# Comparative Load Flow Analysis of a 400/230 KV Grid Substation in Bangladesh

By

Rahat Khan
16121128
Abdullah Ibna Newaz
16321019
Mohd Fahim Haque
16121019
Nur Qutubul Alam Nafis
16121159

A Thesis submitted to the Department of Electrical and Electronic Engineering Of BRAC University, in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering
Brac University
June, 2020

## Declaration

We hereby declare that

1. The thesis was completed entirely based on our original work in requirement to the completion of the degree at BRAC University.

2. The thesis does not contain contents previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.

3. The thesis does not contain contents which has been submitted for any other degree or professional qualification in any other institutions or universities.

4. All the sources have been properly acknowledged.

**Student's Full Name & Signature:**

**Rahat Khan**
**16121128**

**Abdullah Ibna Newaz**
**16321019**

**Mohd Fahim Haque**
**16121019**

**Nur Qutubul Alam Nafis**
**16121159**

## Approval

The thesis titled "Comparative Load Flow Analysis of a 400/230 KV Grid Substation in Bangladesh" submitted by:

| | |
|---|---|
| Rahat Khan | (ID: 16121128) |
| Abdullah Ibna Newaz | (ID: 16321019) |
| Mohd Fahim Haque | (ID: 16121019) |
| Nur Qutubul Alam Nafis | (ID: 16121159) |

of Spring 2020 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on 16th June, 2020.

**Examining Committee:**

Supervisor:
(Member)

_______________________________
A. S. Nazmul Huda, PhD
Assistant Professor, Department of Electrical and Electronic Engineering
Brac University

Thesis Coordinator:
(Member)

_______________________________
A. S. M. Mohsin, PhD
Assistant Professor, Department of Electrical and Electronic Engineering
Brac University

Head of the Department:
(Chair)

_______________________________
Shahidul Islam Khan, PhD
Professor and Chairperson, Department of Electrical and Electronic Engineering
Brac University

## Abstract

A load flow analysis study is performed to a 440/220kV substation using ETAP and DIgSILENT software. This report shows load flow results, and explains how we can use it to implement changes on the feeders that will ameliorate the voltage profile. The power flow study for this station will be performed on ETAP and DIgSILENT power factory. The acronym ETAP stands for Electrical Transient and Analysis Program. This two software were used as an extensive program for the modelling, simulation, and protection of electrical networks. They not only provide solutions to substation designs, but also specialize in generation, transmission, and distribution of power systems.

The software relies on predictive simulation. This allows the user to perform analysis using real-time system parameters and may also simulate abnormal scenarios to predict equipment malfunctioning. It can be used as a preventive simulation, which allows the user to see any automated circuit breakers, relays, alarms and warnings. These alarms and warnings are based on events that could potentially occur and corrective action will be suggested. The results are always verified and analyzed against field results, real system measurements, and hand calculations.

The one-line diagram of the electrical system in question is composed of several pieces of equipment, each with a specific function. All of the components for this substation are high-voltage components. Some of the most important components are the Generators, capacitor banks, transmission lines, buses, potential transformers, and current transformers. These will affect the design for the substation and the operation.

## Acknowledgement

We would like to convey our deepest gratitude to our supervisor Dr. A. S. Nazmul Huda, Assistant Professor, Department of Electrical and Electronics Engineering, Brac University. The work would not have been possible without his able guidance, supervision and persistent effort throughout the entire process. His opinions and suggestions brought the paper to where it stands today. We are also grateful to Brac University for giving us the opportunity and the necessary materials required for the completion of the thesis.

# Table of Contents

## List of Tables:

## List of Figures

# List of Abbreviations

CB: Circuit Breaker

ETAP: Electrical Transient and Analysis Program

GS: Gauss-Seidel

HV: High Voltage

LF: Load-Flow

FDLF: Fast Decoupled Load-Flow

P.F: Power Factor

SLD: Single Line Diagram

# Chapter 1

# Introduction

## 1.1 Load Flow Analysis Objective

The load flow analysis offers nodal voltages and phase angles, and also power administration by interconnecting power channels (transmission lines) at all buses and power flows. It is a very indispensable tool for numerous numerical and algebraic analysis on a power system. Load flow solution is important in the design of a new power system and in the planning of an expansion of the current one for increased load demand [1]. Such analyzes include computing various load flows under both usual and abnormal operating conditions (electrical failure of transmission lines, or of any generating source). Load-flow approach also provides the system's initial conditions when analyzing the system's precise steady-state behavior. Load Flow Analysis requires nominal voltage and voltage angles for all the buses, generator real and reactive power and voltage conditions and real and reactive power flow in lines and transformer including their resistance and impedance [2]. By having all of this data we can apply load Flow Analysis which will show us the actual operating state of the system for a given loading.

Power network load flow approach can be carried out in both directions as it works under normal or abnormal conditions. The following thesis is for a device which only operates under controlled conditions. A single-phase depiction is only possible for such a system.

A power system load-flow solution mainly includes the following steps:

- Network Equations or Formulation.
- Appropriate analytical methodology for equation solving.

The network equations will be in the form of simple algebraic equations as we analyze the system under steady state conditions. In a real power system, the demand and therefore output are constantly shifting. Therefore, we must assume that loads and hence generation are set at a certain value for an acceptable period of time (30 min).

## 1.2 General Layout of Power System

The transmission network by which electric power is provided from generation to consumption is divided into two distinct sections which are the transmission and distribution network. Generation and transmission are predominantly three-phase, 50 Hertz (Hz) at varying voltages. Generation station power is generated in varying voltage by alternator. Generation station may use coal, natural gas, hydro, nuclear, wind or other resources for fuel.

The current is then passed by step up transformers to increase the voltage to supply the power over long distances. The current passes through high voltage transmission lines that stretch across the country. Then it will reach a substation where the voltage is step down so it can be delivered to smaller power lines. The current will then pass to another set of transformers to reduce the voltage for safe usage for consumers [3].

This is a following example of a typical Power station generation, transmission and distribution.

Three phase alternators, at 11 kV, produce power at the generating station.

The voltage is then enhanced for transmission purposes by appropriate 3-phase generation transformers. Between 132kV and 220kV, main or high voltage transmission is done. In choosing the transmission voltages, consideration is given to the total line distance to the substations, as well as the amount of transmission capacity. Using 650 volts per km of the transmission line is a rough basis for deciding the most economical transmission stress. The transmission of high voltage is stopped by a step-down transformer in a substation known as the receiving station, which in most cases is located in the outskirts of the expected consumers. The voltage here is forced down to 66 kV. Transmission system is often planned with redundancy backups in place for reliability of power supply.

First, power is transmitted from the receiving station at 66kV to different substations strategically positioned inside the loading area for network reliability and reduction of power loss. This is the distribution portion. Depending on the reach, voltage at the substation is lowered from 66kV to 33 or 11kV for final distribution. The consumers are then connected to the 415/240 V distribution network.

## 1.3 Operating states of a Power System

A power system's operating state can be categorized into normal, abnormal, or restorative. The normal state is one where the total device demand is satisfied by meeting all of the operating demands. Possibilities such as the outage (electrical failure) of a generating unit, the short circuit and the subsequent tripping of a line and the loss of transmission will result in two exigency situations where, in one, the system remains steady but operates in some of the operating constraints. Although demand from the customer is met, irregular voltage and frequency conditions may occur, and certain lines and equipment may violate loading limits. Nevertheless, for a certain time this sort of emergency can be tolerated.

In the second form of emergency, the power system is dysfunctional, causing a violation of both the loading and operating restrictions, and the system faces the possibility of complete failure if no corrective action is taken immediately. The corrective action is taken in the restore state, so that the system returns either to a new normal state or to the previous normal state. This condition is characterized by the interruption of demand from the customer, which brings the rapid start of units into service.

## 1.4 Bus Classification

Buses in a power system are defined as a line where the power system's various components, such as generators, loads, feeders, motors etc. are connected. In a power system every bus or node in a power network is correlated with four quantities, real and reactive power, the magnitude of the bus voltage and its phase angle. Two out of the four quantities are defined in a load flow solution, and the remaining two are needed to be obtained via equations solution. The buses are graded according to the quantities stated in the following three categories [4].

Load Bus: The real and reactive components or power is specified in this bus. Through the load flow solution, it is desired to find out the voltage magnitude and the phase angle. Only real power and reactive power must be defined in such a bus as to allow a load bus voltage to differ within the permissible values e.g., 2%. The voltage phase angle is also not required for this bus.

2. Generator Bus: The voltage magnitude corresponding to the voltage generation and the real power corresponding to its ratings is required. It's important to find out the reactive power generation and the bus voltage phase angle.

3. Slack, Swing or Reference Bus: There are two types of buses mainly in a power system: load and generator buses.

A slack bus is used in electrical power systems to balance the real power and reactive power within a system when carrying out load flow studies. The slack bus is used into the network to compensate for network losses.

