Mechatronic Design HPS Test Loop of RDE

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Abstract. The electrical, mechanical and control system design of Helium Purification System Experimental Power Reactor Test Loop (RDE) has been conducted. The requirement system designed must be reliable operated, safety to personnel and equipments, ease of maintenance and operation, protection of equipment electrically, interchangeability of equipments and addition of the several model of tranducer. In order to achieve the above goals and obtain the desired results, the system based on electrical and instrumentation practical experiences will be needed. In this paper consist of the HPS electrical design and the instrumentation and control system. The criteria and the methods of designs of electrical and instrument equipments of the system have been discussed and investigated. The electrical and instrumentation control system drawing and requirement of design will be presented as the outcome of the design. The designed of power system analysis is also to overcome the problem of under voltage is consequently simulated by ETAP 12.6.

Keywords : HPS; RDE; electrical; instrumentation and design

1. Introduction

The development of Experimental Power Reactor (RDE) used Pebble Bed Reactor (PBR) technology which has very safe consideration, functioning for cogeneration, fuel flexibility, tested, competitive price and multipurpose. More ever it has flexibility to fulfill the need for electricity supply. On the safety side, the passive safety system of the PBR design ensures a very minimum radiation release to the environment under any circumstances including severe conditions such as those experienced in Fukushima accidents. The PBR design has an inherent safety system that relies only on natural mechanisms so that the reactor core system becomes very simple when compared to today’s commercial nuclear reactor systems. The general schema of the RDE system is shown in Figure 1[1].
RDE is a reactor designed based on HTGR technology, with an indirect cycle, and uses pebble fuel. The reactor power is 10 MWth (3 MWe). The primary coolant is helium gas and the secondary coolant is water. The heat from the primary cooler is transferred to the secondary cooling through the steam generator to generate steam and drive the turbine-generator to generate electricity. Helium Purification System (HPS) is a system part that serves to clean the primary cooling system from various impurities. The primary coolant impurities may be particle and gas. The solid particles are graphite dust coming from the core, while impurity gases (O₂, N₂, H₂O, CH₄, CO, CO₂, and H₂) are formed due to graphite material interaction with water / air ingress. The main components used in HPS are the filter cartridge, the CuO oxidation column, the molecular sieve column and the activated carbon bed of cryogenic conditions. Each of these components has different functions. The filter cartridge serves to filter out particle-shaped impurities, whether graphite dust or fission products. CuO oxidizing column serves to oxidize CO gas impurities to CO₂ and H₂ to H₂O. The molecular sieve column serves to capture CO₂, CH₄ and H₂O impurities. The activated carbon adsorbent of cryogenic temperature serves to absorb the impurities of N₂ and O₂ [1].

Helium gas is best used as a coolant for heat transfer at very high temperature reactors (for HTGR, VHTR and other types of cold gas reactors up to about 950 °C), given the characteristics of helium gas as an ideal gas / inert gas, physical or chemical properties at relatively high temperatures, unreacted with other gases / substances, effective for heat transfer needs and easily compressed up to 30 Bar or more [2]. The characteristic of helium gas can survive like this if its purity can be maintained well. However, impurity gas elements may arise from the consequences of micro-order leakage in the shielding system between the coolant pipe connections, allowing impurity gas to allow entry into the cooling system. To overcome the above obstacle it is absolutely necessary to take care of the purity of helium gas used as a coolant, where purification of helium gas is carried out without having to stop the ongoing reactor operating process. The sustainability of the helium supply should be maintained so that the reactor coolant system's primary pressure remains stable. The research on design of the HPS-RDE aims to obtain the optimal and reliable system. The purpose of this study was to develop a detailed RDE design in terms of optimal primary cooling design. The research method is separated into 3 steps, that is the designing electrical system at HPS-RDE which are with component simulation, electrical load distribution analysis and electrical component specification on HPS-RDE system using ETAP software. Therefore, it is necessary to analyze the flow of power flow in the HPS-RDE. The development of electrical design for HPS-RDE is expected to provide an overview of HPS-RDE design which is planned to be built in Indonesia as in Figure 2[2].
Figure 2. Process Diagram of HPS-RDE [2]

The HPS test facility to be constructed consists of several components, such as HPS-01 (Mixing gases vessel), HPS-04 (Heater), HPS-11 (Cryosorption vessel), HPS-11A (Tube in tube Heat Exchanger), HPS -11B (Subcooler), HPS-11C (Adsorber Column), HPS-11D (Tubular heater) and HPS-14 (LN2 Storage), and HPS-15 (Purified gas vessel).

