CHAPTER ONE
INTRODUCTION

1.1 Background

Several blackouts in recent years related to voltage stability problems have occurred in many countries. In particular, 2003 was an intense year regarding blackouts with a total of 6 major ones affecting the United State of America (US), the United Kingdom (UK), Denmark, Sweden and Italy. The U.S-Canadian blackout of August 14th, 2003 affected approximately 50 million people in eight U.S. states and two Canadian provinces. In the same year, on September 23rd 2003, the Swedish/Danish system went down affecting 2.4 million customers and five days later, September 28th, another major blackout occurred in continental Europe which resulted in a complete loss of power throughout Italy [1].And lastly the famous blackout in national electricity of Sudan in 2009 and 2016 that was result in complete loss of electricity service in Sudan.

The objective in power systems operation is to serve energy with acceptable voltage and frequency to consumers at minimum cost. Reliability and security are also important parameters for power system and should be satisfied, by reliability it’s meant that the system has adequate reserves in the face of changing energy demand and by security it’s meant that upon occurrence of contingency, the system could recover to its original state and supply the same quality service as before. All these objectives can be achieved by proper planning, operating and control of generation and transmission system. But one of the major problems in power system that can contribute to prevent achievement these objective is voltage instability [1]. Therefore special analysis and attention should be given to voltage stability.

Because power systems are operating closer to their limits, voltage stability assessment and control, although not a new issue, is now receiving especial attention. As defined in, voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. The study of voltage stability can be analyzed under different approaches, but specially, the assessment of how close the system is to voltage collapse can be very useful for operators. This information on the proximity of voltage instability can be given through Voltage Stability Indices. These indices can be used online to enable the operators to take action or even to automate control actions to prevent voltage collapse from happening or offline for the designing and planning stages [2].

There are two distinct approaches commonly used in voltage stability studies of a large power system. The first approach uses an appropriate voltage stability index to predict how the system is close to voltage instability or collapses the second approach identifies the buses or areas where the possible voltage instability or collapse my occur. In principle there are two methods commonly used for voltage stability analysis, dynamic and static analysis. Dynamic analysis uses time domain simulation to solve nonlinear system differential algebraic equations (this is method are intended to analyses how different devices and control effect voltage stability), Static analysis (in this is method the system is modeled by means of power flow equation and this method determining the system condition at which the equilibrium point of power equation disappeared) [2].

In this project static approach is used to analysis voltage stability in IEEE 14-bus and simplified Sudan grid.

1.2 Problem Statement

Power systems operation becomes more important as the load demand increases all over the world. This rapid increase in load demand forces power systems to operate near critical limits due to economical and environmental constraints. In economic constrain aspect, investment costs of generation and transmission systems play great in power market in order to be competitive in power market therefore, systems will operate at critical limits since investment costs are high and all this will make construction of new power plants and transmission lines and operation of existing ones should be carried out efficiently[1].

Environmental constraints have negative effect on construction of new power plants and transmission lines. Great portion of the energy produced is consumed by big cities. Most of the time, it is impossible to build generation units near crowded cities which causes significant loss of energy due to long transmission lines[1].

Since generation and transmission units have to be operated at critical limits voltage stability problems may occur in power system when there is an increase in load demand. Voltage instability is one of the main problems in power systems. In voltage stability problem some or all buses voltages decrease due to insufficient power delivered to loads [1].

In case of voltage stability problems, serious blackouts may occur in a considerable part of a system. This can cause severe social and economic problems.

The following are the significant factors contribute to voltage instability or collapse (blackout):

1. Large distance between generation and load (length increase the magnitude of drop).
2. Inability of the power system to meet the demand for reactive

3. Power due to a mismatch between load demand and supply of reactive power.
4. Progressive fall or rise of the voltage at some buses.
5. Loss of load in an area, or tripping of transmission lines and other elements by their protective systems.
6. Loss of load in an area, or tripping of transmission lines and other elements by their protective systems.
7. Heavily stressed and/or weak power systems.
8. The voltage collapse problem may be aggravated by excessive use of shunt capacitor compensation.

1.3 Objectives

Because the amount of power generated in simplified Sudan grid has increased significantly in the last decades in const rate , the electricity consumption in industrial sector has grown at faster rate than generation however ,repeated black out and voltage instability problems associated in this network will increase ,the faults and blackout that have being recorded shown that most of them will result in a big damage for the grid and consumers both , most of power station around the world have voltage collapse ,therefore the need for analysis of voltage stability in transient and steady state is important issues for the all the engineers that work in power system sector.

The main objective of this work study and analysis the voltage stability of Sudan grid to identify the weakest buses from the viewpoint of voltage stability(using voltage changing index)that causes the problem of voltage instability will developed to total black out in this network and how to avoid it in the future.

1.4 Methodology

Voltage stability analysis (static approach) it's based on determining voltage indices, and this is indices required different many way to be calculated, in this is project Voltage change index was used, identifying this is index required determining load flow analysis in steady state and limit operation for network under study (using Newton-Raphson method of load flow solution that implemented through MATLAB programming).

Voltage change index method was applied to IEEE 14-bus benchmark to insure his success, and then it was applied to simplified Sudan grid.

1.5 Thesis Layout

This is Project is consisting from five chapter and details as follows:

Chapter one is introduction and it's involve Background, problem statement, objective and methodology.

Chapter two literature review and its involves classification and definition of stability , voltage stability analysis method and IEEE 14-bus test system.

Chapter three load flow analysis and it's involves introduction for load flow analysis ,load flow using Gauss- Seidel method, Newton- Raphson method, load flow using MATLAB Program and simplified Sudan grid data.

Chapter four Result and its involves discussion result of applying VCI to IEEE 14-bus benchmark and simplified Sudan grid.

Chapter five Conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The problem of defining and classifying power system stability is an old one, and there are several previous reports on the subject by IEEE task, and this however completely reflects the serious of the problem [2].

Power system stability is the ability of electric power system for given initial operating condition to regain a state of operating equilibrium after being subjected to physical disturbance [3].

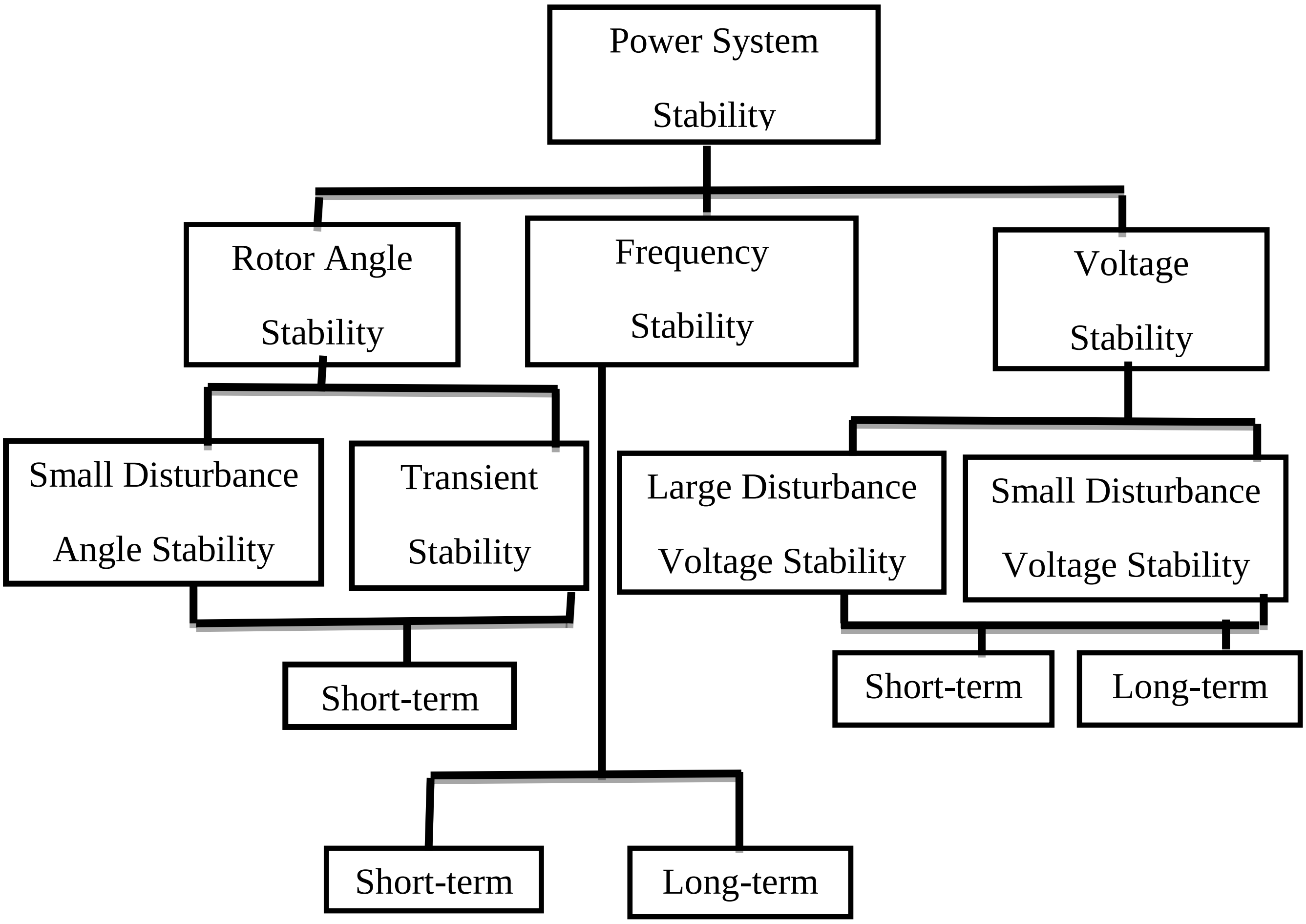

Figure 2.1: Classification of Power System Stability

Analysis of stability including identifying key factors that contribute to instability and dividing methods of improving stable operation is greatly facilitated by classification of stability into appropriate categories.

Classification is essential for meaningful practical analysis and resolution of power system stability problems, and figure below show overall picture of this classification.

2.1.1 Definition of varies type of power system stability

- Rotor angle stability: refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to disturbance.
- Frequency stability: refers to the ability of power system to maintained steady frequency following sever system upset resulting in significant unbalance between generation and load.
- Voltage stability: refers to the ability of power system to maintain steady voltage at all buses in the system after being subjected to a disturbance from given initial operating condition [3].

2.1.2 Classification of voltage stability

As we define stability above the instability that it can be result in forms of progressive fall or raise of voltage of the some buses, voltage instability is coming from loss of the load in area where voltage reach unacceptable low values or completely loss[4].

Also progressive drop in bus voltage can also associated with rotor angle going out of the step, the main factor contributing to voltage instability is voltage drop that occurs when active and reactive power flow thought inductive reactance (transmission network).Also the voltage instability can come from load disturbance (power consumed by the load tends to be restored by action of distribution voltage regulators and tap changer transformer) [4].

Classification of power system stability is an effective to deal with the complexity of the problems it useful to classify the voltage stability into the following sub-categories based on the size of disturbance:

1. Large-disturbance voltage stability refers to system ability to maintain steady voltage following large disturbance such system faults, loss of generation [4].
2. Small-disturbance voltage stability refers to the system ability to maintain steady voltage when it subjected to small perturbation such as incremental changes in the system load [4].

