

MECHANICAL AND ELECTRICAL ANALYSIS ON RDE CONTROL ROD

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Abstract

Experimental Power Reactor called Experimental Power Reactor (Reaktor Daya Eksperimental; RDE) is an experimental nuclear reactor of high-temperature pebble-bed type, which is developed by National Nuclear Energy Agency (BATAN). RDE has ten control rods that work for controlling reactivity, which is driven by a drive mechanism that uses chain and sprocket transmission by actuating of electrical motor. This study was done to determine the strength of the chain using finite element analysis (ANSYS) and analysis control rod electrical power supply. The result analysis chain-sprocket using Inconel 625 material in the RDE design is safe to be used under the temperature of 750 °C. Short circuit failure can cause the flow of the current to be large, the amount of electric current that flows can damage electrical equipment of rod.

Keywords: CRDM, ETAP, RDE, Short circuit analysis.

1. Introduction

As part of nuclear energy contribution to the fulfil energy demand in Indonesia, National Nuclear Energy Agency (BATAN) is developing a design of Experimental Power Reactor (Reaktor Daya Eksperimental; RDE). RDE is a high-temperature pebble-bed type reactor, which has a sound passive safety feature and can be used for cogeneration process [1]. The construction of RDE refers to the HTGR-type pebble-bed design that controls its power in normal operation using a Control Rod Drive Mechanism (CRDM). The control rod is also used to extinguish the reactor. Handono et al. [2] mentioned that if this system fails, a Small Absorber Ball (SAS) System is activated and the reactor must be ensured to be safe. The CRDM and SAS include the internal parts of the Reactor Pressure Vessel (RPV). Therefore, the design of the CRDM (control rods and their screw mechanisms) must use a material that is resistant to temperature and high radiation on its workload and for a long time. The CRDM that used in RDE uses the chain transmission to hang the control rod system. Thus, the mechanical system of gear and chain must be analysed with the finite element method. The chain transmission was used in the CRDM because the distance channel too far ranged from 2700 mm. Besides, it takes a fast time to fall control rod at the time of the shutdown and a straight liner so that control rod right into the channel [3-6].

Relating to the power supply system on the rod, it is very important to ensure energy supply to the electric motor for CRDM. Thus, short circuit analysis on RDE electricity from the system is very important to do. Short circuit failure can cause the flow of the current to be large, the amount of electric current that flows can damage electrical equipment in the circuit. The magnitude of the flow of short-circuit current is influenced by the location of the disturbance. If the disturbance gets closer to the source, the noise current will be even greater. To overcome a short circuit, it is needed to be done short circuit analysis to know how big the short circuit current will happen. Thus, the precise protection system on the power system can be determined. The analysis of short-circuit interfaces was performed using ETAP. The analysis of short-circuit interference is important for determining the short circuit rating to protect the device and the equipment distribution system from the effects of the load [7-15].

1.1. Description of control rod drive mechanism (CRDM)

Based on studies by Yuanqiang et al. [15], the rod drive mechanism is a system used in the RDE to control reactivity on the reactor core and for the shutdown process of the reactor. The RDE design refers to a Chinese HTR-10 design that uses ten independent control rods, in which, each uses one drive system as shown in Fig. 1. The control rod system consists of two parts, namely drive parts and reactivity control parts [8]. In the driving parts, it consists of stepper motor, magnetic damper, gearbox, chain transmission system using sprocket (chain-sprocket), worm gear reducer, and rod control positioning instrument. In the reactivity control section, the control rod device consists of a five-segment pellet array of sintered boron carbide (B₄C) absorber neutrons. Each neutron absorber segment is positioned inside a closed stainless steel annulus tube. Each annulus tube is connected series with another tube by a mechanical connection. At the bottom of this device, it is installed by spring impact dampening factor that serves as a damper when the device goes down in gravity. The link between this control rod device and the drive

system is a chain of chain-sprocket components. The design of this control rod system requires the chain to work at varying temperatures and high radiation. At low temperatures, when the chain is in the control of the rod drive system unit, high temperatures occur inside either the core or the side reflector. Therefore, it is necessary that the chain of material properties match the above conditions and the old lifespan. Based on the literature, the material must be considered to be suitable for chains and sprocket materials. One of the best material is Inconel 625 with allowable yield stress until 517 MPa [12]. Inconel 625 has also better mechanical properties than the Incoloy 800H (HTR-10) [8, 13].

