Power Flow Analysis on RDE Fuel Handling System Using ETAP

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Abstract. The research on design development of Nuclear RDE Fuel Handling System is to get the optimal and reliable Nuclear RDE Fuel Handling System design so that pebble fuel can fill the reactor core, circulate, can be detected its burning fraction with certainty. The optimal process design is based on mass and energy balance calculations on the use of selected components, determining the dimensions and piping materials, and determining the main components of the system. To obtain the design of Power Supply System on RDE Fuel Handling System which is optimal and reliable, then the power flow analysis is analyzed. In order to know the performance of electric power system that flows in the system of RDE fuel handling the research flow of power so that the flow of active and reactive power and voltage profile of each bus in the system can be known. Power flow simulation is done using Electrical Transient Analyzer Program (ETAP) software. Power flow calculation is done using Newton-Raphson method. The results showed an active power flow from a PC-1 bus of 56 kW and a 28 kVAR reactive power while the active power flow in the control system was 2 kVA, and a reactive power of 0 kVAR a compressor-1 and a compressor-2 of 21,141 kW and a 14 kVAR reactive power flow. The voltage drop that occurs on the PC-1 bus is 0.25% of the normal voltage of 0.380 kV the voltage decreases to 0.379 kV, whereas in the fuel handling bus is 0.46% of the normal voltage of 0.380 kV the voltage decreases to 0.378 kV.

Keywords: RDE, ETAP, Power Flow, Voltage Profile, Newton-Raphson.

1. Introduction

The Development of Experimental Reactor (RDE) has selected the Pebble Bed Reactor (PBR) technology with very safe consideration, functioning for cogeneration, fuel flexibility, tested, competitive price, multipurpose, which can be developed throughout Indonesia as needed, and 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.

RDE Detailed Design Development is a challenge for BATAN to continue to develop engineering design capabilities, especially nuclear reactor engineering design, and pursue the ideals of becoming a Technology Provider in the field of nuclear energy [1]. The research on the design of the Nuclear RDE Fuel Handling System design aims to obtain the optimal and reliable Nuclear RDE Fuel Handling System design so that the pebble fuel can fill the reactor core, circulate, detectable its burning fractions. The optimal process design is based on mass and energy balance calculations on the use of selected components, determining the dimensions and piping materials, and determining the main components of the system. Therefore, it is necessary to analyze the flow of power flow in the RDE fuel handling system. The scheme of RDE fuel handling system, can be seen in Figure 1.
Figure 1. Process Diagram of RDE Fuel Handling System

where:

1 Reaktor Pressure Vesel
7 Fuel Handling System
7.1 Storage of Fresh Fuel
7.2 Burnup Gauges
7.3 Fuel Elevators
7.4 Faulty Fuel Separator
7.5 Faulty Fuel Storage
7.6 Dummy Graphite Fuel Storage
7.7 Used Fuel Storage

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[4,9]. 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[7]. Buses in electric power system can be grouped 3 types: The first is a 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. Second is the 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 is fixed. The known parameters or magnitudes are active (P) and voltage (V). This bus is called PV bus. And third is the 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 fuel handling RDE system. For that in need of data associated with these components[9]. The data required for power flow analysis are as follows: First is the generator data, ie active power capacity (P) in Megawatts (MW) and reactive (Q) in Megavolt Ampere (MVA) units, terminal voltage (V) in Kilovolt (KV) and synchronous reactance (X) in units of Ohm (Ω). Second is the Power Transformer Data, ie the
capacity of each transformer in Megavolt Ampere (MVA), voltage (V) in Kilovolt (KV) and leakage reactance (X) in Ohm (Ω). The third is the transmission line data, ie resistance (R) in ohms (Ω) and reactance (X) in Ohm (Ω). And fourth is load data, ie active power (P) in Megawatt (MW) and reactive power (Q) in Megavolt Ampere (MVA) unit.

This study aims to simulate a series of power flows, and the expected result of this study is to provide a brief description of the required power flow in an overall electrical system on each bus used, in this case the electrical power system in the device to test the RDE fuel handling system.

2. Theory
2.1. Admittance and Bus Impedance Matrices.
To be able to calculate and analyze the power flow, the initial step is to establish an electric bus system power admittance matrix. Figure 2 below is an example of a simple electric power system, where its impedance is expressed in terms of perunit on the basis of MVA and the resistance is negligible for simplification.

