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Design Architecture of Instrumentation and Control of RDE Fuel Handling System

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Abstract: Indonesia is currently developing a design nuclear Pebble Bed Modular Reactor (PBMR) with the reactor name is RDE. This type of reactor requires a system to supply fuel into the reactor core. The system is called the Fuel Handling System (FHS). The selected RDE-FHS is a type of online refuelling system, in which there is no need to turn off the reactor during its refueling time. To ensure the continuity of the process, an Instrumentation and Control System (I&C) is needed so that the parameters on the FHS can be monitored and controlled. An architecture of the FHS-I&C is required in the implementation, so that the connection between sensors, transducers, transmitters and valves can be clearly seen. The main instruments in the FHS include burn up measurement and fuel counting measurement. Burning measurement is needed to determine the fuel value, while fuel counting measurement is needed to calculate the amount of fuel entering and leaving the reactor core. FHS interconnection with other systems in RDE uses communication networks with the Hart protocol and SCADA system.

Keywords: Pebble Bed Modular Reactor (PBMR), FHS, Burn up, SCADA, Architecture, I&C

I. INTRODUCTION

The need for electrical energy in Indonesia increases every year. Indonesia as an archipelago country has a challenge in providing the source of electrical energy. There are several primary sources for the electrical energy to meet these needs, most of which come from fossil fuels which have high operational costs and there is also an impact on the environment. Currently, new renewable energy is developed to replace such fossil energy, but for a small scale application only, besides the other new energy which is nuclear energy as an alternative energy. Generally, the commercial nuclear power plant (NPP) has a very large of operational range: 500-1000 MWe. This type of nuclear power plant is suitable for areas with very large electricity needs such as Java and Sumatra Island. For islands having electricity consumption not too large, small power plants are required but the plant must have relatively low operational costs. To answer this challenge, modular technology for modular type nuclear power plant is being developed with having relatively small to medium power. The National Nuclear Energy Agency (BATAN) as the nuclear power research and development institution has participated in developing design of modular type nuclear power plants in this case the type of Pebble Bed Reactor (PBR). The PBR has eminent characteristics such as very safe considerations, functioning for cogeneration, having fuel flexibility, tested, competitive prices, multipurpose, be able to be developed in all regions of Indonesia according to their needs, and to meet the needs of electricity supply. In terms of the safety, the passive safety system from the PBR design guarantees very minimum radiation release to the environment under any conditions including severe conditions such as those experienced in the Fukushima accident. The PBR design has an inherent safety system that depends only on natural mechanisms so that the reactor core system becomes very simple when compared to the current commercial nuclear reactor system. At present, a design developed is still small in power with a maximum of 10 MWe under the name of Experimental Power Reactor (RDE). The general scheme of the RDE system is shown in Fig 1. In PBR nuclear power plants, the fuel handling system of RDE is one of the main installations so that the RDE can be operated continuously without having shut down during refueling time. There are several stages in the supply of RDE fuel in the fuel handling system: the first is fresh fuel entry, the second is selection of damaged fuel (field fuel), and the third is selection of used fuel that can still be used provided that it still meets burn-up below 80% and spent fuel. These three processes need to be monitored and controlled by an integrated instrumentation system. The system is generally called the fuel handling system (FHS) instrumentation and control / control system. To meet these needs, architectural design is currently being carried out which describes the components required for the FHS-I&C. Some components of instrumentation in fuel handling systems include instrumentation components to measure the burn on pebble fuel (burn-up measurement) coming out from the reactor core. This

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component must be able to take measurements online and continuously in a high temperature and pressure environment.

