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Development of the First Indonesia's Experimental Power Reactor: Instrumentation and Control System

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Abstract: The design of Indonesian Experimental Power Reactor (*Reaktor Daya Eksperimental*/RDE) has been engaged since 2015. The ten-MWth RDE, which is a pebble-bed high-temperature gas-cooled reactor, produces 520℃ steam that can be used for cogeneration application. The design of instrumentation and control system to ensure safe plant operation is outlined. Engineering design methodology is applied. The RDE's control system, consisting power control, circulator control, feed water control, steam pressure control, pump control, and turbine and generator control, has been developed. In addition, a reactor protection system for RDE has also been proposed. Its schematic protection measures, starting with detection, triggering conditions, anticipated accidents, and protection trip modules, are described. The design of RDE I&C system architecture, having four levels, i.e. process interface, control & protection system, communication network, and man-machine interface, is provided.

Keywords: Nuclear Power Reactor, RDE, Instrumentation, Control

I. INTRODUCTION

Stretching across the equator, Indonesia is an archipelago country that is bestowed with abundant mineral and energy resources. Development of a power plant able not only to generate electricity but also to boost the exploitation and production of mineral resources is inevitable. Indonesian Nuclear Energy Agency (BATAN), a government institution conducting research and development on nuclear energy, initiated designing the Experimental Power Reactor (*Reaktor Daya Eksperimental* / RDE), which is a High-Temperature Gas-Cooled Reactor (HTGR), in 2015.

In addition to generating power, RDE having capacity of 10 MW_{th} has cogeneration features as it produces steam at 750 °C, which can be applied to hydrogen production, seawater desalination, enhanced oil recovery, coal gasification and liquefaction, and other applications. Moreover, RDE, as one of the Generation IV nuclear energy system, implements principles of sustainability, safety and reliability, as well as proliferation resistance and physical protection [1]. Similar to RDE's capacity, a 10-MWth High-Temperature Gas-Cooled Reactor (HTR-10), which is a modular pebble bed type reactor, has been successfully developed in China [2].

The Experimental Power Reactor (RDE) employs graphite as reflector material and helium as coolant to transfer heat produced in the reactor core to steam generator. Uranium dioxide (UO_2) contained in fuel kernel and coated with silicon and pyrocarbon layers is fabricated into fuel spheres that are loaded in this pebble bed reactor. In the power conversion unit, the steam generated then drives a turbine directly coupled with a generator to produce power [3]. Steam coming out from the turbine is returned to and condensed in a condenser. The water obtained is brought back to the steam generator.

To ensure safe RDE's operation, reliable instrumentation and control system should be implemented to safety- and non-safety-related components through continuous measurement, monitoring, and control. This paper describes the development of instrumentation and control system for RDE. The RDE's power level is controlled by the adjustment of control rod insertion containing B_4C [2,4,5]. Modular HTGR control and protection strategy has been proposed by Wilson et al. [6]. New field instruments for the measurement of temperature, pressure, flow rate, and neutron flux in HTGR have been proposed by Ball et al. [7]. To improve accuracy and reliability, HTR-10 [8] and HTR-PM [5] has utilized digital reactor protection system. Safety aspect of digital instrumentation and control system in nuclear power plant has been evaluated by identifying any possible accidents and system hazards and modelling the safety control structure [9]. A thermal hydraulics transient analysis of HTR-10 has been studied and the results show that this type of reactor has inherent safety properties [10].

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II. RESEARCH METHOD

Engineering methodology is used in designing the instrumentation and control system of RDE. It starts with the preparation of design philosophy and development of design requirements. The next steps are selection of standard and code applied and development of engineering design. Then, the design is evaluated to see if it meets the design requirement. If the design fulfils all the requirements specified, then design finalization is performed. Otherwise, the design experiences further improvement until it meets all the requirements.

