CHAPTER ONE
INTRODUCTION

CHAPTER ONE:

1.1 Introduction:

Power system software can be grouped in many different ways, e.g., functionality, computer platform, etc. also it is grouped by end user. There are four major groups of end users for the software:

- **Major utilities**
- **Small utilities, and industry consumers of electricity**
- **Consultants**
- **Universities**

Large comprehensive program packages are required by utilities. They are complex, with many different functions and must have very easy input/output (IO). They serve the needs of a single electrical system and may be tailor-made for the customer. They can be integrated with the electrical system using SCADA (Supervisory Control and Data Acquisition). Suffice to say that the component programs used in these packages usually have the same generic/development roots as the programs used by the other three end user groups.

They start life as research programs and later are used for teaching and/or consultancy programs. Where the consultant is also an academic, then the programs may well retain their crude research style IO. However, if they are to be used by others who are not so familiar with the algorithms, then usually they are modified to make them more user friendly. Once this is achieved, the programs become commercial and are used by consultants, industry, and utilities. These are the types of programs that are now so commonly seen in the engineering journals quite often bundled together in a generic package.

Two of the earliest programs to be developed for power system analysis were the fault and load flow (power flow) programs. Both were originally produced in the late 1950s. Many programs in use today are either based on these two types of program or have one or the other embedded in them.

1.2 Load Flow (Power Flow)

The object of load-flow calculations is to determine the steady-state operating characteristics of power generation\transmission system for a given set of bus-bar loads.

Five mean properties are required for a load flow solution method.

1- High computation speed (Important for large system, online applications, multiple case load-flow, and in interactive applications.
2- Low computer storage (This not important now).
3- Reliability of solution, necessary for ill-conditioned problems, in outage studies, and for real-time applications.
4- Versatility (an ability on the part of load-flow to handle special features, such as adjust of tap ratio on transformers.
5- Simplicity. The case of coding a computer program of load-flow algorithm.

The type of solution required from a load-flow also determines the method used
It may be Accurate or approximated, adjusted or unadjusted, on line or off line,
Single or multi case.

The need to know the flow patterns and voltage profiles in a network was the driving force behind the development of load flow programs.

Although the network is linear, load flow analysis is iterative because of nodal (bus-bar) constraints. At most bus-bars the active and reactive powers being delivered to customers are known but the voltage level is not. As far as the load flow analysis is concerned, these bus-bars are referred to as PQ buses. The generators are scheduled to deliver a specific active power to the system and usually the voltage magnitude of the generator terminals is fixed by automatic voltage regulation. These bus-bars are known as PV buses.

The system cannot be determined before the load flow solution; one generator bus-bar only has its voltage magnitude specified. In order to give the required two specifications per node, this bus also has its voltage angle defined to some arbitrary value, usually zero. This bus-bar is known as the slack bus. The slack bus is a mathematical requirement for the program and has no exact equivalent in reality.

However, in operating practice, the total load plus the losses are not known. When a system is not in power balance, i.e., when the input power does not equal the load power plus losses, the imbalance modifies the rotational energy stored in the system. The system frequency thus rises if the input power is too large and falls if the input power is too little. Usually a generating station and probably one machine is given the task of keeping the frequency constant by varying the input power. This control of the power entering a node can be seen to be similar to the slack bus.

The algorithms first adopted had the advantages of simple programming and minimum storage but were slow to converge requiring many iterations. The introduction of ordered elimination, which gives implicit inversion of the network matrix, and sparsity programming techniques, which reduces storage requirements, allowed much better algorithms to be used. The Newton-Raphson method gave convergence to the solution in only a few iterations. Using Newton methods of specifying the problem, a Jacobian matrix containing the partial derivatives of the system at each node can be constructed. The solution by this method has quadratic convergence. This method was followed quite quickly by the Fast Decoupled Newton-Raphson method. This exploited the fact that under normal operating conditions, and providing that the network is predominately reactive, the voltage angles are not affected by reactive power flow and voltage magnitudes are not affected by real power flow. The Fast Decoupled method requires more iteration to converge but each iteration uses less computational effort than the Newton-Raphson method. A further advantage of this method is the robustness of the algorithm.

Further refinements can be added to a load flow program to make it give more realistic results. Transformer on-load tap changers, voltage limits, active and reactive power limits, plus control of the voltage magnitudes at buses other than the local bus help to bring the results close to reality. Application of these limits can slow down convergence.

The problem of obtaining an accurate, load flow solution, with a guaranteed and fast convergence has resulted in more technical papers than any other analysis topic. This is understandable when it is realized that the load flow solution is required during the running of many other types of power system analyses. While improvements have been made, there has been no major breakthrough in performance. It is doubtful if such an achievement is possible as the time required to prepare the data and process the results represents a significant part of the overall time of the analysis.

1.3 Fault Analysis

A fault analysis program derives from the need to adequately rate switchgear and other bus-bar equipment for the maximum possible fault current that could flow through them.

Initially only three-phase faults were considered and it was assumed that all bus-bars were operating at unity per unit voltage prior to the fault occurring. The load current flowing prior to the fault was also neglected.

By using the results of a load flow prior to performing the fault analysis, the load currents can be added to the fault currents allowing a more accurate determination of the total currents flowing in the system.

Unbalanced faults can be included by using symmetrical components. The negative sequence network is similar to the positive sequence network but the zero sequence networks can be quite different primarily because of ground impedance and transformer winding configurations.

1.4 Transient Stability:

After a disturbance, due usually to a network fault, the synchronous machine's electrical loading changes and the machines speed up (under very light loading conditions they can slow down). Each machine will react differently depending on its proximity to the fault, its initial loading and its time constants. This means that the angular positions of the rotors relative to each other change. If any angle exceeds a certain threshold (usually between 140° and 160°) the machine will no longer be able to maintain synchronism. This almost always results in its removal from service.

Early work on transient stability had concentrated on the reaction of one synchronous machine coupled to a very large system through a transmission line. The large system can be assumed to be infinite with respect to the single machine and hence can be modeled as a pure voltage source. The synchronous machine is modeled by the three phase windings of the stator plus windings on the rotor representing the field winding and the eddy current paths. These are resolved into two axes, one in line with the direct axis of the rotor and the other in line with the quadrature axis situated 90° (electrical) from the direct axis. The field winding is on the direct axis. Equations can be developed which determine the voltage in any winding depending on the current flows in all the other windings. A full set of differential equations can be produced which allows the response of the machine to various electrical disturbances to be found. The variables must include rotor angle and rotor speed which can be evaluated from knowledge of the power from the turbine into, and power to the system out of the machine. The great disadvantage with this type of analysis is that the rotor position is constantly changing as it rotates. As most of the equations involve trigonometrical functions relating to stator and rotor windings, the matrices must be constantly reevaluated. In the most severe cases of network faults the results, once the dc transient's decay, are balanced. Further, on removal of the fault the network is considered to be balanced. There is thus much computational effort involved in obtaining detailed information for each of the three phases which is of little value to the power system engineer. By contrast, this type of analysis is very important to machine designers. However, programs have been written for multi-machine systems using this method.

