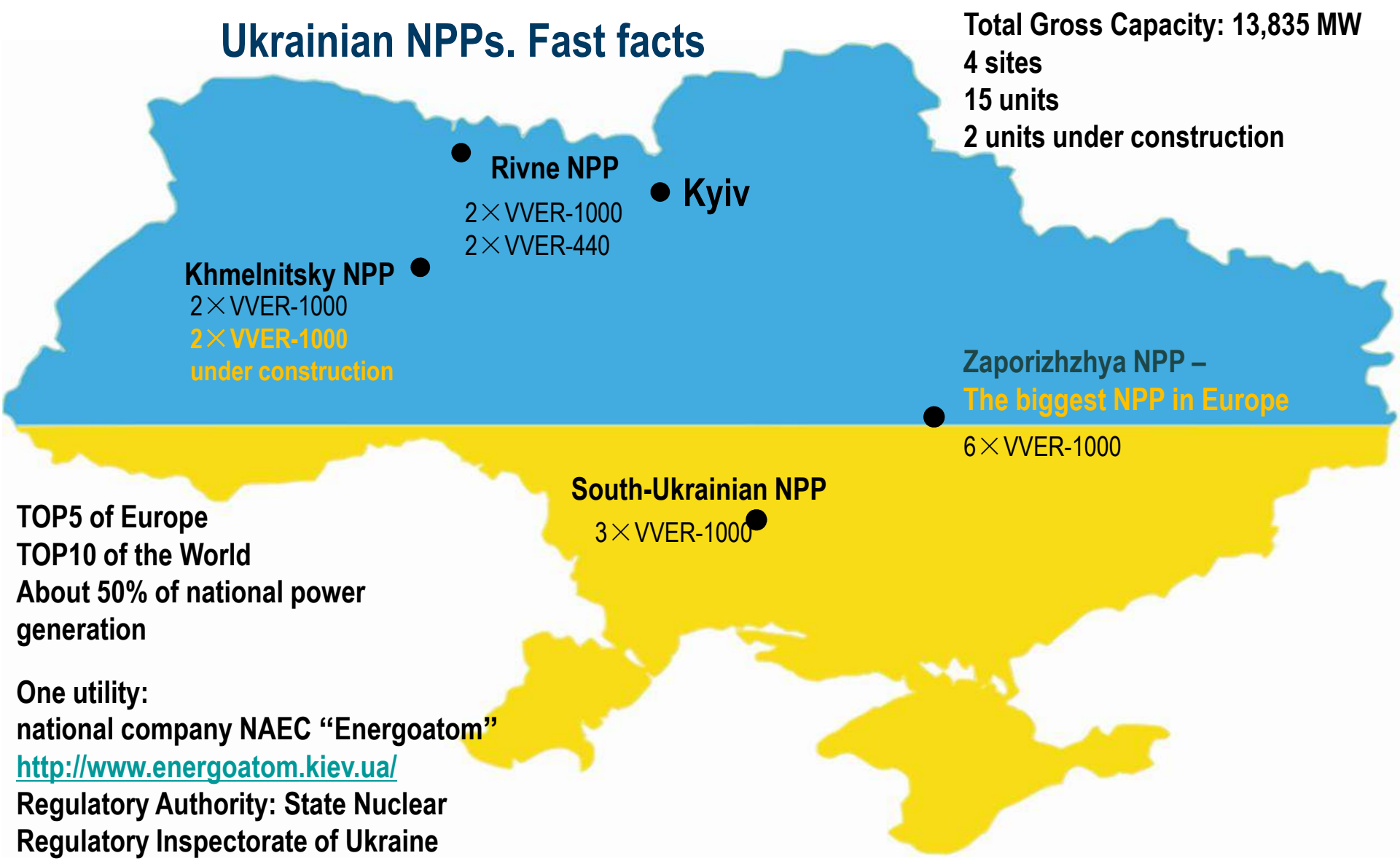
Radiy's reference list (1)

Equipment Supplied	Installed In	# of Installed Systems	Delivery / Installation Year
Reactor Trip System	Zaporizhzhia NPP South-Ukraine NPP Rivne NPP Khmelnitsky NPP	30	2004-2015
Reactor Power Control and Limitation System	Zaporizhzhia NPP South-Ukraine NPP Rivne NPP Khmelnitsky NPP	11	2004-2015
Engineered Safety Features Actuation System	South-Ukraine NPP Rivne NPP Kozloduy NPP, Bulgaria	18	2005-2010
Rod Control System	South-Ukraine NPP	1	2013
Fire Alarm System	Zaporizhzhia NPP South-Ukraine NPP	11	2008-2014
Power Supply for Rod Control System	Kozloduy NPP, Bulgaria South-Ukraine NPP	4	2007-2015
Switchgears cabinets (RTZO)	Rivne NPP South-Ukraine NPP Kozloduy NPP, Bulgaria	1635	2006-2015
Nuclear and Conventional Island Control System	South-Ukraine NPP Rivne NPP	8	2011-2015
I&C System of Research Reactor	Nuclear Research Institute	1	2006