III. RESULTS AND ANALYSIS

A. Design Philosophy and Standard & Codes

The design of RDE instrumentation and control considers the following philosophies: redundancy, which provides protection towards single failure and prevents random and independent failure on a component or system from occurring; separation, which refers to the use of a systematic physical separation such as barrier or distance and the use of decoupling instrument; fail-safe-mode, which is applied for safety related component or system; automation, which is applied to mitigate consequences of an accident where operator's manual action is not required in order to prevent radioactive release to environment; protection, which is implemented to shut down the main components or installation if further operation might cause risks or endanger environment and important components; diversity, which minimizes any possible risks of an error or mistakes in the design or maintenance; and remote shutdown, which is provided to anticipate any emergency condition in case the main control room cannot be operated and/or equipment in the main control room does not work.
Meanwhile, some standard and codes applied to the design of this RDE I&C include IEEE 279, IEEE 308, IEEE 317, IEEE 336, IEC 231, and Title 10 CFR 50.

B. Design Requirements

A number of design requirements have been established. They are related to automatic control and monitoring functions for electricity generation, start-up/shutdown, and refuelling; performance and transient characteristics; normal operation; control over any actuators and device required for power control and start-up/shutdown; standardization of the design, structure, and components; and user-friendly design of RDE.

C. Control System

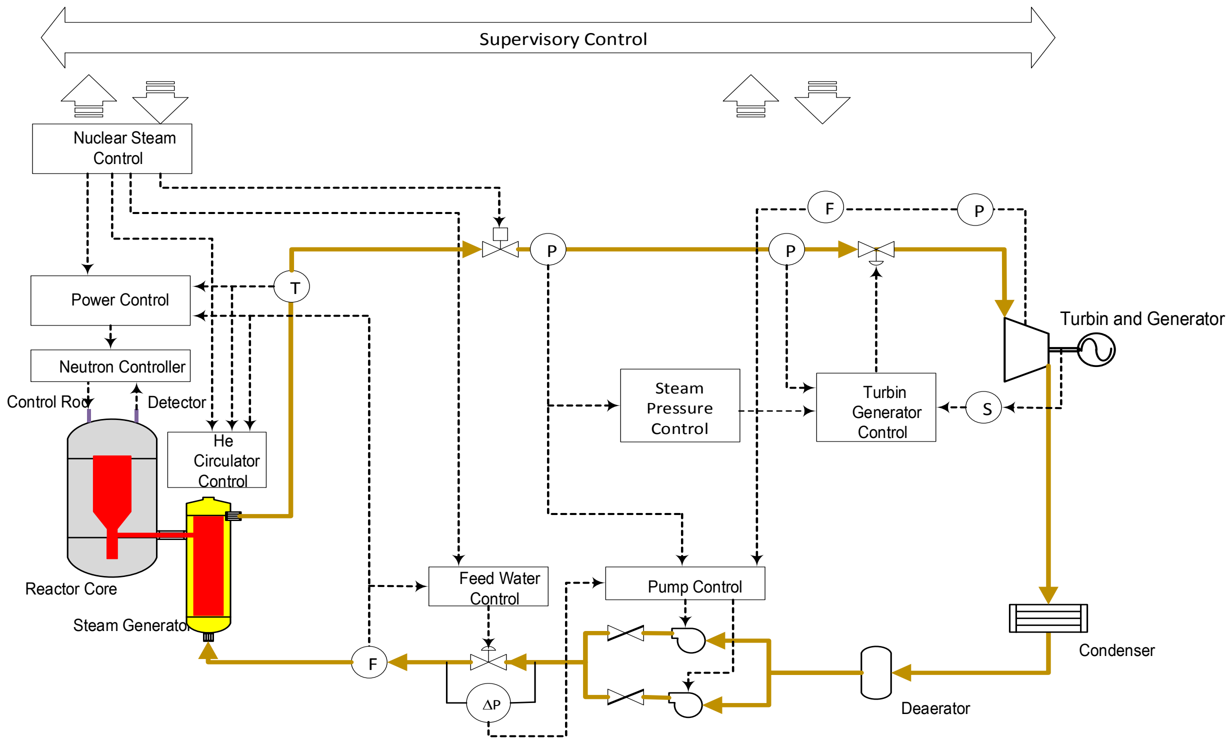

Fig. 1 Typical Layout of Control System of RDE

The safety philosophy of RDE control system is to prevent radioactive release to environment. It can be achieved by controlling the reactor core heat generation and removal. High temperature helium is used as coolant to transfer heat generated in the core to steam generator in a primary loop. Next, a secondary loop conveys the heat to turbine and generator as power conversion unit. The control system in RDE employs two-level cascade control loop, in which feedback input is used to provide corrective action for deviations due to variations in the process. Proportional, integral, and/or differential control action are applied. The set point obtained is then combined with a feed forward input to increase coordination of all heat transfer equipment and to give more rapid responses of actuators.