Several power system disasters in the U.S. and Europe in the 1960s gave a major boost to developing transient stability programs. What was required was a simpler and more efficient method of representing the machines in large power systems.

Initially, transient stability programs all ran in the time domain. A set of differential equations is developed to describe the dynamic behavior of the synchronous machines. These are linked together by algebraic equations for the network and any other part of the system that has a very fast response.

Later work involved looking at the response of the system, not to major disturbances but to the build-up of oscillations due to small disturbances and poorly set control systems. As the time involved for these disturbances to occur can be large, time domain solutions are not suitable and frequency domain models of the system were produced. Lyapunov functions have also been used, but good models have been difficult to produce. However, they are now of sufficiently good quality to compete with time domain models where quick estimates of stability are needed such as in the day to day operation of a system.

1.5 ***Load-flow Instability***

Two kinds of voltage instability have been associated with a load flow model: loss of control voltage instability and clogging voltage instability. Loss of control voltage instability is caused by exhaustion of reactive power supply that produces loss of voltage control on some of the generators or synchronous condensers. Loss of voltage control on these reactive supply devices implies both lack of any further reactive supply from these devices and loss of control of voltage that will increase network reactive losses that absorb a portion of the flow of reactive power supply and prevent it from reaching the sub region needing that reactive supply. Loss of voltage control develops because of equipment outages (generator, transmission line, and transformer), operating condition changes (wheeling, interchange, and transfer transactions), and load/generation pattern changes. Loss of control voltage instability occurs in the sub-transmission and transmission system. It produces either saddle node or singularity-induced bifurcation in a differential algebraic model. On the other hand, clogging develops because of increasing reactive power losses, and switching shunt capacitors and tap changers reaching their limits. These network reactive losses, due to increasing magnetic field and shunt capacitive supply withdrawal, can completely block reactive power supply from reaching the sub region with need. Clogging voltage instability can produce algebraic bifurcation in a differential algebraic model. The VSSAD method can diagnose whether the voltage instability occurs due to clogging or loss of control voltage instability for each equipment outage, transaction combination, or both that have no solution.

1.6 ***Defining of Important Terms:***

***Power system stability*:** The property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to converge to another acceptable state of equilibrium after being subjected to a disturbance. Instability occurs when the above is not true or when the system loses synchronism between generators and between generators and loads.

Small signal stability**:** The ability of the power system to maintain synchronism under small disturbances.

Transient stability**:** The ability of a power system to maintain synchronism for a severe transient disturbance.

Rotor angle stability**:** The ability of the generators in a power system to remain in synchronism after a severe transient disturbance.

Voltage viability**:** The ability of a power system to maintain acceptable voltages at all buses in the system after being subjected to a disturbance. Loss of viability can occur if voltage at some bus or buses is below acceptable levels. Loss of viability is not voltage instability.

Voltage stability**:** The ability of the combined generation and transmission system to supply load after a disturbance, increased load, or change in system conditions without an uncontrollable and progressive decrease in voltage . Loss of voltage instability may stem from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system. Both small signal and transient voltage instability can occur.

Voltage collapse**:** An instability that produces a cascading (1) loss of stability in subsystems, and/or (2) outage of equipment due to relaying actions.

CHAPTER TWO
NEWTON RAPHSON METHOD

Chapter two
Newton-Raphson's method

2.1 Introduction to Unbalanced Distribution Power Flow

Determination of the steady state behavior of the system is the foremost step to be performed. In power systems, this calculation is the steady state power flow problem.

Thus, a power flow study is a steady-state simulation of the power flows in power system circuits and can determine bus voltages and angles for specified system operating conditions. These operating conditions may be normal or emergency operating conditions, present or future conditions. The results of a power flow study can be used for planning, voltage profile, **KW** and **KVAR** losses, transformer tap settings, and to specify equipment and system capabilities and limitations. The power flow study is a very useful tool for system design and expansion, and for the economic planning and operation of large complex power systems. The power flow study is a first step in a stability study to establish power flows and machine power angles before the initiation of a disturbance.

The fields of power system optimization and distribution automation especially use this study, since they need repeated fast power flow solutions.

Cables in TDS (**T**errestrial **D**istribution **S**ystems) and SPS (**S**hipboard **P**ower **S**ystem) provide service to unbalanced three-phase, two-phase and single-phase loads. This service leads to unbalanced three-phase voltages and currents, which necessitate three-phase unbalanced power flow analysis. A terrestrial system and ship distribution system may consist of:

- **Three-phase primary main feeder**
- **Three-phase, two-phase, and single-phase laterals**
- **Inline transformers**
- **Shunt Capacitor Banks**
- **Distribution Transformers**
- **Three-phase, two-phase and single-phase loads**

Three different types of requirements can play a role in specifying the load; constant power, current, or voltage requirements.

The power flow equations are non-linear equations, and solving the equations requires iterative methods. The introduction of small capacity generators, called

Distributed Generators (DG), to the distribution systems necessitates that their modeling be included with other component models for the power flow analysis.

The load flow algorithm is used to determine the voltages and line flows for a large-scale power system from a given load and generation data. It is a very important and fundamental tool for the analysis of power systems and is used in operational as well as planning stages. The single-phase power flow methods are normally used in the systems that unbalances can be neglected. In distribution systems, however, the three phase balanced hypothesis cannot be applied. Therefore, a three-phase load flow algorithm with complete three-phase models is required for these cases. Additionally, it is important to solve the load flow problem as efficiently as possible since certain applications, particularly in distribution automation and optimization, require the solution of the load flow problem repeatedly.

Several load flow algorithms specially designed for distribution systems have been proposed in the literature .Those formulations can be divided into two categories. The first category was based on the general topology of a distribution system and used the bus voltages as state variables to solve the load flow problem. In this category, the most time-honored load flow method is the Gauss implicit Z-Bus method. This method has been implemented in many power companies and utilized by numerous applications. A fast-decoupled algorithm used the rectangular-form voltages as state variables and the Newton–Raphson (N-R) algorithm, which was developed to improve the execution time of the three-phase load flow, was proposed.

The second category was based on the special network structures of distribution systems. The author proposed a compensation-based technique for weakly meshed distribution networks. The radial parts are solved by a two-step procedure in which the branch currents are first calculated (backward sweep), and then, the bus voltages are updated (forward sweep). Branch power flows rather than branch currents were later used in the improved version. Extension of the method, with the emphasis on modeling unbalanced loads and dispersed generations, was presented.

