Chapter - I
CHAPTER - 1

INTRODUCTION

1.1 Introduction

As recently as 1955 all electrical network problems, usually restricted to small networks, were solved either by long hand or by a network analyzer. The advent of digital computers made the investigation of large networks possible. The superiority of the network analyzer as a tool for educating electrical power system operating and system planning personnel is justified, since the network response to various combinations of voltage levels and phase angles can readily be observed. However, because of the speed and larger capability of computer programs and the almost universal availability of digital computers, the computer is far more superior and economical for detailed analytical studies of large systems.

The availability of the digital computers radically changed the mathematical approaches for network solution. In order to use computers for the solution of power system problems, the problems must be defined precisely and the objectives determined. Once a problem has been defined, a mathematical model has to be developed to represent the physical system. The model must describe the characteristics of individual network components as well as the relations that govern the inter-connections of these elements. Matrices are amenable to computer programming and a network matrix equation provides a convenient mathematical model for a digital computer solution.

The form of the network matrix depends on the selection of a suitable frame of reference, viz. bus or loop. The formation of appropriate network matrix is an integral part of a digital computer program for the solution of power system problems. The bus impedance matrix for a given power system is normally obtained by either inverting the bus admittance
matrix or is formed by a building algorithm. In the recent past, the use of the bus impedance matrix for power system studies was not favoured because of the longer time required to form the impedance matrix and the greater storage space required to store the full impedance matrix. However, a survey of literature reveals that the bus impedance matrix may be used advantageously as the model of the power system for solution of several problems.

Load flow study is a fundamental study carried out on a power system and it forms the basis for several other planning and operational studies. A lot of research has been carried out in this area and several fast and efficient algorithms have been proposed; and efforts are still continuing to develop algorithms which are faster, reliable and require less computer memory. Fast decoupled load flow (FDLF) models, second order load flow models and exact decoupled load flow model have been developed to improve the convergence properties and reliability on the one hand, and reducing the memory requirements on the other. Several versions of Constant Jacobian models have also been proposed to affect a reduction in computer time and memory.

Digital computers are being used for continuous monitoring and analysis of interconnected power systems. For secure and on-line control of a power system, the latest state of the power system is continually needed. This state of the power system is used by the modern control centers to perform several other studies in addition to implement appropriate control strategies. To obtain a reliable data base for every power system, state estimators were developed. State estimator is a data processing algorithm which processes a set of redundant measurements obtained from various measuring devices installed all over the power system and gives out a reliable estimate of the power system state. This objective is currently achieved by two techniques. In the first, the real and reactive injections are used to obtain an approximate system state and then line flows are used to improve the state. In the second approach, a statistical method based on the weighted least squares (WLS) estimator is used. The problem of state estimation is a real-time problem and, therefore, efficient, fast, and reliable models were developed based on Gauss-Seidel (GS), Newton-Raphson (NR), fast
decoupled and exact decoupled methods. Once the state of the system is obtained from a reliable estimator, it is used for security and optimisation studies of the power system and also to implement control.

An important obligation of a power system engineer is to supply a good quality, reliable and continuous power supply. This requires that the power system be operated in a secure state under all circumstances. Hence, security assessment studies are to be carried out under various possible contingencies which may occur in a power system. These studies basically consist of the analysis of a power system under disturbed conditions. The disturbance may be caused by the outage of power system component, e.g., a line, a transformer or a generator. Several methods are available for calculating the state of the system under conditions of outage of any of the above three elements. A full load flow can be used to estimate the system state after modifying the system model for the outage under consideration. Sensitivity matrix approaches have also been proposed for solving the outage problem. However, it may not be necessary to study the effect of the outage of each element if the severity of this contingency is known apriori. Several methods for ranking the contingencies on the basis of severity are available. They are based on the load flow methods, the performance index methods, the local solution methods and the methods employing distribution factors. As some of these methods are found to be unreliable and they sometimes misrank the contingencies, attention is currently being directed towards the development of more reliable and efficient methods for ranking critical contingencies.

In this Chapter, state of the art and motivation of the proposed work is discussed in Section 1.2. In Section 1.3 organisation of the thesis is explained.