For RDE, the control system, including power control, helium circulator control, feed water control, main steam pressure control, pump control, and turbine-generator control, has been developed. A typical layout of control system of RDE is shown in Fig. 1. The instrumentation and control (I&C) system covers measurement of process variables, such as neutron flux, temperature, pressure, coolant flow rate, humidity, et cetera. The control system employs a supervisory control system that receives inputs, such as power load demand, load allocation, system frequency, and others, from a main control room. As to illustrate the control process, the power control is achieved by adjustment of the control rods, which uses feed water flow rate as a feed forward input and measured steam temperature as a feedback input. The setting point obtained is then used for controlling the neutron flux. By comparing the setting point and the input from the neutron detector, the neutron controller can provide actuation of the control rods.

D. Reactor Protection System

RDE protection system is provided to monitor and process variables important to reactor safety and environment, to detect early any possible accident, and to initiate automatically protective actions. In an accidental event, the reactor protection system (RPS) shuts the reactor down and activates any required protection measures to mitigate the consequences. RPS has separate and redundant channels configured to meet independency requirement. Process variables monitored, initiating criteria and actuation signal generation for protection system are conducted based on RDE accidental analysis. During abnormal conditions, RPS applies automatic and manual actuation of safety system and related monitoring functions required to achieve controlled condition by initiating reactor trip and safety system, including reactivity control, residual heat removal, and radioactive release prevention by maintaining primary and secondary system integrity.

RDE implements two separate and independent shutdown systems: control rods and small absorber spheres that are inserted into columns in the reflector surrounding the reactor core. The ten control rods made of B_4C are able to bring the reactor to zero power and maintain in subcritical condition for a particular duration. Small absorber spheres of 10 mm in diameter contain about 4% volume of B_4C. They are stored above the reflector and used for cold shutdown. Other protective actions to shutdown RDE are shutting down the helium circulator, isolating the secondary system, isolating the primary system, and relieving the steam generator and discharging the water. Safety shutdown and protection measures for RDE are categorized in three trip modules, i.e. Trip Module 1 consisting of dropping of the control rods, shutdown of the circulator, and isolation of the secondary loop; Trip Module 2 comprising Trip Module 1 plus isolation of the primary loop system; and Trip Module 3 containing Trip Module 1 plus steam generator emergency drainage. RDE's safety shutdown and protection diagram has been developed and shown schematically in Fig. 2. Detection of neutron flux, helium temperature, coolant mass flow rate, steam pressure, and humidity in the primary loop is required for safety shutdown and protection. Detection of these five parameters is used to identify the triggering conditions and envisage any possible accidents if the triggering values are exceeded. Then, the trip module signals are transferred to logic circuit and display for actuation and operator actions.

E. I&C System

Instrumentation and control (I&C) system is provided to perform measurement, monitoring, and control of RDE installation. I&C system includes operational system, protection system, and monitoring system. Operational system, which is non-safety related, is used to operate the installation under normal condition and to monitor operational condition. The information required to monitor operational condition is displayed a main control room. Instrumentation of protection system is considered safety related and used to prevent excessive load on the important components in order to minimize accidental consequences to environment. Full range monitoring system provides information on operational condition and parameters through display, alarm, and reports.

A diagram of I&C system architecture for RDE has been developed. As shown in Fig. 3, it consists of four levels, i.e. process interface, control and protection system, communication network, and man-machine interface. In the process interface, field instrumentation senses operation parameters of the plant, i.e. neutron flux (ϕ), temperature (T), pressure (P), coolant flow rate (f), humidity (h), circulator velocity (v). Neutron flux instrumentation include a number of channels for source range, intermediate range, and power range detectors. Neutron flux detectors should be placed in

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metal tube in the primary cavity. BF_3 source range detectors are installed in two guide tubes located at position 240°. Intermediate and power range detectors employ common guide tubes, which are symmetrically install around the core. Meanwhile, for temperature measurement, type K thermocouples are used since the RDE operation temperature reaches 900℃. On the other hand, pressure measurement is achieved by the use of deflection mechanism sensors, such as SiCN composite ceramic. In addition, hot wire anemometer or heated-lance flow meter is suitable for flow measurement. Humidity in the reactor hall of RDE can be measured using steam detector.

