# EXPERIMENT P7: LOAD FLOW ANALYSIS (OPEN-ENDED)

Related course: KIE4004 (Power System)

**OBJECTIVES:**

1. To model a five-bus system network using PowerWorld Simulator software to understand the input data for Load Flow analysis
2. To perform load flow analysis using Newton Raphson method and Fast Decoupled method using PowerWorld Simulator software
3. To study the effect of generation changes, line outage and shunt capacitor bank

**EQUIPMENT:**
PC with PowerWorld Simulator software

**INSTRUCTIONS:**

1. Save all your results in a folder on the PC you are using
2. Follow the demonstrator's instructions throughout the experiment
3. Handle the PC with care
4. Use only PowerWorld Simulator for this experiment

**REFERENCE(S):**
Refer to the main references of KIE4004

**INTRODUCTION:**

In power engineering, load-flow or power-flow study is a numerical analysis of the flow of electric power in an interconnected system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation.

A load flow study is valuable for a system with multiple load centers, such as a refinery complex. The power flow study is an analysis of the system's capability to adequately supply the connected load. The total system losses and individual line losses, also are tabulated. Transformer tap positions are selected to ensure the correct voltage at critical locations such as motor control centers. Performing a load flow study on an existing system provides insight and recommendations as to the system operation and optimization of control settings to obtain maximum capacity while minimizing the operating costs. The results of such an analysis are in terms of active power, reactive power, magnitude and phase angle.

The goal of a power-flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch and generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance.

The solution to the power-flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the slack bus.

The most popular methods to solve the nonlinear system of equations are the Newton–Raphson method and Fast-decoupled-load-flow method.

**PROCEDURES:**

Figure 1 shows a single-line diagram of a five-bus power system. Input data are given in Tables 1, 2, and 3. As shown in Table 1, bus 1, to which a generator is connected, is the swing bus. Bus 3, to which a generator and a load are connected, is a voltage-controlled bus. Buses 2, 4 and 5 are load buses. Note that the loads at buses 2 and 3 are inductive since $Q_2 = -Q_{L2} = -2.8$ and $Q_{L3} = -0.4$ are negative.

1. Use the given data as input data to model this system in the PowerWorld Simulator.

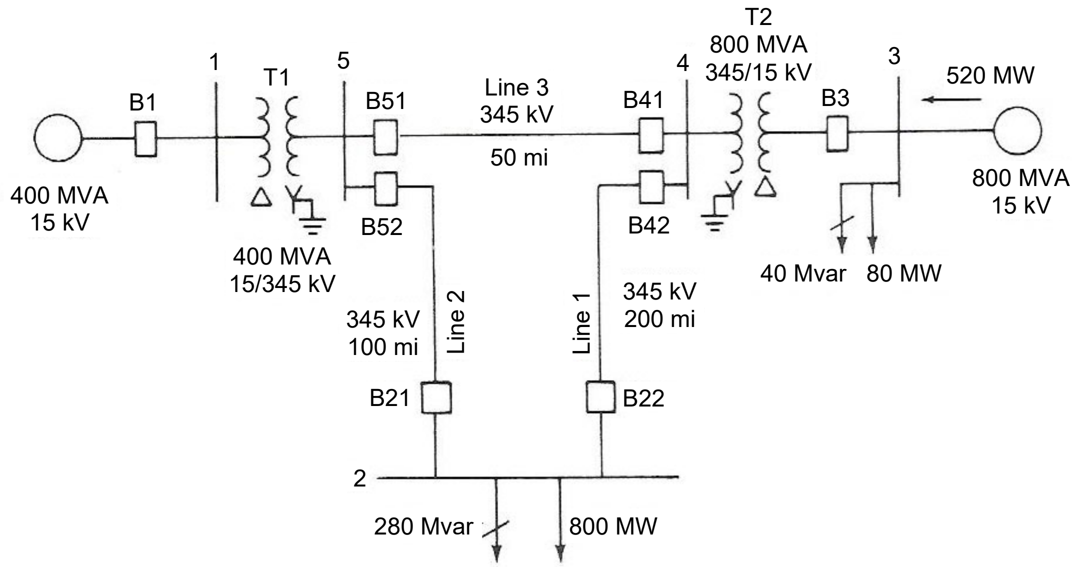


Figure 1. Single Line diagram five-bus system

Table 1. Bus input data

| BUS | TYPE | V (per unit) | δ (degrees) | $P_G$ (per unit) | $Q_G$ (per unit) | $P_L$ (per unit) | $Q_L$ (per unit) | $Q_{Gmax}$ (per unit) | $Q_{Gmin}$ (per unit) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Swing | 1.0 | 0 | — | — | 0 | 0 | — | — |
| 2 | Load | — | — | 0 | 0 | 8.0 | 2.8 | — | — |
| 3 | Generator | 1.05 | — | 5.2 | — | 0.8 | 0.4 | 4.0 | -2.8 |
| 4 | Load | — | — | 0 | 0 | 0 | 0 | — | — |
| 5 | Load | — | — | 0 | 0 | 0 | 0 | — | — |