One of the main disadvantages of the compensation-based methods is that in addition to the conventional bus-branch oriented data format, new data bases have to be built and maintained for these methods. Since the feeder-lateral based model is adopted, the “layer-lateral” based data format is required. In addition, the relationship between the system status and control variables cannot be expressed as a mathematical expression, which makes the applications of the compensation- based algorithm difficult.

The algorithm proposed in this paper is a “novel but classic” technique. The proposed method is classic since its input data is the same as the conventional bus-branch oriented data used by most utilities. The proposed method is also novel since it takes advantage of the topological characteristics of distribution systems and solves the distribution load flow efficiently. The proposed method is based on the N-R formulation and utilizes the branch voltage as state variables. By using those ideas, a constant Jacobian matrix can be developed, and the traditional N-R technique can be utilized to find the solution. Test results show that the proposed method is robust and very efficient compared with the conventional methods.

2.2 PROBLEM FORMULATION

Fig.1 shows a three-phase line section between bus ***i*** and ***j***. A 4X4 matrix, which takes into account the self and mutual coupling effects, can be expressed as (1).

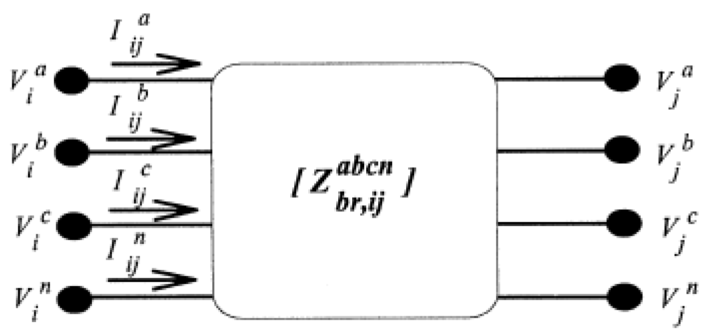

Fig. 1. Three-phase line section.

After Kron's reduction is applied, the matrix dimension will reduce to 3 X 3, whereas the effects of the neutral or ground wire are still included in this model, as shown in (2).

$$[Z_{br,ij}^{abcn}] = \begin{bmatrix} Z_{ij}^{aa} & Z_{ij}^{ab} & Z_{ij}^{ac} & Z_{ij}^{an} \\ Z_{ij}^{ba} & Z_{ij}^{bb} & Z_{ij}^{bc} & Z_{ij}^{bn} \\ Z_{ij}^{ca} & Z_{ij}^{cb} & Z_{ij}^{cc} & Z_{ij}^{cn} \\ Z_{ij}^{na} & Z_{ij}^{nb} & Z_{ij}^{nc} & Z_{ij}^{nn} \end{bmatrix} \quad (1)$$

$$[Z_{br,ij}^{abc}] = \begin{bmatrix} Z_{ij}^{aa-n} & Z_{ij}^{ab-n} & Z_{ij}^{ac-n} \\ Z_{ij}^{ba-n} & Z_{ij}^{bb-n} & Z_{ij}^{bc-n} \\ Z_{ij}^{ca-n} & Z_{ij}^{cb-n} & Z_{ij}^{cc-n} \end{bmatrix}. \quad (2)$$

For any phase failed to present, the corresponding row and column in this matrix will contain null-entries.

The relationships between bus voltages and branch currents as shown in Fig. 1 can be expressed as

$$\begin{bmatrix} V_j^a \\ V_j^b \\ V_j^c \end{bmatrix} = \begin{bmatrix} V_i^a \\ V_i^b \\ V_i^c \end{bmatrix} - \left[Z_{br,ij}^{abc}\right] \begin{bmatrix} I_{ij}^a \\ I_{ij}^b \\ I_{ij}^c \end{bmatrix}. \qquad (3)$$

Then

$$\left[V_{br,ij}^{abc}\right] = \left[Z_{br,ij}^{abc}\right]\left[I_{br,ij}^{abc}\right] \qquad (4a)$$

or

$$\left[I_{br,ij}^{abc}\right] = \left[Y_{br,ij}^{abc}\right]\left[V_{br,ij}^{abc}\right] \qquad (4b)$$

the branch voltages and branch currents between bus $\boldsymbol{i}$ and $\boldsymbol{j}$, respectively. $[Y_{br,ij}^{abc}]$ Is the admittance matrix of a three-phase line section between bus $\boldsymbol{i}$ and $\boldsymbol{j}$ can be obtained by inversing $[Z_{br,ij}^{abc}]$.

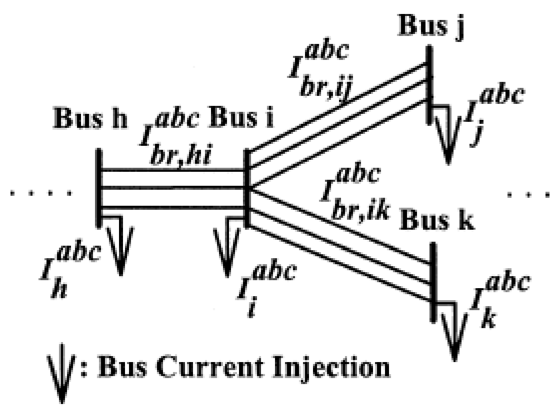

Fig. 2. Diagram of a distribution network.

Then, for a distribution network as shown in Fig. 2, the relationships between branch voltages and bus current injections for bus can be expressed as

$$\left[I_i^{abc}\right] = \left[Y_{br,hi}^{abc}\right]\left[V_{br,hi}^{abc}\right] - \left[Y_{br,ij}^{abc}\right]\left[V_{br,ij}^{abc}\right] - \left[Y_{br,ik}^{abc}\right]\left[V_{br,ik}^{abc}\right]. \qquad (5)$$

The relationships for other buses can be obtained similarly. From (5), it can be seen that a bus current injection can be expressed as a function of the branch admittance matrices and branch voltage vectors. The current-injection equations in the branch-voltage form can be expressed as

$$I_i^{cal} = h_i\left(V_{br,ij}^{abc}, Y_{br,ij}^{abc}\right) \quad j \in U_i', \ i = 1 \cdots N \qquad (6)$$

Where U_i' is the set of branches connected to bus $\boldsymbol{i}$, N is the bus number.

Since the current injections can be expressed as functions of the branch voltages and line parameters, it provides a possibility to use branch voltages as state variables and to solve the load flow problem.