Table 1.1 Bus classifications

| **Bus Type** | **Variables Specified** | **Variables to be obtained** |
|---|---|---|
| Load Bus | P, Q | $\|V\|$, $\delta$ |
| Generator/PV Bus | P, $\|V\|$ | Q, $\delta$ |
| Slack/Swing Bus | $\|V\|$, $\delta$ | P, Q |

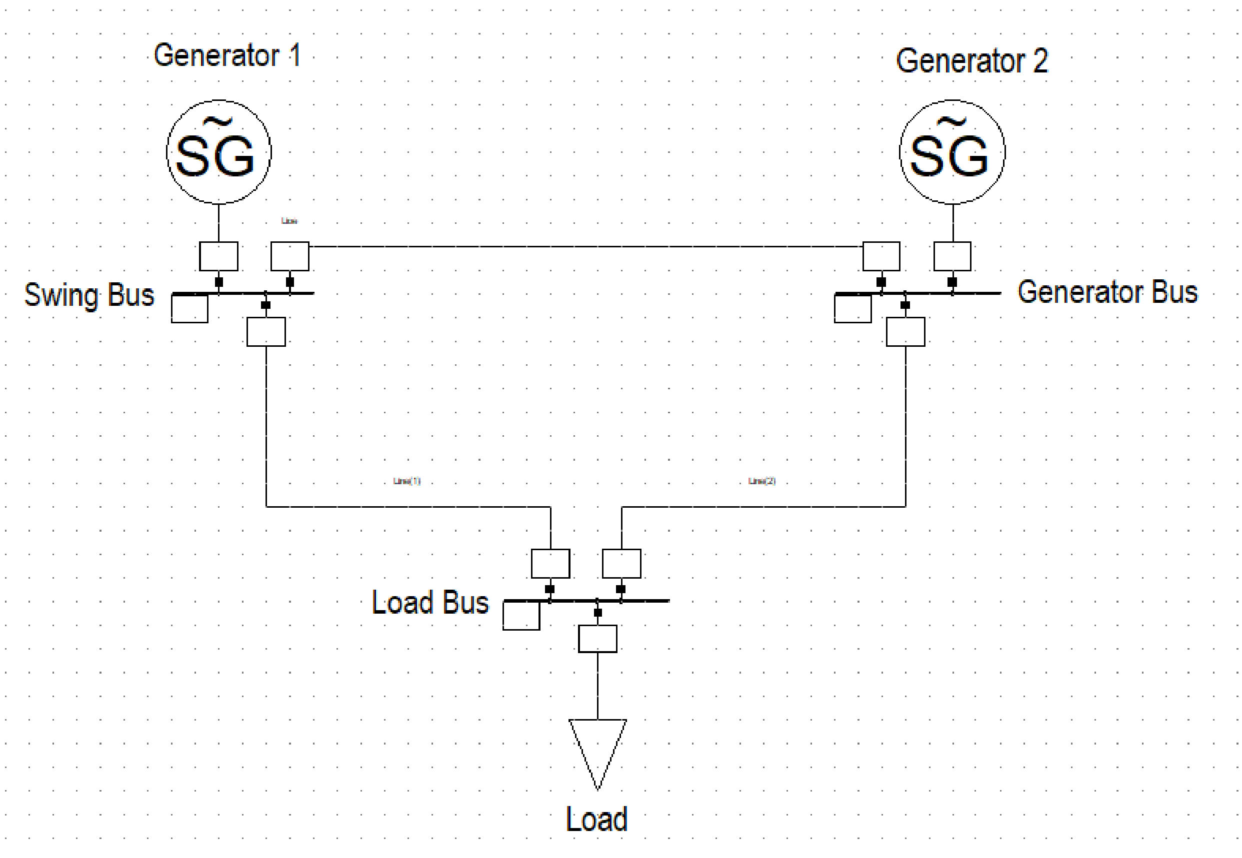


Figure 1.1 Simple bus system

## 1.5 Network Description

The nodes are called buses in a power system on a wide scale, as they represent a physical bus bar where various components of the network meet (transformer, load, motor and generator). A bus is comparable to a single point on a circuit and marks the position of one of two things: a power-injecting generator or a power-consuming load. The load buses reflect aggregations of loads (or very large individual industrial loads) at the location where they connect to the high-voltage transmission network at the level of detail usually required on a larger scale of analysis [2]. In fact, such an aggregation can be a transformer link to a sub-transmission network, which in turn branches out to several distribution substations; or it can be a single distribution substation from which a collection of distribution feeders originates. In any case, for power flow analysis purposes, whatever lies behind the bus is taken as a single unit. Transmission lines link the buses within the network.

A balanced three-phase system is often resolved as a single-phase circuit consisting of one of the three lines and a neutral. The circuit diagram is also simplified by omitting the completed circuit through the neutral and by using standard symbols rather than their corresponding circuits to denote the component parts. Circuit specifications are not shown, and a single line between its two ends represents a transmission line. A single-line diagram is used to simplify the vast diagram of an electric network [5].

A single line diagram has the function of providing the significant details about the system in a descriptive way. The Figure 1 displays a basic single-line diagram showing the generators, circuit breakers, buses, loads and transformers.

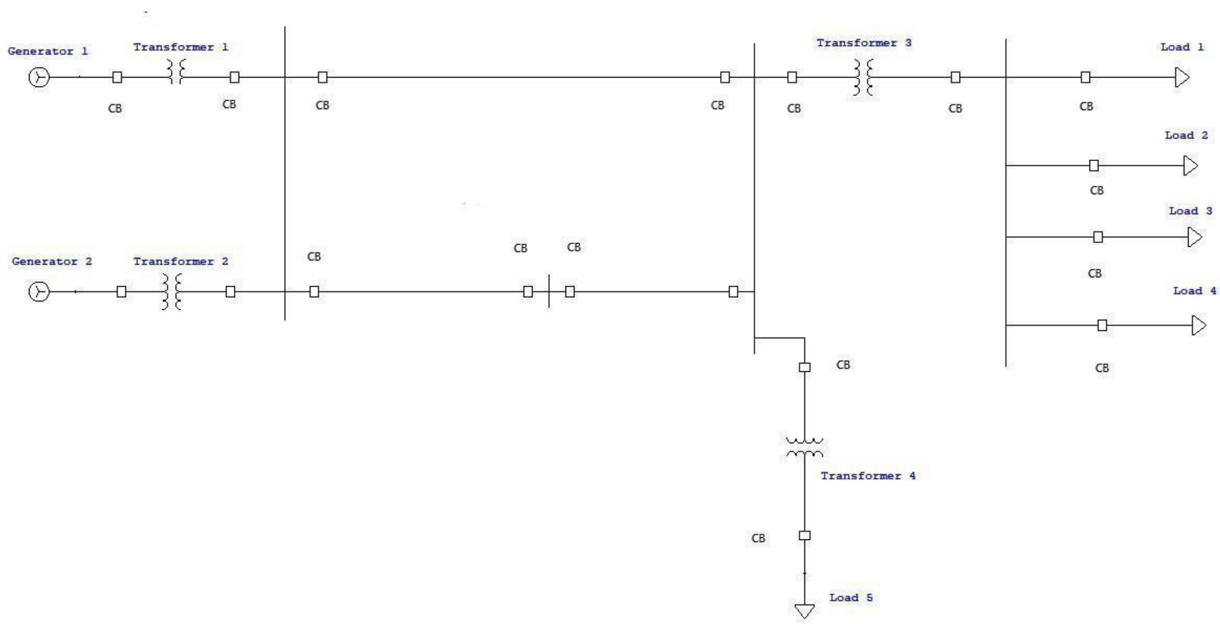


Figure 1.2 Typical power system

## 1.6 Variables for Balancing Real and Reactive Power

For system balance, all generators in the system cumulatively have to supply power in exactly the amount provided by the load, moreover the power loss on transmission lines, which are the resistive R and reactive X power losses by maintaining system frequency constant at 50 Hz. This applies to actual as well as reactive power. To balance real power, P is chosen as one generator whose output can be modified, depending on the needs of the system. The generator is connected to a slack bus and generates more power if system losses are greater than margin. Hence the one generator bus is called the slack or swing bus in power flow analysis. Thus, the real power is defined for in the power flow study [6]. The voltage angle which is the requirement that the system stays balanced will take the place of real power. The generator is controlled to maintain a certain voltage magnitude at its bus for the balancing of reactive power. The voltage is regulated continuously and automatically via the field current of the generator, and is thus a straightforward variable to control. The total amount of reactive power, Q needed for the device need not be specifically specified for power flow analysis, since determining the voltage magnitude is basically equivalent to having a balanced Instead of reactive power, voltage magnitude is defined for all generator buses, so they are called PV buses. Therefore, device variables are defined as follows in power flow analysis:

• Actual and reactive power from generators injected into generator (PV) buses, which are control or independent variables. Real power from PV buses affects the angles of bus voltage while reactive power from PV buses affects the magnitudes of bus voltage.

• Real and Reactive loads tapped from the load (PQ) buses and calculated by consumers are therefore uncontrollable.

# Chapter 2

# Methodology of Load Flow Analysis

## 2.1 Data and Process Required for Load-Flow Analysis

The following steps are implemented in the collection of system data for load flow analysis:

- Draw a single-line diagram of the system.
- The linear impedances and shunt admittances in per-unit values are then found, including transformer impedances, shunt capacitor ratings and transformer ratings and transformer tapping (not always required).
- Node or bus self-admittances are found, using the nodal analysis.
- Run it through as a suitable Mathematical iterative model.

A suitable mathematical model of the system is developed or used after obtaining the above type of data, which competently describes the relationships between the voltages and powers in the interconnected system. Power and voltage constraints are then defined at different buses in the network and the load flow equations are solved numerically. When evaluating different bus voltages, the real load flow is determined in all the transmission lines.

The mathematical formulation of the problem of load flow leads to a system of nonlinear algebraic equations. The equations can be defined using either the reference bus. The equation coefficients depend on the set of dependent variables, which are voltages or currents. And either the matrices for the network entry or impedance are used.

The method using the bus frame reference in the admission form, which gained widespread use due to the simplicity of data preparation and ease with which the bus admittance matrix could be shaped and changed for network changes. This method continues to be the most economical in terms of machine time and memory capacity.

## 2.2 Per-Unit Method in Load Flow Analysis

For an analysis of power systems different values are required, per unit system provides the value of voltage (V), current (A), real power (W), reactive power (VAR), apparent power (VA), impedance (Ohms) and admittance (Ohms). Per unit system makes it easier to calculate the value and makes the calculation simple.

The equivalent circuits are linked together in the network through transformers and interconnections at different voltages. The component ratings are expressed in values common to the same reference base, by expressing the quantities in per-unit values helps to find solution to the power system quickly. The base kVA and base voltage are to be chosen for that representation [7].

