الآيـــــــــــة

قال تعالى:

﴿ وَاللَّهُ أَخْرَجَكُمْ مِنْ بُطُونِ أُمَّهَاتِكُمْ لَا تَعْلَمُونَ شَيْئًا وَجَعَلَ لَكُمُ السَّمْعَ وَالْأَبْصَارَ وَالْأَفْئِدَةَ لَعَلَّكُمْ تَشْكُرُونَ ﴾

سورة النحل- الآية (٧٨)

DEDICATION

To our parents who always inspiring and devising us, nothing of this could be done without them, may Allah saves them always.

To our dears, all of our family members whom always be there when we need them.

To our best friends and colleagues whom are always with us and support us to go forward.

To everyone who is an integral part of our support group, we dedicate this work.

We hope this project may add new knowledge, information and techniques for the electrical Sudanese gird.

AKNOWLEDGEMENT

The greatest thanks always to Allah for completing this project successfully.

Most grateful and appreciation to our supervisor Dr. Mohammed Osman Hassan for his expertise support and endless valuable advices which guided us throughout this work and our engineering career life.

We also would like to thank all of our teachers in the school of electrical and nuclear engineering for all the help and knowledge that they gave to us.

ABSTRACT

Load flow study epitomize the backbone of power system analysis and design; because many other analyses such as transient stability and contingency analysis are based on power flow analysis.

Mainly Load flow study used to specify the various aspects of AC power parameters in the electric power system and the bus voltages is the most important one of these.

Conventional techniques for solving the load flow problem are iterative, using the Newton-Raphson and the Gauss Seidel methods.

Necessary the electric power system exposed to some probable conditions i.e.: sync M/C out of service, transmission line out of service, load out of service, and adding new loads to the system. These conditions may cause the voltages levels to be out of the specified limit, therefor the power flow studies might be carried out on power system to verify that voltages levels within the acceptable limit under these conditions.

The weak buses in the system exemplify the optimal locations which the compensators set on to improve the voltages levels and to achieve system reliability and stability. Load flow study carried out on partial of Sudan national grid, consequently found out that voltages levels remain the specified limit under all studied conditions. Also the weak buses were determined. Besides SVC compensator has been used to improve voltages levels. Consequently, the objectives of this study were achieved.

المستخلص

دراسة إنسياب القدرة في المنظومة الكهربية تمثل العمود الفقري لتحليل وتصميم نظم القدرة الكهربية؛ لأن كثيرا من الدراسات الأخرى لنظم القدرة الكهربية مثل دراسة الاستقرارية العابرة ودراسة تحليل الطوارئ تعتمد على تحليل انسياب القدرة.

تتمثل أهمية دراسة إنسياب القدرة في تحديد البارمترات المختلفة لقدرة التيار الترددي في منظومة القدرة والتي تعتبر فيها جهود القضبان من أهم هذه البارمترات.

الطرق التقليدية لدراسة وتحليل انسياب الحمولة في منظومة القدرة هي الطرق العددية التكرارية ومن أكثرها استخداما طريقة نيوتن رافسون وطريقة قاوس سايدل.

منظومة القدرة الكهربية قابلة للتعرض لبعض الطوارئ أو الحالات المحتملة مثل خروج أي من الماكينات المتزامنة أو أحد خطوط النقل أو نقصان الحمولة أو زيادة حمولة جديدة للمنظومة. هذه الحالات المحتملة قد تتسبب في خروج مستويات جهود القضبان عن الحد المسموح به، لذلك دراسات انسياب القدرة يمكن تطبيقها على منظومة القدرة باستخدام البرامج الرقمية لانسياب القدرة للتحقق من كون مستويات جهود القضبان في الحد المسموح به تحت ظروف هذه الحالات.

القضبان ذوات الجهود الضعيفة في منظومة القدرة تمثل المواضع المثالية لتثبيت معوضات القدرة لتحسين مستويات جهود القضبان والحصول على منظومة معتمدة ومستقرة.

تم تطبيق دراسة إنسياب الحمولة علي جزء من الشبكه القومية السودانية وبناءا على ذلك تم التحقق من مستويات جهود القضبان تظل في الحد المسموح به تحت جميع هذه الحالات المدروسة كذلك تم التعرف على القضبان الضعيفة واستخدمت المعوضات لتحسين مستويات الجهود، وبذلك تحققت الأهداف المنشودة من هذه الدراسة.

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LIST OF SYMPOLES

V_{bus}	Vector of Bus Voltages
I_{bus}	Vector of the Injected Currents
Y_{bus}	Admittance Matrix
$\lvert V \rvert$	Voltage Magnitude,pu
δ	Power/Load Angle
P	Active Power,pu
Q	Reactive Power,pu
S	Apparent Power, pu
Z_{ik}	Impedance Between Bus i and Bus k
Y_{ik}	Admittance Between Bus i and Bus k
α	Acceleration Factor
V_i^*	Voltage Conjacet of Bus i,pu
$P_i{}^{sch}$	The Net Real Power, pu
$Q_i{}^{sch}$	The Net Reactive Power, pu
X	Reactance of Transmission Line, pu
R	Resistance of Transmission Line, pu
ΔP_i	Real Power Changes
ΔQ_i	Reactive Power Changes
Δδ	Power Angle Changes
B_{ii}	Is the Sum of Susceptance of All Elements Incident To Bus i
B',B''	Imaginary Part of the Bus Admittance Matrix Y_{bus}
θ	Phase Angle

LIST OF ABBREVIATIONS

DIgSILENT	Digital Simulation of Electrical Network
NR	Newton Raphson
Sch	Scheduled
SVC	Static VAR Compensator
VAR	Volt Ampere Reactive
TCR	Thyristor- Controlled Reactor
FC	Fixed Capacitor
Sync M/C	Synchronous Machine
T.L	Transmission Line

CHAPTER ONE
INTRODUCTION

1.1 Background:

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

Power-flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing system.