Also the voltage stability can classify into two categories:

1. Short-term voltage stability refers to dynamics that occurs due to fast acting load such as induction motor [4].
2. Long –term voltage stability refers to dynamics that occurs due to slower acting equipment such as tap changer transformer [4].

2.2 Voltage Instability

Voltage instability implies an uncontrolled decrease in voltage triggered by a disturbance(the transfer of power through transmission network is accompanied by drops between the generation and consumption point in addition to reactive power constrain, in normal operating condition these drop are in the order of a few percent of the nominal voltage. One of the tasks of power system planner and operator is to check that under heavy stress condition all the bus voltage remain within acceptable bound .in some circumstances, however in the seconds following a disturbance the voltage may be large then it progressive falls so the all system will be threatened, all these event refers to voltage instability and it is dangerous result voltage collapse [3].

2.3 Voltage Collapse

Voltage collapse problems normally occur in heavily stressed system,it is the process by which the sequence of events accompanying voltage instability leads to low un acceptable voltage profile in a significant part of power system (partial) or it extend to involves all power system network(blackout)[3].

2.4Methods of Voltage Stability Analysis

Many algorithms have been proposed in for voltage stability analysis. Most of the utilities have a tendency to depend regularly on conventional load flows for such analysis. Some of the proposed methods are concerned with voltage instability analysis under small perturbations in system load parameters. The analysis of voltage stability, for planning and operation of a power system, involves the examination of two main aspects:

1. How close the system is to voltage instability (Proximity).
2. When voltage instability occurs, the key contributing factors such as the weak buses, area involved in collapse and generators and lines participating in the collapse are of interest (Mechanism of voltage collapse).

Proximity can provide information regarding voltage security while the mechanism gives useful information for operating plans and system modifications that can be implemented to avoid the voltage collapse. Many techniques have been proposed for evaluating and predicting voltage stability using steady state analysis methods. Some of these techniques are P-V curves, Q-V curves, modal analysis, minimum singular value and sensitivity analysis, reactive power optimization , artificial neural networks , neuro-fuzzy networks , reduced Jacobian determinant, Energy function methods, thevenin and load impedance indicator and loading margin by multiple power-flow solutions[5].

2.4.1 Q-V Curve

Q-V curve technique is a general method of evaluating voltage stability. It mainly presents the sensitivity and variation of bus voltages with respect to the reactive power injection. Q-V curves are used by many utilities for determining proximity to voltage collapse so that operators can make a good decision to avoid losing system stability. In other words, by using Q-V curves, it is possible for the operators and the planners to know the maximum reactive power that can be achieved or added to the weakest bus before reaching minimum voltage limit or voltage instability. Furthermore, the calculated Mvar margins could relate to the size of shunt capacitor or static var compensation in the load area [5].

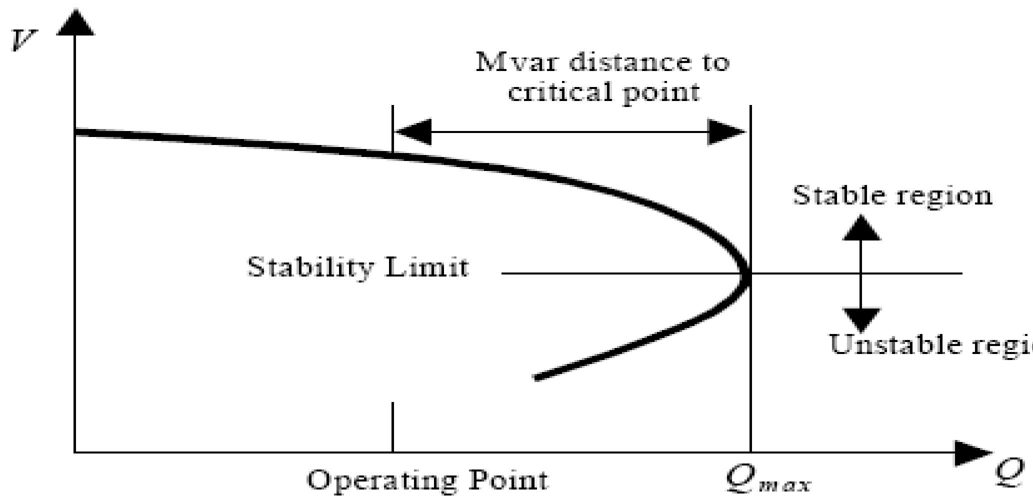

Figure 2.2: A Typical Q-V Curve [5]

2.4.2 P-V Curve

The P-V curves, active power-voltage curve, are the most widely used method of predicting voltage security. They are used to determine the MW distance from the operating point to the critical voltage [5].

2.4.3 Loading margin

The most basic and widely accepted index to assess the proximity to the voltage collapse is loading margin .This index is defined as the amount of additional load ,following specific load increase pattern that may cause voltage collapse, the loading margin can be calculated in the principle by starting at given operating condition ,increasing load with small increments and recomputing load flow at each increment until the voltage collapse is reached. The loading margin is then the total additional load[5].

2.5 Index Formulation

In order to reveal the critical bus and to determine the point of collapse for detecting and predicting voltage collapse of an electrical power system, several stability indices have been proposed. The index used to examine the system stability is briefly described in this section [5].

2.5.1Voltage change index (VCI) method

Let V_i^{init} and V_i^{limit} be the voltage magnitudes at bus (***i***) at the initial operating state and the voltage stability limit, respectively. A voltage change index is defined for each load bus as:

$$VCI = \frac{V_i^{init} - V_i^{limit}}{V_i^{limit}} \qquad i \in j_l \tag{2.1}$$

The 'weak' or critical bus in the network is the most (electrically) remote bus from the point of constant or controllable voltage. It is expected that the critical bus would be the worst affected (voltage wise) because of a shortage of local Vars or Vars transferred from a remote source. This is a typical scenario in the reported cases of voltage collapse problems**.** It is anticipated that for a specified operating regime, going from an initial operating point to the voltage stability limit, the weakest bus would experience the largest voltage change (or drop), this means the largest index (*VCI),* defined by eqn. (2.1)**.** Therefore if bus k is the weakest bus,

$VCI = \max\{VCI\}$ (2.2)

Based on the index VCi the system buses may be arranged in order of weakness, the weakest bus corresponding to that with the largest index. The voltage change index defined in eqn. (2.2) to identify the weakest bus may be extended to identify the weakest area in a power network [7]

2.6 Power Flow solutions

Power flow studies, commonly known as load flow, from an important part of power system analysis .They are necessary for planning, economic scheduling, and control of existing system as well as planning its future expansion.

The problem consists of determining the magnitudes and phase angle of voltages at each bus and active and reactive power flow in each line [8].

In solving a power flow problem, the system to be operation under balanced conditions and single-phase model is used. Four quantities are associated with each bus. These are voltage magnitude (v), phase angle (δ), real power (P) and reactive power (Q) [8]. (Power flow solution is described intensively in chapter three).

2.7 Determination of Voltage Stability Limit in Multi-machine Power Systems

The voltage stability limit occurs for the maximum load that can be supplied by the transmission system, so the problem of determining this limit in a general multi-machine power network is formulated as a nonlinear optimization problem, this means maximize (total MVA demand) subject to:

i. Specified patterns of increase of the MVA demand.
ii. MVAR and MW limits on generators.
iii. Generator MW participation.
iv. Specified power factor for the additional MVA demand at each bus (optional constraint).

v. Limits on controlled voltages and LTC transformer Taps With regard to the above constraints [7].

2.8 IEEE 14-bus Benchmark

A single line diagram of the IEEE 14-bus standard system shown in Figure1.It consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 Mvar. Line data and bus data are shown in appendix (A.1)[9].

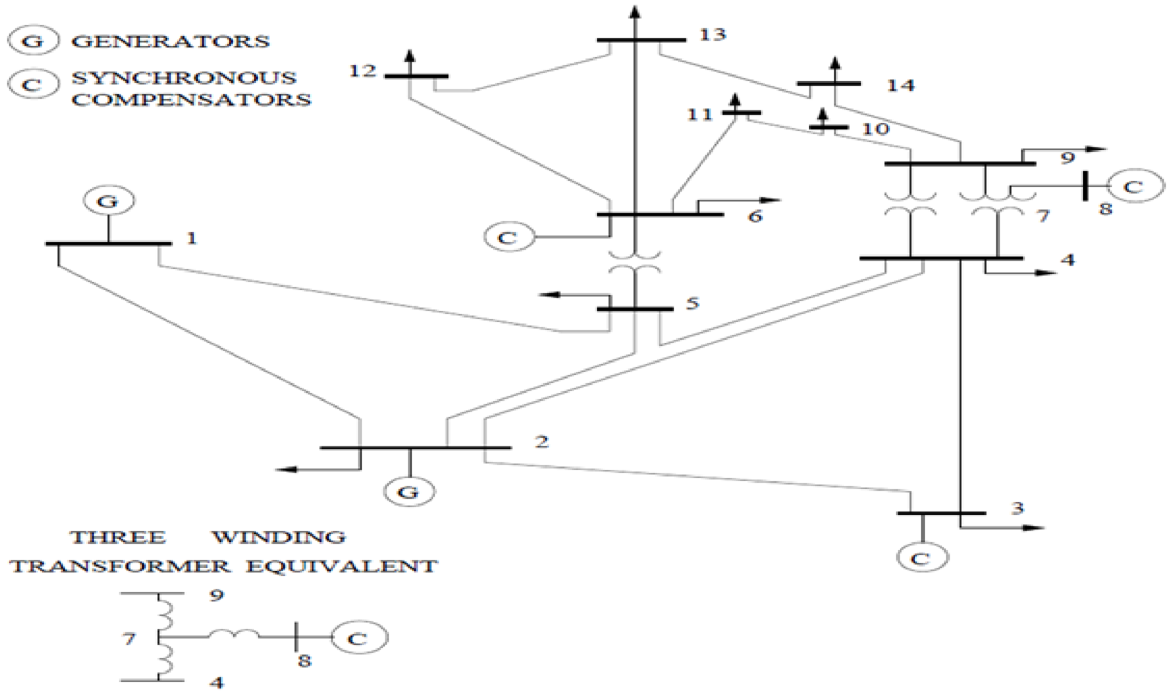

Figure 2.3: Single line diagram for IEEE (14-bus)[9]

2.8.1 Load Flow for IEEE14-bus

Results of power flow of IEEE 14-bus was obtained in steady state operations using MATLAB program (Newton-Raphson method) was shown in appendix (A.1), and power flow at limit state using MATLAB program (Newton-Raphson method) was shown in appendix(A.2).

CAPTER THREE

LOAD FLOW ANALYSIS AND MODELLING

3.1 Introduction

Load flow or power flow is the solution obtained for the power system under static (steady state) conditions of operation , the symmetrical steady state is, In fact the most important mode of operation of a power system three major problems encountered in this mode of operation are listed below in their hierarchical order[2].

1. Load flow problem
2. Optimal Load scheduling problem
3. Systems control problem

Load flow studies are undertaken to determine:

1. The line flows (active & reactive power flow).
2. The bus voltages and system voltage profile.
3. The phase angles of load bus voltages, reactive power at generator bus.
4. The effect of changes in circuit configuration, and incorporating new circuits on system loading.
5. The effect of temporary loss of transmission capacity and/or generation on system loading and accompanied effects.
6. The effect of in-phase and quadrate boost voltages on system loading.
7. Economic system operation.
8. Transformer tap setting for economic operation, and
9. Possible improvements to an existing system by change of conductor sizes and system voltages.