**<u>Formulas for Per-unit calculations</u>**

$$\text{Per unit kV} = \frac{\textit{Actual}\text{ kV}}{\textit{Base}\text{ kV}} = \frac{kV_{actual}}{kV_B}$$

$$\textit{Base}\text{ current, } \mathrm{I}_B = \frac{\textit{Base kVA}}{\textit{Base}\text{ kV}} = \frac{kVA_B}{kV_B}\text{ amperes}$$

$$\text{Per unit current, } \mathrm{I}_{pu}\ \frac{\textit{Actual}\text{ current}}{\textit{Base}\text{ current}} = \frac{\textit{Actual}\text{ current}}{kVA_B} \times kV_B$$

$$\textit{Base}\text{ impedance, } \mathrm{Z}_B = \frac{\textit{Base}\text{ kV} \times 1000}{\textit{Base}\text{ current}} = \mathrm{kV}_B \times \frac{kV_B}{kVA_B} \times 1000 = \frac{(kV_B)^2 \times 1000}{kVA_B}\ \textit{ohms}$$

$$\textit{Base}\text{ power, } \mathrm{S}_B = \text{Base kVA}$$

$$\text{Per unit impedance, } Z_{pu} = \frac{\textit{Actual}\text{ impedance}}{\textit{Base}\text{ impedance}}$$

$$\textit{Actual}\text{ impedance} \times \frac{kVA_B}{(kV_B)^2 \times 1000}$$

## 2.3 Node Admittance Matrix Equations

**Node Admittance Matrix**

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & Y_{23} & \cdots & Y_{2n} \\ Y_{31} & Y_{32} & Y_{33} & \cdots & Y_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Y_{n1} & Y_{n2} & Y_{n3} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_n \end{bmatrix}$$

*Where*

n is the total number of nodes

$Y_{ii}$ is the self admittance of node i

$Y_{ij}$ is the mutual admittance between nodes i and j

$V_i$ is the phasor voltage to ground at node i

$I_i$ is the phasor current flowing into the network at node i

The relations between node currents, P,Q and V are as follows:

$$I_1 = \frac{P_i - jQ_i}{V_i^*}$$

*Where*

$P_i$ is the active power at node i

$Q_i$ is the reactive power at node i

## 2.4 Load Flow Solution Techniques

There are several method of load flow analysis using the iterative method, and the most commonly used are:

- Gauss-Seidel method
- Newton- Raphson method
- Fast Decoupled method

The steps in solving the load flow problem by the iterative methods are always pretty similar:

- Make an initial guess of all unknown voltage magnitudes and angles. Start in which all voltage magnitudes are set to 1.0 per-unit and the voltage angles set to zero.
- Equate the equation using the most recent magnitude values.
- Linearize the system around the most recent voltage magnitude and voltage angles.
- Solve for voltage magnitude and voltage angle change.
- Place the new voltage magnitude and angle and equate.
- Check for convergence of the solution, if it converges then stop and check the final result, else continue the process.

### 2.4.1 Gauss-Seidel Iterative Method

Based on the Gauss method, this method is built. This is an iterative approach used to solve a series of algebraic nonlinear equations. In order to obtain a measured value of a particular element, the system uses an initial guess for voltage value. The initial value of the guess is replaced with a calculated value. The process is then repeated until the solution converges to iteration. The convergence is quite sensitive to the starting values assumed [9].

But this method suffers from poor convergence characteristics. This is an iterative method which is used to solve the equation for the value of Vi, and the iterative sequence becomes

$$V_i^{(k+1)} = \frac{\dfrac{P_i^{sch} - JQ_i^{sch}}{V_i^*} + \sum y_{ij} V_j^{(k)}}{\sum y_\theta} \; j \neq i$$

Using Kirchhoff current law, the current injected into bus i is considered positive, then the real and the reactive powers supplied into the buses, such as generator buses, Pi and Qi have a positive value. The real and the reactive powers flowing away from the buses, such as load buses, Pi and Qi have a negative value. Pi and Qi are solved from equation which gives

$$P_i^{(k+1)} = \mathrm{Re}\, al\left[ V_i^{*(k)} \left\{ \sum_{i=1}^{n} y_\theta - \sum_{ji}^{n} V_i^k \right\} \right] j \neq i$$

$$Q_i^{(k+1)} = \mathrm{Im}\, aginary\left[ V_i^{*(k)} \left\{ \sum_{j=1}^{n} y_{ij} - \sum V_i^{(k)} \right\} \right] j \neq i$$

The power flow equation is usually expressed in terms of the bus admittance matrix by using the diagonal elements of the bus admittance and the non-diagonal elements of the matrix, then the equation becomes,

$$V_i^{(k+1)} = \frac{\dfrac{P_i^{sch} - JQ_i^{sch}}{V_i^*} - \sum y_{ij} V_j^{(k)}}{y_{ii}}$$

$$P_i^{(k+1)} = \mathrm{Re}\,al\left[V_i^{*(k)}\left\{V_i^{*(k)} y_{ii} + \sum_{i=1,\, j=1}^{n} y_{ij} V_j^{*(k)}\right\}\right] j \neq i$$

$$P_i^{(k+1)} = \mathrm{Im}\,aginary\left[V_i^{*(k)}\left\{V_i^{*(k)} y_{ii} + \sum_{i=1,\, j=1}^{n} y_{ij} V_j^{*(k)}\right\}\right] j \neq i$$

The admittance to the ground of line charging susceptance and other fixed admittance to ground are included into the diagonal element of the matrix.

Convergence is very slow, Gauss-Seidel is characteristically long in solving and sometimes faces trouble with uncommon network situations such as negative reactive branches.

Each bus is handled independently using the Gauss-Seidel process. Any correction to a single bus involves subsequent correction of all the buses it is connected to.

### 2.4.2 Newton-Raphson Method

The Newton-Raphson (N-R) approach has strong convergence characteristics although the criteria for computation and storage are high. The sparsity techniques and ordered elimination resulted in its earlier acceptability and it remains an effective load-flow algorithm for large systems and optimization even in today's setting. A smaller number of iterations are needed for convergence compared to the Gauss Seidel process, as long as the initial estimate is not far from the final results, and the size of the system does not increase [10]. This process uses the Gauss – Seidel process to obtain reasonable initial voltages as starting values and as starting estimate the results input into the N-R system. These voltages are used to measure real power P at each bus except the swing bus and also reactive power Q wherever reactive power is defined to apply the Newton-Raphson method to the solution of load flow equations, bus voltages and line admittances may be represented in polar or rectangular form [12]. Then the voltages, line admissions and real and reactive forces are represented for polar form representation as:

**Newton-Raphson Method**

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_i| < \theta_{ij} + \delta_j$$

The real and reactive power at bus i is

$$P_i - jQ_i = V_i^* I_i$$

Substituting for Ii in the equation gives

$$P_i - jQ_i = \left|V_i\right| < -\delta_i \sum_{j=1}^{n} \left|Y_{ij}\right|\left|V_j\right| < \delta_{ij} + \delta_j$$

The real and imaginary parts are separated:

$$P_i = \sum_{j=1}^{n} \left|V_i\right|\left|V_j\right|\left|Y_{ij}\right| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = \sum_{j=1}^{n} \left|V_i\right|\left|V_j\right|\left|Y_{ij}\right| \sin(\theta_{ij} - \delta_i + \delta_j)$$

The above equations consist of a set of non-linear algebraic equations in terms of |V| in per unit and δ in radians. These equations are expanded in Taylor's series, the following set of linear equations are obtained.

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \dfrac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \dfrac{\partial P_2^{(k)}}{\partial \delta_n} & \dfrac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \dfrac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \dfrac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \dfrac{\partial P_n^{(k)}}{\partial \delta_n} & \dfrac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \dfrac{\partial P_n^{(k)}}{\partial |V_n|} \\ \hline \dfrac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \dfrac{\partial Q_2^{(k)}}{\partial \delta_n} & \dfrac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \dfrac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \dfrac{\partial Q_n^{(K)}}{\partial \delta_2} & \cdots & \dfrac{\partial Q_n^{(K)}}{\partial \delta_n} & \dfrac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \dfrac{\partial Q_n^{(k)}}{\partial |V_n|} \end{array}\right] \begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix}$$

In the above equation, the element of the slack bus variable voltage magnitude and angle are omitted because they are already known. The elements of the Jacobian matrix are obtained after partial derivatives of the equations are expressed which gives a linear relationship between small changes in the voltage angle and magnitude. The equation can be written in matrix form as:

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

J1, J2, J3, J4 are the elements of the Jacobian matrix.

The difference between the schedule and calculated values known as power residuals for the terms (k) ΔPi and (k) ΔQi is represented as:

$$\Delta P_i^{(k)} = p_i^{sch} - p_i^{(k)}$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)}$$

The new estimates for bus voltage are

$$\delta^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}$$

$$\left|V^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right|$$

**Advantages of Newton-Raphson method:**

- The Newton-Raphson approach has properties of quadrature convergence, and hence has less iterations. It is quicker, more precise and more robust for large systems than the Gauss-Seidel process.
- This is used for large structures with benefit
- The N-R method is based on calculating the voltage corrections while taking into account all the interactions as opposed to the Gauss-Seidel which treats each bus independently and requires subsequent correction of all the buses connected to it.

**Limitation of Newton-Raphson method:**

- The Newton-Raphson method takes longer time as Jacobian elements must be determined for each iteration.

.

### 2.4.3 Fast Decoupled Load Flow Method

The Fast-Decoupled Load Flow Method is a Newton-Raphson algorithm approximation, using knowledge of the physical characteristics of electrical systems. The theory of decoupling acknowledges that active powers are closely related to voltage angles in a steady state, and reactive powers to voltage magnitudes. This means that the problem of load flow can be solved separately [11].