Commercial power systems are usually too complex to allow for hand solution of the power flow. Special purpose network analyzers were built between 1929 and the early 1960s to provide laboratory scale physical models of power systems. Large-scale digital computers replaced the analog methods with numerical solutions.

Load flow studies using software is accurate and gives highly reliable results. This project makes effective use of DIgSILENT Power Factory software to carry out load flow studies of 14bus Sudanese national grid.

DIgSILENT is an acronym for digital simulation of electrical networks. DIgSILENT version 7 was the world’s first power system analysis software with an integrated graphical single-line interface. Use of a single data base, with the required data for all equipment within a power system (e.g. line data, generator data, protection data harmonic data, controller data), means that power factory can easily execute all power simulation functions within a single program environment – functions such as load-flow, short-circuit calculation, harmonic analysis, protection coordination, stability calculation, and modal analysis.

Besides load flow studies are often used to identify the need of power system for compensation, which conserves the system voltage within specified limits. The compensation devices used for this purpose classified into passive compensators like series and shunt capacitors and reactors, and active compensators like SVC, TCSC, and STATCOM…etc.

This project helps to determine if the system voltage levels remain within the specified limits when occurrence of some probable conditions i.e.: increase in load, element out of service for maintenance and replacing purpose or to be isolated when the fault take place, whatever. Therefor load flow simulation used to verify of this.

Also this project helps to identify the weak buses, hence static VAR compensation (SVC) used to improve the voltage levels according to achieve system reliability and stability.

1.2 Project Objectives:

- Voltage levels improvement for the weak buses.
- Planning future expansion or addition to existing system new loads.
- Possibility of maintenance and replacing for grid components whenever needed.
- Improvement of system reliability and stability.

1.3 Problem statement:

The problem of this project is to verify if the buses voltages levels within the specified limit (Sudanese national electrical company applies $\pm$10% of the nominal voltage as acceptable limit) when the probable condition happens. Also to determine the weak buses then SVC system of suitable rating placed to over com this problem.

1.4 Methodology:

- Drive the methods of power flow solution i.e.: GS, NR, and fast decouple.
- Mathematical modeling of SVC system.
- Using DIgSILENT power factory software to find out power flow solution.

1.5 Project Outlines:

Chapter 1: represents general literature, project objectives statement of the problem, project layout and methodology.

Chapter 2: represents general introduction to power system and load flow study.

Chapter 3: includes the solution methods of load flow problem and compensation by using SVC.

Chapter 4: represents the results and simulation of partial Sudan network high voltages by using DIgSILENT program.

Chapter 5: represents the project conclusion and recommendation.

CHAPTER TWO

INTORDUCTION TO LOAD FLOW

2.1 Introduction:

The power system is assumed to be operating under balance condition and can be represented by single line diagram. The power system network contains hundreds of buses and branches with impedances specified in per-unit on a common MVA base. Power flow studies commonly referred to as load flow, are essential of power system analysis and design. Load flow studies are necessary for planning, economic operation, scheduling and exchange of power between utilities. Load flow study is also required for many other analyses such as transient stability, dynamic stability, contingency and state estimation. The load flow results give the bus voltage magnitude and phase angles and hence the power flow through the transmission lines, line losses and power injection at all the buses. [1]

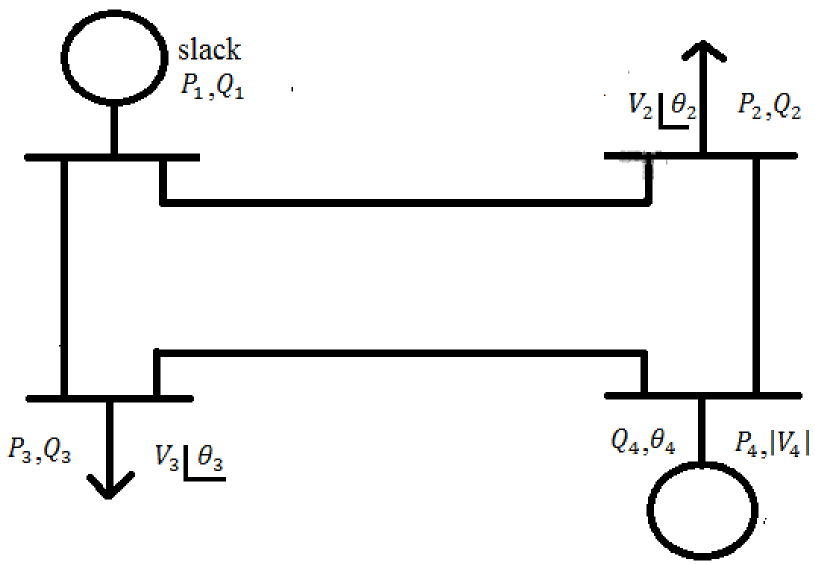

Figure 2.1: A power Distribution System

2.2 Importance of load flow study:

- Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.
- The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.
- It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- System transmission loss minimizes.
- Economic system operation with respect to fuel cost to generate all the power needed.
- The line flows can be known. The line should not be overloaded, it means, we should not operate the close to their stability or thermal limits.