2. Theory

Power flow analysis is an analysis used to determine the condition of the system under normal circumstances, so it is needed in system planning for the future and is an evaluation of the existing system. This analysis includes determining the magnitude of the voltage value (V), active power (P) and reactive (Q) and the phase angle (φ) of each bus in the system. Furthermore, buses in electric power system can be grouped into 3 types [3,4,5,6]:

1. Reference bus (Swing or Slack bus)
   This bus serves to supply the lack of active power (P) and reactive power (Q) in the system. The parameters or quantities specified are voltage (V) and phase angle (φ). Each power system has only one reference bus, a bus in which there is a generator or generator that has the largest capacity among other plants in the system.

2. Bus generator (Voltage Control Bus)
   This bus is a bus whose voltage can be controlled through the regulation of reactive power so that the voltage will remain. The known parameters or magnitudes are active (P) and voltage (V). This bus is called PV bus.

3. Bus Load (Load bus)
   This bus is a bus connected to the system load. The specified parameter or quantity is active power (P) and reactive power (Q), then this bus is also called PQ bus.

Before the power flow analysis is performed, system components consisting of generators, transformers, transmission lines and loads must be represented or modeled through an one line diagram by assuming a three phase system is in balance. This diagram is intended to provide a brief overview of an overall power system, in this case the electrical system in the Helium Purification and Supply System of RDE. For that in need of data associated with these components. According to Stevenson (1996), the data required for power flow analysis are as follows:

a. Generator data, i.e. active power capacity (P) in Megawatt (MW) and reactive (Q) units in Megavolt Ampere (MVA) units, terminal voltage (V) in Kilovolt (KV) and synchronous reactance (X) in unit of Ohm (Ω).
b. Power Transformer Data, i.e. the capacity of each transformer in Megavolt Ampere (MVA), voltage (V) in Kilovolt (KV) and leakage reactance (X) in Ohm (Ω) units.

c. The data of transmission line, i.e. resistance (R) in ohm (Ω) and reactance (X) in Ohm (Ω).

d. The load data, i.e. the active power (P) in Megawatt (MW) and reactive power (Q) in Megavolt Ampere (MVA) units.

**Admittance and Bus Impedance Matrices [7,8]**

To be able to calculate and analyze the power flow, the initial step is to establish an electric bus system power admittance matrix. Figure 3 below is an example of a simple electric power system, where its impedance is expressed in terms of per unit on the basis of MVA and the resistance is negligible for simplification.

\[
y_{ij} = \frac{1}{Z_{ij}} = \frac{1}{r_{ij} + jx_{ij}}
\]

**Figure 3. Impedance Diagram of Simple Power System**

Based on the Kirchoff Current Law the impedances in the figure 3 can be changed to the admittance-form by using the equation (1):

\[
y_{ij} = \frac{1}{Z_{ij}} = \frac{1}{r_{ij} + jx_{ij}}
\]

**Figure 3 is changed to:**

**Figure 4. Admittance Diagram of Simple Power System**
The power system network as shown in Figure 4 of the transmission line can be illustrated by the model π whose impedances have been converted to per unit admittances on the basis of MVA. The use of Kirchoff Current Law on this bus is given in the equation (2):

\[ I_j = y_{i0}V_j + y_{i1}(V_j - V_1) + y_{i2}(V_j - V_2) + ... + y_{in}(V_j - V_n) \]  

\[ \cdots \] 

\[ \cdots \] 

\[ \cdots \] 

\[ (2) \]

Newton-Raphson method for Load Flow Calculation

There are basically 3 methods that are often used for calculation of power flow. For large-scale power systems the Newton-Raphson method is more efficient and practical, where the number of iterations required for computation is less when compared with other methods. In this method the power flow equation is formulated in polar form. From Figure 5 we can write the equation (3):

\[ \begin{bmatrix} \Delta \phi \\ \Delta V \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \phi \\ \Delta V \end{bmatrix} \]

\[ \cdots \] 

\[ \cdots \] 

\[ \cdots \] 

\[ (3) \]

3. Methodology

This research will be carried out in several steps as follows:

1. Drawing circuit Power System Modeling using ETAP 12.6.0 Software
2. Input data, namely: data PLN Source, Transformers, Line, and loads obtained from the Helium Purification and Supply System of RDE (HPS-RDE).
3. Power System Modeling run the using ETAP 12.6.0 Software
4. Check the result of running software
5. Evaluate the flow of power and bus voltages in each bus in the system.

The research method conduct at 3 steps. These main steps can be separated in more detail such as follow which are designing electrical system at HPS-RDE with component simulation, electrical load distribution analysis and electrical component specification on HPS-RDE system.