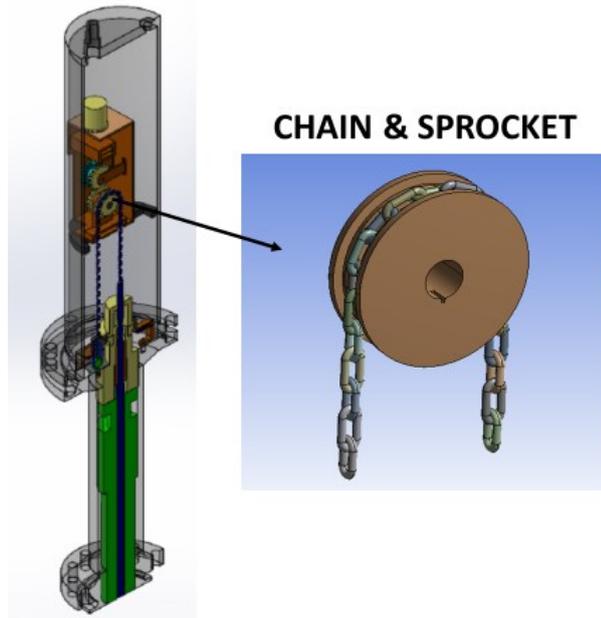


Fig. 1. Control rod drive mechanism [7].

The power supply of CRDM must have sufficient supply of electrical energy and a reliable protection system (in the load flow, the grounding system related to the protection of direct, and indirect lightning strikes). Thus, short circuit analysis and setting CB or electrical component protection is very important. The test facility shall be equipped with a neutral ground earth system. This is because neutral ground earth systems will affect the measurement results in the instrumentation system, control, and data acquisition. The electrical single line diagram of the CRDM power supply is shown in Fig. 2 [9].

Figure 2 shows that the main TR-1 transformer, D_1 , and D_2 emergency diesel generator supplying the CRDM system are designed to be sufficient for the electrical energy requirements of the CRDM facility. The protection system equipment must be set properly in the sense that the protection system must have good coordination. This means that if the Circuit Breaker on M_1, M_2, M_{10} , trip, the only option is CB in QMF-8 instead of CB in PC 1. The rating and the settings of CB and Fuse protection equipment are important [9]. The electrical short circuit analysis using ETAP is important for determining the flow of load and the setting of safety component protection on RDE electrical supply of CRDM.

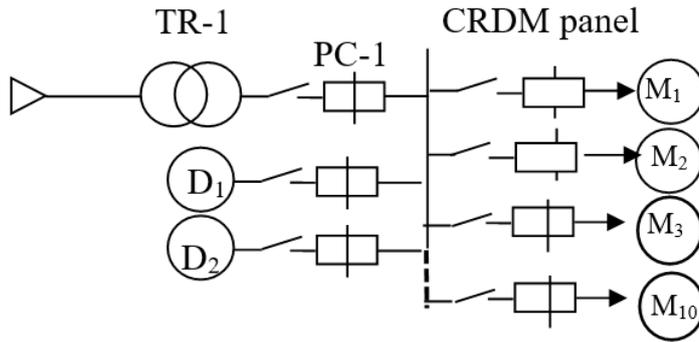


Fig. 2. Electrical power supply diagram of CRDM.

1.2. Short circuit analysis on CRDM supply using ETAP

The modelling of the electric bus system on CRDM is shown in Fig. 3 [9].

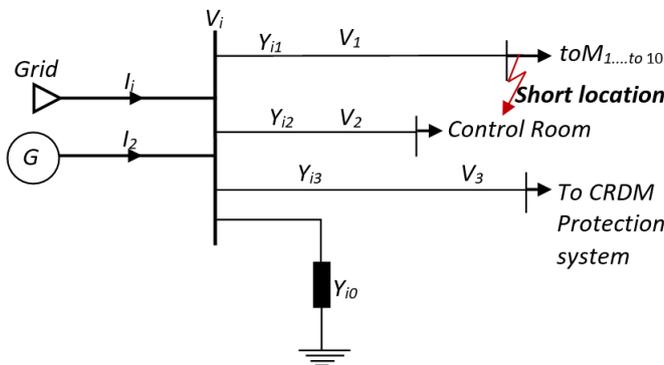


Fig. 3. Bus model of electric power system of CRDM.