2.3 Bus Classification:

A bus is a node at which one or many lines, one or many loads and generators A are connected. In a power system each node or bus is associated with four quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem two out of these four quantities are specified and remaining two are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into three categories.

- **Load bus:** No generator is connected to the bus. At this bus the real and reactive power are specified.it is desired to find out the voltage magnitude and phase angle through load flow solutions. It is required to specify only P and Q at such bus as at a load bus voltage can be allowed to vary within the permissible values.

- **Generator bus or voltage controlled bus:** Here the voltage magnitude corresponding to the generator voltage and real power P corresponds to its rating are specified. It is required to find out the reactive power generation Q and phase angle of the bus voltage.
- **Slack (swing) bus:** For the Slack Bus, it is assumed that the voltage magnitude $|V|$and voltage phase (δ) angle are known, whereas real and reactive powers P and Q are obtained through the load flow solution.

The following Table summarizes the above discussion:

Table 2.1:bus classification

Bus Type	Specified quantities	Unknown quantities
Slack bus	$|V|$, δ	P, Q
Load bus	P, Q	$|V|$, δ
Voltage control bus	$P, |V|$	Q, δ

2.4 Formation of Bus Admittance Matrix:

Power system analysis, like load flow studies, short circuit studies, and transient stability studies, has become very convenient with the advent of digital computers. More and more complex systems can now be handled by suitable mathematical models, constituting an ordered collection of system parameters in the form of matrices. These models depend on the selection of independent variables. When the voltages are selected as independent variables, the corresponding currents are dependent and the matrix relating the voltages to the currents is then nodes), the reference is the bus frame, and the resulting equations are usual independent nodal equations. The voltages and currents, when referred to independent loops, are related by the admittance matrix in the loop frame of reference. When the currents are treated as independent variables, the matrices are impedance matrices in the respective frames of reference. In order to obtain the bus –voltage equations, consider the sample of four bus power system as shown in Figure 2.2. [1]

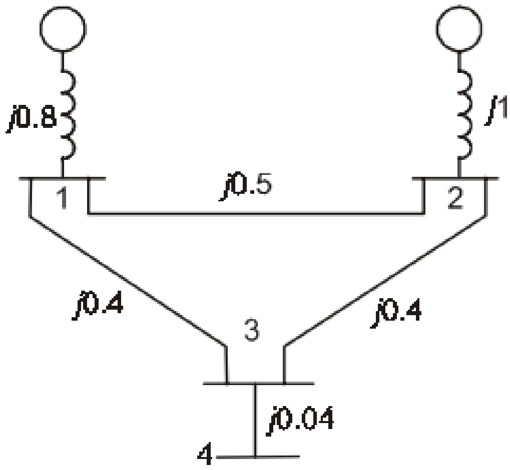

Figure 2.2: The Impedance Diagram of Sample 4-Bus power system

For simplicity resistance of the lines are neglected and the impedance shown in Figure 2.2.are expressed in per-unit on common MVA base.

Now impedance is converting to admittance, i.e.

$$y_{ik} = \frac{1}{Z_{ik}} = \frac{1}{r_{ik} + jx_{ik}} \tag{2.1}$$

Figure 2.3.shows the admittance diagram and transformation to current sources and injects $I_1$and I_2at buses 1and 2 respectively. Node 0(which is normally ground) is taken as reference.