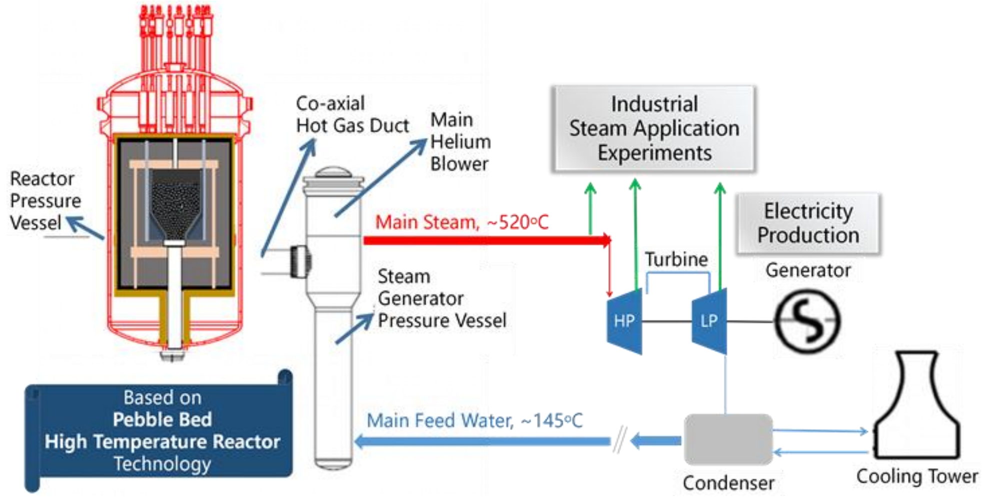

Fig 1. General Scheme of Experimental Power Reactor (RDE) [7]

Other components for the burn measurement are designed using a smart detector with output in the form of an energy spectrum that will be the number of counts in the spectrum of energy CS-137. It will be used as the value of representation of the degree of the fuel burn. Instrumentation component for calculating the fuel that enters and exits the reactor must be working without direct contact to the fuel. To meet this need, sensors for the presence of fuel balls use graphite detector and changing the electric current of the coil that surrounds the pipes of the fuel line. The two instruments are the key to the success of the FHS system on RDE or HTGR. Other components will be described in more detail in the discussion.

II. RESEARCH METHOD

In addition to conducting literature studies, research and development activities also refer to engineering principles using input data based on Piping & Instrument Diagram (P & ID) fuel handling processes along with supporting documents for identifying the components needed in the process. In addition, it was also determined that the installation management organization to determine the communication network model and its supporting devices, then made it in the design of the instrumentation and control system architecture for the system based on the specified process parameters and workflow. Next is the verification process. The detail method of I&C project management are show in Fig 2.