Radiy's reference list (2)

Seismic Sensors	Khmelnitsky NPP Zaporizhzhia NPP South-Ukraine NPP Rivne NPP	63	2010-2014
UKTS-Based Reactor and Turbine Control System	Rivne NPP Zaporizhzhia NPP	15	1998-2004
PHT Pump Motor Speed Measuring Devices	Embalse NPP, Argentina	1	2014
MCR and SCA Window Annunciators	Embalse NPP, Argentina	1	2014
PCBs for Rod Ready Indicator Chassis	Pickering NPP, OPG, Canada	56	2014
Vibration-Measuring System for Seismic Sensors calibration	South-Ukraine NPP	1	In progress
DC Distribution System for Transformer Plant	Khmelnitsky NPP	1	In progress
Neutron Flux Monitoring System	South-Ukraine NPP	1	2014
I&C System	Trypilska TPP	1	2015

Ukrainian NPPs. Fast facts

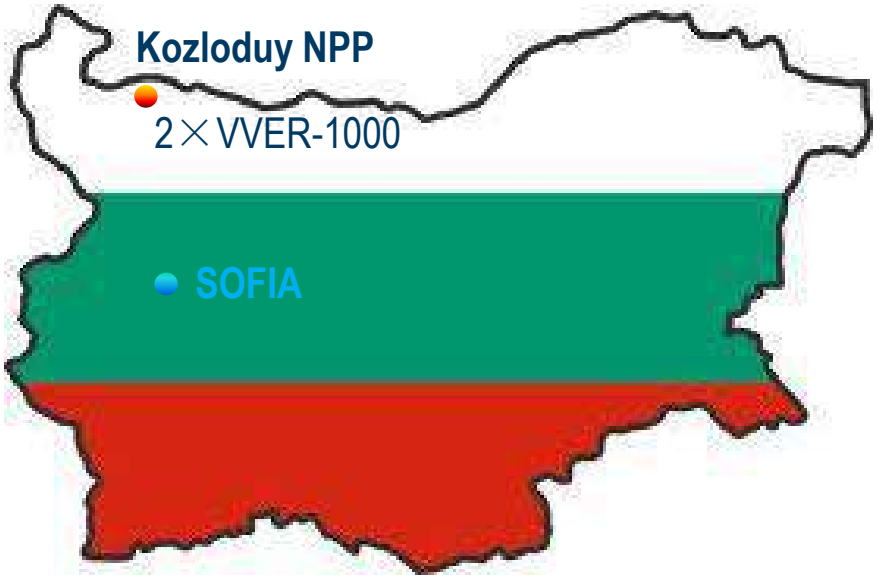


Total Gross Capacity: 13,835 MW
4 sites
15 units
2 units under construction

TOP5 of Europe
TOP10 of the World
About 50% of national power generation

One utility:
national company NAEC "Energoatom"
http://www.energoatom.kiev.ua/
Regulatory Authority: State Nuclear Regulatory Inspectorate of Ukraine
http://www.snrc.gov.ua/nuclear