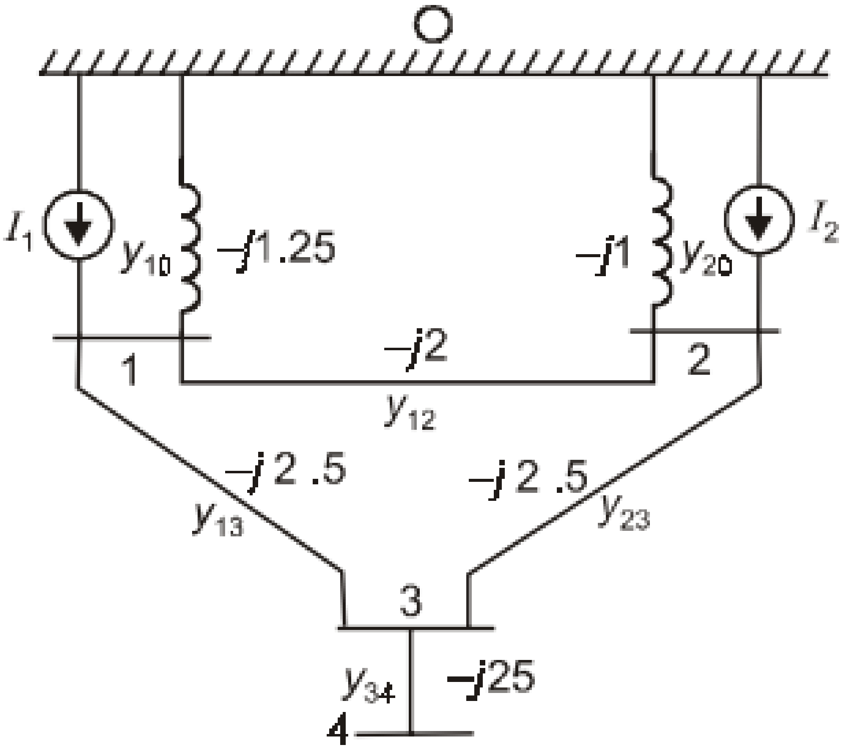

Figure 2.3: The Admittance Diagram of Figure 2.2

Applying KCL to the independent nodes 1,2,3,4 we have,

$$I_1 = y_{10}V_1 + y_{12}(V_1 - V_2) + y_{13}(V_1 - V_{3)}$$

$$0 = y_{20}V_2 + y_{12}(V_2 - V_1) + y_{23}(V_2 - V_3)$$

$$0 = y_{23}(V_3 - V_2) + y_{13}(V_3 - V_1) + y_{34}(V_3 - V_4)$$

$$0 = y_{34}(V_4 - V_3)$$

Rearranging the above equations, we get

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

$$I_2 = -y_{12}V_1 + (y_{20} + y_{12} + y_{23})V_2 - y_{23}V_3$$

$$0 = -y_{13}V_1 - y_{23}V_2 + (y_{13} + y_{23} + y_{34})V_3 - y_{34}V_4$$

$$0 = -y_{34}V_3 + y_{34}V_4$$

Let,

$Y_{11} = (y_{10} + y_{12} + y_{13})$ $\quad\quad$ $Y_{22} = (y_{20} + y_{12} + y_{23})$

$Y_{33} = (y_{13} + y_{23} + y_{34})$ $\quad\quad$ $Y_{44} = y_{44}$

$Y_{12} = Y_{21} = -y_{12}$

$Y_{13} = Y_{31} = -y_{13}$

$Y_{23} = Y_{32} = -y_{23}$

$Y_{34} = Y_{43} = -y_{34}$

The node equations reduce to

$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$

$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4$

$I_3 = Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + Y_{34}V_4$

$I_4 = Y_{41}V_1 + Y_{42}V_2 + Y_{43}V_3 + Y_{44}V_4$

Note that, in Figure 2.3 there is no connection between bus 1 and bus 4.

$\therefore$ $Y_{14} = Y_{41} = 0$ Similarly $Y_{24} = Y_{42} = 0$. Also note that in this case I_3=0, $I_4 = 0$.

Above equation can be written in matrix form,

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \quad (2.2)$$

Or in general $\quad I_{bus} = Y_{bus}V_{bus}$ $\quad\quad$ (2.3)

Diagonal element of Y matrix is known as self-admittance or driving point admittance, i.e.,

$$Y_{ii} = \sum_{K=0}^{n} Y_{ik} V_k \ \ ,j \neq i \tag{2.4}$$

Off-diagonal element of Y matrix is known as transfer admittance or mutual admittance, i.e.

$$Y_{ik} = Y_{ki} = -y_{ik} \tag{2.5}$$

V_{bus}can be obtained from equation (2.3),i.e.

$$V_{bus} = Y_{bus}^{-1} \ I_{bus} \tag{2.6}$$

2.5 Formation of Bus Loading Equation:

Consider i-the bus of power system as shown in Figure 2.4. Transmission lines are represented by their equivalent π models -y_{i0} is the total charging admittance at bus. [2]

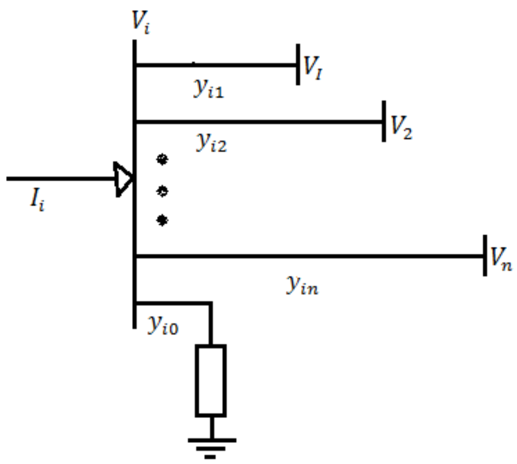

Figure 2.4: i-th Bus of Power System

Net injected current I_i into the bus i can be written as:

$$I_i = y_{i0}V_i + y_{ii}(V_I - V_2) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2})V_i - y_{i1}V_1 - y_{i2}V_2 \cdots y_{in}V_n \tag{2.7}$$

in Let us define

$$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in}$$

$$Y_{i1} = -y_{i1}$$

$$Y_{i2} = -y_{i2}$$

$$\vdots$$

$$Y_{in} = -y_{in}$$

$$\therefore \; I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n \tag{2.8}$$

Or

$$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \tag{2.9}$$

The real and reactive power injected at bus i is

$$P_i - jQ_I = V_i^* \; I_i$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.10}$$

From equations (2.9) and (2.10) we get

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \tag{2.11}$$

$$\therefore Y_{ii}V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \tag{2.12}$$

2.6 Methods for Load Flow Studies:

There are three methods for load flow studies mainly

- Gauss Seidel method.
- Newton Raphson method.
- Fast decoupled method.