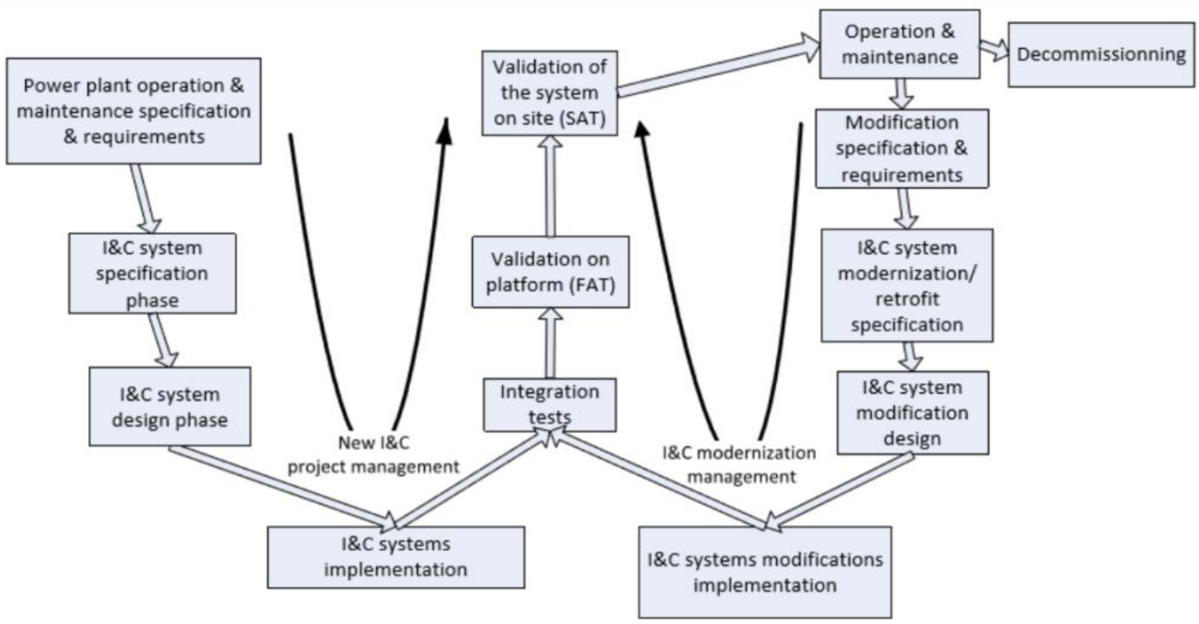

Fig 2. I & C project management [4]

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III. RESULTS AND ANALISYS

In normal operation, the fuel handling device has the role of supplying fuel to the reactor core continuously by replacing every fuel that comes out from the reactor core through the fuel discharge tube. Block diagram of the fuel handling is shown in Fig 3.

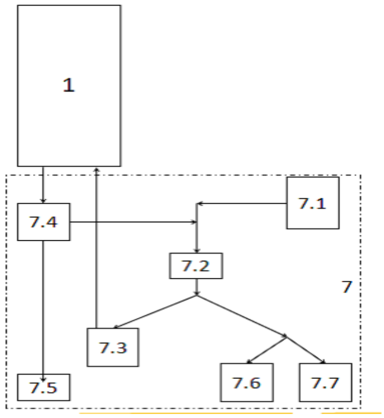

Fig 3. Block diagram of fuel handling system [6]

Where, (1) Reactor pressure vessel, (7.1) Storage of fresh fuel, (7.2) Burner, (7.3) Fuel elevators, (7.4) Damaged fuel separator, (7.5) Fuel storage damaged, (7.6) Dummy graphite fuel storage, (7.7) Used fuel storage [3].

The working principles of the fuel handling system are as follows:

- The fuel coming out from the reactor core through the fuel discharge tube will be physically examined (fragment test) by a failed fuel separator. This tool works by rotating so that the physically damaged fuel will be separated out through holes with a diameter of <60mm. Then the used and damaged fuel is stored in cask failed fuel.
- Fuels that pass through the fragment test will be forwarded to the burn-up measurement. If the burn rate has not been reached or is still below 80%, the fuel is returned to the terrace with the help of pneumatic[2].
- If the value of the fuel is more than 80%, the used fuel will be forwarded to spent fuel shipping cask for disposal.
- If the burn-out value is not detected, it is assessed as a fuel dummy, a fuel dummy is needed at the start of the operation of the reactor for the first time with a ratio of 50:50.
- The ratio of the change in fuel in each cycle is 1: 1 (one out - one in), with the total replacement of new fuel is 25 fuel per day, the rest is used fuel which the value of the fuel fraction still meets the requirements.

A. I & C Architecture Development Guide

The primary functions assigned to I&C systems involve protection, control and monitoring. The functions are derived from the plant design both basis and consideration of design extension conditions. The functions also sense basic physical parameters, monitor performance, integrate information and make automatic adjustments to plant operations as necessary. Physically, an I&C system is composed of electrical, electronic and/or programmable electronic components, whose purpose is to perform defined I&C functions, as well as any service and surveillance functions that are necessary for the operation of the system itself. The elements within the boundary of an I&C system can include the processing and logic equipment, internal power supplies, sensors and other input devices, data highways and other communication paths and interfaces to actuators and other output devices. Many of these elements are dedicated to one system but some may be shared among several systems. Certain architectural decisions need to be made early on, such as [4]:

- The number of levels of defence in depth to be provided;
- The degree of independence required between levels;
- The manner in which non-classified systems will be separated from systems important to safety;
- The number of independent channels to be provided for safety systems;
- The degree of separation required between safety channels.