2.3 FORMULATION DEVELOPMENTS:

At each bus ***i***, the complex load S_i is specified by

$$S_i = (P_i^{\text{spec}} + jQ_i^{\text{spec}}) \quad i = 1 \cdots N \qquad (7)$$

and the corresponding specified current injection at the ***k***th iteration is

$$I_i^{(k),spec} = \left(\frac{P_i^{\text{spec}} + jQ_i^{\text{spec}}}{V_i^{(k)}} \right)^* \qquad (8)$$

where $I_i^{(k),\text{spec}}$ and $V_i^{(k)}$ are the specified current injection and voltage of bus ***i*** at the ***k***th iteration of the solution procedure. The current injection mismatch (CIM) equations are

$$CIM_i^{(k)} \left(V_{br}^{(k)}, Y_{br} \right) = I_i^{(k),\text{spec}} - I_i^{(k),cal} \quad i = 1 \cdots N. \qquad (9)$$

Combining the CIM equations and N-R algorithm, the proposed novel algorithm can be developed. Taylor’s series expansions for the mismatch functions are the basis for the N-R method of solving the power flow problem. By using branch voltages as state variables, the complex Jacobian matrix and mismatch equation can be obtained as

$$\left[\frac{\partial CIM}{\partial V_{br}} \right]^{(k)} [\Delta V_{br}]^{(k)} = \left[0 - CIM \left(V_{br}^{(k)}, Y_{br} \right) \right]$$

$$\Rightarrow [J] [\Delta V_{br}]^{(k)} = \left[-CIM \left(V_{br}^{(k)}, Y_{br} \right) \right] \qquad (10a)$$

$$[V_{br}]^{(k+1)} = [V_{br}]^{(k)} + [\Delta V_{br}]^{(k)} \qquad (10b)$$

Where $[V_{br}]$ is the vector of branch voltages, and $\Delta[V_{br}]$ is the correction vector of branch voltages. By differentiating (9) with respect to the branch voltages, the Jacobian matrix can be obtained. Using the line admittance matrix as the building-block matrix, i.e., 3X 3 matrix for a three phase line section, 2X 2 matrix for a double-phase line section, and 1X 1 matrix for a single-phase line section, the Jacobian matrix can be built according to the following rules.

2.4 *Jacobian Matrix Building*

The N-R method is typically applied on the real form of the power-flow equations:

$$\left.\begin{aligned} P_i &= \sum_{k=1}^{n} |V_i||V_k||y_{ik}|\cos(\delta_k - \delta_i + \gamma_{ik}) = f_{ip} \\ Q_i &= -\sum_{k=1}^{n} |V_i||V_k||y_{ik}|\sin(\delta_k - \delta_i + \gamma_{ik}) = f_{iq} \end{aligned}\right\} \quad i = 1, \ldots, n$$

….(11)

Assume, temporarily, that all busses, except bus 1, are of the "load" type. Thus, the unknown parameters consist of the (*n* _ 1) voltage phasors, , . . . , . In terms of real variables, these are:
Angles _2, _3, . . . , _*n* (*n* _ 1) variables
Magnitudes _*V*2_, _*V*3_, . . . , _*Vn*_ (*n* _ 1) variables

$$\begin{bmatrix} \Delta P_2^{(0)} \\ \Delta P_3^{(0)} \\ \vdots \\ \Delta P_n^{(0)} \\ \Delta Q_2^{(0)} \\ \Delta Q_3^{(0)} \\ \vdots \\ \Delta Q_n^{(0)} \end{bmatrix} = \begin{bmatrix} \frac{\partial f_{2p}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{2p}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{2p}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{2p}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{2p}}{\partial |V_n|}\Big|^{(0)} \\ \frac{\partial f_{3p}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{3p}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{3p}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{3p}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{3p}}{\partial |V_n|}\Big|^{(0)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_{np}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{np}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{np}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{np}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{np}}{\partial |V_n|}\Big|^{(0)} \\ \frac{\partial f_{2q}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{2q}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{2q}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{2q}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{2q}}{\partial |V_n|}\Big|^{(0)} \\ \frac{\partial f_{3q}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{3q}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{3q}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{3q}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{3q}}{\partial |V_n|}\Big|^{(0)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_{nq}}{\partial \delta_2}\Big|^{(0)} & \frac{\partial f_{nq}}{\partial \delta_3}\Big|^{(0)} & \cdots & \frac{\partial f_{nq}}{\partial \delta_n}\Big|^{(0)} & \frac{\partial f_{nq}}{\partial |V_2|}\Big|^{(0)} & \cdots & \frac{\partial f_{nq}}{\partial |V_n|}\Big|^{(0)} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^{(0)} \\ \Delta \delta_3^{(0)} \\ \vdots \\ \Delta \delta_n^{(0)} \\ \Delta |V_2|^{(0)} \\ \Delta |V_3|^{(0)} \\ \vdots \\ \Delta |V_n|^{(0)} \end{bmatrix} \quad (12)$$

Before proceeding any further, we need to account for voltage-controlled busses. For every voltage-controlled bus in the system, delete the corresponding row and column from the Jacobian matrix. This is done because the mismatch element for a voltage controlled bus is unknown.