2.6.1 Gauss Seidel method:

The Gauss Seidel method solves the power flow equations in rectangular (complex variable) coordinates until differences in bus voltages from one iteration to anther are sufficiency small.

Gauss Seidel method is very simple in concept but may not yield convergence to the required solution. However, when the initial solution or starting point is very close to the actual solution convergence is generally obtained. The rate of convergence can be increased by using acceleration factors to the solution obtained after each iteration. Affixed acceleration factor α (1$\leq \alpha \leq 2$) is normally used for each voltage change.

2.6.2 Newton Raphson method:

The most widely used method for solving simultaneous nonlinear algebraic equations is Newton Raphson method. Newton's method is a successive approximation procedure based on an initial estimate of the unknown and use of Taylor's expansion. There are two methods of solution for the load flow using Newton - Raphson method. The first method uses rectangular coordinates for the variables, while the second method uses the polar coordinate formulation. For large power systems, the Newton-Rapson method is to be more efficient and practical.

2.6.3 Fast decoupled method:

When solving large-scale power transmission systems, an alternative strategy for improving computational efficiency and reducing computer storage requirements is the decoupled power flow method.

The principle of decoupled approach is based on two observations:

- Change in the voltage angle δ at bus primarily affects the flow of real power P in the transmission lines and leaves the flow of reactive power Q relatively unchanged.
- Change in the voltage magnitude $|V|$ at bus primarily affects the flow of reactive power Q in the transmission lines and leaves the flow of real power P relatively unchanged.

This method is faster to solve than the coupled set of equation in full Newton Raphson procedure. This technique can be very useful for calculating power flow for contingencies where the speed of calculations is of primary important, even if the accuracy is somewhat sacrificed compared to the full N.R method.

2.6.4 Comparison between load flow methods:

The methods basically distinguish between themselves in the rate of convergence, storage requirement and time of computation.

In Gauss Seidel, rate of convergence is slow. It can be easily program and the number of iterations increases directly with the number of buses in the system and in Newton-Raphson, the convergence is very fast and the number of iterations is independent of the size of the system, solution to a high accuracy is obtained. The NR Method convergence is not sensitive to the choice of slack bus. Although a large number of load flow methods are available in literature it has been observed that only the Newton-Raphson and the Fast Decoupled load-flow methods are most popular. The fast decoupled load flow is definitely superior to the Newton-Raphson Method from the point of view of speed and storage. The following points summarize the above discussion:

- ❖ Gauss Seidel method is very simple in concept but needs many iterations to achieve desired accuracy.
- ❖ The Newton Raphson is reliable in convergence, computationally faster, and more economical in storage requires.

- Fast decoupled method, this method is faster to solve than the coupled set of equation in full Newton Raphson procedure. [3]

CHAPTER THREE

SOLUTION METHODS OF LOAD FLOW PROBLEMS AND COMPENSATION

In this chapter the basic methods to solve the nonlinear power flow equations, and the modeling static VAR compensation (svc).

3.1 Solution of nonlinear algebraic equation:

In all realistic cases the power flow problem cannot be solved analytically and hence iterative solutions implemented in computers must be used. [4]

The most common techniques used for the iterative solution of nonlinear algebraic equations are

- Gauss Seidel Newton-Raphson.
- Quasi-Newton methods (Fast Decoupled Method).

The Gauss Seidel and Newton-Raphson methods are discussed for one dimensional equation and are then extended to n-dimensional equation. [2]

3.2 Gauss Seidel Method:

The Gauss Seidel method also known as the method of successive displacement.to illustrate the technique consider.

The solution of the nonlinear equation given by:

$$f(x) = 0 \qquad (3.1)$$

The above function is rearranged and written by:

$$x = g(x) \qquad (3.2)$$

If $x^{(k)}$is an initial estimate of the variable x, the following iterative sequence is formed

$$x^{(k+1)} = g(x^{(k)}) \qquad (3.3)$$

A solution is obtained when the difference between the absolute value of the successive iteration is less than specified accuracy.

$$x^{(k+1)} - x^{(k)} \leq \in \quad (3.4)$$

where is ∈ the desired accuracy. [2]

3.3 Gauss Seidel by using load flow:

Return to Figure 2.4

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n) \quad (3.5)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 \ldots y_{in}V_n \quad (3.6)$$

$$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in} \quad (3.7)$$

$$Y_{i1} = -y_{i1}$$

$$Y_{i2} = -y_{i2}$$

$$\vdots$$

$$Y_{in} = -y_{in} \quad (3,8)$$

$$\therefore\ I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n \quad (3.9)$$

The I_i may be written

$$I_i = Y_{ii}V_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} Y_{ij}\, V_j \quad (3.10)$$

The real and reactive power injected bus I is

$$P_i + jQ_i = V_i I_i^* \quad (3.11)$$

$$P_i - jQ_i = V_i^* I_i \quad (3.12)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad (3.13)$$

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii}V_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} Y_{ij}V_j \quad (3.14)$$

$$Y_{ii}V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij}V_j \qquad (3.15)$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij}V_j\right] \qquad (3.16)$$

3.4 Newton Raphson Method:

The Newton Raphson method is widely used for solving nonlinear equations. It transforms the original nonlinear problem into a sequence of linear problems whose solutions approach the solution of the original problem. The method can be applied to one equation in one unknown or to a system of simultaneous equations with as many unknowns as equations. [5]

3.4.1 One-Dimensional Case:

Let f(x) is a nonlinear equation. Any value of x that satisfies f(x) =0 is a root of f(x).