SSG–39 [2] describes the overall I&C architecture as the organizational structure of the multiple plant I&C systems, each playing specific roles. The safety guide amplifies the description of the overall I&C architecture by indicating the items the architectural design establishes [5]:

- The I&C systems that comprise the overall architecture;
- The organization of these systems;

The allocation of I&C functions to these systems;
- The interconnections across the I&C systems and the respective interactions allocated and prohibited;
- The design constraints (including prohibited interactions and behaviours) allocated to the overall architecture;
- The definition of the boundaries among the various I&C systems.

B. P & ID of RDE Fuel Handling System

In engineering activities, any details of industrial processes are needed. Details of the process described in the piping and instrumentation diagram (P &ID). The P&ID of RDE fuel handling system are shown in Fig 4.

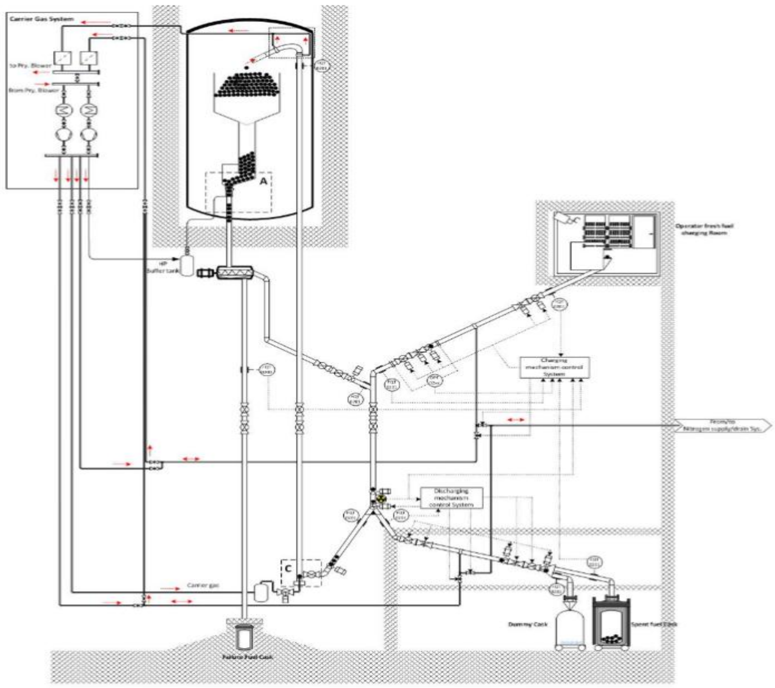

Fig 4. A simple P&ID of RDE fuel handling system

From P & ID image it appears that there are several instrumentation and others components needed:
- Burn up measurement, to measure the fuel burn-up of RDE used fuel
- Fuel counting measurement, to calculate the amount of fuel entering and leaving to / from the reactor
- Isolation valve, to isolate pipe installation of fuel handling when a vacuum process is carried out.
- Pneumatic valve, to hold the fuel so it doesn't slide in the pipe.
- Fuel rotary escarpment, to regulate the fuel queue to get through the pipes one by one.
- Swing direction gate, to select the pipe output line (one in two out / K Valve)
- Pneumatic tube, for means of providing pressure when launching fuel into the reactor core.

C. Architecture design of RDE Fuel Handling System

FHS-I&C architecture is designed on 5 (five) layers, namely instrument layer, module input layer, controller module layer, communication network layer and operator and supervisory layer. The figure of design architecture of FHS-I&C RDE shown in figure 5. The detail function of the layers is:

Supervisory and Data Acquisition (SCADA)

The primary functions of SCADA are:
- Development and test of the HMI allowing commands to be issued to the plant system I&C and to visualize the plant system I&C state and status.
- Handling and visualization of the alarms generated by the plant system I&C.
- Handling and visualization of the logging messages generated by the plant system I&C.
- Storage of the data generated by the plant system I&C and access to this data.