This method is a modification of Newton-Raphson. The Jacobian matrix of the equation is reduced to half by ignoring the element of J2 and J3. This will allow for only one single matrix then performing repeated inversion.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & 0 \\ 0 & j_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$$

$$\Delta P = J_1 \Delta\delta = \left[ \frac{\delta P}{\partial\delta} \right] \Delta\delta$$

$$\Delta Q = J_4 \Delta|V| = \left[ \frac{\partial P}{\partial|V|} \right] \Delta|V|$$

$$\frac{\Delta P}{V_i} = -B^{'} \Delta\delta$$

$$\frac{\Delta Q}{V_i} = -B^{"} \Delta|V|$$

$$\Delta\delta = -\left|B^{'}\right|^{-1} \frac{\Delta P}{|V|} \qquad \Delta|V| = -\left|B^{"}\right|^{-1} \frac{\Delta Q}{|V|}$$

## 2.5 Comparison between Gauss-Seidel, Newton-Raphson and Fast-Decoupled Load Flow Method

Table 2.1 Comparison between G.S, N-R and FDLF

| | G. S | N-R | FDLF |
|---|---|---|---|
| 1 | The number of iterations needed for convergence increases with the size of the system | The number of iterations does not depend on the size of the system | The number of iterations does not depend on the size of the system |
| 2 | Computation per unit iteration is less | Computation per unit iteration is more | Computation per unit iteration is less |
| 3 | Does not require a large memory | Requires more memory | This method requires less memory than NR method |
| 4 | This method requires large number of iterations to reach convergence | This method requires a smaller number of iterations to reach convergence | This method requires a greater number of iterations to reach convergence than NR method |
| 5 | It has a linear convergence characteristic | It has a quadratic convergence characteristic | - |

# Chapter 3

# Software Implementation

## 3.1 Software Development

Simulation of power systems requires a wide variety of timeframes. For certain cases the same method can need to be modelled and solved. Different forms, occurrence of interest depending on the studies. It was beneficial to provide a single software interface from which many functions of power system analysis can be enabled easily from the same power system. For both academic and educational purposes, many high-level programming languages, such as MATLAB, Mathcad, Mathematica, and so on, have become more popular over the last decade. However, for power system analysis recent software like DIgSILENT PowerFactory and ETAP can be used for more variables. In the field of power system research, each of those languages can lead to good results. These are high-performance languages for technical computing and integration, simulated the power flow problem. ETAP and DIgSILENT PowerFactory is a numerical computing environment and programming language offering suitable solutions for matrix and vector computations. They were built during the simulation process using raw data from the 440kV and 220kV transmission system. Bangladesh power system network simulated transmission grid consists of 6 buses, 5 generators, 12 branches, 3 transmission transformers and 0 general loads. All transformers in this single line diagram are believed to be 2-winding transformers.

## 3.2 Addressing the problem

The program for solving power flow problems has been developed using the Newton-Raphson method to simulate the model developed. All calculations were performed in a per unit system during the stimulation phase. The solution approach consists of two software ETAP and DIgSILENT [13]. Within the following steps the Newton-Raphson algorithm is outlined, and the flow chart shown in Figure 3.1

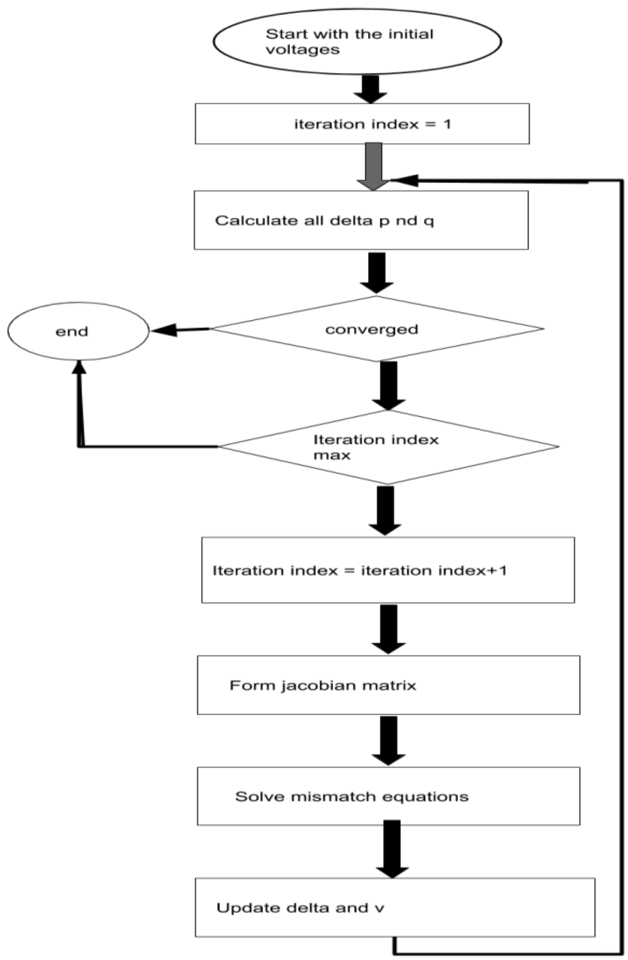


Figure 3.1 Flowchart of Newton-Raphson algorithm

## 3.3 Actual Representation on ETAP and DIgSILENT

The grid station shown in Figure 3.2 and 3.3 is based on the real power system in Aminbazar, Dhaka, Bangladesh. It is a 400/230 kV grid station with two incoming feeders of 400 kV. There are three step-down auto transformers which convert the 400kV to 230kV at 50Hz frequency. These three 230kV outputs from the transformers are then transmitted to other grid stations.

There are some assumptions required to carry out this analysis.

- 400kV buses are taken as reference bus.
- The temperature for the transformers is set at 75 °C
- The system frequency is set at 50 Hertz.
- The line losses that were encountered before entering the system were not included in the calculations.