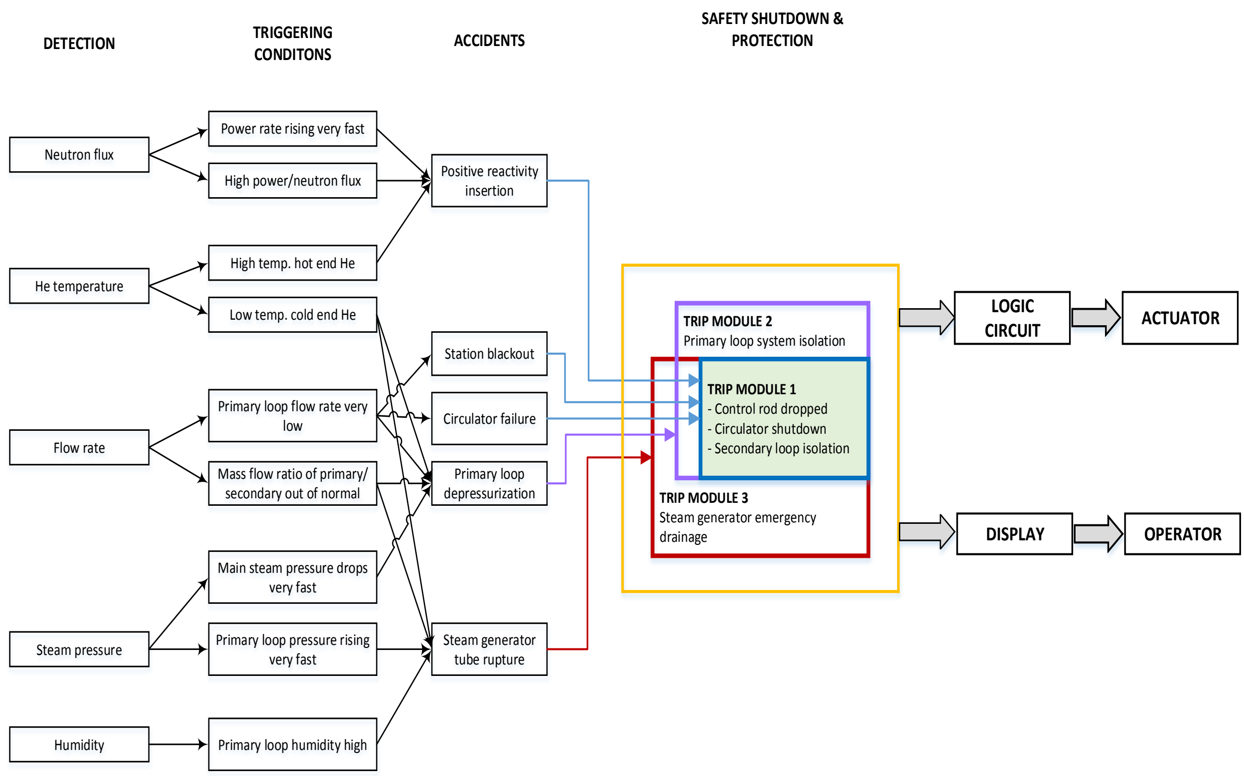

Fig. 2 Schematic Safety Shutdown and Protection for RDE

Signals obtained from the field are processed, digitized, and transmitted through wired connection to control system, employing programmable logic controllers, and trip logic at control and protection system level. The output of the trip logic is used by the safety system if trip modules need to be activated. Communication network, i.e. Ethernet, is established to provide access to data and information on the plant status. They are displayed or printed at man-machine interface level. Main control room displays the status of the primary system that include primary loop, fuel storage and handling, small absorber spheres, primary loop depressurization, steam generator, residual heat removal, cooling system, helium purification and auxiliary system as well as low pressure ventilation system of the vessel. Meanwhile, the secondary system displayed in the main control room should cover the status of gas sampling and analysis system, feed water system, start-up and shutdown system, condensation system, de-aerator system, vacuum and water circulation system, and electricity system.