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- Development and management of test software.
- Development and testing of the supervisory functions to be integrated in the SCADA System. - Generation for test purposes of software events transmitted to the plant system I&C from the SCADA System.
- Generation for test purposes of data flows transmitted to the plant system I&C from the SCADA System.
- Management and storage of the configuration data for the plant system I&C.
- Data visualization (real-time and history).

Plant System Host

PSH is a standardized computer supplied by IO that is a component of the plant system I&C. PSH is connected to the Plant Operation Network. PSH is designed for implementing the standard functions for plant system I&C, not for plant-specific programming. The primary functions of PSH are:

- Handle commands from the SCADA and dispatch commands to the plant system controllers.
- Monitor the plant system state and status and update this in the system.
- Transfer alarms from the plant system I&C to the SCADA system.
- Transfer logging messages from the plant system I&C to the SCADA system.
- Distribute software events from the SCADA system to the plant system controllers and vice versa.
- Monitor its own state and update this state in the SCADA system.
- Reconfigure the plant system I&C when in maintenance mode.

Plant System Controllers

Plant system controllers are local units in charge of implementing the functional and physical part of the control and data acquisition of the plant system. All plant system controllers include a processor and I/O interfaces, as required. I/O interfaces are either I/O embedded within the controller hardware system, or remote I/O interfaced with a field bus. FHS-I&C used plant system controllers categories is slow controllers using industrial components (Programmable Logic Controllers, PLC).