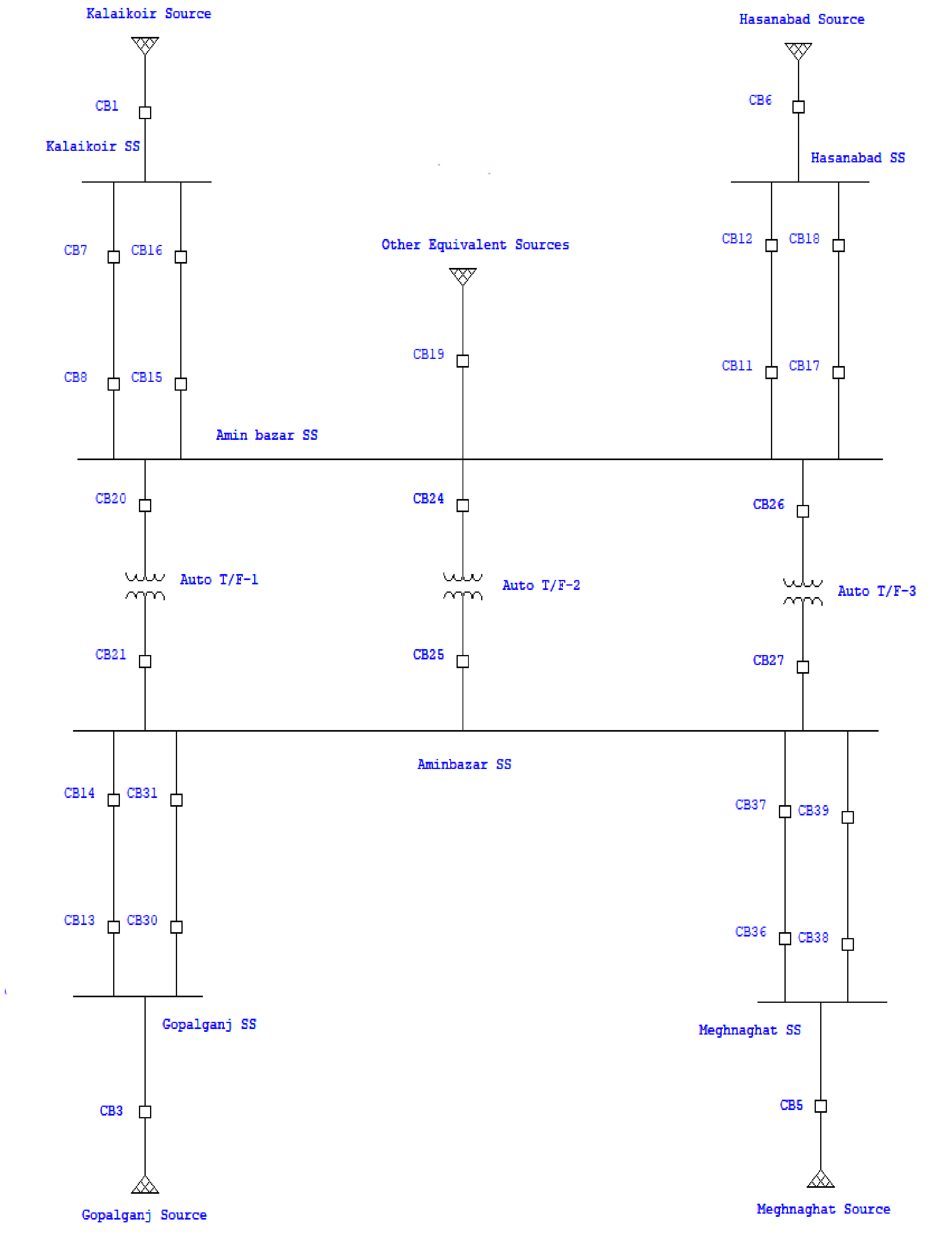


Figure 3.2 Power system on ETAP

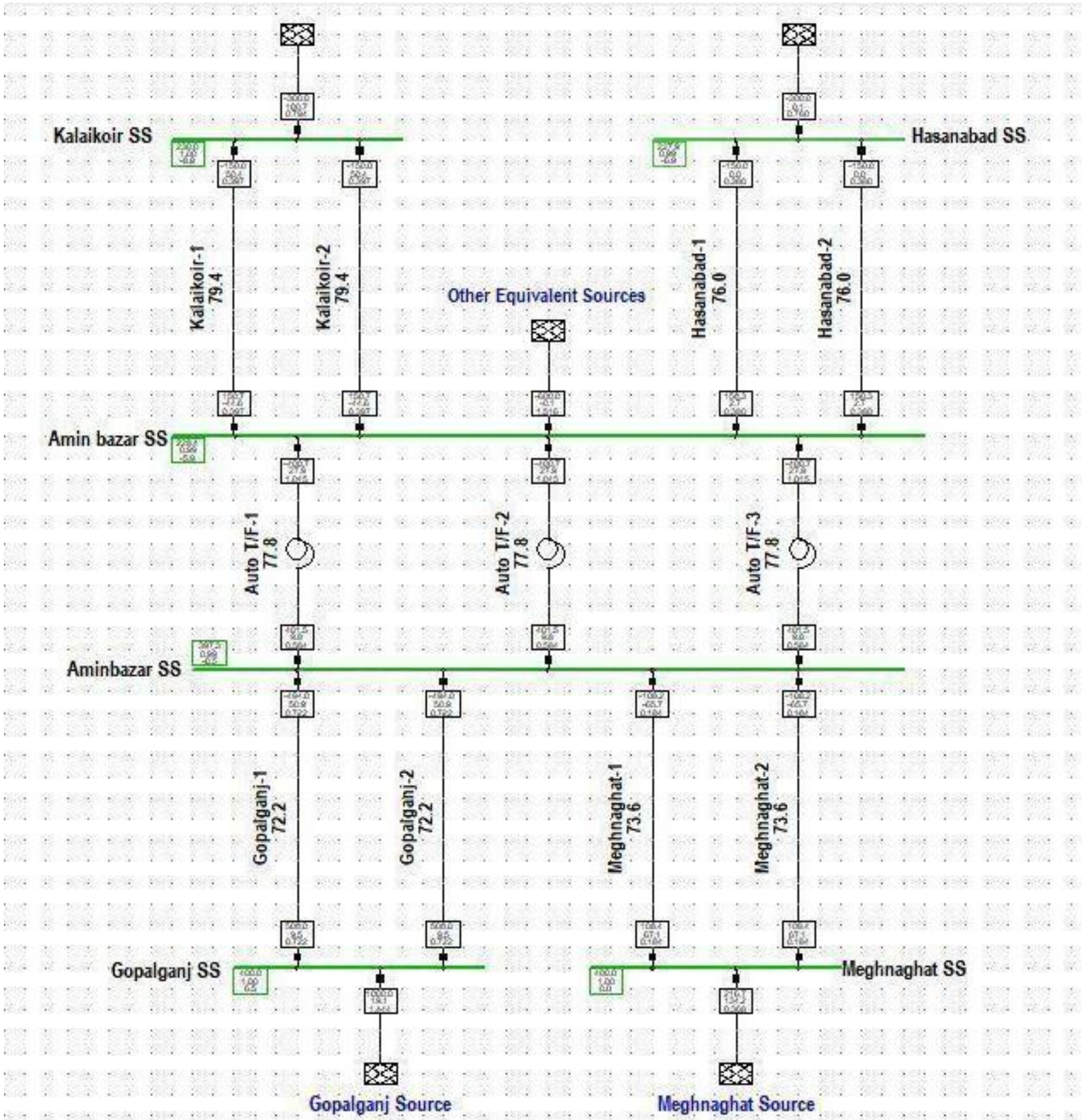


Figure 3.3 Power system on DIgSILENT

## 3.4 DIgSILENT and ETAP initialization with Data

The single line diagram and the data represented in the tables were collected from the Aminbazar 400/230kV power grid which were used in the simulation.

**Bus Input Data**

Table 3.1 Input data of all the buses.

| Bus | | | Generation | MVAR Limits | |
|---|---|---|---|---|---|
| Name | Nominal Voltage (KV) | Type | Real power (MW) | Max | Min |
| Amin bazar | 230.00 | Voltage Control | -600 | 0.00 | -500.00 |
| Aminbazar | 400.00 | Voltage Control | - | - | - |
| Gopalganj | 400.00 | Voltage Control | 1000 | 400.00 | 0.00 |
| Hasanabad | 230.00 | Voltage Control | -300 | 0.00 | -150.00 |
| Kalaikoir | 230.00 | Voltage Control | -300 | 363.00 | 0.00 |
| Meghnaghat | 400.00 | Swing | - | - | - |

**Line Input Data**

Table 3.2 Input data of all the lines.

| Line | Ohms/km per Phase (Line) | | | | | |
|---|---|---|---|---|---|---|
| Name | Length (km) | Phase | T (°C) | Resistance/km | Impedance/km | Admittance/km |
| Gopalganj-1 | 150.000 | 1 | 75 | 0.007742 | 0.078608 | - |
| Gopalganj-2 | 150.000 | 1 | 75 | 0.007742 | 0.078608 | - |
| Hasanabad-1 | 21.500 | 1 | 75 | 0.010516 | 0.089032 | - |
| Hasanabad-2 | 21.500 | 1 | 75 | 0.010516 | 0.089032 | - |
| Kaliakoir-1 | 41.400 | 1 | 75 | 0.010516 | 0.089032 | - |
| Kaliakoir-2 | 41.400 | 1 | 75 | 0.010516 | 0.089032 | - |
| Meghnaghat-1 | 55.000 | 1 | 75 | 0.007742 | 0.078608 | - |
| Meghnaghat-2 | 55.000 | 1 | 75 | 0.007742 | 0.078608 | - |

## Transformer Input Data

Table 3.3 Transformer input data

| Transformer | | Rating | | | | | Adjusted | Phase Shift | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Phase | MVA | Primary (KV) | Secondary (KV) | %Z1 | X1/R1 | %Z | Type | Angle |
| Auto T/F-1 | 3-phase | 520.00 | 400.00 | 230.00 | 12.00 | 45.00 | 12.000 | YNyn | 0.000 |
| Auto T/F-2 | 3-phase | 520.00 | 400.00 | 230.00 | 12.00 | 45.00 | 12.000 | YNyn | 0.000 |
| Auto T/F-3 | 3-phase | 520.00 | 400.00 | 230.00 | 12.00 | 45.00 | 12.000 | YNyn | 0.000 |

## Branch Connections

Table 3.4 Branch connections

| Circuit/Branch | | Connected Bus names | | %Impedance, Pos.Seq.,100 MVA Base | | | |
|---|---|---|---|---|---|---|---|
| ID | Type | From Bus | To Bus | Resistance | Reactance | Impedance | Admittance |
| Auto T/F-1 | 2W XFMR | Aminbazar | Amin bazar | 0.05 | 2.31 | 2.31 | - |
| Auto T/F-2 | 2W XFMR | Aminbazar | Amin bazar | 0.05 | 2.31 | 2.31 | - |
| Auto T/F-3 | 2W XFMR | Aminbazar | Amin bazar | 0.05 | 2.31 | 2.31 | - |
| Gopalganj-1 | Line | Gopalganj | Aminbazar | 0.24 | 2.42 | 2.43 | - |
| Gopalganj-2 | Line | Gopalganj | | 0.24 | 2.42 | 2.43 | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hasanabad-1 | Line | Amin bazar | Hasanabad | 0.14 | 1.19 | 1.20 | - |
| Hasanabad-2 | Line | Amin bazar | Hasanabad | 0.14 | 1.19 | 1.20 | - |
| Kaliakoir-1 | Line | Amin bazar | Kaliakoir | 0.27 | 2.29 | 2.30 | - |
| Kaliakoir-2 | Line | Amin bazar | Kaliakoir | 0.27 | 2.29 | 2.30 | - |
| Meghnaghat-1 | Line | Meghnaghat | Aminbazar | 0.09 | 0.89 | 0.89 | - |
| Meghnaghat-2 | Line | Meghnaghat | Aminbazar | 0.09 | 0.89 | 0.89 | - |

# Chapter 4

# Result and Analysis

## 4.1 Results and Summary Reports based on ETAP and DIgSILENT analysis.

Table 4.1 shows the nominal voltage, magnitude, phase angle, real power and reactive power based on the simulation done by ETAP and DIgSILENT on the entire power system.

Table: 4.1 Result of the load flow report

| **Bus** | | **Voltage** | | **Generation** | | **Load** | | **Load Flow** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
| Name | kV | %Magnitude | Angle | MW | Mvar | MW | Mvar | Name | MW | Mvar | Amp | %PF |
| Amin bazar | 230 | 99.318 | -5.9 | -600 | 0 | 0 | 0 | Hasanabad | 150.321 | 2.720 | 380.0 | 100.0 |
| | | | | | | | | Hasanabad | 150.321 | 2.720 | 380.0 | 100.0 |
| | | | | | | | | Kaliakoir | 150.676 | -44.614 | 397.2 | -95.9 |
| | | | | | | | | Kaliakoir | 150.676 | -44.614 | 397.2 | -95.9 |
| | | | | | | | | Aminbazar | -400.665 | 27.929 | 1015.1 | -99.8 |
| | | | | | | | | Aminbazar | -400.665 | 27.929 | 1015.1 | -99.8 |
| | | | | | | | | Aminbazar | -400.665 | 27.929 | 1015.1 | -99.8 |
| Aminbazar | 400 | 99.315 | -0.5 | 0 | 0 | 0 | 0 | Gopalganj | -494.045 | 50.941 | 721.8 | -99.5 |
| | | | | | | | | Gopalganj | -494.045 | 50.941 | 721.8 | -99.5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Meghnaghat | -<br>108.210 | -65.642 | 183.9 | 85.5 |
| | | | | | | | | Meghnaghat | -<br>108.210 | -65.642 | 183.9 | 85.5 |
| | | | | | | | | Amin Bazar | 401.503 | 9.800 | 583.7 | 100.0 |
| | | | | | | | | Amin Bazar | 401.503 | 9.800 | 583.7 | 100.0 |
| | | | | | | | | Amin Bazar | 401.503 | 9.800 | 583.7 | 100.0 |
| *Gopalganj | 400 | 100.00 | 6.5 | 1000 | 19.052 | 0 | 0 | Aminbazar | 500.00 | 9.526 | 721.8 | 100.0 |
| | | | | | | | | Aminbazar | 500.00 | 9.526 | 721.8 | 100.0 |
| Hasanabad | 230 | 99.090 | -6.9 | -300 | 0.000 | 0 | 0 | Amin Bazar | -150.00 | 0.000 | 380.0 | 100.0 |
| | | | | | | | | Amin Bazar | -150.00 | 0.000 | 380.0 | 100.0 |
| *Kaliakoir | 230 | 100.000 | -8.0 | -300 | 100.67<br>3 | 0 | 0 | Amin Bazar | -150.00 | 50.337 | 397.2 | -94.8 |
| | | | | | | | | | 150.00 | 50.337 | 397.2 | -94.8 |
| *Meghnaghat | 400. | 100.000 | 0.0 | 216.7<br>04 | 134.16<br>3 | 0 | 0 | Aminbazar | 108.352 | 67.082 | 183.9 | 85.0 |
| | | | | | | | | Aminbazar | 108.352 | 67.082 | 183.9 | 85.0 |

## 4.2 Bus Loading Summary Report on ETAP and DIgSILENT:

The Table 4.2 shows the nominal voltage, magnitude, phase angle, real power and reactive power based on the simulation done by ETAP and DIgSILENT on the buses.