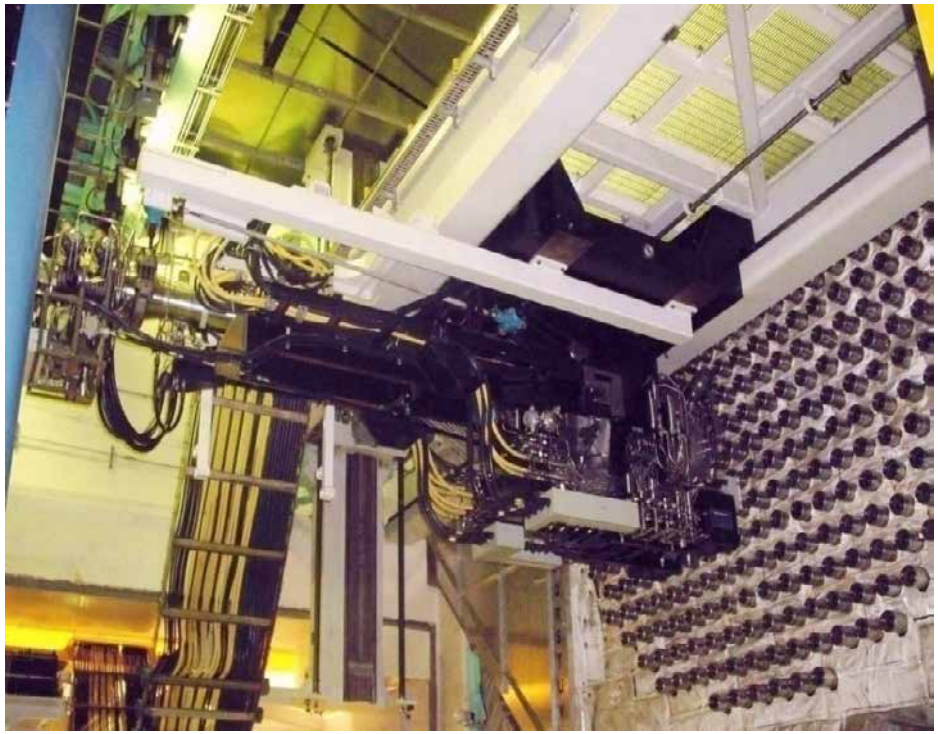
Radiy's contracts with Kozloduy NPP



- Modernization of 2 sets of Power Supply equipment for Rod Control System for Units 5,6 (2007– 2008)
- Modernization of 6 Engineering Safety Actuation Systems (ESFAS) for Units 5,6 (2008-2010)
- Modernization of 10 switchgears sets (RTZO cabinets) of ESFASs and of Nuclear and Conventional Island Control Systems for Units 5,6 (2013 – 2015)

Radiy's contracts with Candu Energy Inc.

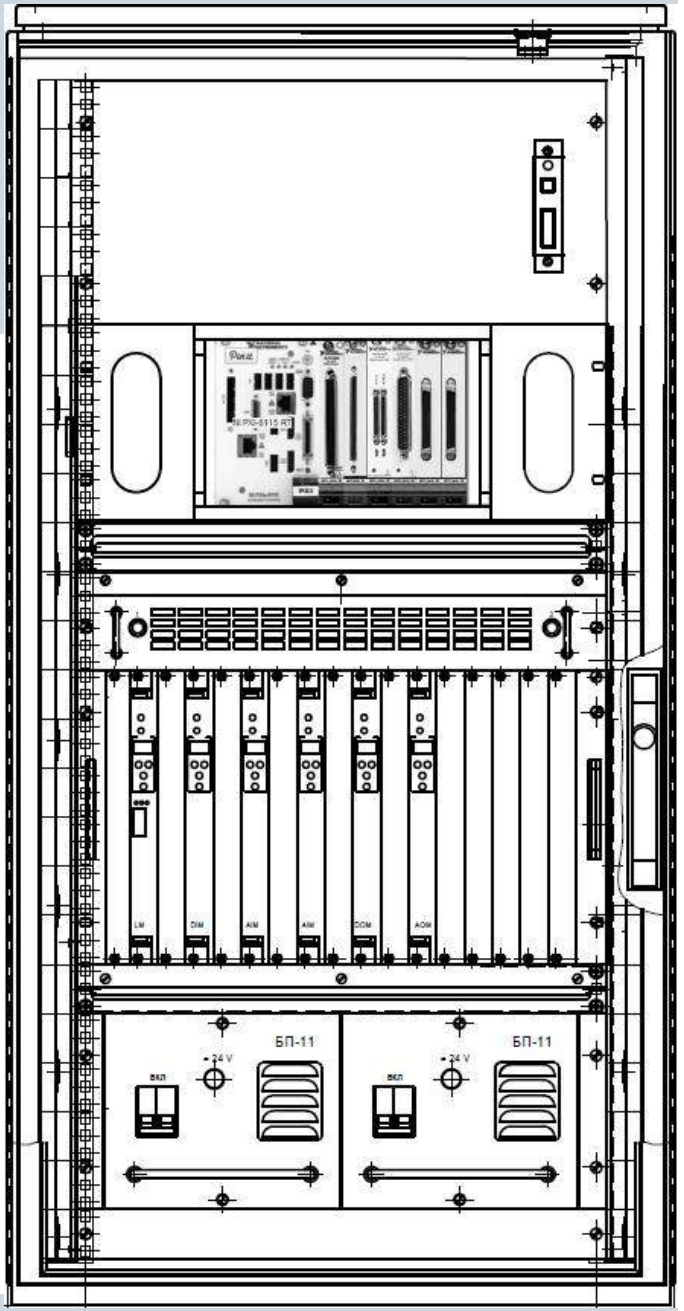
- Radiy is a Candu Energy supplier which meets Z299.1 requirements; QMS audits took place in 2010 and 2013
- 2014: shipment of Control Rooms Window Annunciators for Embalse NPP (Argentina)
- 2014: shipment of Pump Motor Speed Measuring Devices for Embalse NPP (Argentina)
- 2014: shipment of PCBs for Rod Ready Indicator Chassis for Pickering NPP (Canada)
- Radiy is qualified as a supplier of I&C equipments for Enhanced CANDU6 (EC6)