This information is essential for continuous monitoring of the current state of the system and for analyzing the effectiveness of alternative plans for future system expansion to meet increased load demand.

For the purpose of Load flow studies, a single phase representation of the power network is used since the system is generally balanced. When systems had not grown to the present size, networks were simulated on network analyzers for the Load flow studies. These analyzers are of analogue type, scaled down miniature models of power systems with resistances, reactances, capacitances, autotransformers, loads, and generators. The generators are just supply sources operating at a much higher frequency than 50 Hz to limit the size of the components. The generators are provided with voltage magnitude and phase angle controls. The loads are represented by constant impedances. The loads are generally represented by constant powers. In the network at each bus or node there are four variables [2]:

1. Magnitude.
2. Voltage phase angle.
3. Real power.
4. Reactive power.

Out of these four quantities, two of them are specified at each bus and the remaining two are determined from the load flow solution. To supply the real and reactive power losses in lines which will not be known till the end of the power flow solution, a generator bus, called slack or swing bus is selected. At this bus, the generator voltage magnitude and its phase angle are specified so that the unknown power losses are also assigned to this bus in addition to balance of generation if any. Generally, at all other buses, voltage magnitude and real power are specified. At all load buses the real and the reactive load demands are specified. Table 3.1 illustrates the types of buses and the associated known and unknown variables.

Table 3.1 Types of buses and the associated known and unknown variables[8]

Bus	Specified Variables	Computed Variables
Slack-bus	Voltage magnitude and its phase angle	Real and reactive powers
Generator bus(PV-bus or voltage controlled bus)	Magnitude of bus voltages and real powers (limit on reactive powers)	Voltage phase angle and reactive power
Load bus (PQ)	Real and reactive powers	Magnitude of phase angle of bus voltages

- Slack bus: The voltage angle of the slack bus serves as reference for the angles of all other bus voltages, the particular angle assigned to the slack bus voltage is not important because voltage-angle differences determine the calculated values of P_i and Q_i. The usual practice is to set δ_1=0.
- Load buses: At each non-generator bus, called a load bus, both P_{gi} and Q_{gi} are zero and the real power P_{di} and reactive power Q_{di} drawn from the system by the load (negative inputs into the system) are known from historical record, load forecast, or measurement. Quite often in practice only real power is known and the reactive power is then based on an assumed power factor such as 0.85 or higher. A load bus i is often called P-Q bus because the scheduled values $P_{i,sch} = - P_{di}$ and $Q_{i,sch} = - Q_{di}$ are known and mismatches ΔP_i and ΔQ_i can be defined. The corresponding equations are then explicitly included in the statements of the power-flow problem and the two unknown quantities to be determined for the bus are δ_i and $|V_i|$.

- Voltage-controlled buses: Any bus of the system at which the voltage magnitude is kept constant is said to be voltage controlled. At each bus to which there is a generator connected the megawatt generation can be controlled by adjusting the prime mover, and the voltage magnitude can be controlled by adjusting the generator excitation. Therefore, at each generator bus i, we may properly specify P_{gi} and $|V_i|$. With P_{di} also known, we can define mismatch ΔP_i. Generator reactive power Q_{gi} required supporting the scheduled voltage $|V_i|$ can not be known in advance, and so mismatch ΔQ_i is not defined. Therefore, at a generator bus i voltage angle δ_i is the unknown quantity to be determined. After the power flow problem is solved, Q_i can be calculated. For obvious reasons a generator bus is usually called voltage-controlled or PV bus. Certain buses without generators may have voltage control capability; such buses are also designated voltage-buses at which the real power generation is simply zero.

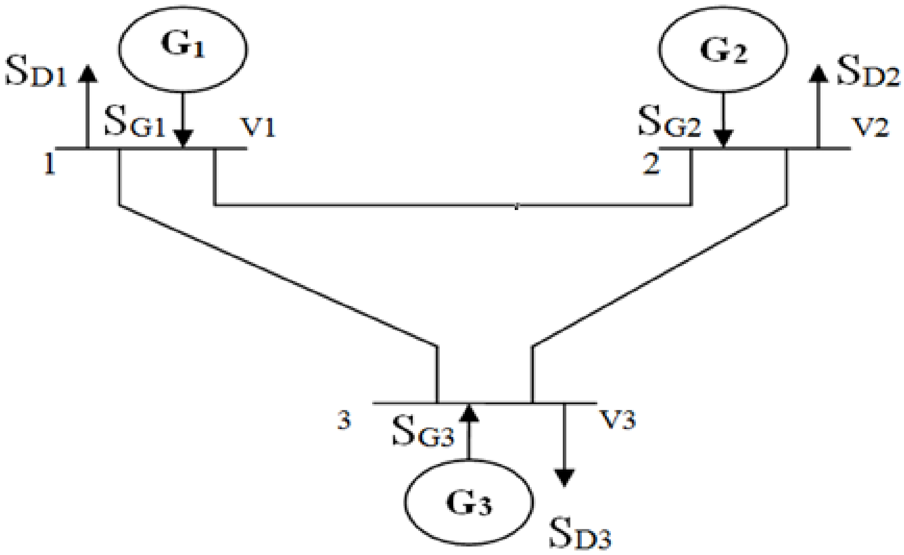

Figure 3.1: Single line diagram for Simple system contain 3-bus[2]

3.2 Modeling for Load Flow Studies

3.2.1 Bus admittance formation

Consider the transmission system shown in figure (1.1). The line impedances joining buses 1, 2, and 3 are denoted by Z_{12}, Z_{23} and Z_{13} respectively. The corresponding line admittances are y_{12}, y_{23} and y_{13}. The total capacitance susceptances at the buses represented by y_{10}, y_{20} and y_{30}. Applying Kirchoff's current law at each bus

$$I_1 = V_1.y_{10} + (V_1 - V_2).y_{12} + (V_1 - V_3).y_{13} \quad (3.1)$$

$$I_2 = V_2.y_{20} + (V_2 - V_1).y_{21} + (V_2 - V_3).y_{23} \quad (3.2)$$

$$I_3 = V_3.y_{30} + (V_3 - V_1).y_{31} + (V_3 - V_2).y_{32} \quad (3.3)$$

In matrix form

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} y_{10} + y_{12} + y_{13} & -y_{12} & -y_{13} \\ -y_{12} & y_{20} + y_{12} + y_{23} & -y_{23} \\ -y_{13} & -y_{23} & y_{30} + y_{13} + y_{23} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (3.4)$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (3.5)$$

Where

$$Y_{11} = y_{10} + y_{12} + y_{13} \quad (3.6)$$

$$Y_{22} = y_{20} + y_{22} + y_{23} \quad (3.7)$$

$$Y_{33} = y_{30} + y_{32} + y_{33} \quad (3.8)$$

Y_{11}, Y_{22} and Y_{33} are the self admittances forming the diagonal terms and $Y_{12}= Y_{21}= -y_{12}$, $Y_{13}= Y_{31}= -y_{13}$, and $Y_{23}= Y_{23}= -y_{23}$ are the mutual admittances forming the off-diagonal elements of the bus admittance matrix. For an n-bus system, the elements of the bus admittance matrix can be written down merely by inspection of the network as Diagonal terms:

$$Y_{ii} = y_{i0} + \sum_{\substack{k=1 \\ k \neq i}}^{n} y_{ik} \tag{3.9}$$

Off-diagonal terms

$$Y_{ik} = -y_{ik} \tag{3.10}$$

If the network elements have the mutual admittance (impedance), the above formulae will not apply. For the system formation of the y- bus, linear graph theory with singular transformations may be used.

3.2.2 System for load flow studies

The variables and parameters associated with bus *i* and a neighboring bus *k* are represented in the usual notation as follows :

$$V_i = |V_i| \exp j\delta_i = V_i(\cos\delta_i + j\sin\delta_i) \tag{3.11}$$

$$Y_{ik} = |Y_{ik}| \exp\ j\theta_{ik} = Y_{ik}(\cos\theta_{ik} + j\sin\theta_{ik}) \tag{3.12}$$

Complex power

$$S_i = P_i + jQ_i = V_i I_i^* \tag{3.13}$$

Using the indices G and L for generation and load,

$$P_i = P_{G_i} - P_{L_i} = \mathrm{Re}[V_i I_i^*] \tag{3.14}$$

$$Q_i = Q_{G_i} - Q_{L_i} = \mathrm{Im}[V_i I_i^*] \tag{3.15}$$

The bus current is given by

$$I_{bus} = Y_{bus}.V_{bus} \tag{3.16}$$

Hence, from the equations (1.3) and (1.4), for an n-bus system:

$$I_i = \frac{P_i - jQ_i}{V_i^*} = Y_{ii}.V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} y_{ik}.V_k \tag{3.17}$$

And from equation (1.7)

$$V_i = \frac{1}{Y_{ii}}[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}.V_k\ ] \tag{3.18}$$

Further,

$$P_i + jQ_i = V_i \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik}.V_k \tag{3.19}$$

In the polar form

$$P_i + jQ_i = \sum_{k=1}^{n} \left|V_i.V_k.Y_{ik}\right| \exp\ j(\delta_i - \delta_k - \theta_{ik}) \tag{3.20}$$

So that

$$P_i = \sum_{k=1}^{n} \left|V_i.V_k.Y_{ik}\right| \cos(\delta_i - \delta_k - \theta_{ik}) \tag{3.21}$$

And

$$Q_i = \sum_{k=1}^{n} \left|V_i.V_k.Y_{ik}\right| \sin(\delta_i - \delta_k - \theta_{ik}) \tag{3.22}$$

$i = 1,2,\ldots,n \quad \& \quad i \neq$ slack bus

The power flow equations (1.11) and (1.12) are nonlinear and it is required to solve 2(n-1) such equations involving $|V_i|$, δ_i, P_i, and Q_i at each bus I for the load flow solution. Finally, the powers at the slack bus may be computed from which the losses and all other line flows can be ascertained. Y-matrix interactive methods are based on solution to power flow relations using either current mismatch at a bus given by

$$\Delta I_i = I_i - \sum_{k=1}^{n} Y_{ik}.V_k \qquad (3.23)$$

or by using the voltage form

$$\Delta V_i = \frac{\Delta I_i}{Y_{ii}} \qquad (3.24)$$

The convergence of the iterative methods depends on the diagonal dominance of the bus admittance matrix. The self- admittances of the buses are usually large, relative to the mutual admittances and thus, usually convergence is obtained. Junctions of very high and low series impedances and large capacitances obtained in cable circuits long EHV lines, series and shunt compensation are detrimental to convergence as these tend to weaken the diagonal dominance in the Y-matrix. The choice of slack bus can affect convergence considerably. In different cases, it is possible to obtain convergence by removing the least diagonally dominant row and column of Y. The salient features of the Y- matrix iterative methods are that the elements in the summation terms in equations (1.7) and (1.8) are on the average only three even for well-developed power systems. The sparsely of the Y-matrix and its symmetry reduces both the storage requirement and the computation time for iteration. For a large, well- conditioned system of n-buses, the number of iterations required are of the order of n and the total computing times varies approximately as n^2. Instead of using equation (1.6), one can select the impedance matrix and rewrite the equation as

$$V = Y^{-1}.I = Z.I \qquad (3.25)$$

The Z-matrix method is not usually very sensitive to the choice of the slack bus. It can easily be verified that the Z-matrix is not sparse. For problems that can be solved by both Z-matrix and Y-matrix methods, the former are rarely competitive with the Y-matrix methods.