Table 4.2 Bus loading summary report

| | | | Directly Connected Load | | | | | | | | Total Bus Load | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus | | | Constant KVA | | Constant Z | | Constant I | | Generic | | | | | |
| Name | kV | Rated Amp | MW | Mvar | MW | Mvar | MW | Mvar | MW | Mvar | MVA | %PF | Amp | Percent loading |
| Amin Bazar | 230.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1205.302 | 99.7 | 3046.3 | - |
| Aminbazar | 400.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1211.643 | 99.4 | 1760.9 | - |
| Gopalganj | 400.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1000.181 | 100.0 | 1443.6 | - |
| Hasanabad | 230.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 300.000 | 100.0 | 760.0 | - |
| Kaliakoir | 230.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 316.441 | 94.8 | 794.3 | - |
| Meghnaghat | 400.000 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 254.873 | 85.0 | 367.9 | - |

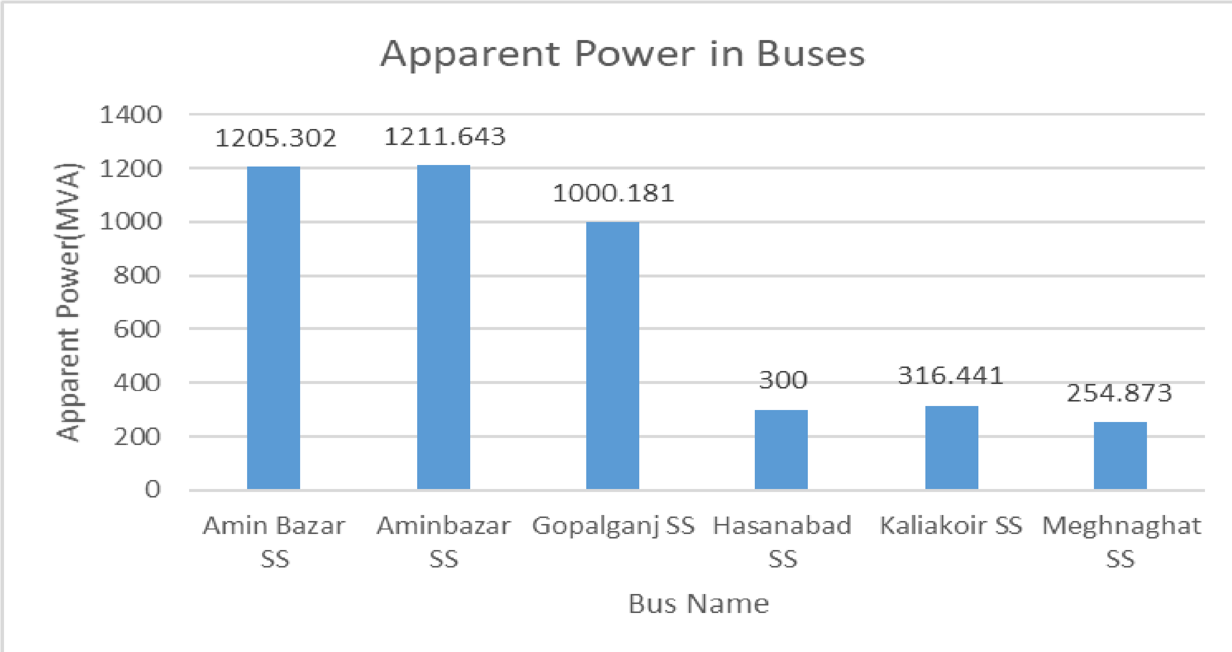


Figure 4.1 Apparent power in buses

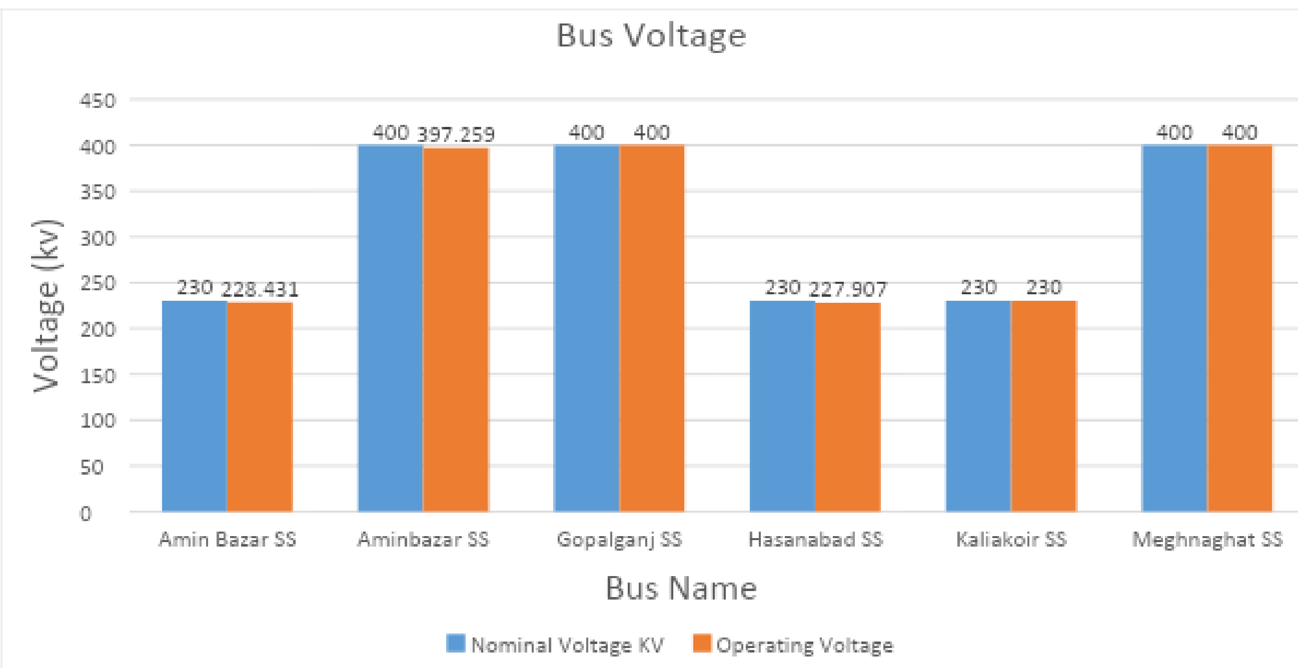


Figure 4.2 Bus voltages

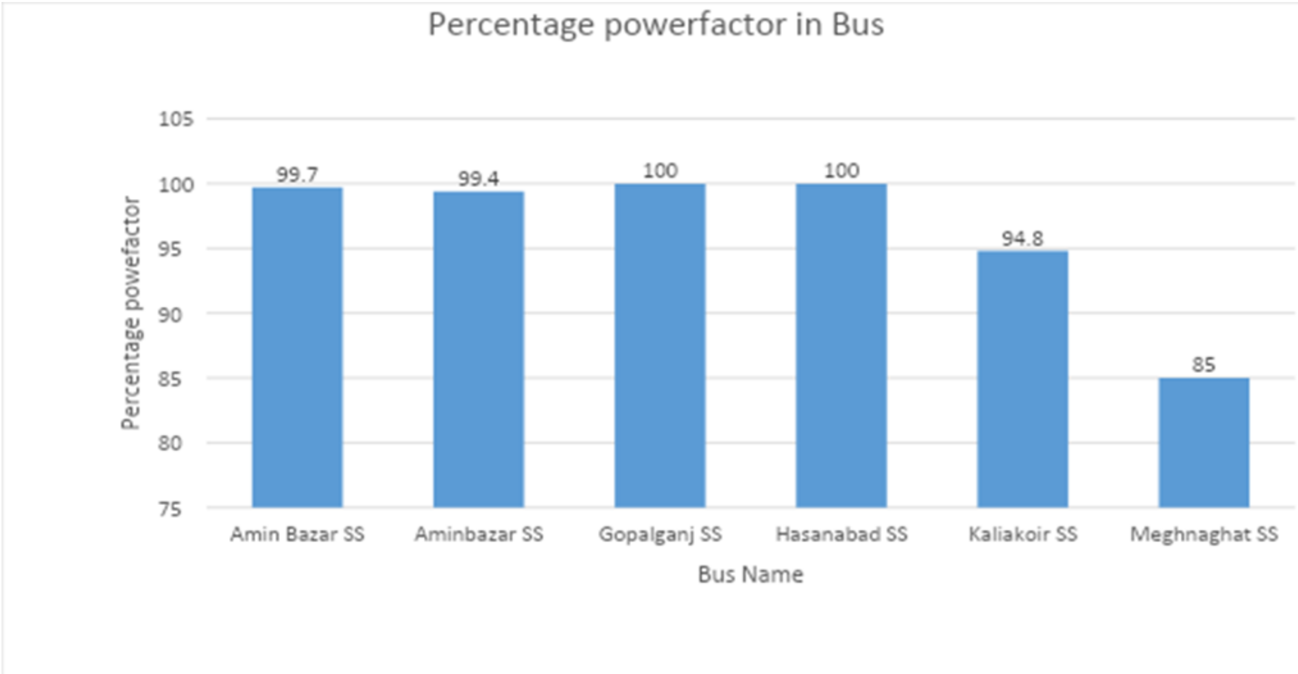


Figure 4.3 Percentage power factor of the buses

## 4.3 Transformer Summary

Table 4.3 Auto transformers report

| Circuit/Branch | | Voltage Rating | | | Transformer | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Type | Primary (kV) | Secondary (kV) | Loss | Capability | Loading (input) | | Loading (output) | |
| | | | | | | MVA | % | MVA | % |
| Auto T/F-1 | Transformer | 400.000 | 230.000 | - | 520.000 | 401.637 | 77.2 | 401.623 | 77.2 |
| Auto T/F-2 | Transformer | 400.000 | 230.000 | - | 520.000 | 401.637 | 77.2 | 401.623 | 77.2 |
| Auto T/F-3 | Transformer | 400.000 | 230.000 | - | 520.000 | 401.637 | 77.2 | 401.623 | 77.2 |