1.2 State of the Art and Motivation of the present work

Modern power systems are probably the largest real physical systems in existence today. Therefore, any meaningful study will have to be restricted to few aspects only. It may be noticed that the Y-Bus models are easy to assemble. However, Z-Bus models, though requiring
more memory and assembly time, convey more meaningful information in the sense that they result in reduced complexity and solution time. In the following study, applications of Z-Bus models for developing efficient algorithms have been demonstrated.

Bus impedance matrix can be built by any one of the following methods:
- inverting the bus admittance matrix
- non-singular transformations and
- graph theoretic approach

Glimn et. al. [63] developed a power system model using the driving point impedance and transfer impedances for network calculations. They used nodal currents to calculate the above impedances for the network. Byerly et. al. [23], [24] developed a method for calculation of network impedances using digital computers. Hale et. al. [66] also presented a digital computation method to compute the driving point and transfer impedances. Brown et. al. [21] presented a building algorithm to construct the bus impedance matrix, and, till date, the same algorithm or its modifications are used by the researchers to build the system bus impedance matrix. Baumann [11] presented a method for the generation of impedance matrix based on network topology. Reitan et. al. [140] proposed a method to modify the bus impedance matrix for system changes involving mutual couplings.

Due to the large storage space required to store the complete bus impedance matrix and the greater computational time required to construct the \( Z_{\text{bus}} \), initially the use of \( Z_{\text{bus}} \) was not encouraged for many power system problems. However, later it was realized that \( Z_{\text{bus}} \) can be used very efficiently for the short circuit studies as well as the stability studies. Even for some outage studies, the use of bus impedance matrix is preferred. Hence, an attempt has been made, in this thesis, to develop algorithms for building the bus impedance matrix in lesser time as compared to the algorithm proposed by Brown et. al. [21].

The algorithms and programs to solve the power flow problem have steadily improved over the last three decades in terms of speed and reliability. The difficulties and the importance of the load flow problem have fascinated mathematicians and engineers throughout the world.
for a number of years. Many people have devoted a large portion of their professional lives
to the solution of the problem. It has received more attention than all the other power system
problems combined. The amount of effort devoted to the problem has resulted in an enormous
amount of technical literature. The nature of the problem, probably, precludes the development
of a perfect procedure. The brief introduction given here is only to highlight the most popular
techniques.

First successful load flow program was developed by Ward and Hale [183]. They used
the nodal formulation of the problem and solved the simultaneous quadratic equations that
describe the electrical network by a modified Newton iterative procedure. The success of
the Ward and Hale method was quickly accepted by power engineers and a number of
papers by Glimn and Stagg [62], Brown and Tinney [22], and others, proposed modifications
to the algorithm; also, they incorporated additional features in their programs. Stott [170]
gives an excellent review of the load flow methods developed before 1974. Among the
Y-matrix iterative methods GS method was the most popular because of its simplicity and
low storage space requirements. But as the size of the systems grew, this method was found
to be unsuitable because of the longer solution time and poor convergence due to the presence
of lines having large R/X ratios or lines having large series capacitance.

Z-matrix methods have been used to overcome the problem of long solution time and
poor convergence of the Y-matrix GS method. But, the Z-matrix was subsequently discarded
because of the large storage requirement of the full Z-matrix. However, the problem of
severe storage was overcome by tearing the system into sub-systems and applying the
diakoptics techniques of Kron [94]. The initial Z-matrix building time being very large as
compared to the Y-matrix building, the search for another load flow techniques based on
the Y-matrix continued.

The NR method of solution for the load flow problem was unveiled by Van Ness
[177]. This method involves linearisation of load flow equations during each iteration. In
spite of its quadratic convergence characteristics, its storage requirement is large.
Stott and Alsac [169] made a significant contribution by proposing the FDLF method. This method employs P-δ and Q-V decoupling. Use of decoupling techniques reduces the memory requirement of the Jacobian and the time per iteration as compared to the standard Newton’s method. Later, decoupled methods in rectangular coordinates were also proposed, taking advantage of the fact that lesser computation time is required for rectangular coordinates as compared to its polar counterpart. Rao et. al. [138] discussed the convergence criterion of FDLF methods.