From Fig. 3, for electric power systems with n -bus quantities, the node current equations can be written as:

$$I_{bus} = Y_{bus} V_{bus} \tag{1}$$

where I_{bus} is the vector of the injected bus current. The flow is positive if heading for the bus, while it is negative if it is leaving the bus. V_{bus} is the bus voltage vector measured from the reference node. The Y_{bus} is the bus admittance matrix. This matrix is in the shape of the diagonal elements of each node and the diagonal between the vertices. If the bus current is known, equation (1) can be solved for the n -bus voltage. The equation is rewritten as:

$$V_{bus} = Y_{bus}^{-1} I_{bus} \tag{2}$$

where Y_{bus}^{-1} is the inverse of the bus admittance matrix or impedance matrix bus (Z_{bus}). The power system network as shown in Fig. 4. The line can be converted to be per unit admittances on the basis of MVA. The use of Kirchoff Current Law on this bus is given in the equation [11]:

$$I_i = V_i \sum_{j=0}^n y_{ij} - \sum_{j=1}^n y_{ij} V_j \quad j \neq i \tag{3}$$

Then, the active power (P) and the reactive power (Q) on bus- i are:

$$P_i + jQ_i = V_i I_i^* \tag{4}$$

or

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{5}$$

Substituting Eqs. (5) to (3) can create:

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^n y_{ij} - \sum_{j=1}^n y_{ij} V_j \quad j \neq i \tag{6}$$

A short-circuit is an accidental or intentional low resistance or impedance connection established between two points in an electric circuit. This bypasses part of the circuit. The location of the short circuit is CRDM- bus.

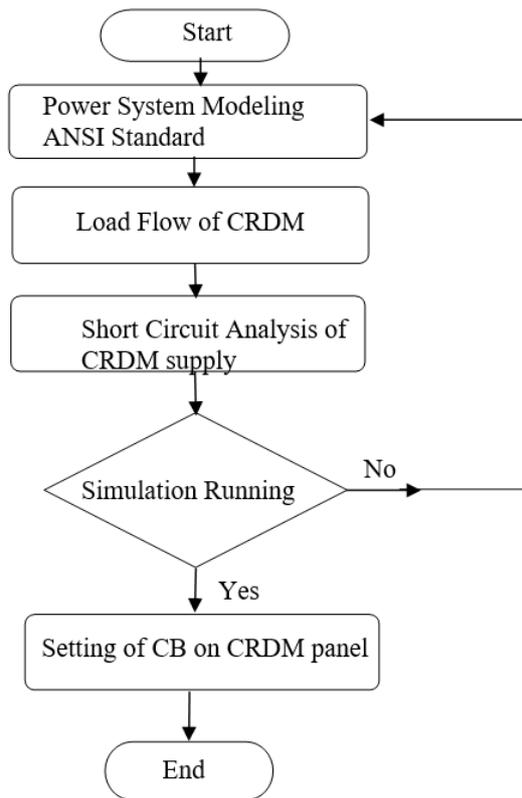


Fig. 4. Flow chart for short circuit analysis of CRDM supply.

2. Methodology

2.1. Mechanical analysis on CRDM

The chain-sprocket analysis of the control rod drive mechanism in Non-Commercial Experimental Reactor type of HTGR uses the following methodology [14]: 3D image modelling of control rod drive mechanism, especially chain-sprocket using solid works software. Performing stress analysis on chain-sprocket using finite element

software with loading two multiple loads of control rod device to anticipate impact load. The given constraint is fixed to support the extreme loading of the structure (i.e., chain and sprocket). The stress analysis is performed by the temperature variation as an assumption of control rod condition on the vessel reactor, starting from the temperature of 150 °C (i.e., the temperature inside the control rod drive unit) up to 750 °C (i.e., the approximate temperature inside the reactor).

2.2. Electrical power analysis on CRDM Supply

The step of short circuit analysis in the electrical power supply of CRDM- RDE component test loop is based on the load flow of calculation. Flow chart of short circuit analysis (the algorithm used in this study) is presented in Fig. 4.

3. Results and Discussion

Mechanical analysis

The results of the analysis of the control rod drive mechanism on the Chain and Sprocket suitable are shown in Table 1. This mechanical analysis is very important since the change in the process condition gives impacts on the mechanical properties [16, 17]. Von-misses stress occurring in the chain is 409.51 MPa, and the results of the analysis on the sprocket of the control rod drive mechanism are 398.94 MPa. Maximum recommended operation at 750 °C was suffering the maximum stress value is still below the material permit yield stress of 517 MPa. The safety factor decreased as increases in temperatures. But, it is still safe and recommended for the operation of below than 750 °C with the assumption of the minimum safety factor of 1 with the static load or no loading when control of rods falls in maximum condition on core reactor or limits on chain conditions in the side reflector. Therefore, based on the analysis results, it can be concluded that chain and sprocket with Inconel 625 material can be used on the RDE control rod drive mechanism at the maximal temperature of 750 °C. Sprocket increases as the rising temperature conditions during operation. Specifically, the maximum value in the chain is 398.94 MPa on the sprocket.

Table 1. Result of analysis chain and sprocket.