Control Rooms Window Annunciators for Embalse NPP (Argentina) based on RadICS platform

Pump Motor Speed Measuring Devices for Embalse NPP (Argentina) based on FPGAs

Radiy's contract with EdF

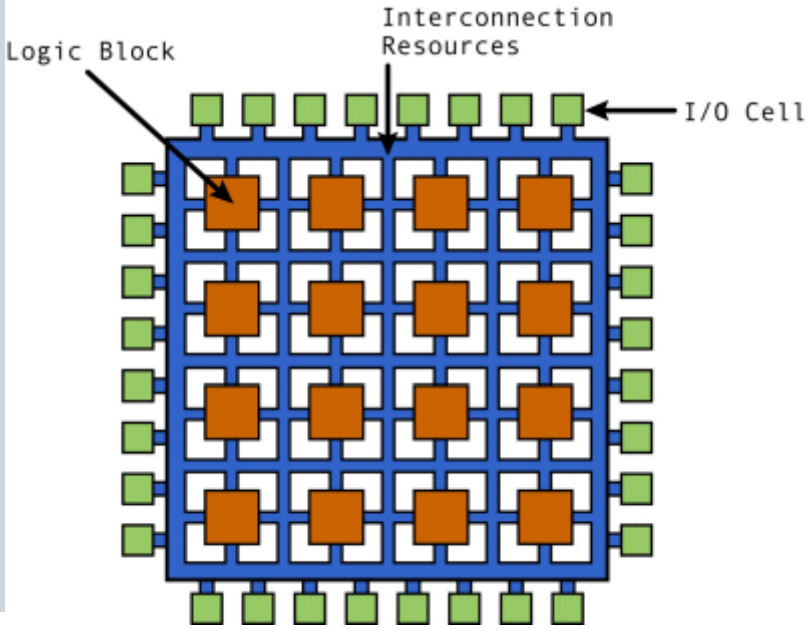


- The subject of the contract is leasing of the Radiy's I&C test platform
- The hardware of I&C test platform includes a cabinets, power supply modules, platform chassis and modules (LM, DIM, AIM, DOM, AOM) and test equipment (National Instruments)
- Services include application design and implementation onto the platform, installation the platform at the EdF site, training and technical assistance
- The project duration is 3 years with an option to extend the duration of the lease on a yearly basis for a maximum of 3 additional years

I&C system of IEA-R1 Research Reactor, IPEN-CNEN institute (Sao Paulo, Brazil)

- IEA-R1 Open-pool Reactor built by Babcock-Wilcox and commissioned in 1957, 2-5 MW power, is currently operating with 3.5 MW power
- The contract scope includes turnkey modernization of five neutron flux measurement channels with appropriate control logic section and HMI
- Equipment list includes two Signal Processing Cabinets, Computer Cabinet and Operator Panel
- Contract performance time is 2015-2016

Challenges of FPGA technology using for NPPs I&C Systems



FPGA-based modernization drivers and advantages

- Proven in use technology with extensive experience of operation at NPPs in certain countries and other applications in safety-critical industries
- Implementation of safety functions without the use of any software and operating system
- Parallel performance of all control algorithms with communication functions ensures fast response time with deterministic value
- Providing transparent and relatively simple design what allows to reduce the efforts necessary for development and V&V

FPGA-based modernization drivers and advantages
Continued

- Resilience to obsolescence due to the portability of the Hardware Description Language (HDL) code between various FPGA-chips produced by different manufacturers
- Fit for reverse engineering via emulation of obsolete CPU without modification of existing software code
- Specific beneficial properties regarding cyber security that are different from those of Programmable Logic Controller (PLC) based technologies (no viruses for FPGA)

RadICS platform benefits

- SIL3 Certificate is a warranty of the highest safety requirements implementation
- RadICS-based systems have been implemented at NPPs in Ukraine, Bulgaria and Argentina
- FPGA technology benefits:
  - → Diversity versus PLC-based equipment
  - → Transparency, parallelism, and determinism of design
  - → High speed performance
  - → Absence of system software and high level of cybersecurity
  - → Obsolescence resistance
  - → Proven in use operation experience: about 100 000 FPGA chips in operation, the oldest are since 1998; no FPGA chips failure is observed
  - → Cost effectiveness highly depends from the project

Conclusions: Radiy FPGA-based I&C modernization projects

- Customized solutions and products
- Flexibility to meet customer expectations
- Working closely with customer in each project phase
- Accommodates outage schedules with minimum installation time
- Long-term technical support, spare parts, warranties
- Licencing support, adapting to national licensing processes
- Using pre-certified or standardized universal components (RadICS platform) to easy regulatory approval
- Working with local partner companies, subcontractors, and service providers

Thank you for your attention!

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