![Figure 2. Impedance diagram of Simple Power System[4]](image)

Based on the Kirchoff Current Law the impedances in the figure above can be changed to the admittance form by using the following equation as showed in Figure 3

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

(1)
2.2 The power flow equation

The power system network as shown in Figure 3 of the transmission line can be illustrated by the model $\pi$ 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 of Active power and Reactive power at bus to-$i$ are:

$$P_i + jQ_i = V_i \cdot I_i^* \quad \text{..............................................}(2)$$

or

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad \text{..............................................}(3)$$

So the equation becomes:

$$\frac{P_i - jQ_i}{V_i^*} = V \sum_{j=0}^{n} y_{ij} \cdot V_j \quad j \neq i \quad \text{..............................................}(4)$$
2.3 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 4 we can write the equation in Polar form will be obtained as follows:

$$I_i = \sum_{j=1}^{n} Y_{ij} |V_j| \angle \theta_j + \delta_j$$

next power complex on bus 1 can be written:

$$P_i - jQ_i = V_i * I_i$$

In this case bus 1 is a reference bus (Swing bus). Then the Jacobian matrix provides a linear comparison between the changes in the voltage angle $\Delta \theta^{(k)}$ and the magnitude of the voltage $\Delta |V^{(k)}|$ with slight changes in the active power ($\Delta P^{(k)}$) and reactive power ($\Delta Q^{(k)}$) in an easy form or short can be written:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

3. Methodology

ETAP is software used to design/plan electrical systems that exist in an industry in a Region. This software is very useful to perform a variety of analysis is very help full to facilitate the work, especially on electrical systems. In a design and analysis of a power system, an application software is needed to represent real conditions before a system is realized. ETAP (Electric Transient and Analysis Program) is one of the application software used to simulate electric power system.

ETAP is able to work offline for power simulation, and online for real-time data management or is used to control the system in real-time. Features contained in it also vary among other features that are used to analyze the generation of electricity, transmission systems and power distribution systems. Electrical power system analysis that can be done ETAP include: Power Flow Analysis, Quick Connect, Arc Flash Analysis, Starting motor, Coordination protection Transient stability analysis, etc.

ETAP has two kinds of standards used to perform electrical analysis, ANSI and IEC. Basically the difference that occurs between the two standards is the frequency used, which results in different equipment specifications corresponding to that frequency.

This research will be carried out in several stages as follows: First is to model the electrical system used in the RDE fuel handling loop test tool using ETAP Software, then do the data entry, including data PLN Source, Trafo, Channels, and load on the data list on the RDE fuel handling system. Then proceed with calculating the power flow with the Newton-Raphson method and the last one is an evaluation of the power flow and bus voltages in each bus in the one line diagram system to be modeled[4]. Flow chart of electrical power system analysis is shown in Figure 5.
This research will be carried out in several steps as follows: The first is to draw a single line diagram on the ETAP worksheet, then perform parameters of each component including Power grid (rated kV, MVAsc, %V, Vangle, etc.), Bus (Nominal Kv), Transformer (kV primary, kV secondary, MVA rating, %Z, X/R, etc.), Line (length, R0, X0, Y0, R1,2, X1,2, Y1,2, etc.), Load (1 phase/3 phase, MVA, PF, Amps, rated kV, etc.) and then followed by replacing load-flow mode by click load flow analysis in toolbar mode. And next is to select the flow power method by click load flow study case, here there are several choice of methods are: Newton Raphson, Gaus Siedel, Fast Decouple. Then do a run load flow by clicking on the run load flow icon on the load flow toolbar. And to see the results completely click report manager. Here there are several choices of formats of power flow results are: Pdf, Microsoft word, Microsoft Excel, and others.

4. Results and Discussion
Results of simulation of single line diagram of power distribution system on nuclear RDE fuel handling system using ETAP is shown in Figure 6.
From Figure 6 it can be seen that the main source comes from PLN and Genset in anticipation in case of blackouts from PLN. The source is then connected to a PC-1 bus, and connected to QFM-6 bus which is then connected to a fuel handling bus, which is located at the load of the RDE fuel handling system. What load is used consists of control system load, compressor-1 load and compressor-2 load. Overall the loads there is then done a one-line diagram in the ETAP software, and next by doing the simulation. The results of the simulation can be seen in Figure 7 below.