IV. CONCLUSION

Instrumentation and control system of RDE has been designed. The design process follows the engineering design methodology, starting with the preparation of design philosophy, standard and codes, and design requirements. The control system implementing two-level cascade control loop includes the controls of power, helium circulator, feed water, steam pressure, pumps, and turbine and generator. Safety shutdown and protection system applies three trip modules to be actuated in case of emergency. The digital I&C system architecture consists of four levels, i.e. process interface, control and protection system, communication network, and man-machine interface. The main control room is provided to display the status of the primary and secondary system. The design of this I&C system supports the development of RDE, which is planned to be the first Indonesian high-temperature gas-cooled reactor.

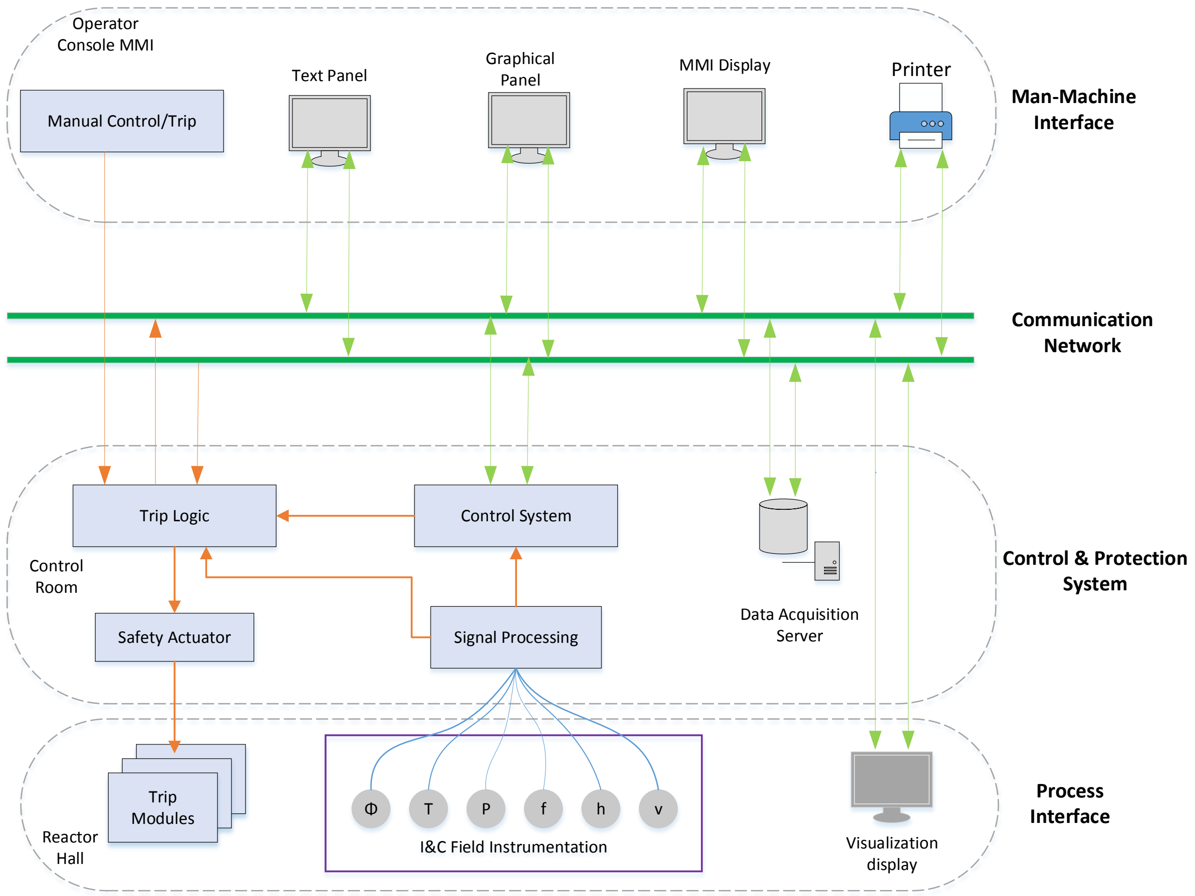

Fig. 3 I&C System Architecture for RDE

V. ACKNOWLEDGMENT

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