## 4.4 Branch Losses Summary:

Table 4.4 Branch losses summary report

| Circuit/Branch | From-To Bus Flow | | To-From Bus Flow | | Losses | | %Bus Voltage | | Vd % Drop in Vmag |
|---|---|---|---|---|---|---|---|---|---|
| Name | MW | Mvar | MW | Mvar | kW | kvar | From | To | |
| Hasanabad-1 | 150.321 | 2.720 | -150.000 | 0.000 | 321.3 | 2720.4 | 99.3 | 99.1 | 0.23 |
| Hasanabad-2 | 150.321 | 2.720 | -150.000 | 0.000 | 321.3 | 2720.4 | 99.3 | 99.1 | 0.23 |
| Kaliakoir-1 | 150.676 | -44.614 | -150.000 | 50.337 | 675.9 | 5722.7 | 99.3 | 100.0 | 0.68 |
| Kaliakoir-2 | 150.676 | -44.614 | -150.000 | 50.337 | 675.9 | 5722.7 | 99.3 | 100.0 | 0.68 |
| Auto T/F-1 | -400.665 | 27.929 | 401.503 | 9.800 | 838.4 | 37729.4 | 99.3 | 99.3 | 0.00 |
| Auto T/F-2 | -400.665 | 27.929 | 401.503 | 9.800 | 838.4 | 37729.4 | 99.3 | 99.3 | 0.00 |
| Auto T/F-3 | -400.665 | 27.929 | 401.503 | 9.800 | 838.4 | 37729.4 | 99.3 | 99.3 | 0.00 |
| Gopalganj-1 | -494.045 | 50.941 | 500.000 | 9.526 | 5955.3 | 60467.3 | 99.3 | 100.0 | 0.69 |
| Gopalganj-2 | -494.045 | 50.941 | 500.000 | 9.526 | 5955.3 | 60467.3 | 99.3 | 100.0 | 0.69 |
| Meghnaghat-1 | -108.210 | -65.642 | 108.352 | 67.082 | 141.8 | 1439.7 | 99.3 | 100.0 | 0.69 |
| Meghnaghat-2 | -108.210 | -65.642 | 108.352 | 67.082 | 141.8 | 1439.7 | 99.3 | 100.0 | 0.69 |

Table 4.4 shows the losses and the percentage voltage drop incurred on the branches during the power flow analysis.