*$S_{base}$ = 100 MVA, $V_{base}$ = 15 kV at buses 1, 3, and 345kV at buses 2, 4, 5

Table 2. Line input data

| Bus-to-Bus | R' (per unit) | X' (per unit) | G' (per unit) | B' (per unit) | Maximum MVA (per unit) |
|---|---|---|---|---|---|
| 2 – 4 | 0.0095 | 0.105 | 0 | 1.70 | 12.0 |
| 2 – 5 | 0.0040 | 0.055 | 0 | 0.90 | 12.0 |
| 4 – 5 | 0.00338 | 0.022 | 0 | 0.45 | 12.0 |

Table 3. Transformer input data

| Bus-to-Bus | R (per unit) | X (per unit) | $G_C$ (per unit) | $B_M$ (per unit) | Maximum MVA (per unit) | Maximum TAP Setting (per unit) |
|---|---|---|---|---|---|---|
| 1 – 5 | 0.00160 | 0.018 | 0 | 0 | 6.0 | — |
| 3 – 4 | 0.00080 | 0.012 | 0 | 0 | 10.0 | — |

Table 4. Input data and unknowns

| BUS | INPUT DATA | UNKNOWNS |
|---|---|---|
| 1 | $V_1 = 1.0$, $\delta_1 = 0$ | $P_1$, $Q_1$ |
| 2 | $P_2 = P_{G2} – P_{L2} = -8$<br>$Q_2 = Q_{G2} – Q_{L2} = -2.8$ | $V_2$, $\delta_2$ |
| 3 | $V_3 = 1.05$, $P_3 = P_{G3} – P_{L3} = 4.4$ | $Q_3$, $\delta_3$ |
| 4 | $P_4 = 0$, $Q_4 = 0$ | $V_4$, $\delta_4$ |
| 5 | $P_5 = 0$, $Q_5 = 0$ | $V_5$, $\delta_5$ |

2. Simulate your circuit in PowerWorld Simulator for load flow analysis using Newton Raphson method for one iteration.
3. From your simulation, determine the Y-bus matrix of the test system.
4. From your simulation, determine the dimension of the Jacobian matrix for the power system in Figure 1.
5. From your simulation, calculate $\Delta P_2(0)$ and $J1_{24}(0)$ of the first Newton-Raphson iteration. Assume zero initial phase angles and 1.0 per unit initial voltage magnitudes (except $V_3 = 1.05$).
6. From your simulation, calculate the power mismatches for the first iteration at bus 4.
7. Simulate your circuit in PowerWorld Simulator for load flow analysis using Fast Decoupled method.
8. Using your circuit in PowerWorld Simulator, determine the acceptable generation range at bus 3, by keeping each line and transformer loaded at or below 100% of its MVA limit. Discuss your observation and finding in your lab report.
9. From procedure no. 8, change the generator 1 voltage set point between 1.00 and 1.08 per unit in 0.005 per unit steps. Show the variation in the reactive power output of generator 1, $V_2$ and total real power losses. In your report, discuss your observation.
10. From procedure no. 1, modify your circuit by inserting a second line between bus 2 and bus 5. Give the new line circuit identifier of “2” to distinguish it from the existing line. The line parameters of the added line should be identical to those of the existing line 2 -5. Determine the effect of this new line on $V_2$, the line loading and on the total real power losses. In your report, discuss your observation.

**QUESTIONS:**

1. In your report, compare your simulation results between Newton-Raphson and Fast Decoupled methods.
2. In your report, verify your simulation results from steps 3, 4, 5 and 6 using manual calculation.

**OPEN-ENDED TASKS (complete these tasks during lab session):**

Continued from your simulation in step 1 (from PROCEDURES),

1. Explain the effect of adding a 225 MVar shunt capacitor bank at bus 2 on this power system.
2. Determine the MVar rating of the shunt capacitor bank that can increase $V_2$ by 2%. Also, explain the effect of this capacitor bank on line loading and the total real power losses.

**END OF EXPERIMENT**