To find a particular root, an initial guess for x in the vicinity of the root is needed. Let this initial guess be xo Thus

$$f(x^\circ) = \Delta f^\circ \qquad (3.17)$$

Where f° is the error since Xo is not a root.

Corresponding to xo' and is projected until it intercepts the x-axis to determine a second estimate of the root. Again the derivative is evaluated, and a tangent line is formed to proceed to the third estimate of x. The line generated in this process is given by:

$$\text{y(x)} = f(x_n) + f'(x_n)(x - x_n) \qquad (3.18)$$

Which, when y(x) = 0, gives the recursion formula for iterative estimates of the root:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \qquad (3.19)$$

3.4.2 N-Dimensional Case:

The single dimensional concept of the Newton-Raphson method can be extended to N dimensions. All that is needed is an N-dimensional analog of the first derivative. This is provided by the Jacobian matrix. Each of the N rows of the Jacobian matrix is composed of the partial derivatives of one of the equations of the system with respect to each of the N variables. [5]

An understanding of the general case can be gained from the specific example N = 2. Assume that we are given the two nonlinear equationsf_1, f_2. Thus

$$f_1 = (x_1,x_2) \quad , \quad f_2 = (x_1, x_2) \tag{3.20}$$

The Jacobian matrix for this (2*2) system is

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix} \tag{3.21}$$

If the Jacobian matrix is numerically evaluated at some point $(x_1{}^{(k)},x_2{}^{(k)})$ the following linear relationship is established for small $(\Delta x_1,\Delta x_2)$

$$\begin{bmatrix} \frac{\partial f_1{}^{(k)}}{\partial x_1} & \frac{\partial f_1{}^{(k)}}{\partial x_2} \\ \frac{\partial f_2{}^{(k)}}{\partial x_1} & \frac{\partial f_2{}^{(k)}}{\partial x_2} \end{bmatrix} \begin{bmatrix} \Delta x_1{}^{(k+1)} \\ \Delta x_2{}^{(k+1)} \end{bmatrix} = \begin{bmatrix} \Delta f_1{}^{(k)} \\ \Delta f_2{}^{(k)} \end{bmatrix} \tag{3.22}$$

For at some point ($x_1{}^{(0)},x_2{}^{(0)}$)

$$\begin{bmatrix} \frac{\partial f_1{}^{(0)}}{\partial x_1} & \frac{\partial f_1{}^{(0)}}{\partial x_2} \\ \frac{\partial f_2{}^{(0)}}{\partial x_1} & \frac{\partial f_2{}^{(0)}}{\partial x_2} \end{bmatrix} \begin{bmatrix} \Delta x_1{}^{(1)} \\ \Delta x_2{}^{(1)} \end{bmatrix} = \begin{bmatrix} \Delta f_1{}^{(0)} \\ \Delta f_2{}^{(0)} \end{bmatrix} \tag{3.23}$$

Where

$$\Delta f_1{}^{(0)} = -f_1\left(x_1{}^{(0)},x_2{}^{(0)}\right) \ , \Delta f_2{}^{(0)} = -f_2\left(x_1{}^{(0)},x_2{}^{(0)}\right) \tag{3.24}$$

This system of linear equations is then solved directly for the first correction. The correction is then added to the initial guess to complete the first iteration:

$$\begin{bmatrix} {x_1}^{(1)} \\ {x_2}^{(1)} \end{bmatrix} = \begin{bmatrix} {x_1}^{(0)} \\ {x_2}^{(0)} \end{bmatrix} + \begin{bmatrix} \Delta {x_1}^{(1)} \\ \Delta {x_2}^{(1)} \end{bmatrix} \tag{3.25}$$

Equations (3.23) and (3.25) are rewritten using matrix symbols and a general superscript n for the iteration count:

$$[J^{n-1}][\Delta x^n] = [\Delta f^{n-1}] \tag{3.26}$$

$$[x^n] = [x^{n-1}] + [\Delta x^n] \tag{3.27}$$

3.5 Newton-Raphson method for load flow solution:

Newton-Raphson method is mathematically superior to the Gauss Seidel method and is found to be more efficient and practical the number of iteration required to obtain as solution is independent of the system size there are several distinctly different ways of applying the Newton-Raphson method to solving the load-flow equations. We illustrate a popular version employing the polar form. As we have seen for each generator bus (except for the slack bus),we have the active power equation and the corresponding unknown phase angleδ. We write this equation in the form

$$\Delta p_i = {p_i}^{sch} - p_i = 0 \tag{3.28}$$

For each load bus we have the active and reactive equations and the unknowns $|V_i|$andθ_i. We write the two equations in the form

$$\Delta P_i = {P_i}^{sch} - P_i \ = 0 \tag{3.29}$$

$$\Delta Q_i = {Q_i}^{sch} - Q_i \ = 0 \tag{3.30}$$

In the above equations, the superscript "sch" denotes the scheduled or specified bus active or reactive powers. Using the polar form, we have

$$P_i = \sum_{j=1}^{K} |V_i| \, |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.31}$$

$$Q_i = -\sum_{j=1}^{K} |V_i|\,|V_j||Y_{i1}|\sin(\theta_{ij} - \delta_i + \delta_j) \qquad (3.32)$$