Figure 6. Single Line Diagram Electrical for RDE Fuel Handling System

Figure 7. Single Line diagram using ETAP before running
From the simulation results using ETAP program shown in Figure 7 shows that the flow of power flows from PLN sources with a supply voltage of 20 kV, by TR-1 transformer with 1000kVA power is lowered to 380 Volt, this voltage is required by the load used in the system electrical RDE fuel handling system, the resulting voltage drop occurs 99.75% on the PC-1 bus, while the voltage drop is 99.57%. While the flow of power that flows on the load used in the RDE fuel handling system is 2 kWatt for the load on the control system, and at 27 kWatt for the active load and for 14 kVAR for the reactive load at compressor one and compressor two. While to see the flow of flow reports can be seen in Figure 8 below.

![LOAD FLOW REPORT]

**Figure 8. Load Flow Report Electrical System for RDE Fuel Handling system**

Figure 8 is the result of the current load report that has been done, it seems that there is no abnormality in PC-1 bus as well as on the fuel handling bus system on electricity at the the RDE fuel handling system.

![Branch Losses Summary Report]

**Figure 9. Losses Report Electrical System for RDE Fuel Handling system**
Figure 9 shows the electrical system losses in RDE fuel handling system on the transformer and wiring equipment, the power load generated by the transformer occurs with a reactive power of 0.3 kVAR while the active power is 0.0 kWatt. While the power loss on the wiring occurs at the active power of 0.1 kWatt and the amount of reactive power of 0.0 kVAR. For traffic (% Volt bus) on transformer equipment or packing equipment 49.8%. While decreasing ($V_d$ % drop in $V_{mag}$) on transformer equal to 0.25% while for cable of 0.21%.

| From bus | To Bus | Load Flow | Current (Amp) | Power Factor (%) |
|----------|--------|-----------|---------------|-----------------|
| PLN Source | Panel PC-1 | 56 | 28 | 95,2 | 89,7 |
| Fuel Handling | Control system | 2 | - | 3 | 89,7 |
| | Compresor-1 | 27 | 14 | 46,2 | 89,7 |
| | Compresor-2 | 27 | 14 | 46,2 | 89,7 |

Table 1 shows that the power flow generated on the PC-1 bus is 56 kWatt at active power while the reactive power is 28 kWatt, 95.2 Ampere with 89.7% power factor. The control system power is 2 kWatt at active power, 3 Ampere with power factor 89.7%. Power flow for two compressors is 27 kWatt for active power, and 14 kVAR in reactive power, 46.2 Ampere with each power factor 89.7%.

| Bus Name | Bus Voltage (kV) | Calculation results (ETAP) | $V_d$ Drop in $V_{mag}$ (%) |
|----------|------------------|---------------------------|-----------------------------|
| PC-1     | 0,380            | 0,379                     | 99,75                       | - |
| Fuel Handling | 0,380            | 0,378                     | 99,54                       | - |
| TR-1     | 20/0,380         | 0,380                     | 99,75                       | 0,25 |
| Cable    | 0,380            | 0,380                     | 99,59                       | 0,21 |

While the voltage drop that occurs on the PC-1 bus is 0.25% (0.001 KV) from the normal voltage of 0.380 kV to 0.379 kV, where as in the fuel handling bus the voltage drop is 0.46% (0.002 kV) from the normal voltage of 0.380 kV to 0.378kV.

5. Conclusion
Power flow analysis is an analysis of active power flow (P) and reactive power (Q) from a generating system through a channel up to the load. The amount of power that flows depends on the amount of load installed on the bus. The active power flowing from the PC-1 bus is 56 kW and 28 kVAR of reactive power for the active power flow in the control system of 2 kVA, compressor-1 and compressor-2 of 21,141 kW. While the reactive power that flows each of 14 kVAR. The voltage drop that occurs on the PC-1 bus is 0.25% (0.001 KV) from the normal voltage of 0.380 kV to 0.379 kV, while the voltage drop on the fuel handling bus is 0.46% (0.002 kV) from the normal voltage of 0.380 kV to 0.378 kV.
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