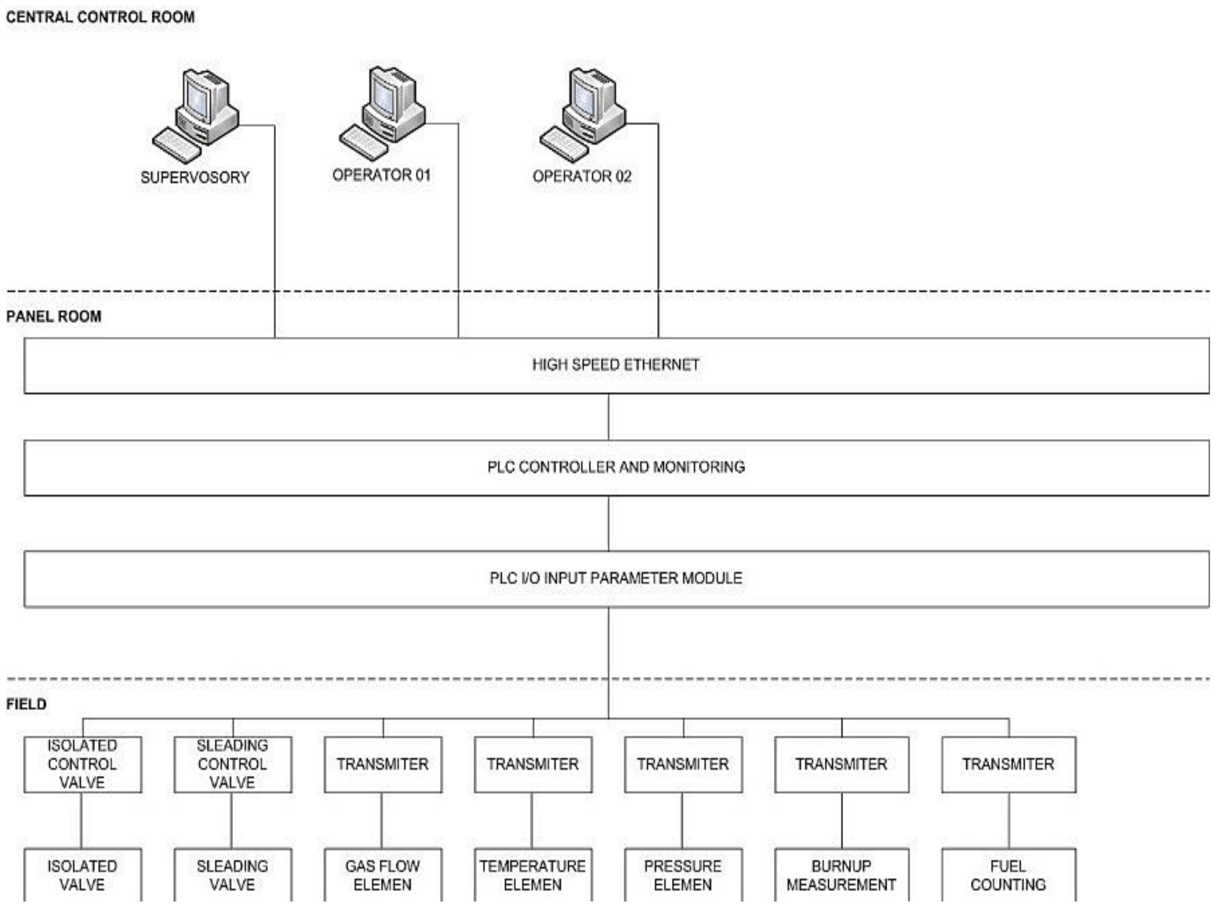

Fig 5. Design architecture of SIK RDE fuel handling system

Field instrument

The instrument is a collection of instrumentation components consisting of sensors, transducers, transmitters, and valve. The main components of instrumentation from FHS-I&C are:

- Gas Flow element is equipped with a transmitter, its function is to detect and measure the flow rate of helium gas flowing through the FHS pipe, with a working temperature of 250 ^{o}C at 30 Bar pressure. Sensor type uses pressure differential.
- Temperature element is equipped with a transmitter, serves to measure the temperature of the helium gas flowing in the FHS pipe, the working temperature is assumed to be 250 ^{o} C and at 30 Bar pressure. Sensor type uses ceramic type thermocouple.
- Pressure element is equipped with a transmitter, its function is to measure the pressure on the FHS pipe. This instrument works at a temperature of 250 ^{o}C and a pressure of 30 bar, a type of helium fluid.
- Burn up measurement [3], its function is to determine the value of fuel combustion that has come out from the reactor core, working at a temperature of 250 ^{o}C and a pressure of 30 bar. This Burn-up measurement operates online and will provide actuation commands on the valve. The nuclear detector used is the gamma smart detector type with the output of the enumeration in the form of a gamma energy spectrum. Later this spectrum output will be obtained and correlated with the value of fuel burn. Radioactive markers used by CS-137.
- Fuel counting, serves to calculate the amount of fuel entering and exiting to and from the reactor core, through the FHS pipe. The detection sensor uses an eddy current sensor type [1], equipped with signal processing and transmitter. This sensor works at temperatures less than 250^{o}C and ambient pressure because it is non-contact and outside the FHS pipe.
- Isolated valve, its function is to isolate airflow when vacuum is carried out in order to equalize temperature and pressure on the FHS pipe so that pebble balls can travel gravitationally in the pipe. Works at temperatures of 250 ^{o}C and 30 bar pressure. The actuator uses a motorized valve type.
- Sledding valve, functions to hold pebble balls in the FHS pipe so as not to glide immediately. Works at a temperature of 250 ^{o} C and a pressure of 30 bar. The actuator uses a pneumatic type.

IV. CONCLUSION

The results and analysis it can be concluded that the I & C architecture is needed to determine the appropriate communication components and systems so that each parameter on the RDE FHS can be monitored online through the SCADA mechanism. This FHS is only a small part of the RDE system that is quite complex, so the I & C architecture will make it easier to integrate the main system. In determining the F & I & C architecture, input data in the form of P & ID is required with the parameters of the process and the objects to be observed and or controlled.

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