Part of CRDM	Analysis	Result analysis	Reference
Chain	Von misses stress	409.51 MPa	517 MPa
	Safety factor	1.33-6.48	1-15
Sprocket	Von misses stress	398.94 MPa	517 MPa
	safety factor	1.29-6.42	1 15

3.2. Electrical analysis

System design consists of the design of CRDM electrical power systems. The main design principles are defined to meet the project objective, including technical feasibility, safety and reliability, flexibility, and later-upgrade sustainability. The load flow analysis of CRDM electrical system supply CRDM of RDE is presented in Fig. 5.

Figure 5 shows load flow analysis with field data input on PC1 panel and grid of electricity transformer. Data were also obtained from the load design for load requirements of the CRDM facilities. After the load flows on all buses are no

problem, the simulation of the short circuit analysis is run. If there is a problem in one of its buses (i.e., there is a red bus indicated at panel bus), we should check the error of parameters in the data input. The short circuit analysis of the CRDM electrical system using ETAP is shown in Fig. 6.

Figure 6 shows that the voltage drop at CRDM-Panel. The short circuit current is 16.585 kA. From the control room panel, the voltage is 0 volt. There is no current flow from its bus because of the location of short circuit at CRDM-bus panel. The setting of CB is 16.6 kA. The current flow at the electricity line is 284 kA (setting CB of TR-1). The voltage at the emergency generator decreased to be 55% or 209 V. The short circuit report from ETAP is shown in Table 2. Table 2 shows the short circuit analysis of the CRDM facilities. It shows both the current flows and the voltage drop on the load component. The total realistic current component is 10.906 kA and the reactive current is -12.854 kA. Thus, the total current magnitude of CRDM panel is 16.858 kA. The panel bus of PC 1 is 16.803 kA.

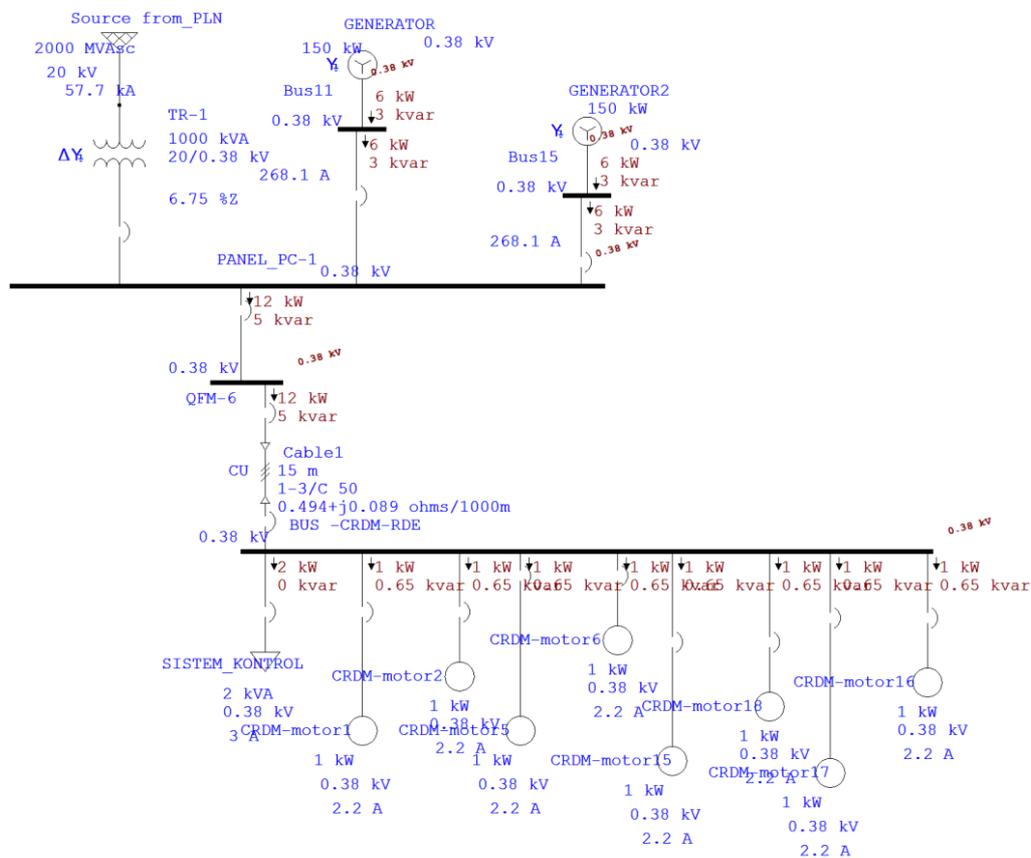


Fig. 5. Load flow analysis of CRDM power supply.

Therefore, chain and sprocket with Inconel 625 material can be used on the RDE control rod drive mechanism at a maximum temperature of 750 °C.

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