Sachdev and Medicherla [146] proposed a second order load flow model in polar coordinates retaining the first three terms of Taylor series expansion and neglecting the remaining higher order terms. Iwamoto and Tamura [81] proposed a second order load flow model in rectangular coordinates. This method is exact because it retains all the terms of Taylor series expansion. However, this method requires large time and memory to solve large problems, although it is very reliable and accurate. Based on the second order load flow model in rectangular coordinates, an exact decoupled load flow model was developed by Quintana [128]. In spite of its high reliability, this method did not find popular acceptance because of its larger time and memory requirements. An improved and accurate method was later developed by Rao et. al. [136]. This method is a hybrid load flow method and uses the $Z_{bus}$ model for PQ buses and the second order load flow model in rectangular coordinates for PV buses and has a memory requirement comparable to that of the FDLF method while being faster than FDLF for ill-conditioned systems.

Ekwue et. al. [44], Keyhani et. al. [88] and Mohammed [113] presented comparative studies of various load flow methods available in polar and rectangular coordinates. Singh et. al. [158] proposed a constant matrix model of load flow in rectangular coordinates using the matrix similar to polar FDLF method. El-Hawary et. al. [49] compared the load models and their effects on the convergence of Newton’s model. Haley et. al. [70] proposed a super decoupled load flow method with distributed slack bus.

Basic objective of state estimation is to obtain the best possible estimate of the state
of a power system from a set of noise corrupted redundant measurements.

The application of state estimation theory to power systems started in 1969. In Jan. 1970, Schweppe published a three part [153-155] series on state estimation. The first part [153] attempts to address the nature of the problem, provides its mathematical modelling and gives an iterative technique for calculating the state estimates. In the second part, Schweppe and Rom [154] discuss an approximate mathematical model (related to DC load flow model) which yields non-iterative state estimation equations. A simplified prediction of the effects of network and generation load pattern changes on the network flows, and simplified detection and identification of modelling errors were also discussed. In the third part, Schweppe [155], presented implementation problems associated with computational time requirements, dimensionality resulting from a large number of buses and the actual time varying (non-static) character of power systems. About the same time, Smith [160] presented an algorithm to compute the steady state voltages and phase angles from measured power flows. The weighted difference between measured power and computed power flows is a scalar error that was minimized using a modified Newton’s method and a second order method. In the same year Larson et. al. [97-98] published a two-part paper. The first part of the paper deals with the theory and the feasibility of state estimation. In this paper, the theory of least squares state estimation for electric power systems was presented and the feasibility of several state estimation algorithms based on a linear power flow model and an AC power flow model and parameter estimation and outage detection with AC model were developed. In the second part, the on-line implementation of an efficient state-estimator on a 400-bus system was presented.

Dopazo et. al. [37] developed a state estimation algorithm which combines the load flow procedure with WLS techniques. The measurement set consists of line flows only. Park et. al. [123] developed a two-part estimation algorithm for estimation and detection based on the WLS approach. Alvarado et. al. [7] developed a method for state estimation using augmented blocked matrices. A block GS algorithm for static estimation was reported by
Koronides et al. [92]. Later, Rao [134] developed a modified version of the WLS technique based on Levenberg-Marquardt algorithm.

Consequent to the success of decoupled load flow methods, decoupling techniques were applied to state estimation also and Rao et al. [133] and Horrisberger et al. [73] developed state estimators employing decoupling between the $P$-$\delta$ and $Q$-$V$ loops. This method has been shown to be superior to the WLS method but inferior to lines only algorithm, wherein only the line flows are used to estimate the state of the system. Rao et al. [132] proposed a cartesian coordinates algorithm for state estimation. Srinivasan et al. [164] presented three algorithms for state estimation. The first is a modified fast decoupled state estimator, the second employed a constant matrix model and the third, a second order load flow model. It is found that the modified fast decoupled estimator is the fastest of the three, while the estimator based on the second order load flow model has far superior convergence characteristics as compared to the other two. A fast decoupled state estimator based on a new approach to decoupling is developed by Monticelli et al. [116]. Recently, Habiballah et al. [65] presented an exact decoupled version of the state estimator employing data structure management in rectangular coordinates.