3.3 Power Flow Solutions Method

3.3.1 Gauss-Seidel method

In this method, voltages at all buses except at the slack bus are assumed. The voltage at the slack bus is specified and remains fixed at that value. The (n-1) bus voltage relations

$$V_i^{(K+1)} = \frac{\dfrac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} + \sum y_{ij} V_j^{(k)}}{\sum y_{ij}} \quad j \neq i \tag{3.26}$$

These equations are solved simultaneously for an improved solution. In order to accelerate the convergence, all newly-computed values of bus voltages are substituted in equation (3.26). The bus voltage equation for the (k+1)th iteration may then be written as:

$$V_i^{(k+1)} = \frac{\dfrac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} - \sum_{j \neq i} Y_{ij} V_j^{(k)}}{Y_{ij}} \tag{3.27}$$

For load buses where real and reactive powers are following away from the bus P_i^{sch} and Q_i^{sch} have negative values. if(3.17) is solved for P_i and Q_i we have

$$P_i^{(K+1)} = R\{V_i^{*(k)} [V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=0}^{n} y_{ij} V_j^{k}]\} \quad j \neq i \tag{3.28}$$

$$Q_i^{(K+1)} = -J\{V_i^{*(k)} [V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=0}^{n} y_{ij} V_j^{k}]\} \quad j \neq I \tag{3.29}$$

The power flow equation is usually expressed in of the elemenats of the bus admittance matrix .since the off-diagonal elements of the admittance matrix Y_{bus},shown by suppercase letters are $Y_{ij} = -y_{ij}$ the diagonal elements are $Y_{ii=} \sum y_{ij}$ (3.27) becomes

$$V_i^{(K+1)} = \frac{\frac{P_i^{sch} - Q_i^{sch}}{V_i^{*(K)}} - \sum_{j=1}^{n} Y_{ij} V_j^k}{Y_{ii}} \quad (3.30)$$

And

$$p_i^{(K+1)} = R\{V_i^{*(k)} [V_i^{(k)} y_{ii} + \sum_{\substack{j=0 \\ j \neq i}}^{n} Y_{ij} V_j^k]\} \quad j \neq i \quad (3.31)$$

$$Q_i^{(K+1)} = -I\{V_i^{*(k)} [V_i^{(k)} y_{ii} + \sum_{\substack{j=0 \\ j \neq i}}^{n} Y_{ij} V_j^k]\} \quad j \neq i \quad (3.32)$$

For P-Q buses, the real and reactive power P_{is}^{ch} and Q_i^{sch} are known .starting with an initial estimate as equation (3.30).is solved for the real and imaginary components of voltage .for PV-Bus where P_i^{sch} and $|V_i|$ are specified first (3.32), is solved for $Q^{(k+1)}$ and then is used in(3.30) to solver for $V_i^{(K+1)}$.however since $\lfloor V_i \rfloor$ is specified only the imaginary part of $V_i^{(K+1)}$ is retained and its real part is selected in order to satisfy

$$(e_i^{(k+1)})^2 + (f_i^{(k+1)})^2 = \lfloor V_i \rfloor^2 \quad (3.33)$$

$$\left(e_i^{(k+1)}\right) = \sqrt{\lfloor V_i \rfloor^2 - (f_i^{(k+1)})^2} \quad (3.34)$$

Where $\left(e_i^{(k+1)}\right)$and $(f_i^{(k+1)})$are the real and imaginary components of the voltage $V_i^{(k+1)}$ in the iterative sequence.

The rate of convergence is increased by applying acceleration factor to the approximate solution obtained from each iteration.

$$V_i^{(k+1)} = V_i^{(k)} + \propto (V_{i\,cal}^{(k)} - V_i^{(k)}) \quad (3.35)$$

Where ∝ is the acceleration factor. Its value depends on upon the range of 1.3 To 1.7 is found to be satisfactory for typical systems.

The update voltage immediately replace the previous values in the solution of the subsequent equations. The process is continued until change in the real and imaginary components of the bus voltages between successive iteration are with in a specified accuracy i.e.,

$$\left|e_i^{(k+1)} - e_i^{(k)}\right| \leq \epsilon \quad (3.36)$$

$$\left|f_i^{(k+1)} - f_i^{(k)}\right| \leq \epsilon \quad (3.37)$$

3.3.2 Newton –Raphson method

The most widely used power flow solution employs Newton-Raphson technique. Because of its quadratic convergence, Newton's method is mathematically superior to the Gauss-seidel method and is less prone to divergence with ill-conditioned problems. For large power systems, the Newton-Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required for each iteration[8]. Since in the power flow problem real power and voltage magnitude are specified for the voltage-controlled buses, the power now equation is formulated in polar form. For the typical bus of the power, the equation can be written in terms of the bus admittance matrix as;

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad (3.38)$$

In the above equation, j includes bus i. Expressing this equation in polar form, we have;

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j < -\delta_{ij} + \delta_j \quad (3.39)$$

The complex power at bus i is;

$$P_i - JQ_i = V_i^{*} I_i \quad (3.40)$$

Substituting from (2) for I_i in (3)

$$P_i - Q_i = |V_i| < -\delta \sum_{j=1}^{n} |Y_{ij}| \, |V_j| < \theta_{ij} + \delta_j \tag{3.41}$$

Sepreating the real and imaginary parts:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.42}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.43}$$

Equations (3.42) and (3.43) constitute a set of nonlinear algebraic equations in terms of the independent variables, voltage magnitude in per unit, and phase angle in radians. We have two equations for each load bus, given by (3.42) and (3.43), and one equation for each voltage-controlled bus, given by (3.42). Expanding (3.42) and (3.43) in Taylor's series about the initial estimate and neglecting all higher order terms results in the following set of linear equations [8]

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \vdots \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdot\cdot & \frac{P_2^{(k)}}{\partial \delta_n} & \cdots\cdot & \frac{\partial P_2^{(k)}}{\partial |v_2|} & \cdot\cdot & \frac{\partial P_2^{(k)}}{\partial |v_n|} \\ \vdots & & \vdots & \vdots & \vdots & \vdots & \\ \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdot\cdot & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \cdot\cdot & \frac{\partial P_n^{(k)}}{\partial |v_2|} & \cdot\cdot & \frac{\partial P_2^{(k)}}{\partial |v_n|} \\ \vdots & & \vdots & & \vdots & & \vdots \\ \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdot\cdot & \frac{\partial Q^{(K)}{}_2}{\partial \delta_n} & \cdot\cdot & \frac{\partial Q_n^{(k)}}{\partial |v_2|} & \cdot\cdot & \frac{\partial Q_2^{(k)}}{\partial |v_n|} \\ \vdots & & \vdots & & \vdots & & \vdots \\ \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdot\cdot & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \cdot\cdot & \frac{\partial Q_n^{(k)}}{\partial |v_2|} & \cdot\cdot & \frac{\partial Q_n^{(k)}}{\partial |v_n|} \end{bmatrix} \begin{bmatrix} \Delta \delta_{2_1}^{(k)} \\ \vdots \\ \Delta \delta_{n_1}^{(k)} \\ \\ \Delta |v_2^{(k)}| \\ \\ \Delta |v_n^{(k)}| \end{bmatrix} \tag{3.44}$$

In the above equation, bus 1 is assumed to be the slack bus. The Jacobian matrix gives the linear relationship between small changes in voltage angle $\Delta\delta^{(k)}_i$ and voltage magnitude $\Delta\left|V_i^{(k)}\right|$ with the small changes in real and reactive power $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$.

Elements of the Jacobian matrix are the partial derivatives of (3.42) and (3.43) evaluated at $\Delta\delta^{(k)}_i$ and $\Delta\left|V_i^{(k)}\right|$ .In short form, it can be written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{3.45}$$

The diagonal and the off-diagonal elements of J_1 are:

$$\frac{\partial \mathrm{P_i}}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.46}$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \tag{3.47}$$

The diagonal and the off-diagonal elements of J_2 are:

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}| \cos\theta_{ii} + \sum_{j \neq i} |V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j). \tag{3.47}$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad j \neq i \tag{3.48}$$

The diagonal and the off-diagonal elements of J_3 are:

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq i} |V_i| |V_j||Y_{ij}| \cos(\theta_{ij} - \delta_{i+} \delta_j \tag{3.49}$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_{i+} \delta_j) \quad j \neq i \tag{3.50}$$

The diagonal and the off-diagonal elements of J_4 are:

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}| \sin(\theta_{ii}) - \sum_{j \neq i} |V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.51}$$

$$\frac{\partial Q_i}{\partial |V_j|} = -|V_j||Y_{ij}| \sin(\theta_{ij} - \delta_{ij} + \delta_j) \qquad j \neq i \tag{3.52}$$

The terms $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the difference between the scheduled and calculated values, known as the power residuals, given by

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \tag{3.53}$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \tag{3.54}$$

The new estimates for bus voltage are:

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{3.55}$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k}\right| + \Delta\left|V_i^{(k)}\right| \tag{3.56}$$

Procedures [8]:

1. For Load buses (P,Q specified), flat voltage start. For voltage controlled buses (P,V specified),δ set equal to 0.
2. For Load buses, $P_i^{(k)}$ and $Q_i^{(k)}$ are calculated from Eqns.(3.42) and (3.43) and $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are calculated from Eqns. (3.53) & (3.54).
3. For voltage controlled buses, and $P_i^{(k)}$ and $\Delta P_i^{(k)}$ are calculated from Eqns. (3.42) & (3.43) respectively.
4. The elements of the Jacobian matrix are calculated.
5. The linear simultaneous equation (3.45) is solved directly by optimally ordered triangle factorization and Gaussian elimination.
6. The new voltage magnitudes and phase angles are computed from (3.55) and (3.56).
7. The process is continued until the residuals $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are less than the specified accuracy:

$$\left|\mathrm{P}_\mathrm{i}^{(\mathrm{k})}\right| \leq \epsilon \tag{3.57}$$

$$\left|Q_i^{(k)}\right| \leq \epsilon \tag{3.58}$$

3.4 Power Flow Programs

A program named load flow (lfnewton) is developed for power flow solution by the Newton-Raphson method for practical power system. This program must be preceded by the lfybus program. busout and lineflow program can be used to print the load flow solution and the line flow results[8].

3.4.1Data preparation

In order to perform a power flow analysis by the Newton-Raphson method in the MATLAB environment, the following variables must be defined power system base MVA, power mismatch accuracy, acceleration factor, and maximum number of iterations. The name (in lowercase letters) reserved for these variables are base Mega Volte Ampere (MVA), accuracy and maximum iterations, respectively.

The initial step in the preparation of input file is numbers of each bus, buses are numbered sequentially. Although the numbers are sequentially assigned, the buses need not be entered in sequence. in addition, the following data files are required:

1. Bus Data File: busdata the format for the bus entry is chosen to facilitate the required data for each bus in a single row. The information required must be included in a matrix called bus data. Column 1 is the bus number. Column 2 contains the bus code. Columns 3 and 4 are voltage magnitude in Per Unit (P.U) and phase angle in degrees. Column 5 and 6 are load Mega Watt (MW) and Mega Volte ampere (Mvar). column 7 through 10 are MW , Mvar minimum (Qmin) and maximum Mvar (Qmax) of generation (Gen) , in that order the last column is the injected Mvar of shunt capacitors.
2. Line Data File: are identified by the node-pair method. the information required must be included in a matrix called line data .column 2 are the line bus number .column 3 through 5 contain the line

resistance ,reactance ,and one –half of the total line charging susceptance (B) in per unit on the specified MVA base . the last column is for the transformer tap setting ,for lines ,1 must be entered in this column . the lines may be entered in any sequence or order with the only restriction being that if the entry is a transformer , the left bus number is assumed to be the tap side of the transformer[8].