4. Result And Discussion

Results of simulation of single line diagram of power distribution system on Helium Purification and Supply System of RDE (HPS-RDE) using ETAP 12.6.0. The single line diagram by using ETAP is shown in Figure 6.
Figure 6 shows that the single line diagram of the power supply system that supplies electrical energy for the RDE HPS needs. This diagram was used for input load analysis. The analysis was significant result shows no red compound found is the figure that indicates the input created or the decoded does not indicated input error, or over / under design.

The load flow analysis by running ETAP is shown in Figure 7.
Figure 7 shows the electrical power flow to the load component of the HPS, with a total requirement of 11 kW of BUS -QFM-7i consisting of loads of 2 kVA control system, 3.5 kVA coil heater and 6 kVA Tuber Heater. All parameters in each line of electricity will be displayed in the report table of ETAP program running results. The magnitude of power, current, voltage and power loss can be seen in the report table. The result in detail is presented in Table 1.
From Table 1 it can be identified that the voltage drop that occurs on the PC-1 panel bus is zero % (0 kV) from the normal voltage of 0.380 kV. Voltage drop at HPS panel is also 0 %. That mean the design of bus system is good. While the voltage drop at RCCS from the normal voltage of 0.380 kV to 0.379 kV or 0.24 % (9 Volt).

Table 2. Losses Report Electrical System for HPS-RDE

| From | To | Load | Load Flow | NFMR |
|------|----|------|-----------|------|
| ID   | kV | MVA  | MW        | MW   |
| P1   | 20.00 | 100.00 | 0.00 | 0.00 |
| P2   | 90.5 | 100.00 | 0.84 | 0.84 |
| QNM | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-2 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-3 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-4 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-5 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-6 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-7 | 100.00 | 0.38 | 0.01 | 0.01 |
| QNM-8 | 100.00 | 0.38 | 0.01 | 0.01 |
| RCCS-RDE | 100.00 | 0.38 | 0.01 | 0.01 |

Table 3. Active and reactive power flow

| From bus | To Bus | Load Flow | Current (Amp) | Power Factor (%) |
|----------|--------|-----------|---------------|------------------|
| PLN Source | Panel PC-1 | 11 | 1 | 17.4 | 99.5 |
| Panel for Control System | 2 | 3 | 99.5 |
| HPS - Coil Heater | 3 | - | 5.3 | 99.5 |
| RDE Tubler Heater | 6 | 1 | 9.1 | 99.5 |

The simulation results of in detail power flow using ETAP 12.6.0 software as presented in Table 2 & 3 indicated the power flowing on each bus. The amount of power that flows
depends on the load attached to the bus. The active power flowing from the PC-1 panel bus is 11 kW and 1.0 kVAR of reactive power for the active power flow in the control system for HPS-RDE of 2 kVA, Coil Heater of 3.5 KVA and Tubular heater of 6 KVA. While the reactive power that flows each of 1 kVAR.

Table 4 shows that fluctuations in voltage is very small which less than 1%, It mean the electrical supply system is very safe.

Table 4. Losses Report of Electrical System for HPS-RDE

| Bus Name      | Bus Voltage (kV) | Calculation results (ETAP) | % Alert Settings |
|---------------|-----------------|---------------------------|-----------------|
|               | Voltage         | Voltage. (%)              | Critical        | Marginal |
| PC-1 Panel    | 0.380           | 100                       | 100.0           | 95.0     |
| HPS-RDE       | 0.380           | 0.379                     | 99.93           | -        |
| TR-1          | 20/0.380        | 0.380                     | 100             | -        |
| Cable         | 0.380           | 0.380                     | 99.59           | 0.21     |

As shown in Table 5 the voltage drop that occurs on the PC-1 panel bus is 0% (0 KV) from the normal voltage of 0.380 kV, while the HPS-RDE panel is 0.07% (0.001 kV) from the normal voltage of 0.380 kV to 0.379 kV.
5. Conclusion
The analysis results were obtained in this study and layout of electric load distribution and electrical component specification in HPS-RDE. Electrical system design on HPS-RDE is conducted by simulation using ETAP software. From the simulation is done analysis of electric load distribution and electrical component specification on HPS-RDE system. The power flow analysis is the analysis of active power flow (P) and reactive power (Q) from the generating system through the channel to the load. The amount of power that flows depends on the amount of load mounted on the bus. The analysis result showed the active power flowing from PC-1 panel bus is 11 kW and 1 kVAR of reactive power for active power flow in 2 kW control system, 3 kW Coil Heater and 6 kW Tubler Heater. While the reactive power flowing each 1 kVAR. The voltage drop on PC-1 panel bus is 0% (0 KV) from the normal voltage of 0.380 kV, while the HPS-RDE panel is 0.07% (0.001 kV) from the normal voltage of 0.380 kV to 0.379 kV.

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