2.5 N-R Algorithm

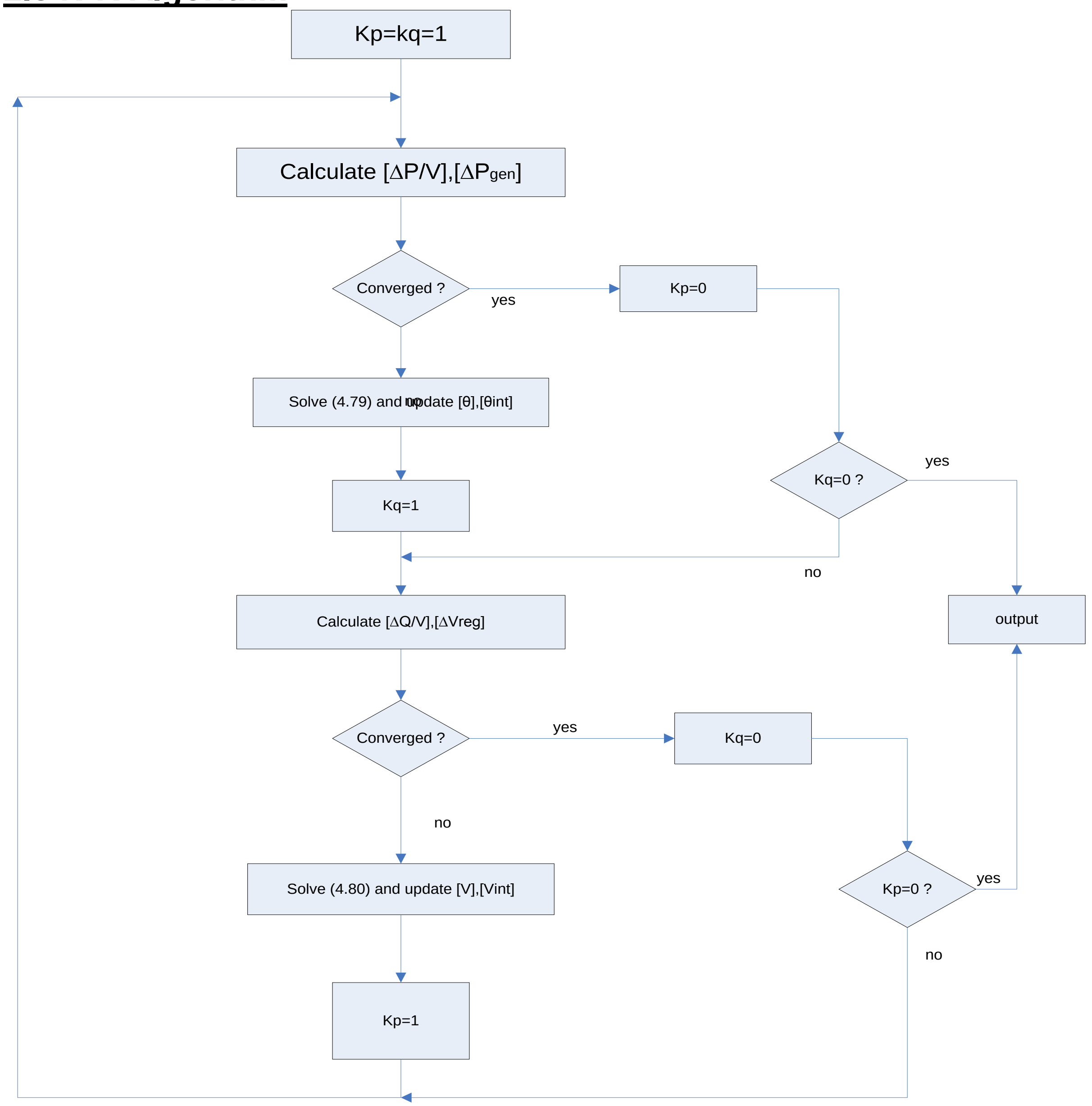

Fig.3 newton flow chart

Step 0. Formulate and Assemble Ybus in Per Unit

Step 1. Assign Initial Guesses to Unknown Voltage Magnitudes and Angles for a Flat Start

_V_ _ 1.0, _ _ 0

Step 2. Determine the Mismatch Vector _U for Iteration **k**

Step 3. Determine the Jacobian Matrix J for Iteration **k**

Step 4. Determine Error Vector _X from Eq. (55)

Set **X** at iteration (*k* _ 1): **X**(*k*_1) _ **X**(*k*) _ _**X**(*k*). Check if the power mismatches are within tolerance. If so, go to Step 5. Otherwise, go back to Step 2.
Step 5. Find Slack Bus Power* PG *and* QG *from Eqs. (27) and (28)
Step 6. Compute Line Flows Using Eqs. (39) and (40) and the Total Line Losses from Eq. (41)

2.6 Decoupled and Fast Decoupled load-flow solution

The paper presents a new fast, reliable and relatively simple Decoupled Quadratic Load Flow (DQLF) algorithm for Q-adjustments in power flow solutions. Q-adjusted solutions are inevitable for reactive power planning and management studies. For solving power flow problems, the Fast Decoupled Load Flow (FDLF) is probably the most popular, because of its efficiency. But for Q-adjusted studies, the matrix updating problem associated with B" matrix remains unresolved. Refactorization of B" matrix demands more CPU time. The proposed approach eliminates formation and refactorization of B" matrix, for both well behaved and ill-conditioned systems of Q unadjusted and adjusted cases. The new method minimizes the computational burden by solving for the bus-bar voltage magnitudes (V) using a non-linear quadratic equation and it reduces the execution time significantly.

The solution of this non-linear equation undoubtedly offers better solution than that of a linear version. Improved and reliable convergence on normal and ill-conditioned system is expected. Enforcement of Q-limits is also very simple and effective. The proposed algorithm also proved to handle large degrees of ill-conditioning in Q-adjusted studies compared to the standard FDLF model. The performance of the proposed model is investigated by a number of case studies on IEEE test systems (14, 30, 57 & 118 bus) and results are reported for IEEE 118 bus system. The results indicate the established better convergence and reliability of the proposed model. It is at least 50% faster than the traditional FDLF model for Q-adjusted case studies.

CHAPTER THREE
THREE-PHASE LOAD FLOW

Chapter three

3.1Three phase Load Flow

For most purposes in the steady state analysis of power, the system unbalance can be ignored and the single phase analysis described in pervious sections is adequate. However, in practice it is uneconomical to balance the load completely or to achieve perfectly balanced transmission system impedance, as a result of un-transposed high voltage lines and lines sharing the same right of way for considerable lengths.

A realistic assessment of the unbalanced operation of an interconnected system, including the influence of any significant load unbalance, requires the use of three phase load flow algorithms. The object of the three phase load flow is to find the state of the three phase power system under the specified condition of load, generation and system configuration.

The basic three phase models of system plant and the rules for their combination into overall network admittance matrices can be used as the frame work for the three phase load flow.

The storage and computational requirements of a three phase load flow program are much greater than those of the corresponding single phase. The need for efficient algorithms is, therefore, significant even though in contrast to single phase analysis, the three phase load flow is likely to remain a planning, rather than an operational.

3.2 Derivation of equations

The three phase system behavior is described by the equation

$$[I] - [Y][V] = 0 \quad ....(1)$$

Where the system admittance matrix [Y], represents each phase independently and models all inductive and capacitive mutual couplings between phases and between circuits. The mathematical statement of the specified conditions is derived in terms of the system admittance matrix

$$[Y] = [C] + j[B] \quad \ldots\ldots.(2)$$

as follow:

(i) For each of the three phase (P) at every load and generator terminal busbar(i)

$$\Delta P_i^p = (P_i^p)^{sp} - P_i^p$$

$$= (P_i^p)^{sp} - V_i^p \sum_{k=1}^{n} \sum_{m=1}^{3} V_k^m \{G_{ik}^{pm} \cos\theta_{ik}^{pm} + B_{ik}^{pm} \sin\theta_{ik}^{pm}\} \quad (3)$$

And

$$\Delta Q_i^p = (Q_i^p)^{sp} - Q_i^p$$

$$= (Q_i^p)^{sp} - V_i^p \sum_{k=1}^{n} \sum_{m=1}^{3} V_k^m \{G_{ik}^{pm} \sin\theta_{ik}^{pm} - B_{ik}^{pm} \cos\theta_{ik}^{pm}\}$$

(4)

(ii)For every generator j, with the exception of the slack machine, i.e.

$$j \neq nb + ng$$

$$(\Delta P_{gen})_j = (P_{gen}^{sp})_j - (P_{gen})_j$$

$$= (P_{gen}^{sp})j - \sum_{p=1}^{3} V_{int} \sum_{k=1}^{n} \sum_{m=1}^{3} V_k^m \,[G_{jk}^{pm} cos\theta_{jk}^{pm} + B_{jk}^{pm} sin\theta_{jk}^{pm}] \quad \ldots\ldots.(5)$$

Where, although the summation for k is over all system busbars, the mutual terms G_{jk} and B_{jk} are non- zero only when k is the terminal busbar of the jth generator.

