Computational Techniques for three-phase Load Flow Analysis

Nazaruddin*1, Mahalla2, Fauzi3
1,2,3Electric Engineering Study Program – Politeknik Negeri Lhokseumawe

*Correspondent Author: nazaruddin@pnl.ac.id

Abstract. This paper aims to compute a three-phase load flow for balanced load and unbalanced loads conditions. Unbalanced loading can occur if the power demand of each phase is not equal, this happens because the load usage of each phase varies. Three-phase load flow is a study in the electric power system that will provide information on voltage, phase angle, current, power and power losses of each bus on phases a, b and c. Three phase power flow is carried out for operation planning and control of three-phase electric power systems. The imbalance in the electric power system will affect the use of electrical energy, that is, there will be a decrease in voltage received by consumers. Three-phase load flow computing will be done using the Etap version 12.0 software which will be tested on the IEEE 6 bus system. The computational results show that the unbalanced load flow converges on the 2nd iteration of the bus. The IEEE 6 bus system has the largest voltage drop on bus 3 by 3%, 2.9% and 2.2% for each phase a, b and c. The biggest power losses of the IEEE 6 bus system occur in the connecting line between bus 1 with bus 2 which is 32.5 KW, 28.1 KW and 37.1 KW, with total losses of 254.1 KW and 778.5 KVAR.

Keywords: Load flow, Unbalanced load, and Three Phase load

1. Introduction

Computation of three-phase load flow is a calculation process for the completion of the flow to get an overview of the flow of power that occurs in a system along with a voltage profile is very necessary for the purposes of the system situation analysis. Calculation of load flow needs to be done because what is known is the active power load and reactive power load that is present in each GI or node in the system [4].

A load of a balanced phase is a load with a current flowing in symmetrical loads and the load is connected to a voltage that is symmetrical. The analysis of systems that serve these loads is usually assumed to be supplied by a symmetrical voltage, the analysis can be done in one phase [5].

Analysis of a balanced three-phase system is simpler, a symmetrical component transformation will separate a balanced three-phase system into 3 stand-alone systems, namely positive sequence sequences,
negative sequences and zero sequences. The solution can be done in the form of a single phase, used only positive sequence models [8].

This paper is computational for three-phase load flow that can be applied for balanced and unbalanced load conditions. The computational process is done by software Etap version 12.0, which will be tested on the IEEE 6 bus system.

2. Modeling system

2.1. Unbalanced three-phase system model

A three-phase network between bus i and j as shown in figure 1.

Network parameters can be determined based on the method developed by Carson (1926). A 4x4 matrix that enters its own inductance and shared inductance, [8]:

\[ [Z_{abc}] = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} & Z_{an} \\ Z_{ba} & Z_{bb} & Z_{bc} & Z_{bn} \\ Z_{ca} & Z_{cb} & Z_{cc} & Z_{cn} \\ Z_{na} & Z_{nb} & Z_{nc} & Z_{nn} \end{bmatrix} \]  

(1)

For systems with neutral conductors connected to the ground, VN and Vn as shown in Figure 1, assumed to be zero. Equation (1) without including neutral influence or neutral conductors are connected to the ground, used to calculate unbalanced power flow.

\[ [Z_{abc}] = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \]  

(2)

The relation between the bus voltage and branch current in Figure 1 can be written:

\[ \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} - \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \begin{bmatrix} I_{Aa} \\ I_{Bb} \\ I_{Cc} \end{bmatrix} \]  

(3)

2.2. Unbalanced three-phase power flow equation

The current flowing between bus i and bus j in each phase in figure 1 can be calculated based on equation 1:
Suppose the transmission line is described in the form of a three-phase system as shown in Figure 2 [1]:

![Figure 2 Three phase power system bus model](image)

From Figure 2 the three-phase current equation on the bus \( i \) can be written:

\[
I_i^p = \sum_{q=a,b,c} V_i^p \sum_{j=a}^{n} y_i^{p,q} - \sum_{j=a}^{n} y_i^{p,q} V_j^q
\]

with \( p = a, b, c \)

Power equation:

\[
S_i^p = V_i^p I_i^{p*}
\]

\[
S_i^p = P_i^p + jQ_i^p
\]

and

\[
P_i^p + jQ_i^p = V_i^p I_i^{p*}
\]

\[
I_i^p = \frac{P_i^p - jQ_i^p}{(V_i^p)^*}
\]

substitute equation 4 to equation 8, so that it can be written

\[
\frac{P_i^p - jQ_i^p}{(V_i^p)^*} = \sum_{q=a,b,c} V_i^p \sum_{j=a}^{n} y_i^{p,q} - \sum_{j=a}^{n} y_i^{p,q} V_j^q, j \neq i
\]

with \( p = a, b, c \)

2.3. Research steps

To complete this research steps can be described as follows:

1) Make network configuration to be examined.
2) Enter the value of network parameters (R and X values) on the channel between buses.
3) Enter the voltage values on each bus.
4) Enter the load value (P and Q)
5) The simulation process is carried out using ETAP 12.0.0 software for unbalanced load conditions.
6) Calculate the amount of voltage drop and network losses of each phase on the connecting line between buses.