3.5 Generator Representation

In order to represent each power plant by one equivalent generator, the capacity of the equivalent generator is the sum of all individual generator capacities, and the actual active power generated by the equivalent generator is the some of the individual generator outputs [10] as shown in appendix ((B), table (1)) and the new parameters are based on a common base (100 MVA) .

3.6 Transmission Line & Transformer Representation

A line is represented by its (Π) equivalent circuit with series resistance and inductive reactance and one half of the parallel capacitive reactance at each of the two ends. A double circuited line is represented by its parallel equivalent, that is their resistances and reactances are considered in parallel as shown in appendix ((B), table (2)). Charging capacitances of each circuit is added and the current capacity is the summation of the two circuit's capacities. Transformer equivalents are obtained in the same manner. In case of two or more transformers operate in parallel treatment is as for parallel lines [10].

3.7 Load Representation

The load is represented in load flow analysis by separately considering the active power and the reactive power. Load is generally represented by constant power elements [10]. as shown in appendix ((B), table (1)).

3.8 Case Study

In this project the case study is the simplified National grid of Sudan (82 bus-bars). The lines ohmic per unit length data and transformer data are obtained and then converted and expressed in per unit representation. Bus data which represent power generation P_{Gi} and load P_{li}, Q_{li} as shown in appendix ((B), table (1)) of the transmission network are obtained.

3.8.1 Simplified Sudan Grid (82 Bus)

The real network of Sudanese electrical power grid was chosen as a test power network. This regional network can be assumed as the typical for the whole country's network in terms of its design and existing problems. The simplified one line diagram of the network is given at figure 3.2. The network has the following characteristics:

1- Number of busses (82)
2- Number of lines (81)
3- Power plants (8)
4- Loads (53)
5- Shunts (10)
6- Transformers (15)

This network include four voltage levels: a 500, 220, 110 and 66 kV Which forms the main part of the transmission system in the Sudanese Electrical network, the power generated in the Sudan comes from seven Power plants, Merowe which represent the slack bus bar, Garri, Roseires, Khartoum North, Rabak, Sennar , and Girba, and one tie line feeder from Ethiopia.

Transmission line charge supplies the network by a proper amount of Reactive power due to the long length of lines which totaling 5469.735 km Length.

This data is taken at normal load condition, the total loading level of the System is 1553.3 MW and 1083.3 MVAr, and the total power generated is 1603.517 MW, 227.008 MVAr. Network data is shown at appendix B

3.8.2 Data survey for simplified Sudan grid (82- bus)

Data of the network of the national grid are obtained from the National grid control center and it covered all of the following items:

Transmission lines types and parameters as series resistances, series reactance's and charging capacitances per unit length and lines total length in kilometers.

Number of circuits of transmission lines and its current capacity limited by circuit breakers and relays settings.

Number of transformers and its data.

Generation unit’s maximum output powers and its VAR limits.

Last modifications on the system configuration.

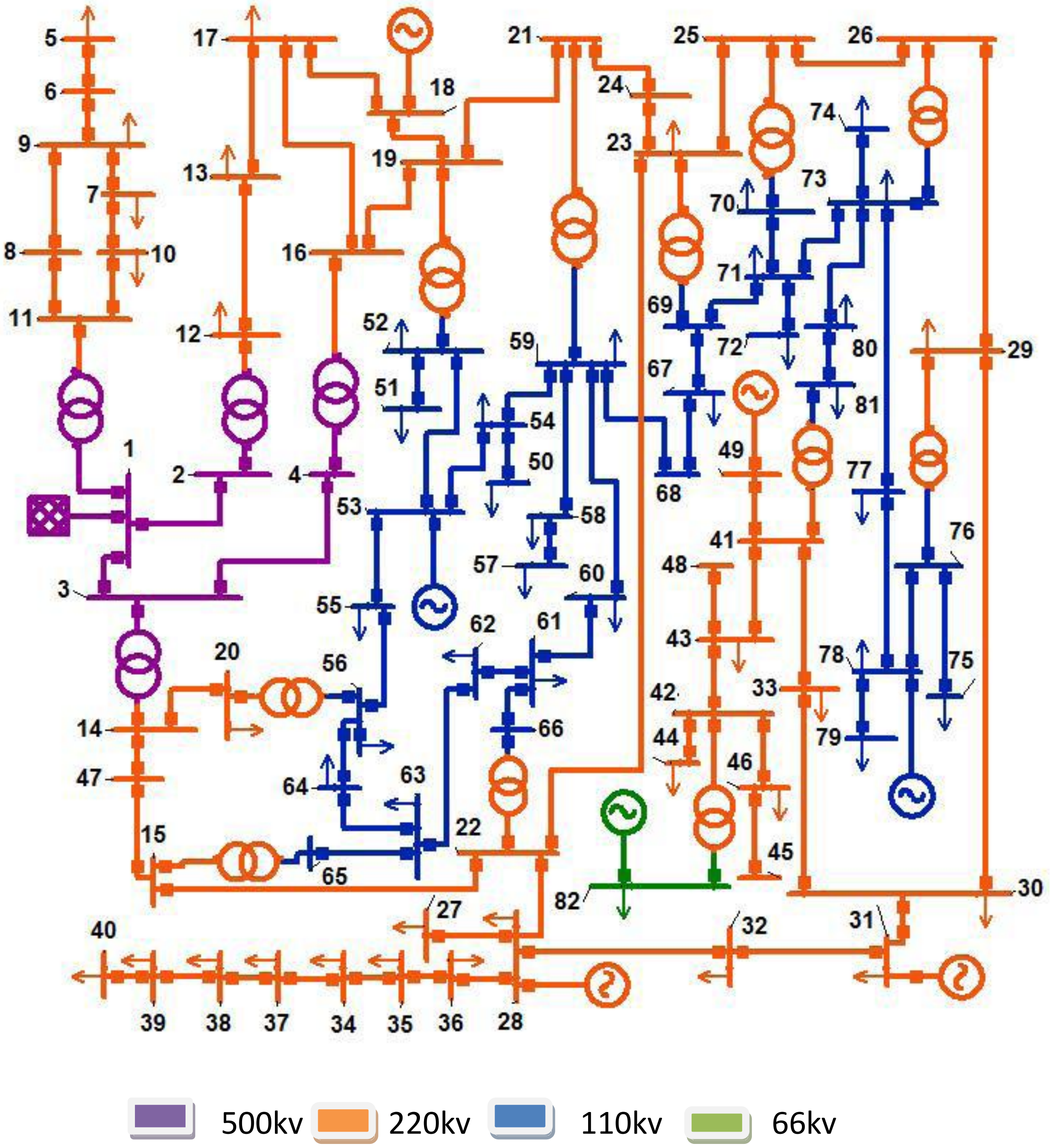

Figure 3.2: Single line diagram for simplified Sudan grid

3.8.3 Load flow for simplified Sudan grid

Line data and bus data for simplified Sudan and program (using Newton-Raphson) for load flow shown in appendix (B). Program used for simplified Sudan grid limit are shown in appendix

CHAPTER FOUR

RESULT DISCUSSION

4.1 Applying VCI on IEEE 14-bus

Single line diagram for IEEE 14-bus shown in Figure (2.3) load flow in steady state and limit operation using program in appendix (A.1) and (A.2) respectively VCI result on this is network shown below.

Table 4.1: VCI Result of IEEE 14-bus

Busbar	VCI %
14	113.1959
9	90.7609
10	87.3214
7	44.0217
11	38.7648
4	32.9412
5	31.9948
13	27.2727
12	17.8771
3	5.2083
2	5.0251
6	4.902
8	4.8077
1	0

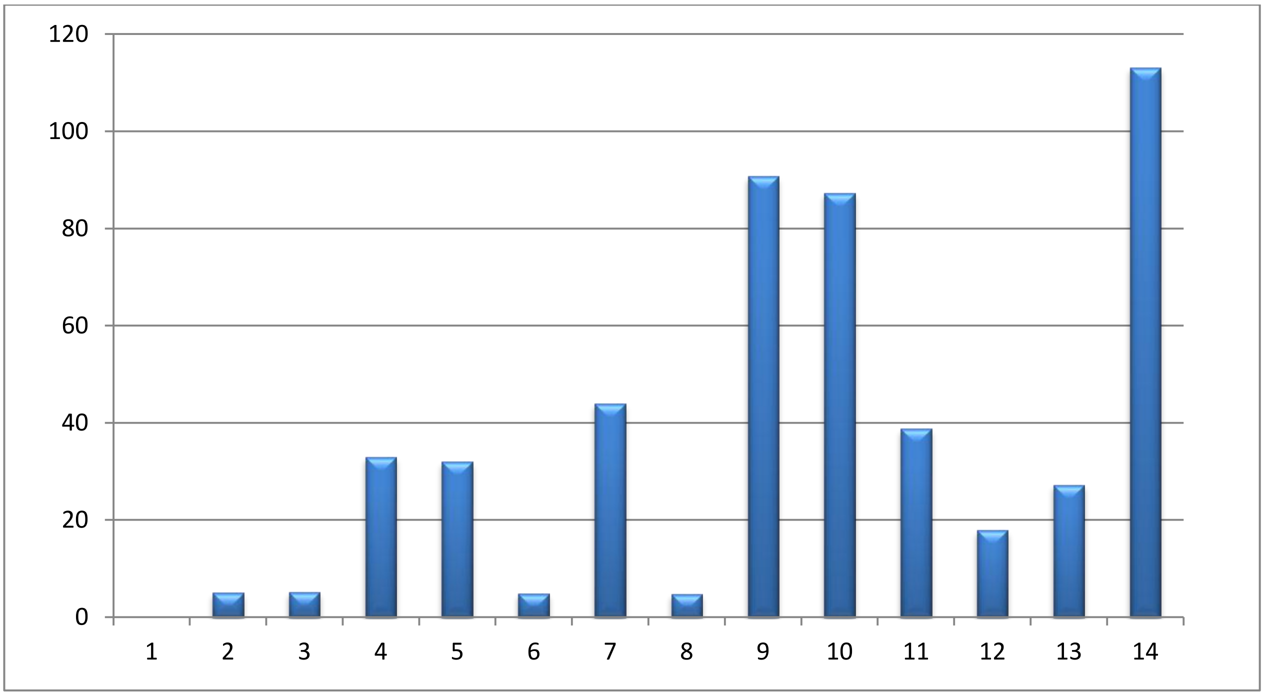

Figure 4.1: VCI Result of IEEE 14-bus

Applying VCI and ranking on IEEE 14-bus give a result that a agree with previous studies [11] has being carried out on this test system to identify weakest bus using another indices and this ensure the validity of using VCI.

4.2 Applying VCI on simplified Sudan grid

Single line diagram for simplified Sudan grid shown in Figure (3.2) load flow in steady state and limit operation using program in appendix (B) respectively VCI result on this is network shown below.