It should be noted that the real power specified for the generator is the total real power at the internal or excitation busbar whereas in actual practice the specified quantity is the power leaving the terminal busbar. This, in effect, means that the generator's real power loss is ignored.

The generator losses have no significant influence on the system operation and may be calculated from the sequence impedances at the end of the load flow solution, when all generator sequence currents have been found. Any other method would require the real power mismatch to be written at busbars remote from the variable in question.

That is, sum of the powers leaving the generator may be calculated in exactly the same way and by the same subroutines as power mismatches at other system busbars. This is possible because the generator internal busbar not connected to any other element in the system. Inspection of the Jacobean sub matrices derived later will show that this feature is retained throughout the study. In terms of programming, the generators present to additional complexity.

Equation (3) to (5) from the mathematical formulation on the three phase load flow as a set of independent algebraic equations in terms of the system variables.

The solution to the load flow problem is the set of variables which upon substitution make the left hand side mismatches in Equations (3) to (5) equal to zero.

3.3 Decoupled three phase algorithm

The standard Newton- Raphson algorithm may be used to solve Equations (3) to (5). This involves an iterative solution of the matrix equation:

$$\begin{bmatrix} \Delta p \\ \Delta p_{gen} \\ \Delta Q \\ \Delta V_{reg} \end{bmatrix} = \begin{bmatrix} A & E & I & M \\ B & F & J & N \\ C & G & K & P \\ D & H & L & R \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta\theta_{int} \\ \Delta V/V \\ \Delta V_{int}/\Delta V_{int} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

For the right hand side vector of variable updates; the right hand side matrix in Equation (6) is the Jacobian matrix of first order partial derivatives.

Following decoupled single phase load flow practice, the effects of $\Delta\theta$ on reactive power flows and ΔV on real power flows are ignored. Equation (6) may therefore be simplified by assigning.

$$[I] = [M] = [J] = [N] = 0$$

And

$$[C] = [G] = 0$$

In addition, the voltage regulator specification is assumed to be in terms of the terminal voltage magnitudes only and therefore:

$$[D] = [H] = 0$$

Equation (6) may then be written in decoupled from as:

$$\begin{bmatrix} \Delta p_i^p \\ \Delta p_{gen} \end{bmatrix} = \begin{bmatrix} A & E \\ B & F \end{bmatrix} \begin{bmatrix} \Delta\theta_k^m \\ \Delta\theta_{inti} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

For I, k= i.nb and j.l= l,ng-l (i.e. excluding the slack generator)

$$\begin{bmatrix} \Delta Q_i^p \\ \Delta V_{reg.f} \end{bmatrix} = \begin{bmatrix} K & P \\ L & R \end{bmatrix} \begin{bmatrix} \Delta V_k^m \\ \Delta V_{inti}/\Delta V_{inti} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

For l,k =l,nb and j,l = l,ng (i.e. excluding the slack generator)

To enable further development of the algorithm, it is necessary to consider the Jacobian sub-matrices in more details.

In deriving these Jacobians from Equations (3) to (5) it, must be remembered that

$$V_l^1 = V_l^2 = V_l^3 = V_{int\ l}$$

$$\theta_l^1 = \theta_l^2 - \frac{2\pi}{3} = \theta_l^3 + \frac{2\pi}{3} = \theta_{int\ l}$$

When l refers to a generator internal busbar.

The coefficients of matrix Equation (7) are:

$$[A_{ik}^{pm}] = [\partial \Delta p_i^p / \partial \theta_k^m]$$

Or:

$$A_{ik}^{pm} = V_i^p V_k^m [G_{ik}^{pm} sin\theta_{ik}^{pm} - B_{ik}^{pm} cos\theta_{ik}^{pm}]$$

Except for:

$$A_{kk}^{mm} = -B_{kk}^{mm} (V_k^m)^2 - Q_k^m$$

$$[B_{ik}^m] = [\partial \Delta p_{gen\ j} / \partial \theta_k^m]$$

$$= \sum_{p=1}^{3} V_{int\ j} V_k^m [G_{jk}^{pm} sin\theta_{jk}^{pm} - B_{jk}^{pm} cos\theta_{jk}^{pm}]$$

$$[E_{il}^p] = [\partial p_i^p / \partial \theta_{int\ l}]$$

$$= \sum_{m=1}^{3} V_{int\ j} V_i^p [G_{il}^{pm} sin\theta_{il}^{pm} - B_{il}^{pm} cos\theta_{il}^{pm}]$$

$$[F_{jl}] = [\partial P_{gen} / \partial \theta_{int\ l}]$$

Where $[F_{jl}] = 0$ for all $j \neq l$ because the jth generator has no connection with the lth generator's internal busbar, and

$$[F_{il}] = \sum_{p=1}^{3} \left(-B_{ll}^{pp} (V_{int\ l})^2 - Q_1^p\right) + \sum_{\substack{m=i \\ m \neq p}}^{3} \sum_{p=1}^{3} (V_{int\ l})^2 [C_{ll}^{pm} sin\theta_{ll}^{pm} - B_{ll}^{pm} cos\theta_{ll}^{pm}]$$

The coefficients of matrix Equation (8) are

$$-[K_{ik}^{pm}] = V_k^m [\frac{\partial \Delta Q_i^p}{\partial V_k^m}]$$

Where

$$K_{ik}^{pm} = V_k^m V_i^p [G_{ik}^{pm} sin\theta_{ik}^{pm} - B_{ik}^{pm} cos\theta_{ik}^{pm}]$$

Except

$$K_{kk}^{mm} = -B_{kk}^{mm}(V_k^m)^2 + Q_k^m$$

$$-[P_{il}^p] = V_{int\ l}[\partial\Delta Q_i^p / V_{int\ l}]$$

$$= V_{int\ l} \sum_{m=1}^{3} V_i^p [G_{il}^{pm} sin\theta_{il}^{pm} - B_{il}^{pm} cos\theta_{il}^{pm}]$$

Although the above expressions appear complex, their meaning and derivation are similar to those of the usual single phase Jacobian elements.

3.4 Jacobian approximations

Approximations similar to those applied to the single phase load flow are applicable to the Jacobian elements as follows:

(i) At all nodes (i.e. all phases of all busbars)

$Q_k^m \ll B_{kk}^{mm}(V_k^m)^2$

(ii) Between connected nodes of the same phase.

$cos\theta_{ik}^{mm} \approx 1$ i.e. θ_{ik}^{mm} is small

And:

$G_{ik}^{mm} sin\theta_{ik}^{mm} \ll B_{ik}^{mm}$

(iii) Moreover, the phase – angle unbalance at any busbar will be small and hence an additional approximation applies to the three phase system. i.e.

$$\theta_{kk}^{pm} \approx \mp 120^\circ \text{ for } p \neq m$$

(iv) Finally, as a result of (ii) and (iii), the angle between different phases of connected busbars will be approximately 120^0. i.e.

$$\theta_{ik}^{pm} \approx \pm 120^\circ \text{ For } p \neq m$$

Or

$cos\theta_{ik}^{pm} \approx -0.5$

And

$sin\theta_{ik}^{pm} \approx \pm 0.866$

The final approximation (iv), necessary if the Jacobians are to be kept constant, is the least valid, as the cosine and sine values change rapidly with small angle variations around $120°$. This accounts for the slower convergence of the phase unbalance at busbars as compared with that of the voltage magnitudes and angles.

