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A user-friendly, digital console for the control room parameters supervision in old-generation nuclear plants

Fabrizio Memmi[2], Luca Falconi[1], Mauro Cappelli[*,1], Mario Palomba[1], Massimo Sepielli[1]

ENEA, Casaccia Research Center, via Anguillarese 301, Rome, Italy

HIGHLIGHTS

- We propose a user-friendly monitoring system for reactor supervision.
- Statistics from data analysis can be used to optimize reactor management.
- The tool has been designed in order to include a simulation tool for prediction.
- The proposed system could help operators in training and continuous learning.

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ABSTRACT

In this work a user-friendly, digital monitoring system for supervision of process variables coming from a fission nuclear reactor of TRIGA type (1-MW TRIGA reactor RC-1) is presented. The system, developed on the basis of COTS tools, can easily interface the control room instrumentation and display the typical monitoring parameters (e.g. nuclear power, temperatures, flow rates, radiological variables) in an intuitive, user-adjustable way for plant operators. A front panel of a virtual instrument allows for a direct measure while the acquisition system, for signals coming from the reactor, can process the data and generate a detailed representation of the results, whose statistics can be interpreted to optimize the reactor management parameters. This system has been also designed so as to include a simulation tool able to predict specific performances and investigate critical phenomena, and to optimize overall plant performances. In particular, it allows to have a feedback control and to perform several predictive statistical surveys of all main process parameters. The proposed system could help operators in training and continuous learning activities, and serve as a basis for an advanced decision support system and for a remote training tool for students and trainees not authorized to work in a radiation environment.

1. Introduction

In a nuclear plant the problem of supervision and control is crucial for enhancing all monitoring and operation tasks. In the last years, following a similar trend in conventional industry, supervisory systems for new nuclear plants tend to be designed as totally digital systems, thus providing more advanced operational and maintenance functionalities, together with a greater cost-efficiency (IAEA, 2011a). On the other hand, the most part of working reactors are "old-fashioned" reactors, i.e. they are partially or totally supervised and controlled by analogue systems (Bradley, 2009).

The problem of coping with the best solution for Instrumentation and Control (I&C) systems in nuclear plants is a crucial one. This is especially true when dealing with the renovation of old plants where a total replacement of the existing I&C systems is normally to be avoided for guaranteeing a cost-effective design. Digital processors-based architectures provide a strong and wide platform for implementing as many functions as one needs. On the other hand, they show some drawbacks. First of all, digital processors are usually available as commercial-off-the-shelf (COTS) systems, i.e. as general-purpose components not directly designed for nuclear applications. As a consequence they are driven by nonspecific requirements, thus providing too many unused functionalities, a too complex architecture (for the purpose of the application) and low reliability (very short lifetime). To try to face the problem, new hardware platforms are to be considered. Among others, FPGAs (Field Programmable Gate Arrays) seem to be ready for a practical validation campaign in the context of a nuclear plant modernization, thanks to their inherent property to

* Corresponding author. Tel.: +39 3298313966.
E-mail address: mauro.cappelli@enea.it (M. Cappelli).
[1] These authors are with ENEA, FSN Department, Rome.
[2] This author is a graduate student of the University of Romatre, Rome, and visiting student at ENEA, Rome.

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be programmed as dedicated systems, both from the hardware and software viewpoint (Compton and Hauck, 2002; IAEA, 2016). Presently, digital platforms that have passed FPGA-based Class 1 safety system qualification are very few (IAEA, 2011a; Ranta, 2012), though a partial refurbishment of existing electronic systems and microprocessor boards could be easily achieved without a strong impact on operation or cabling (IAEA, 2011b). In fact, many countries do not provide the regulatory background for licensing this kind of technology, while a standard dedicated to complex electronic components seems to be necessary in order to guarantee a serious validation process. The introduction of such a technology could contribute to improve the overall plant safety, making the qualification phase easier and more robust compared with general-purpose processor-based systems. Moreover, the FPGA main features (standard hardware languages, reliability of integrated circuits, robust design, modularity, specific application approach, lesser vulnerability to cyber attacks) could make this technology capable of a long lifetime usability, also due to a design based on few components.

In order to gradually improve the Human–Computer Interface (HCI) for old-generation plants, it could be worthwhile to introduce simple supervisory systems based on general-purpose technology but able to satisfy the reliability requirements demanded by plant equipment. The simplest way to test such a system is in the context of a research reactor, due to its inherent capability of mimicking some processes of a real nuclear power plant.

The purpose of this paper is to present an intuitive, user-adjustable tool for monitoring and supervising variables coming from a nuclear research reactor. This supervisory system has been tested and validated on the basis of the control system for the 1-MW TRIGA RC-1 reactor installed at the ENEA, Casaccia Research Center in Rome (Italy). In Section 2, we present a description of the reactor, with a particular focus on the Instrumentation and Control aspects, and how the supervising tool has been designed and implemented for working in the reactor control room. The potentiality of the simulation tool and some preliminary results of the validation process on the TRIGA reactor control room are presented in Section 3. Finally, results and open problems are discussed in Section 4.