3. Test performed on a system

To test the formulation proposed in this paper, the IEEE 6 bus system as shown in Figure 3:

![Network configuration of the IEEE 6 bus system](image)

Figure 3 Network configuration of the IEEE 6 bus system

4. Results and Discussion

System testing carried out in the research is on the IEEE 6 bus system with a base value of 100 MVA and 150 kV, then compute unbalanced load flow with Etap software. The results of the power flow simulation for unbalanced loads show an overview of system conditions namely the parameters on the bus which include voltage, power and power losses in phases a, b and c. Simulation of unbalanced load flow calculation is convergent in the 2nd iteration for the IEEE 6 bus system, the test results can be shown in Table 1.

| Bus | Mag(%) | Angl(deg) | Mag(%) | Angl(deg) | Mag(%) | Angl(deg) |
|-----|--------|-----------|--------|-----------|--------|-----------|
| 1   | 100    | 0.0       | 100    | 0.5       | 100    | 0.5       |
| 2   | 99.20  | -0.1      | 98.90  | -0.1      | 99.80  | -0.1      |
| 3   | 97.00  | -0.1      | 97.10  | -0.1      | 97.80  | -0.1      |
| 4   | 99.20  | -0.1      | 98.90  | -0.1      | 99.80  | -0.1      |
| 5   | 98.40  | -0.1      | 98.80  | -0.1      | 98.80  | -0.1      |
| 6   | 98.30  | -0.1      | 98.05  | -0.1      | 98.85  | -0.1      |

The results of Table 1 can be made in the graphical form, respectively the graph of the voltage magnitude for each bus of each phase for the IEEE 6 bus system can be seen in Figure 6.
Figure 6. IEEE 6 bus system voltage profile characteristics

Figure 6 shows the voltage of each bus of each phase for the IEEE 6 bus system, a vertical axis as the value of the voltage in per unit (pu) and the horizontal axis is the number of the bus, with bus 1 as the reference bus (slack bus). The simulation results show that the voltage magnitude on bus 1 is a reference voltage of 100% for phases a, b and c. The minimum voltage value on bus number 3 is 97%, 97.1% and 97.8% for each phases a, b and c, so that bus number 3 has a voltage drop of 3%, 2.9% and 2.2% for each phase a, b and c.

Table. 2  Power losses for the IEEE 6 bus system

| Bus | Line  | Losses |
|-----|-------|--------|
|     | from to | KW(a)  | KW(b)  | KW(c)  |
| 1   | 2      | 32.50  | 28.10  | 37.10  |
| 1   | 3      | 18.70  | 16.40  | 24.20  |
| 1   | 5      | 21.60  | 19.40  | 23.20  |
| 2   | 3      | 1.35   | 0.95   | 1.70   |
| 2   | 4      | 0.15   | 0.08   | 0.17   |
| 2   | 5      | 1.20   | 0.80   | 1.30   |
| 2   | 6      | 6.10   | 4.70   | 6.70   |
| 3   | 5      | 0.10   | 0.08   | 0.10   |
| 3   | 6      | 0.60   | 0.40   | 1.20   |
| 4   | 5      | 0.90   | 0.80   | 1.20   |
| 5   | 6      | 3.20   | 2.80   | 3.40   |

The simulation results shown in table 2 are a description of the losses of each phase (phases a, b and c), for the IEEE 6 bus system. The results of table 2 can be made in graphical form as shown in Figure 7.
Figure 7 Characteristics of IEEE 6 bus system power losses

Figure 7 shows the characteristics of power losses (losses) in each connecting line between buses on the IEEE 6 bus system, the highest value of power losses on the channel between bus number 1 and bus number 2 is 32.5 KW, 28.1 KW and 37.1 KW respectively for phases a, b and c, while the smallest power losses occur on the channel between bus number 3 to bus number 5 which is 0.1 KW, 0.08 KW and 0.1 KW respectively for phases a, b and c.

5. Conclusion

From the simulation results of the three-phase load flow for unbalanced loads on the IEEE 6 bus system, conclusions can be drawn

1) The results of a load flow simulation calculation with the Etap software converge the 32nd iteration for the IEEE 6 bus system.
2) The highest voltage drop on the IEEE 6 bus system is on bus number 3 is 3 %, 2,9 % and 2,2 % respectively for phases a, b and c.
3) The highest power losses occur in cable 1 which connects bus 1 with bus 2 which is 32.5 KW, 28.1 KW and 37.1 KW for phase a, b and c, respectively. The lowest power losses occur in the connecting line between bus 3 to 5 which is 0.1 KW, 0.08 KW and 0.1 KW respectively for phases a, b and c.
4) Total losses that occur in the IEEE 6 bus system are 254.1 KW and 778.5 KVAR

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