The general form as

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_2{}^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2{}^{(k)}}{\partial \delta_n} & \frac{\partial P_2{}^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2{}^{(k)}}{\partial |V_2|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n{}^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n{}^{(k)}}{\partial \delta_n} & \frac{\partial P_n{}^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n{}^{(k)}}{\partial |V_n|} \\ \hline \frac{\partial Q_2{}^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2{}^{(k)}}{\partial \delta_n} & \frac{\partial Q_2{}^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2{}^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n{}^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n{}^{(k)}}{\partial \delta_n} & \frac{\partial Q_n{}^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n{}^{(k)}}{\partial |V_n|} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta \left|V_2^{(k)}\right| \\ \vdots \\ \Delta \left|V_n^{(k)}\right| \end{bmatrix} \qquad (3.33)$$

In the above equation bus1 is assumed to be the slack bus the jacobian matrix gives the linearized relationship between small changes in voltage angle$\Delta\delta_i{}^{(k)}$ and voltage magnitude $\Delta|V_i|^{(k)}$with small changes in real and reactive power$\Delta P_i{}^{(k)}$ and $\Delta P_i{}^{(k)}$. [2]

Above equation can be written

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \qquad (3.34)$$

When

$$J_1 = \frac{\partial P}{\partial \delta} \qquad (3.35) \quad , \quad J_2 = \frac{\partial P}{\partial |V|} \qquad (3.36)$$

$$J_3 = \frac{\partial Q}{\partial \delta} \qquad (3.37) \quad , \quad J_4 = \frac{\partial Q}{\partial |V|} \qquad (3.38)$$

The new value for bus voltages are

$$\delta_i{}^{(k+1)} = \delta_i{}^{(k)} + \Delta\delta_i{}^{(k)} \qquad (3.39)$$

$$\left|V_i{}^{(k+1)}\right| = \left|V_i{}^{(k)}\right| + \Delta\left|V_i{}^{(k)}\right| \qquad (3.40)$$

3.6 Fast Decoupled Method:

Transmission lines of power system have a very high X/R ratio. For such a system, real power changes ΔP are less sensitive to change in the voltage magnitude and are most sensitive to change in phase angle $\Delta\delta$. Similarly, reactive power is less sensitive to changes in angle and is mainly dependent on changes in voltage magnitude. Therefore, it is reasonable to set elements$J_2 and J_3$ and of the jacobian matrix to zero. [2]

Thus (3.34) becomes

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}\begin{bmatrix}J_1 & 0\\ 0 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \tag{3.41}$$

$$\Delta P = J_1\Delta\delta = \frac{\partial P}{\partial\delta}\Delta\delta \tag{3.42}$$

$$\Delta Q = J_4\Delta|V| = \frac{\partial Q}{\partial|V|}\Delta|V| \tag{3.43}$$

The diagonal element ofJ_1 may be written

$$\frac{\partial P_i}{\partial\delta_i} = \left[\sum_{j=1}^{n}|V_i|\,|V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j)\right] - |V_i|^2|Y_{ii}|\sin\theta_{ii} \tag{3.44}$$

Replacing the first term of the above equation with $-Q_i$ as given by (3. 32), results in

$$\frac{\partial P_i}{\partial\delta_i} = -Q_i - |V_i|^2|Y_{ii}| = -Q_i - |V_i|^2 B_{ii} \tag{3.45}$$

Where $B_{ii} = |Y_{ii}|\sin\theta_{ii}$is the imaginary part of the diagonal element of the bus admittance matrix.

The self susceptance $B_{ii} \gg Q_i$ we may neglect Q_i

Further simplification is obtained by assuming $|V_i|^2 \approx |V_i|$ which yields

$$\frac{\partial P_i}{\partial\delta_i} = -|V_i|\,B_{ii} \tag{3.46}$$

Under normal operating condition, $\delta_j - \delta_i$ is quite small. Assuming

$\theta_{ii} - \delta_i + \delta_j \approx \theta_{ii}$ the off-diagonal elements of J_1 becomes

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j|\, B_{ij} \tag{3.47}$$

Further simplification is obtained by assuming $|V_j| \approx 1$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i|\, B_{ij} \tag{3.48}$$

Similarly, the diagonal element of J_4 may be written as

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}| \sin\theta_{ii} - \left[\sum_{j=1}^{n} |V_i|\,|V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)\right] \tag{3.49}$$

Replacing the second term of the above equation with $-Q_i$ result in

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}| \sin\theta_{ii} + Q_i \tag{3.50}$$

Again, since $B_{ii} = |Y_{ii}| \sin\theta_{ii} \gg Q_i$,$Q_i$may be neglected

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i|\, B_{ii} \tag{3.51}$$

Assuming $\theta_{ij} - \delta_i + \delta_j \approx \theta_{ij}$yields

$$\frac{\partial Q_i}{\partial |V_j|} = -|V_i|\, B_{ij} \tag{3.52}$$

With these assumptions equation (3.42), (3.43) becomes

$$\frac{\Delta P}{|V|} = -B'\Delta\delta \tag{3.53}$$

$$\frac{\Delta Q}{|V|} = -B''\Delta|V| \tag{3.54}$$

Here, $B'$and $B''$are the imaginary part of the bus admittance matrix There for fast decoupled power now algorithm, the successive voltage magnitude and phase angle change are

$$\Delta\delta = -[B']^{-1}\frac{\Delta P}{|V|} \tag{3.55}$$

$$\Delta|V| = -[B'']^{-1}\frac{\Delta Q}{|V|} \tag{3.56}$$

3.7 Static VAR Compensator:

The SVC is a solid-state reactive power compensation device based on high power thyristor technology. In its simplest form, the SVC consists of a TCR in parallel with bank of capacitor. From an operational point of view, the SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate voltage magnitude at the point of connection to the AC network. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response.