Table 4.2: VCI Result of simplified sudan grid

Bus name	Bus number	VCI %
BAGAIR 1	67	7.5269
GIAD B2	69	7.0664
FAROUG 1	57	6.72
SOBA 1 B2	68	5.8201
AFRA 1	58	5.82
ATBARA 2	12	5.59
MINA ALSHAREF 1	79	5.4852
LOCAL MARKET 1	60	5.042
KILO X 1	59	5.04
SHAGRA 1	61	4.2752
MUGRAN	62	3.9501

BANAT 1	63	3.5197
OMDURMAN 1	64	3.4126
IZBA 1	51	3.3
NEW HASAHESA 2	25	3.19
MARINJAN 2	26	2.98
IED BABIKER 1	52	2.56
MAHDIA 1	56	2.46
SHANDI 2	13	2.04
IZERGAB 1	55	1.83
KHARTOUM EAST 1	50	1.62
KUKU 1	54	1.42
GAMOEIA 1	65	1.2146
SENNAR JUNCTION 2	29	1.21
JABEL AWLIA STATION 2	22	1.11
GIAD 2	23	1.01
GAMOEIA 2	15	0.7
KABASHI 2	16	0.5
SOBA 2	24	0.4
KILO X 2	21	0.3
MASHKOUR 2	27	0.2
FREE ZONE 2	17	0.1
IED BABIKER 2	19	0.1
MARWI POWER PLANT 500	1	0
GERBA 2	18	0
RABAK 2	28	0
ROSSERIES 2	31	0
SHIHID 2	49	0
KHARTOUM NORTH 1	53	0
SENNAR POWER PLANT 1	78	0
GRBA 6	82	0
GADAREF 2	41	-0.1186
SENGA 2	30	-0.2991
GRBA 2	42	-0.3984
NHLF 2	44	-0.3984
MAHDIA 2	20	-0.5964
JABEL AWLLA STATION 1	66	-0.5964
HUD	47	-0.6951
FAOW 1	80	-0.6951
RANK 2	32	-0.7936
KASALA 2	46	-0.9900
MRKHIAT 2	14	-1.0880
SHOWAK 2	43	-1.0880
ARM 2	45	-1.0880

HAG ABDALLAH 1	77	-1.0880
UTP 2	48	-1.1856
HAWATA 2	33	-1.1858
OLD RABK 1	75	-1.2833
SENNAR JUNCTION 1	76	-1.2833
TANDALTY 2	36	-1.3807
UM RWABA 2	35	-1.6716
MANAGEL 1	74	-1.6716
MRKHIAT 5	3	-2.2483
OBIED 2	34	-2.3437
KABASHI 5	4	-2.6290
GADAREF 1	81	-2.6290
MARINJAN 1	73	-2.7237
ATBARA 5	2	-3.0068
GENAD 1	72	-3.3816
DBT 2	37	-3.5679
OHAS 1	71	-3.6609
MARWI TOWN 2	10	-3.9385
NEW HASAHESA 1	70	-3.9385
ZBD 2	38	-4.1227
MARWI POWER PLANT 2	11	-4.2145
DEBA-B1	7	-4.3977
FULA 2	39	-5.3030
BBN 2	40	-5.4820
DONGOLA 2	9	-6.0150
DEBA-B2	8	-6.3670
WAWA 2	6	-7.4931
WADI HALFA 2	5	-8.4249

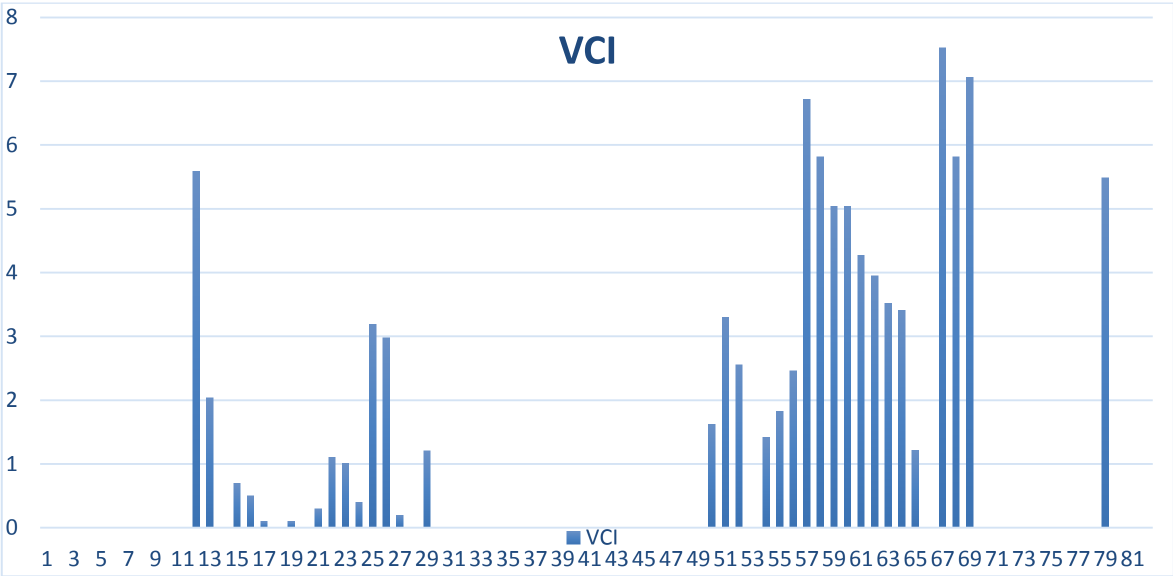

Figure 4.2: VCI Result of simplified Sudan grid

After successive applying for VCI for IEEE 14-bus benchmark the result show that the ranking of buses from weakest to strongest is agree with result was attained from anther indices that was applied on this electrical power system and this ensure the validity of using this index ,when it is apply to any system.

Appling VCI on simplified Sudan grid (table(4.2)) has show that the weakest buses in this network are locate in middle -Sudan area and specially in Khartoum (head of table(4.2)) where heavy load in residential and industrial sector are presented ;heavy load in these buses result in a big absorption of reactive power and this will result in acute shortage in reactive power in this buses and it’s strong co-relation with voltage in this buses(when reactive power absorption increase voltage magnitude decrease) .

Acute shortage in reactive power is coming from reduction of generation unit in Khartoum area that must be meet this big demand in reactive power ,this will make these buses depend on reactive coming from very far generation units (MARWI power plant 13.8KV , ROSSERIES 11KV and SENNAR power plant11KV) , long distance between these generation units location and these buses (it’s hundred of Km) will aggravated the problem (will increase the set of weakest buses) because the connection between these buses and the generation units location is complete through reactance network and it’s has bad direct effect on reactive power flow from these units and the set of weakest buses.

VCI and ranking result in table (4.2) also show that the set of strongest buses are coming in tail of table (4.2) this is because; these buses are generation units or buses that absorb small amount of reactive power and locate near generation units.

CHAPTER FIVE

CONCULOSION AND RECOMMANDATION

5.1 Conclusion

VCI and ranking result of simplified Sudan grid has been show that the structure architecture of this grid has set of weak and strong buses (from point view of voltage stability),weakness of weak buses coming from heavy load in these buses in addition to her location away from generation units (main source of reactive power for the network),these buses are locate in Khartoum area (for example BAGAIR 1 , GIAD B2 , FAROUG 1 , AFRA 1 SOBA 1 B2).

Strong buses (from point view of voltage stability) are always generator units buses (MARWI POWER PLANT 2, DEBA-B1, DONGOLA 2 , DEBA-B2 And WADI HALFA 2) or load buses locate near generation or have small reactive power load.

5.2 Recommendation

1- Expanding the work to make it involves all Sudan National grid.

2-Increase the generation unit in Khartoum area to enhance reactive power demand in the system; because the most of weak buses are locate in Khartoum area.

3- Using reactive power support devices compensator directly in this buses for local compensate in this buses.

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APPENDIX (A)

IEEE 14-BUS DATA AND MATLAB PROGRAMS

APPENDIX (A.1)

Table1: IEEE 14-bus data [3]

Bus no	Cod Bus	Volt. Mag	Ang. Deg	MW Load	Mvar Load	MW Gen.	Mvar Gen.	Q-Gen	Q+ Gen.	INJ Mvar
1	1	1.06	0	0	0	0	0	0	0	0
2	2	1.045	0	21.7	0	40	-42.4	-40	50	0
3	2	1.01	0	94.2	19	0	0	0	40	0
4	0	1	0	47.8	0	0	0	0	0	0
5	0	1	0	7.6	1.6	0	0	0	0	0
6	2	1.07	0	11.2	7.5	0	0	-6	24	0
7	0	1	0	0	0	0	0	0	0	0
8	2	1.09	0	1.09	0	0	0	-6	24	0
9	0	1	0	29.5	16.6	0	0	0	0	19
10	0	1	0	9	5.8	0	0	0	0	0
11	0	1	0	3.5	1.8	0	0	0	0	0
12	0	1	0	6.1	1.6	0	0	0	0	0
13	0	1	0	13.5	5.8	0	0	0	0	0
14	0	1	0	14.9	5	0	0	0	0	0

(1) Slack bus (0) load bus (2) voltage controlled bus

Table 2: IEEE 14-line data [3]

From Bus	To Bus	Resistance (P.U)	Reactance (P.U)	½ Susceptance (P.U)	TAP setting (pu)
1	2	0.01938	0.05917	0.02640	1
2	3	0.04699	0.19797	0.02190	1
2	4	0.05811	0.17632	0.01870	1
1	5	0.05403	0.22304	0.02460	1
2	5	0.05695	0.17388	0.01700	1
3	4	0.06701	0.17103	0.01730	1
4	5	0.01335	0.04211	0.0064	1
5	6	0.0	0.25202	0.0	0.932
4	7	0.0	0.20912	0.0	0.978
7	8	0.0	0.17615	0.0	1
4	9	0.0	0.55618	0.0	0.969
7	9	0.0	0.11001	0.0	1
9	10	0.03181	0.08450	0.0	1
6	11	0.09498	0.19890	0.0	1
6	12	0.12291	0.25581	0.0	1
6	13	0.06615	0.13027	0.0	1
9	14	0.12711	0.27038	0.0	1
10	11	0.08205	0.19207	0.0	1
12	13	0.22092	0.19988	0.0	1
13	14	0.17093	0.34802	0.0	1

APPENDIX (A.2)

Program for power flow steady state solution for IEEE 14-bus (using Newton-Raphson MATLAB algorithms)

```
basemva=100;accuracy=.001; maxiter=22;
%       Bus Bus  vol   deg  -----LOAD----   ----GENERATOR----  INJ
%       NO  cod  MAg   ang  MW      Mvar    Mw   Mvar  Q-   Q+  Mvar
busdata=[1   1   1.06   0   0       0       0     0    0    0   0
         2   2   1.045  0   21.7    0       40  -42.4 -40   50  0
         3   2   1.01   0   94.2    19      0     0    0    40  0
         4   0   1      0   47.8    0       0     0    0    0   0
         5   0   1      0   7.6     1.6     0     0    0    0   0
         6   2   1.07   0   11.2   7.5      0     0   -6    24  0
         7   0   1      0   0       0       0     0    0    0   0
         8   2   1.09   0   0       0       0     0   -6    24  0
         9   0   1      0   29.5    16.6    0     0    0    0   19
         10  0   1      0   9       5.8     0     0    0    0   0
         11  0   1      0   3.5     1.8     0     0    0    0   0
         12  0   1      0   6.1      1.6    0     0    0    0   0
         13  0   1      0   13.5    5.8     0     0    0    0   0
         14  0   1      0   14.9     5      0     0    0    0   0];
 %        From     To      R           X          (½)B       Tap
 %        Bus      Bus    (pu)        (pu)        (pu)      setting
 linedata=[1       2     0.01938     0.05917     0.02640    1
           2       3     0.04699     0.19797     0.0219     1
           2       4     0.05811     0.17632     0.0187     1
           1       5     0.05403     0.22304     0.0246     1
           2       5     0.05695     0.17388     0.017      1
           3       4     0.06701     0.17103     0.0173     1
           4       5     0.01335     0.04211    0.0064      1
           5       6     0           0.25202     0         0.932
           4       7     0           0.20912     0         0.978
           7       8     0          0.17615      0          1
           4       9     0          0.55618      0          0.969
           7       9     0          0.11001      0          1
           9       10    0.03181     0.0845      0           1
           6       11    0.09498     0.1989      0          1
           6       12    0.12291     0.25581     0          1
           6       13    0.06615     0.13027     0          1
           9       14    0.12711     0.27038     0          1
           10      11    0.08205     0.19207     0          1
           12      13    0.22092     0.19988     0          1
           13      14      0.17093    0.34802     0         1];
      lfybus
      lfnewton
      busout
      lineflow
```