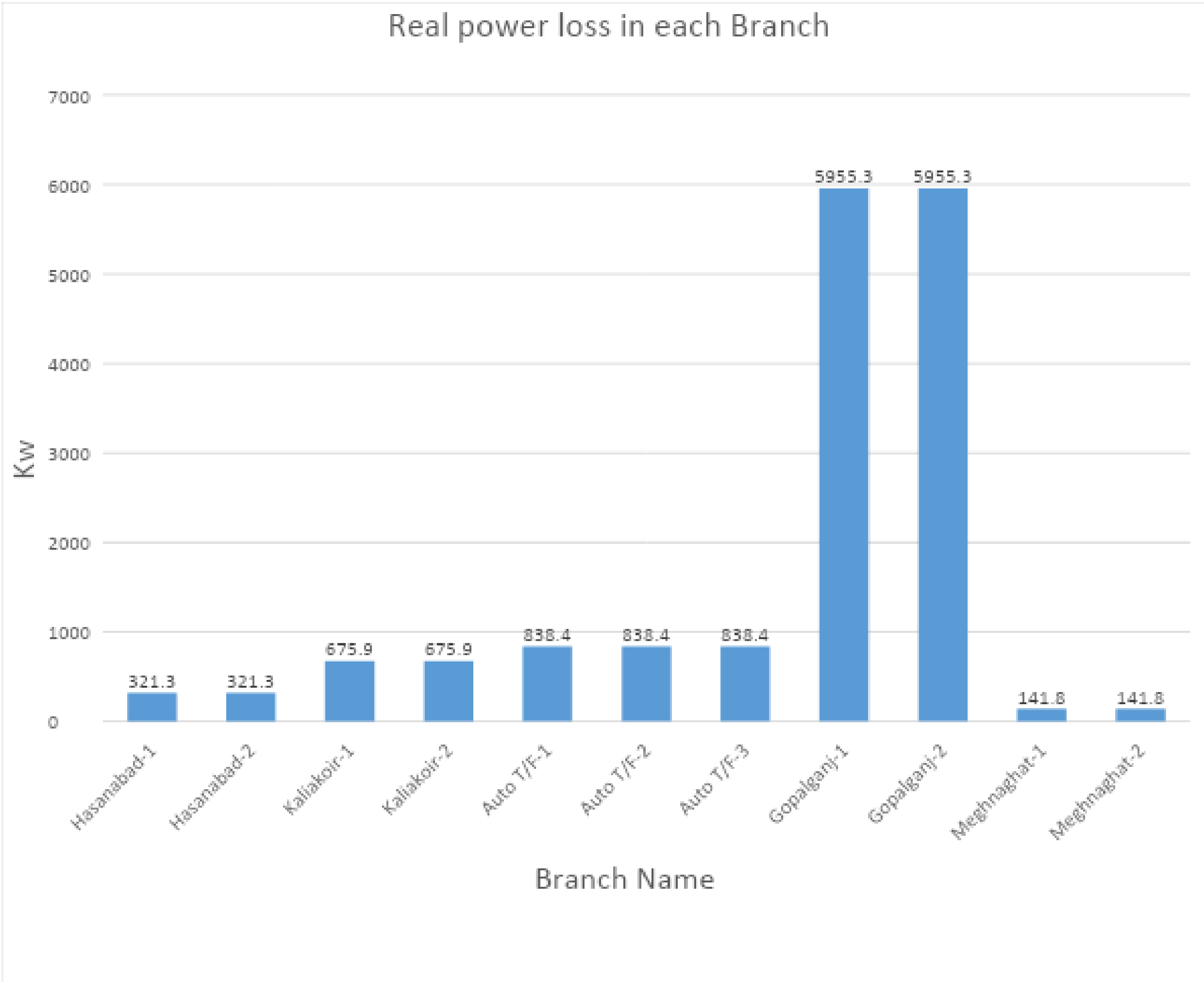


Figure 4.4 Bar chart of the real power losses

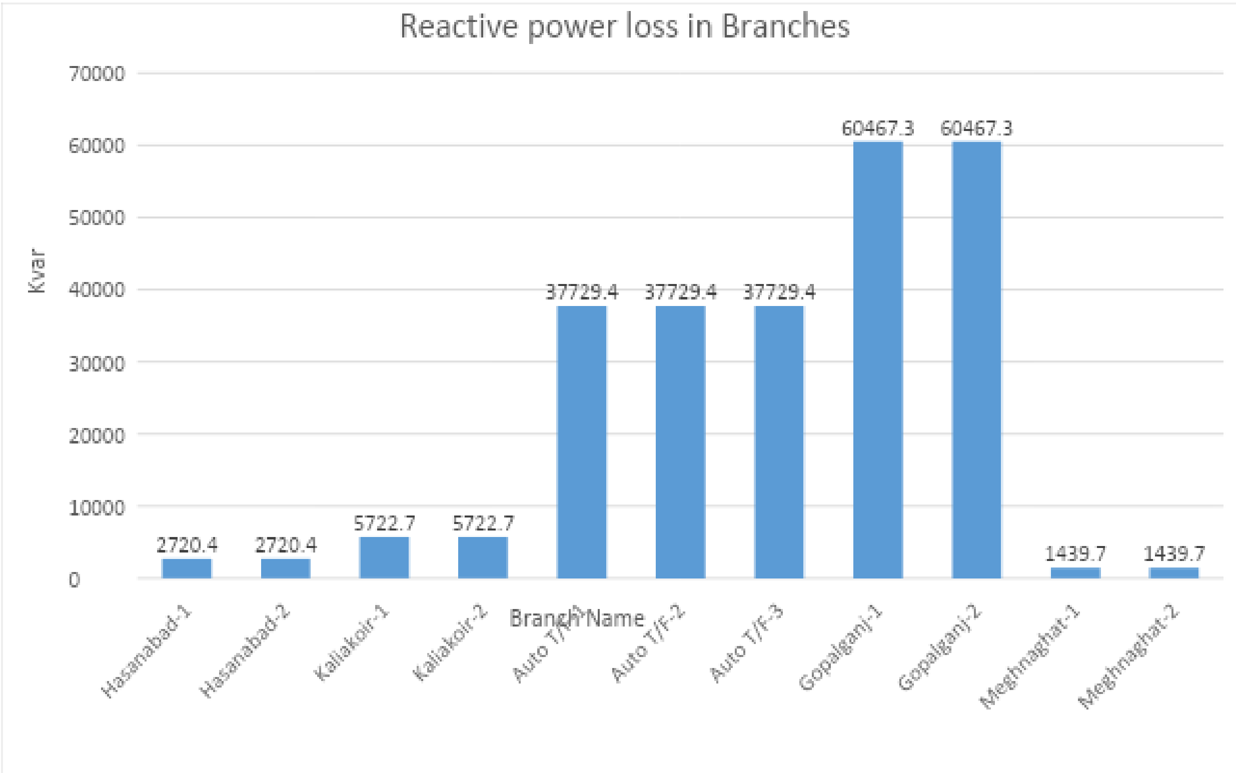


Figure 4.5 Bar chart of the reactive power losses

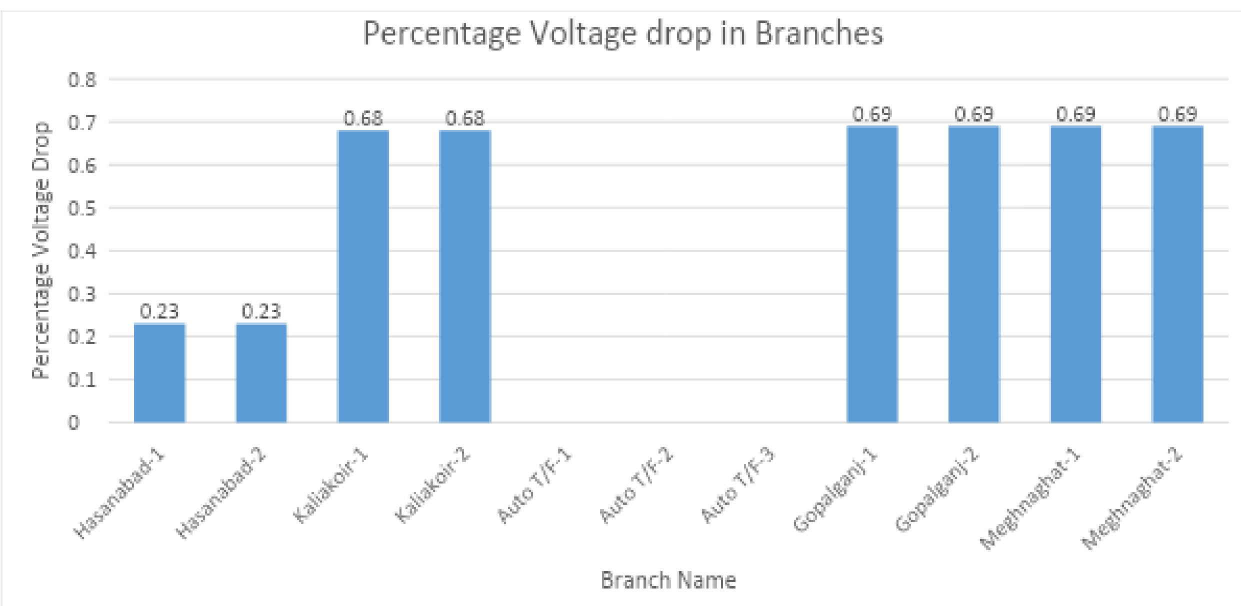


Figure 4.6 Bar chart of the percentage voltage drop in branches

## 4.5 Summary of Total Generation, Loading and Demand

The following Table 4.5 shows the total demand of the system which is also showing the total system losses during the analysis. The number of iterations is 2.

Table 4.5 Total generation, loading and demand

| | MW | Mvar | MVA | %PF |
|---|---|---|---|---|
| Source (Swing Buses) | 216.704 | 164.163 | 254.873 | 85.02 Lagging |
| Source (Non-Swing Buses) | -200.000 | 119.725 | 233.097 | 85.80 Leading |
| Total Demand | 16.704 | 253.888 | 254.437 | 6.57 Lagging |
| Total Motor Load | 0.000 | 0.000 | 0.000 | - |
| Total Static Load | 0.000 | 0.000 | 0.000 | - |
| Total Constant I Load | 0.000 | 0.000 | 0.000 | - |
| Total Generic Load | 0.000 | 0.000 | 0.000 | - |
| Apparent Losses | 16.704 | 253.888 | - | - |
| System Mismatch | 0.000 | 0.000 | - | - |

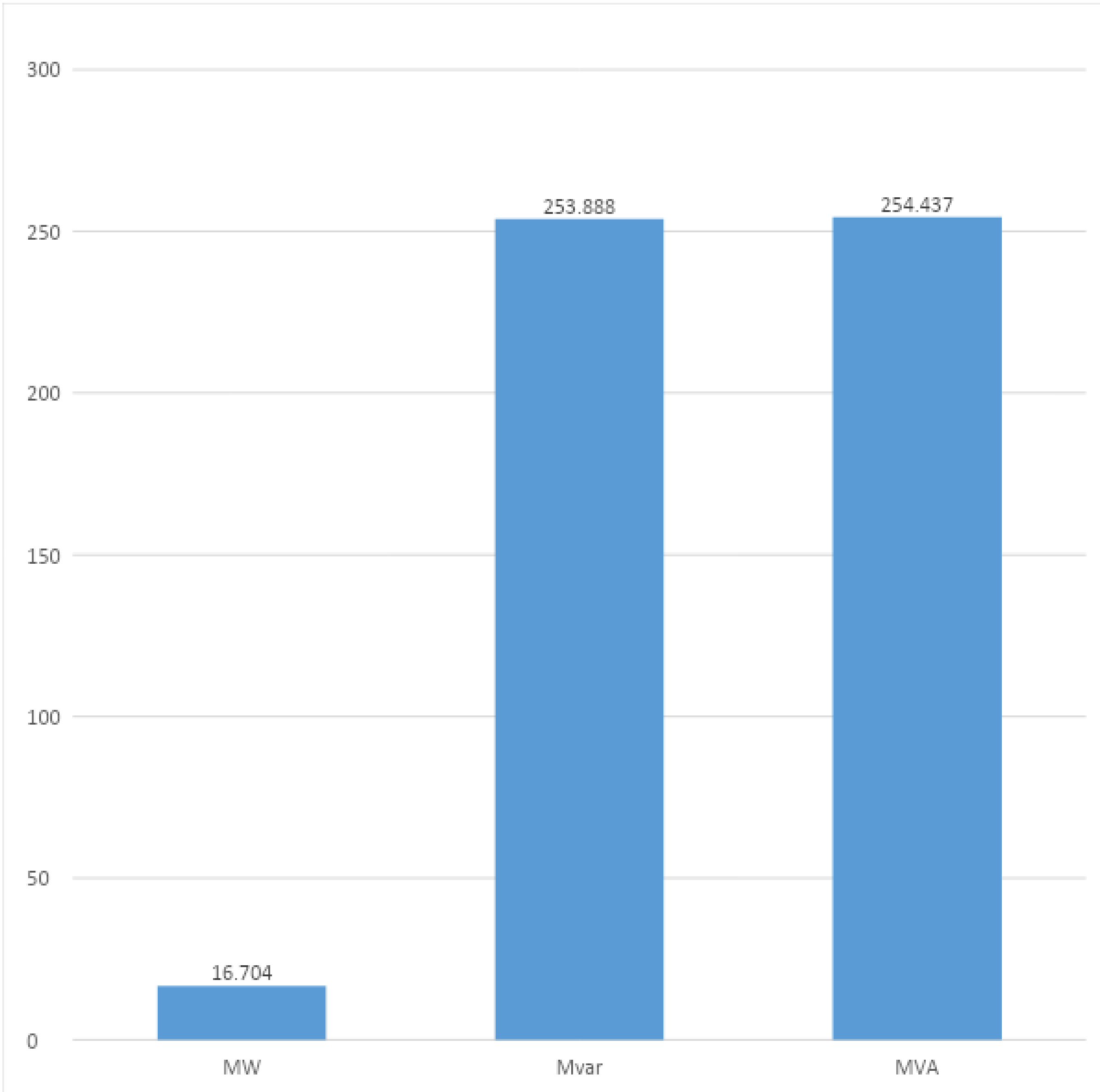


Figure 4.7 Total demand/losses of the system

# Chapter 5

# Conclusion and Future Work

## 5.1 Summary

The research purpose was to use two similar power system analyzers currently available, DIgSILENT and ETAP, to analyze the Aminbazar grid system located in Dhaka, Bangladesh. DIgSILENT and ETAP are versatile software which can be used to do different tasks regarding power systems. We have chosen load flow analysis because it is one of the most important analyses needed to develop or modify existing power systems. This analysis then can be used to detect faults, anomaly in system behaviors and can also be used to give the relevant system information required to improve existing or future power systems. With the help of the two advanced level software we performed load flow analysis and compared the values with each other to see how differently they both worked.

Based on the results of two different software, the results were found to be identical. Both software uses Newton-Raphson method and the results were identical without any variation.

## 5.2 Future work

This thesis was carried out with time being constant. There was no analysis done with a variation of time. However, in a power system the load flow analysis varies with changes in time, temperature, weather conditions, demand etc. In the future, we would like to carry out the same load flow analysis taking into account all the variations so that we can get a more accurate result.

# References

[1] T. Ackermann, G. Andersson and L. Söder, "Distributed generation: A definition", *Electric Power Systems Research*, vol. 57, no. 3, pp. 195-204, 2001. doi: 10.1016/s0378-7796(01)00101-8

[2] J. McDonald, B. Wojszczyk, B. Flynn and I. Voloh, "Distribution Systems, Substations, and Integration of Distributed Generation", in *Encyclopedia of Sustainability Science and Technology*, R. A. Meyers, Ed. New York: Springer, 2012, pp. 2976-3022. doi: 10.1007/978-1-4419-0851-3_761

[3] A. Meier, *Electric power systems*, Hoboken, N.J.: Wiley-Interscience, 2006.

[4] C. Wadhwa, *Electrical power systems*, New Delhi: New Age International Publishers, 2006.

[5]. M.V. Deshpande, *Electrical power system design*, New Delhi: Tata McGraw Hill, 1984.

[6]. G. Benysek and M. Parko, *Power theories for improved power quality*, London: Springer-Verlag London, 2012.

[7] H. Saadat, *Power system analysis*, 3rd ed. United States: PSA Publishing LLC, 2011.

[8] H. Kabisama, *Electrical power engineering*, New York: McGraw-Hill, 1993.

[9] G. M. Gilbert, D. E. Bouchard and A. Y. Chikhani, "A comparison of load flow analysis using DistFlow, Gauss-Seidel, and optimal load flow algorithms," *Conference Proceedings. IEEE Canadian Conference on Electrical and Computer Engineering (Cat. No.98TH8341)*, Waterloo, Ontario, Canada, 1998, pp. 850-853 vol.2, doi: 10.1109/CCECE.1998.685631.

[10] J. D. Glover and M. S. Sarma, *Power system analysis and design*, 3rd ed. Pacific Grove: Brooks/Cole, 2002.

[11] B. Stott and O. Alsac, "Fast Decoupled Load Flow", *IEEE Transactions on Power Apparatus and Systems*, vol. -93, no. 3, pp. 859-869, 1974. doi: 10.1109/tpas.1974.293985.

[12] B. Stott, "Review of load-flow calculation methods", *Proceedings of the IEEE*, vol. 62, no. 7, pp. 916-929, 1974. doi: 10.1109/proc.1974.9544

[13] I. A. Adejumobi, G. A. Adepoju, K. A. Hamzar and O. R. Oyeniran, "Numerical methods in load flow analysis: An application to Nigeria grid system", *International Journal of Electrical and Electronics Engineering*, vol. 3, no. 2, pp. 43-52, Mar 2014.