3.7.1 The Main Function of SVC:

The main function of SVC is to control the voltage at weak nodes in the system. Installation of SVC in load buses used for load compensation help in containing the voltage fluctuations, improve load power factor and also voltage profile. Installation of SVC in transmission networks helps to provide dynamic reactive power injection support to maintain the bus voltage close to the nominal value under varying load conditions and also improve voltage stability.

3.7.2 The Model of SVC:

Basically it consists of a fixed capacitor (FC) and a TCR. As shown in Figure3.2. it is connected in shunt with the transmission line through a transformer.

The model considers SVC as shunt variable susceptance, B_{SVC} which is adapted automatically to achieve the voltage control. The TCR consists of a fixed reactor of inductor L and a bi-directional thyristor valve. The thyristor valves are fired symmetrically in an angle of a control range of 90° to 180° , with respect to the SVC voltage.The TCR at a fundamental frequency can be considered to act like a variable inductance X_{TCR} is given as:

$$X_{TCR} = \frac{\pi}{2(\pi - \alpha) + sin2\alpha} \quad (3.57)$$

where X_{TCR} is the reactance caused by the fundamental frequency without thyristor control and α is the firing angle. Hence, the total equivalent impedance of the controller can be written as

$$X_{SVC} = \frac{X_C X_L}{\frac{X_C}{\pi}[2(\pi - \alpha) + sin2\alpha] - X_L} \quad (3.58)$$

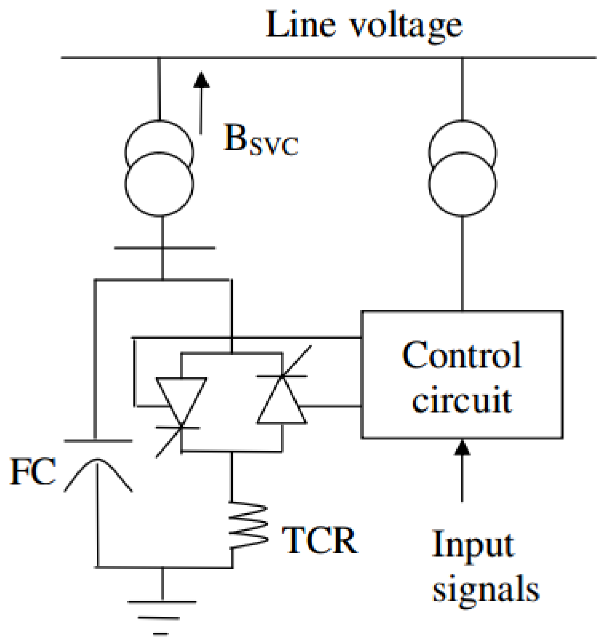

Figure 3.1: SVC Employing FC-TCR

By controlling the firing angle of α of the thyristor (the angle with respect to zero crossing of the phase voltage), the device is able to control the bus voltage magnitude current.

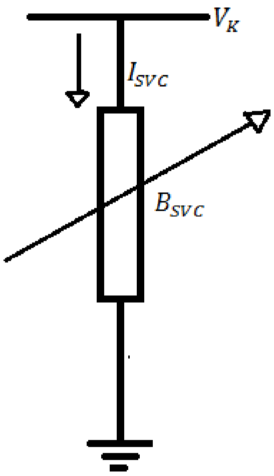

Figure 3.2: Equivalent Steady State Model of The SVC

SVC model is developed with respect to a sinusoidal voltage, and can be written as

$$I_{SVC} = -jB_{SVC}V_K \tag{3.59}$$

CHAPTER FOUR

SIMULATION AND RESULTS ANALYSIS

4.1 Introduction:

The voltage profile of steady state operation obtained from load flow simulation as shown in Table (4.2) represent that all the buses voltages within acceptable limit (±10) these buses will be studied considering four cases (probable conditions outlined in problem statement) to verify, that voltages levels remains within the specified limit.

Besides SVC will be set on the weak buses considering two cases to study effect of SVC in voltage improvement. The power flow diagram based on DIgSILENT power factory software, has been applied to the power system network shown in Figure 4.1 is developed to:

- study each one of cases in the network.
- find out the power flow solution.
- verify that voltage level within the limit.

4.2 Description for Network Would Studied:

The network which has been studied is part of Sudan electrical power system network. It is containing of several transmission lines, load, synchronous machines, two and three winding transformers and buses have been tabulated in Table (4.1)

Table 4.1: Power system network component

Number	Type	Number of Units
1	Synchronous Machine	35
2	Load	9
3	Transmission Line	19
4	Two Winding Transformer	20
5	Three Winding Transformer	21
6	Buses	14