APPENDIX (B)

Simplified SUDAN GRID DATA AND MATLAB PROGRAMS

APPENDIX (B.1)

Table1: simplified Sudan grid bus data

Bus	bus	Pg	Qg	Pd	Qd	Q min	Q max	Base	INJ
No	Name	MW	MVAr	MW	MVAr	MVAr	MVAr	KV	MVAr
1	MWP500	0	0	0	0	125	0	500	0
2	ATB5	0	0	0	0	125	0	500	0
3	MRK5	0	0	0	0	250	0	500	0
4	KAB5	0	0	0	0		0	500	0
5	WHL2	0	0	14.36	11.483	30	0	220	0
6	WWA2	0	0	0	0	40	0	220	0
7	DEB2-B1	0	0	33.456	23.961	0	0	220	0
8	DEB2-B2	0	0	0	0	0	0	220	0
9	DON2	0	0	50.32	46.148	0	0	220	0
10	MWT2	0	0	29.808	20.496	0	0	220	0
11	MWP2	0	0	0	0	0	0	220	0
12	ATB2	0	0	101.338	70.734	0	0	220	0
13	SHN2	0	0	33.264	20.615	0	0	220	0
14	MRK2	0	0	0	0	0	0	220	0
15	GAM2	0	0	0	0	0	0	220	0
16	KAB2	0	0	0	0	0	0	220	0
17	FRZ2	0	0	13.574	8.661	0	0	220	0
18	GER2	186	0	0	0	0	0	220	0
19	IBA2	0	0	0	0	0	0	220	0
20	MHD2	0	0	60.883	37.732	0	0	220	0
21	KLX2	0	0	0	0	0	0	220	0
22	JAS2	0	0	0	0	0	0	220	0
23	GAD2	0	0	14.112	8.746	0	0	220	0
24	SOB2	0	0	0	0	0	0	220	0
25	NHAS2	0	0	0	0	0	0	220	0
26	MAR2	0	0	0	0	0	0	220	0

27	MSH2	0	0	6.989	25.534	0	0	220	0
28	RBK2	85	0	46.704	32.357	0	0	220	0
29	SNJ2	0	0	16.464	8.842	0	0	220	0
30	SNG2	0	0	12.029	5.585	0	0	220	0
31	ROS2	148	0	8.333	5.76	15	0	220	0
32	RNK2	0	0	0.403	22.385	0	0	220	0
33	HWT2	0	0	1.546	0.958	0	0	220	0
34	OBD2	0	0	19.757	31.778	0	0	220	0
35	UMR2	0	0	3.629	25.117	0	0	220	0
36	TND2	0	0	1.008	5.56	0	0	220	0
37	DBT2	0	0	6.25	3.939	0	0	220	0
38	ZBD2	0	0	3.36	23.764	0	0	220	0
39	FUL2	0	0	6.72	4.568	15	0	220	0
40	BBN2	0	0	3.36	2.503	0	0	220	0
41	GDF2	0	0	0	0	30	0	220	0
42	GRB2	0	0	0	0	0	0	220	0
43	SHK2	0	0	0.672	12.515	0	0	220	0
44	NHLF2	0	0	12.029	8.021	0	0	220	0
45	ARM2	0	0	0	0	0	0	220	0
46	KSL2	0	0	16.666	10.678	0	0	220	0
47	HUD	0	0	0	0	0	0	220	0
48	UTP2	0	0	0	0	0	0	220	0
49	SHD2	38	0	0	0	30	0	220	0
50	KHE1	0	0	81.917	53.127	0	0	110	0
51	IZBA1	0	0	68.006	39.992	0	0	110	0
52	IBA1	0	0	41.328	17.854	0	0	110	0
53	KHN1	76	0	0	0	0	0	110	0
54	KUK1	0	0	44.621	20.718	0	0	110	0
55	IZG1	0	0	74.189	46.562	0	0	110	0
56	MHD1	0	0	12.634	8.128	0	15	110	0
57	FAR1	0	0	50.266	33.255	0	0	110	0
58	AFR1	0	0	17.203	8.477	0	0	110	0
59	KLX1	0	0	40.387	18.165	0	0	110	0
60	LOM1	0	0	85.344	58.018	0	0	110	0
61	SHG1	0	0	64.915	40.06	0	0	110	0
62	MUG	0	0	75.466	42.566	0	0	110	0
63	BNT1	0	0	59.069	30.588	0	0	110	0
64	OMD1	0	0	81.312	54.43	0	0	110	0
65	GAM1	0	0	0	0	000	0	110	0
66	JAS1	0	0	0	0	0	0	110	0
67	BAG1	0	0	36.49	24.236	0	0	110	0

68	SOB1 B2	0	0	0	0	0	0	110	0
69	GAD B2	0	0	0	0	0	0	110	0
70	NHAS1	0	0	24.73	12.738	0	0	110	0
71	OHAS1	0	0	11.088	5.864	0	0	110	0
72	GND1	0	0	27.73	14.253	0	0	110	0
73	MAR1 B1	0	0	56.717	26.986	0	0	110	0
74	MAN1	0	0	10.886	4.058	0	0	110	0
75	ORBK1	0	0	0.336	1.476	0	0	110	0
76	SNJ 1	0	0	0	0	0	0	110	0
77	HAG1	0	0	7.594	4.037	0	0	110	0
78	SNP1	7	0	4.704	2.238	0	0	110	0
79	MIN1	0	0	14.381	9.552	0	0	110	0
80	FAO1	0	0	11.021	6.539	0	0	110	0
81	GDF1	0	0	18.614	12.315	0	0	110	0
82	GRB6	2	0	15.254	8.604	0	0	66	0

Table 2: simplified Sudan grid line data

Line NO.	From Bus	TO Bus	R(pu)	Xl(pu)	(pu)	tap setting
1	67	69	0.086281	0.10438	0.00004905	1
2	6	5	0.283781	1.279132	0.02035	1
3	11	10	0.054252	0.287679	0.00237	1
4	9	7	0.218861	1.16054	0.00955	1
5	12	13	0.096901	0.436777	0.0278	1
6	10	7	0.218421	1.158209	0.00955	1
7	11	8	0.272988	1.447553	0.0119	1
8	9	6	0.114897	0.461302	0.00659	1
9	9	8	0.218861	1.16054	0.00955	1
10	2	1	0.02651	0.261317	0.1215	1
11	1	3	0.019376	0.190992	0.3555	1

12	4	3	0.004122	0.45627	0.0189	1
13	13	17	0.79597	0.319576	0.02285	1
14	18	17	0.003461	0.013895	0.000995	1
15	16	19	0.020764	0.093595	0.00595	1
16	52	51	0.030455	0.122273	0.000545	1
17	54	50	0.00886	0.03557	0.000159	1
18	53	52	0.033223	0.133388	0.000595	1
19	55	56	0.022149	0.088926	0.000397	1
20	54	53	0.00714	0.056157	0.0001625	1
21	53	55	0.033223	0.133388	0.000595	1
22	14	20	0.014535	0.058357	0.00417	1
23	59	58	0.030455	0.122273	0.000545	1
24	58	57	0.03876	0.15562	0.000695	1
25	59	54	0.052488	0.228653	0.000525	1
26	59	60	0.008306	0.033347	0.000149	1
27	60	61	0.021595	0.086702	0.000387	1
28	61	62	0.030455	0.122273	0.000545	1
29	62	63	0.010521	0.04224	0.0001885	1
30	64	63	0.016335	0.065583	0.000293	1
31	56	64	0.025748	0.10376	0.0004615	1
32	65	63	0.045682	0.183409	0.00082	1
33	21	24	0.007851	0.041632	0.00137	1
34	24	23	0.025909	0.137386	0.004525	1
35	68	67	0.517686	0.626281	0.000294	1
36	59	68	0.287603	0.347934	0.0001635	1
37	61	66	0.107975	0.433512	0.001935	1
38	23	22	0.024917	0.100041	0.00715	1
39	23	25	0.067521	0.358037	0.0118	1
40	69	71	2.214545	2.679091	0.00126	1

41	71	70	0.013843	0.055579	0.000248	1
42	71	72	0.041529	0.166736	0.000745	1
43	71	73	1.581818	1.913636	0.0009	1
44	22	27	0.10223	0.410447	0.02935	1
45	27	28	0.074198	0.297901	0.0213	1
46	25	26	0.043182	0.228977	0.00755	1
47	74	73	0.566653	1.559645	0.0012	1
48	26	29	0.06595	0.349711	0.0115	1
49	73	77	1.006612	1.217769	0.00098	1
50	77	78	1.72562	2.087603	0.0001635	1
51	76	78	0.287603	0.347934	0.00157	1
52	75	76	2.760992	3.340165	0.00113	1
53	78	79	1.984463	2.400744	0.00116	1
54	73	80	2.041983	2.470331	0.00685	1
55	29	30	0.039256	0.208161	0.0244	1
56	30	31	0.139752	0.741054	0.0278	1
57	31	32	0.096901	0.38905	0.01785	1
58	30	33	0.062293	0.250103	0.02205	1
59	28	36	0.076829	0.308461	0.02205	1
60	35	34	0.174421	0.700289	0.0125	1
61	34	37	0.123202	0.494649	0.00885	1
62	37	38	0.091364	0.366818	0.00655	1
63	38	39	0.164731	0.661384	0.0118	1
64	39	40	0.10936	0.43907	0.00785	1
65	36	35	0.054195	0.21759	0.01555	1
66	28	32	0.11282	0.452965	0.03235	1
67	33	41	0.069215	0.277893	0.01985	1
68	52	46	0.065754	0.263998	0.01885	1
69	41	43	0.005707	0.022912	0.001635	1