2. Materials and methods

2.1. The TRIGA RC-1

TRIGA RC-1 is a thermal pool reactor having a core contained in an aluminum vessel (190.5 cm diameter) and placed inside a cylindrical graphite reflector, bounded with lead shielding. The biological shield is constituted by concrete with average thickness of 2.2 m. Demineralized water fills the vessel thus guaranteeing the functions of neutron moderator, coolant and first biological shield. Reactor control is ensured by four rods: two shims, one safety fuel-follower rods and one regulation rod. The produced thermal power is removed by natural water circulation through a suitable thermal-hydraulic loop including heat exchangers and cooling towers.

Fig. 1 shows an horizontal section of the TRIGA RC-1 reactor. The overall height of the aluminum tank is about 7 m, and the core is shielded by about 6 m of water. The core, surrounded by a graphite reflector, consists of a lattice of fuel elements, graphite dummy elements, control and regulation rods. There are 127 channels divided in seven concentric rings (from 1 to 36 channels per ring). The channels are loaded with fuel rods, graphite dummies and regulation and control rods depending on the power level required. One channel houses the start-up Am–Be source, while two fixed channels (a central channel and a peripheral channel) are available for irradiation or experiments. A pneumatic transfer system allows fast transfer from the peripheral irradiation channel and the radiochemistry end station. The diameter of the core is about

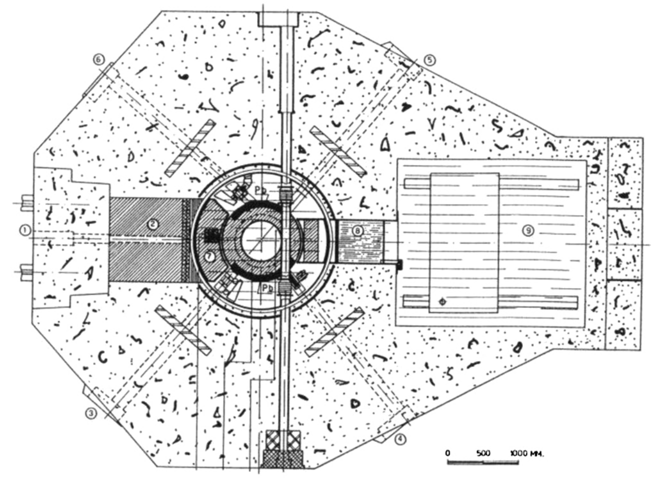

Fig. 1. Horizontal section of the TRIGA RC-1 nuclear research reactor in Rome, Casaccia Research Centre.

56.5 cm while the height is 72 cm. Neutron reflection is provided by graphite contained in an aluminum container, surrounded by 5 cm of lead acting as a thermal shield. The fuel elements consist of a stainless steel clad (AISI-304, 0.05 cm thick, 7.5 g/cm^3 density) characterized by an external diameter of 3.73 cm and a total height of 72 cm (end cap included). The fuel is a cylinder (38.1 cm high, 3.63 cm in diameter, 5.8 g/cm^3 of density) of a ternary alloy Uranium–Zirconium–Hydrogen (H-to-Zr atom ratio is 1.7 to 1; the uranium, enriched to 20% in ^{235}U, makes up 8.5% of the mixture by weight: the total uranium content of a rod is 190.4 g, whose fissile amount is 37.7 g) with a metallic zirconium rod inside (38.1 cm high, 0.5 cm in diameter, 6.49 g/cm^3 of density). There are two graphite cylinders (8.7 cm high, 3.63 cm in diameter, 2.25 g/cm^3 of density) at the top and bottom of the fuel rod. Externally, two end-fittings are present in order to allow remote movements and correct locking to the grid. The regulation rod has the same morphological aspect as the fuel rod: the only difference is the absorber made of graphite with powdered boron carbide instead of the mixture of the ternary alloy Uranium–Zirconium–Hydrogen. The control and safety rods are "fuel followed": the geometry is similar to that of the regulation rod but it has a fuel element at the bottom. The graphite dummies are similar to fuel elements but the cladding is filled with graphite.

The parameters used in order to perform the reactor monitoring can be classified into three large groups: power monitoring, process monitoring and radiological monitoring. The reactor power is monitored by means of one starting channel (up to 1 W), two wide range linear channels (from 0.5 W to 1 MW) and one safety channel (from 10 kW to 1.1 MW). The process parameters to be monitored include 14 temperatures (fuel elements, primary and secondary loops, cooling towers), flow rates (primary and secondary loops, water cleaning system, reactor hall air), levels (reactor pool, shielding tank), conductivities (primary loop, shielding tank loop). The radiological control is carried out by monitoring water activity (primary and secondary loops), air activity (reactor hall and experimental channels) and environmental radiation levels (reactor hall, control room and experimental channels). Only main plant parameters are mentioned herein, but a lot of other parameters can be easily monitored (such as control rods positions, switches status, alarms and so on).

2.2. System development tool

The proposed system is based on the well-known commercial tool LabVIEW® by National Instruments®. This is a graphical