It should be emphasized that these approximations apply to the Jacobian elements only, i.e. they do not prejudice the accuracy of the solution nor do they restrict the type of problem which may be attempted.

Applying approximations (i) to (iv) the Jacobians and substituting into Equations (7) and (8) yields.

$$\begin{bmatrix} \Delta P_i^p \\ \Delta P_{gen\ j} \end{bmatrix} = \begin{bmatrix} [V_i^p M_{ik}^{pm} V_k^m] & \left[\sum_{m=1}^{3} V_i^p M_{il}^{pm} V_{int\ l}\right] \\ \left[\sum_{p=1}^{3} V_{int\ l} M_{ik}^{pm} V_k^m\right] & \left[\sum_{m1}^{3} \sum_{p=1}^{3} V_{int\ l} M_{jl}^{pm} V_{int\ l}\right] \end{bmatrix} \begin{bmatrix} \Delta\theta_k^m \\ \Delta\theta_{int\ l} \end{bmatrix} \quad \text{.........(9)}$$

And:

$$\begin{bmatrix} \Delta Q_i^p \\ \Delta V_{reg\ j} \end{bmatrix} = \begin{bmatrix} [V_i^p M_{ik}^{pm} V_k^m] & \left[\sum_{m=1}^{3} V_i^p M_{il}^{pm} V_{int\ l}\right] \\ V_k^m [L'] & [0] \end{bmatrix} \begin{bmatrix} \Delta V_k^m / V_k^m \\ \Delta V_{int\ l} / V_{int\ l} \end{bmatrix} \quad \text{................(10)}$$

Where:

$M_{ik}^{pm} = G_{ik}^{pm} sin\theta_{ik}^{pm} - B_{ik}^{pm} cos\theta_{ik}^{pm}$

With:

$\theta_{kk}^{mm} = 0$

$\theta_{ik}^{mm} = 0$

$$\theta_{ik}^{pm} = \pm 120° \text{ for } p \neq m$$

All terms in the matrix [M] are constant, being derived solely from the system admittance matrix. Matrix [M] is the same as matrix [-B] except for the off- diagonal terms which connect nodes of different phases. These are modified by allowing for the nominal 120° angle and also including the $G_{ik}^{pm} sin\theta_{ik}^{pm}$ terms

The similarity in structure of all Jacobian sub-matrices reduces the programming complexity normally found in three phase load flows. This uniformity has been achieved primarily by the method used to implement the three phase generator constrains.

The above derivation closely parallels the single phase fast decoupled algorithm but the added complexity of the notation obscures this feature. At the present stage, the Jacobian elements in Equations (9) and (10) are identical except for those terms which involve the additional features of the generator modeling.

These functions are more linear in terms of the voltage magnitude [ ] than are the functions [Δ] and [Δ]P. In the QNewton Raphson and related constantV Jacobian methods, the reliability and speed of convergence improve with the linearity of the defining functions. With this aim, Equation (9) and (10) are modified as follows:

- The left- hand side defining functions are redefined as $(\Delta P_i^p / V_i^p)$ $(\Delta P_{gen}/V_{int\ j})$ and $(\Delta Q_i^p / V_i^p)$
- In Equation (9), the remaining right hand side V terms are set to I p.u.
- In Equation (10), the remaining right- hand side V terms are cancelled by the corresponding terms in the right- hand side vector.

Therefore, the Jacobian matrices $[B']$ and $[B"]$ in Equations (11) and (12) have been approximated to constants.

Based on the reasoning of soft and Alsace, which proved successful in the single phase load flow, the $[B']$ matrix in Equation (11) can be further modified by omitting the representation of those elements that predominantly affect MVAR flows.

In single phase load flows, the shunt capacitance is the positive sequence capacitance which is determined from both the phase- to- phase and the phase- to-earth capacitances of the line. It, therefore, appears that the entire shunt capacitance matrix predominantly affects MVAR flows only. Thus, following single phase fast decoupling practice, the representation of the entire shunt capacitance matrix is omitted in the formulation of $[B']$. This increases dramatically the rate of real power convergence. However, as compared with the balanced load flow: this convergence rate deteriorates requiring on average, twice as many iterations.

With coactively- coupled three phase lines, the interline capacitance influences the positive sequence shunt capacitance. However, as the values of interline capacitances are small in comparison with the self capacitance of the phases, their inclusion makes no noticeable difference.

CHAPTER FOUR
ALGORITHM

Chapter four

4.1Algorithm description

First, the data is read and then the buses/nodes are renumbered by the algorithm (slack bus often taken as number one). The algorithm proceeds from the bus-bars powers (active and reactive) , so the load flow algorithm runs to calculate complex voltages (|V| and θ) which initially given 1 pu and zero respectively.
These results found implicitly from adding the difference of voltages and angles to the initial values and use the result as initial values and repeat this algorithm until find good optimization or make the desired iterations.

4.2 Flow diagram of basic load flow algorithm

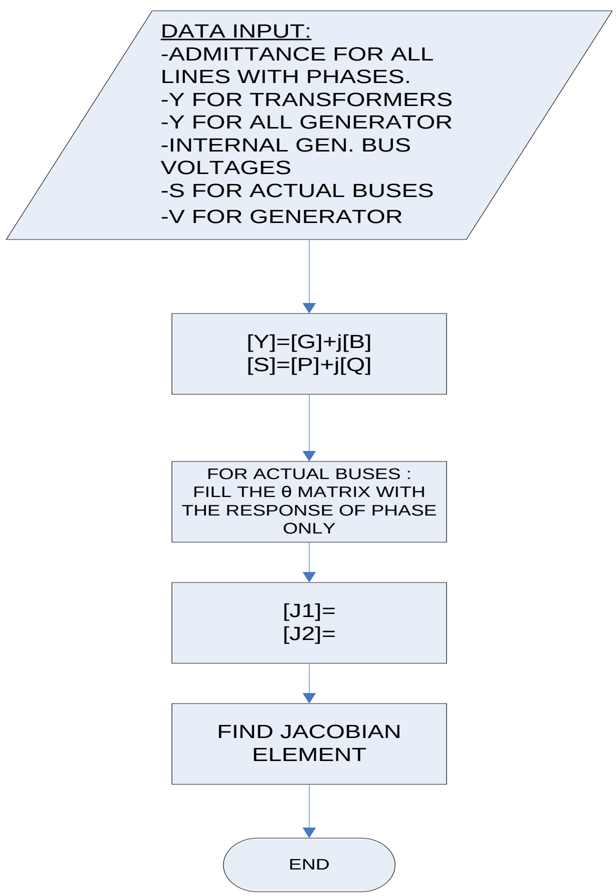

Fig1 :Input the data flow chart

The fully detailed operation described by the next flow-chart:

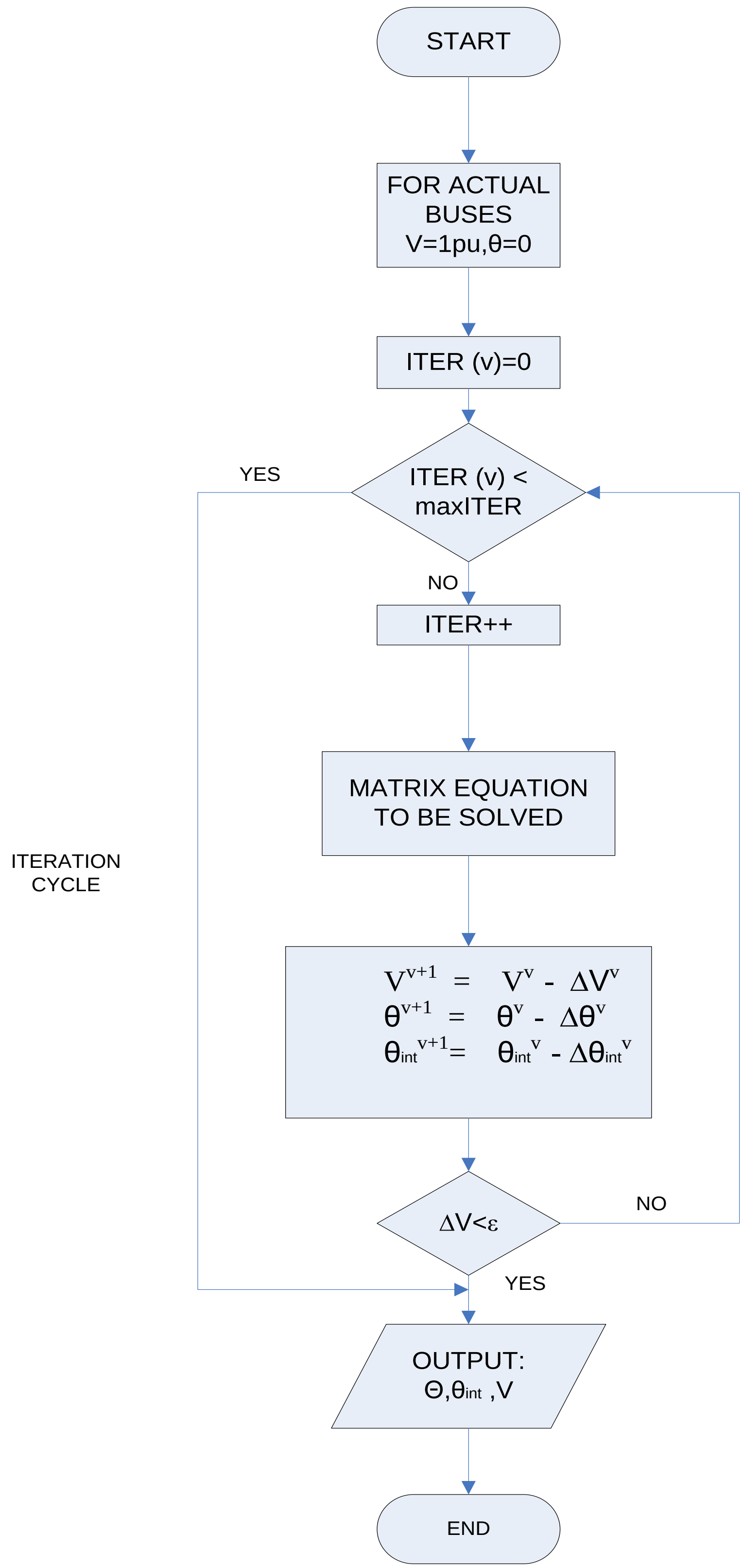

Fig2: Decoupled Newton-Raphson algorithm flow-char

CHAPTER FIVE
CONCLUSION

chapter 5
conclusion

5.1 project overview

It has been shown in this work that the unbalanced three phase load flow study of a given network can be solved to give the flow in any phase within a line.

Using Not very complicated matlab code, which take in consider the unbalance of the load and the unbalance of the transmission line impedance.

The significance of such a code is that, the load is no longer needed to be balance and there is no longer need to use perfectly balanced transmission system impedance as result of untransposed high voltage and line sharing the same right-of-way for Considerable length of the line.
Also in many cases it is uneconomical to have this complete balance.

5.2*Future Research*

Research is needed to:
1. Develop improved nonlinear dynamic load models that are valid at any particular instant and that are valid when voltage decline is severe. The lack of accurate load models makes it difficult to accurately simulate the time behavior and/or assess the cause of the voltage instability. The lack of knowledge of what constitutes an accurate load model makes accurate postmortem simulation of a particular blackout a process of making trial and error assumptions on the load model structure to obtain as accurate a simulation as possible that conforms with time records of the event. Accurate predictive simulation of events that have not occurred is very difficult.
2. Explain (a) why each specific cascading sequence of bifurcations inevitably occurs in a differential algebraic model, and (b) the dynamic signature associated with each bifurcation sequence. Work is underway to explain why instability in generator and load dynamics can inevitably cause a singularity induced bifurcation to occur.
3.Develop a protective or corrective control for voltage instability. A protective control would use constraints on the current operating condition for contingencies predicted to cause voltage instability if they occurred. These constraints on the current operation would prevent voltage instability if and when the contingency occurred. A corrective control would develop a control that correct the instability in the bifurcation subsystems experiencing instability only after the equipment outages or operating changes predicted to produce voltage instability have occurred.

References

[1] W. H. Kersting, W. H. Phillips, and W. Carr, "**A new approach to modeling three-phase transformer connections**,"

[2] IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 17, NO. 4, NOVEMBER 2002 Jen-Hao Teng, *Member*, *IEEE*, and Chuo-Yean Chang

[3] **POWER SYSTEM ANALYSIS course** *Professor Tom Overbye*

[4] **DEVELOPMENT OF POWER FLOW WITH DISTRIBUTED GENERATORS AND RECONFIGURATION FOR RESTORATION OF UNBALANCED DISTRIBUTION SYSTEMS** By ***Sarika Khushalani***

[5] **Power System Analysis**, Arthur R. Bergen & Vijay Vittal

[6] **Power System Analysis Short-Circuit Load Flow and Harmonics** *J. C. Das Amec, Inc. Atlanta, Georgia*

[7] Computer modelling of power system

APPENDIX