70	43	42	0.04845	0.194525	0.0139	1
71	42	44	0.033825	0.135806	0.0097	1
72	46	45	0.030288	0.121606	0.0087	1
73	14	47	0.006229	0.02501	0.001785	1
74	47	15	0.01938	0.07781	0.00555	1
75	16	17	0.026302	0.105599	0.00755	1
76	43	48	0.01938	0.07781	0.00555	1
77	18	19	0.041529	0.166736	0.0119	1
78	19	21	0.00969	0.038905	0.00278	1
79	41	49	0.134277	0.539112	0.03855	1
80	81	80	4.400331	5.019917	0.002605	1
81	22	15	0.01938	0.087355	0.00555	1
82	25	70	0.00000	0.511333	0.00000	0.905
83	59	21	0.00000	0.596000	0.00000	0.922
84	52	19	0.00000	0.643333	0.00000	0.905
85	12	2	0.00000	0.393333	0.00000	0.905
86	16	4	0.00000	0.560000	0.00000	0.915
87	3	14	0.00000	0.560000	0.00000	0.911
88	41	81	0.00000	1.200000	0.00000	0.975
89	42	82	0.00000	1.253000	0.00000	0.905
90	26	73	0.00000	0.704500	0.00000	0.918
91	69	23	0.00000	1.34OOO	0.00000	0.905
92	29	76	0.00000	1.424545	0.00000	0.945
93	56	20	0.00000	0.844667	0.00000	0.975
94	15	65	0.00000	0.858000	0.00000	0.925
95	1	11	0.00000	0.243778	0.00000	0.967
96	22	66	0.00000	0.866667	0.00000	0.913

APPENDIX (B.2)

Program for power flow solution at steady state for simplified Sudan (using Newton-Raphson MATLAB algorithms)

```
basemva=100;accuracy=.0001;  maxiter=50;
%        Bus Bus   vol    deg  -----LOAD----   ----GENERATOR----        INJ
%        NO  cod   MAg    ang   MW       Mvar     Mw    Mvar   Q-     Q+  Mvar
busdata=[1    1     1      0     0        0        0     0     125    0    0
         2    0     1      0     0        0        0     0     125    0    0
         3    0     1      0     0        0        0     0     250    0    0
         4    0     1      0     0        0        0     0     0      0    0
         5    0     1      0     14.36    11.483   0     0     30     0    0
         6    0     1      0     0        0        0     0     40     0    0
         7    0     1      0     33.456   23.961   0     0     0      0    0
         8    0     1      0     0        0        0     0     0      0    0
         9    0     1      0     50.32    46.148   0     0     0      0    0
         10   0     1      0     29.808   20.496   0     0     0      0    0
         11   0     1      0     0        0        0     0     0      0    0
         12   0     1      0     101.338  70.734   0     0     0      0    0
         13   0     1      0     33.264   20.615   0     0     0      0    0
         14   0     1      0     0        0        0     0     0      0    0
         15   0     1      0     0        0        0     0     0      0    0
         16   0     1      0     0        0        0     0     0      0    0
         17   0     1      0     13.574   8.661    0     0     0      0    0
         18   2     1      0     0        0        186   0     0      0    0
         19   0     1      0     0        0        0     0     0      0    0
         20   0     1      0     60.883   37.732   0     0     0      0    0
         21   0     1      0     0        0        0     0     0      0    0
         22   0     1      0     0        0        0     0     0      0    0
         23   0     1      0     14.112   8.746    0     0     0      0    0
```

24	0	1	0	0	0	0	0	0	0	0
25	0	1	0	0	0	0	0	0	0	0
26	0	1	0	0	0	0	0	0	0	0
27	0	1	0	6.989	25.534	0	0	0	0	0
28	2	1	0	46.704	32.357	85	0	0	0	0
29	0	1	0	16.464	8.842	0	0	0	0	0
30	0	1	0	12.029	5.585	0	0	0	0	0
31	2	1	0	8.333	5.76	148	0	15	0	0
32	0	1	0	0.403	22.385	0	0	0	0	0
33	0	1	0	1.546	0.958	0	0	0	0	0
34	0	1	0	19.757	31.778	0	0	0	0	0
35	0	1	0	3.629	25.117	0	0	0	0	0
36	0	1	0	1.008	5.56	0	0	0	0	0
37	0	1	0	6.25	3.939	0	0	0	0	0
38	0	1	0	3.36	23.764	0	0	0	0	0
39	0	1	0	6.72	4.568	0	0	15	0	0
40	0	1	0	3.36	2.503	0	0	0	0	0
41	0	1	0	0	0	0	0	30	0	0
42	0	1	0	0	0	0	0	0	0	0
43	0	1	0	0.672	12.515	0	0	0	0	0
44	0	1	0	12.029	8.021	0	0	0	0	0
45	0	1	0	0	0	0	0	0	0	0
46	0	1	0	16.666	10.678	0	0	0	0	0
47	0	1	0	0	0	0	0	0	0	0
48	0	1	0	0	0	0	0	0	0	0
49	2	1	0	0	0	38	0	30	0	0
50	0	1	0	81.917	53.127	0	0	0	0	0
51	0	1	0	68.006	39.992	0	0	0	0	0

52	0	1	0	41.328	17.854	0	0	0	0	0
53	2	1	0	0	0	76	0	0	0	0
54	0	1	0	44.621	20.718	0	0	0	0	0
55	0	1	0	74.189	46.562	0	0	0	0	0
56	0	1	0	12.634	8.128	0	0	0	15	0
57	0	1	0	50.266	33.255	0	0	0	0	0
58	0	1	0	17.203	8.477	0	0	0	0	0
59	0	1	0	40.387	18.165	0	0	0	0	0
60	0	1	0	85.344	58.018	0	0	0	0	0
61	0	1	0	64.915	40.06	0	0	0	0	0
62	0	1	0	75.466	42.566	0	0	0	0	0
63	0	1	0	59.069	30.588	0	0	0	0	0
64	0	1	0	81.312	54.43	0	0	0	0	0
65	0	1	0	0	0	0	0	0	0	0
66	0	1	0	0	0	0	0	0	0	0
67	0	1	0	36.49	24.236	0	0	0	0	0
68	0	1	0	0	0	0	0	0	0	0
69	0	1	0	0	0	0	0	0	0	0
70	0	1	0	24.73	12.738	0	0	0	0	0
71	0	1	0	11.088	5.864	0	0	0	0	0
72	0	1	0	27.821	14.253	0	0	0	0	0
73	0	1	0	56.717	26.986	0	0	0	0	0
74	0	1	0	10.886	4.058	0	0	0	0	0
75	0	1	0	0.336	1.476	0	0	0	0	0
76	0	1	0	0	0	0	0	0	0	0
77	0	1	0	7.594	4.037	0	0	0	0	0
78	2	1	0	4.704	2.238	7	0	0	0	0
79	0	1	0	14.381	9.552	0	0	0	0	0

80	0	1	0	11.021	6.539	0	0	0	0	0
81	0	1	0	18.614	12.315	0	0	0	0	0
82	2	1	0	15.254	8.604	2	0	0	0	0];

%	From Bus	To Bus	R (pu)	X (pu)	(½) B (pu)	Tap setting
linedata=	[67	69	0.086281	0.10438	0.00004905	1
	6	5	0.283781	1.279132	0.02035	1
	11	10	0.054252	0.287679	0.00237	1
	9	7	0.218861	1.16054	0.00955	1
	12	13	0.096901	0.436777	0.0278	1
	10	7	0.218421	1.158209	0.00955	1
	11	8	0.272988	1.447553	0.0119	1
	9	6	0.114897	0.461302	0.00659	1
	9	8	0.218861	1.16054	0.00955	1
	2	1	0.02651	0.261317	0.1215	1
	1	3	0.019376	0.190992	0.3555	1
	4	3	0.004122	0.040627	0.0189	1
	13	17	0.079597	0.319576	0.02285	1
	18	17	0.003461	0.013895	0.000995	1
	16	19	0.020764	0.093595	0.00595	1
	52	51	0.030455	0.122273	0.000545	1
	54	50	0.00886	0.03557	0.000159	1
	53	52	0.033223	0.133388	0.000595	1
	55	56	0.022149	0.088926	0.000397	1
	54	53	0.00714	0.056157	0.0001625	1
	53	55	0.033223	0.133388	0.000595	1
	14	20	0.014535	0.058357	0.00417	1
	59	58	0.030455	0.122273	0.000545	1

58	57	0.03876	0.15562	0.000695	1
59	54	0.052488	0.228653	0.000525	1
59	60	0.00830	0.033347	0.000149	1
60	61	0.021595	0.086702	0.000387	1
61	62	0.03045	0.122273	0.000545	1
62	63	0.010521	0.04224	0.0001885	1
64	63	0.016335	0.065583	0.000293	1
56	64	0.025748	0.10376	0.0004615	1
65	63	0.045682	0.183409	0.00082	1
21	24	0.007851	0.041632	0.00137	1
24	23	0.025909	0.137386	0.004525	1
68	67	0.517686	0.626281	0.000294	1
59	68	0.287603	0.347934	0.0001635	1
61	66	0.107975	0.433512	0.001935	1
23	22	0.024917	0.100041	0.00715	1
23	25	0.067521	0.358037	0.0118	1
69	71	2.214545	2.679091	0.00126	1
71	70	0.013843	0.055579	0.000248	1
71	72	0.041529	0.166736	0.000745	1
71	73	1.581818	1.913636	0.0009	1
22	28	0.10223	0.410447	0.02935	1
27	28	0.074198	0.297901	0.0213	1
25	26	0.043182	0.228977	0.00755	1
74	73	0.566653	1.559645	0.0012	1
26	29	0.06595	0.349711	0.0115	1
73	77	1.006612	1.217769	0.00057	1
77	78	1.72562	2.087603	0.00098	1
76	78	0.287603	0.349711	0.0001635	1

75	76	2.760992	3.3400165	0.00157	1
78	7	1.984463	2.400744	0.00113	1
73	80	2.041983	2.470331	0.00116	1
29	30	0.039256	0.208161	0.00685	1
30	31	0.139752	0.741054	0.0244	1
31	32	0.096901	0.38905	0.0278	1
30	33	0.062293	0.250103	0.01785	1
28	36	0.076829	0.308461	0.02205	1
35	34	0.174421	0.700289	0.0125	1
34	37	0.123202	0.494649	0.00885	1
37	38	0.091364	0.366818	0.00655	1
38	39	0.164731	0.661384	0.0118	1
39	40	0.10936	0.43907	0.00785	1
36	35	0.054195	0.21759	0.01555	1
28	32	0.11282	0.452965	0.03235	1
33	41	0.069215	0.277893	0.01985	1
42	46	0.065754	0.263998	0.01885	1
41	43	0.005707	0.022912	0.001635	1
43	42	0.04845	0.194525	0.0139	1
42	44	0.033825	0.135806	0.0097	1
46	45	0.030288	0.121606	0.0087	1
14	47	0.006229	0.02501	0.001785	1
47	15	0.01938	0.07781	0.00555	1
16	17	0.026302	0.105599	0.00755	1
43	48	0.01938	0.07781	0.00555	1
18	19	0.041529	0.166736	0.0119	1
19	21	0.00969	0.038905	0.00278	1
41	49	0.134277	0.539112	0.03855	1

81	80	4.400331	5.019917	0.002605	1
22	15	0.01938	0.087355	0.00555	1
25	70	0	0.511333	0	0.905
59	21	0	0.596	0	0.922
52	19	0	0.643333	0	0.905
12	2	0	0.393333	0	0.905
16	4	0	0.56	0	0.915
3	14	0	0.56	0	0.911
41	81	0	1.2	0	0.975
42	82	0	1.253	0	0.905
26	73	0	0.7045	0	0.918
69	23	0	1.34	0	0.905
29	76	0	1.424545	0	0.945
56	20	0	0.844667	0	0.975
15	65	0	0.858	0	0.925
1	11	0	0.243778	0	0.967
22	66	0	0.866667	0	0.913];

```
lfybus
lfnewton
busout
```