Holten et al. [71] compared different methods of state estimation viz.,

- **Normal equation method**: In this method different types of measurements are allotted different weighing factors in the formulation and the measurements are classified as

  i) *Telemetered measurement* which are the on-line telemetered data of line flows, injections, bus voltages etc.

  ii) *Pseudo measurements* or manufactured data such as guessed MW generator or substation load demand based on historical data.

  iii) *Virtual measurements* which are the kind of information that do not require metering such as zero injections at switching stations.
- Orthogonal transformation method

- Hybrid method: it performs orthogonal transformation and solves the normal equation;

- Normal equation with constraints, and

- Hachtel's augmented matrix method

The comparison is made in terms of their numerical stability, computational complexity and implementation complexity. Bijwe [13] also presented a comparison of first and second order static state estimators.

Lo [103], Iwamoto et. al. [82] and Cutsen et. al. [33] used a hierarchical concept to solve the static state estimation problem for large scale composite power systems. A two level calculation is performed to obtain the solution. In the lower level, a conventional state estimation is carried out simultaneously for all sub-systems and at the upper level coordination of these local estimations is realised. Zaborszky et. al. [190] proposed a reorganised solution of the state estimation problem using the advantages of dedicated microprocessors at the local buses. Allemong et. al. [5] examined the problem of static state estimators solvability and proposed a non-trivial alternative to the existing algorithms. Seidu et. al. [157] proposed a parallel multi area approach for static state estimation. It proposes the use of intermediate local computers in conjunction with a central computer to process raw measurements at local computers only. Milli et. al. [112] developed Least Median Squares (LMS) estimator. This estimator is found to be robust in the presence of leverage points, but the computational time grows exponentially with network size. Labudda et. al. [96] used fuzzy multi objective approach for power system state estimation. It has a noticeable advantage over other LP/WLAV approached in the presence of leveraged bad data.

El-Keib et. al. [51-52] used a linear programming approach to state estimation in primal and dual formation. Irving et. al. [80] introduced a linear programming based state estimator and a simplex method used for noise filtering and bad data detection and elimination. Kotigua et. al. [93] used a new method to estimate the state of a power system using weighted least
absolute value (WLAV), which detects and rejects bad data simultaneously while obtaining
an accurate estimate of the state. Celik et. al. [25] developed a robust state estimator using
transformations which remain insensitive to bad measurements even when associated with
leverage points. The causes of leverage points are i) flow and injection measurements at the
terminal of short lines and ii) injection measurements at the buses which have a large number
of lines incident to it. In the Jacobian matrix, if a particular row contains elements that
are significantly different from the ones in the remaining rows, it indicates the presence of
leverage points. These transformations represent a change of coordinates in the state space.
The robustness of the WLAV is lost in the presence of leverage points. Celik et. al. [26]
used scaling in the WLAV estimator to avoid leverage points and improve the computational
performance. This method has the drawback of poor computational efficiency for large
problems.

An important aspect of security studies is to analyze the effect of outage of a line or
a transformer in a power system. Several methods are available to study this problem. If a
load flow method is used for such studies, a lot of computational effort is required for
modelling changes in the system configuration due to each outage. Whereas, for many
planning and operational applications an exact solution may not be necessary. As a result,
efforts were made to develop techniques which give approximate solutions but require less
computational effort and time.

Z-matrix methods [17], [107] are fast but are not capable of ranking the contingencies
and are useful only for planning studies. An approximate linear iterative method for power
flow solution was developed by Peterson et. al. [125]. This method is more accurate than
any other linear approximation and is faster than the Newton-Raphson method and is suitable
for both line and transformer outages. Daniels and Chen [35] developed a method based on
the modifications of the real power injections to simulate a line or transformer outage. The
accuracy of this method is high, but this method does not give any information about the
reactive power flows. Sachdev and Ibrahim [145] suggested a method employing modification
of both real and reactive power injections to simulate the outage of a line or transformer using power injection modification factors to improve the accuracy of the method. Mamandur and Berg [108] used the same approach to simulate the outage of a line or transformer, but used a different approach to calculate the injections at the terminal buses.

In the planning and operation of power systems, the traditional approach towards contingency analysis is to test all contingencies sequentially to evaluate system performance and reliability. This involves the simulation of outages of one or more generating units and transmission elements to investigate their effects on bus voltages and power flows and is a lengthy and laborious process. The alternative is a faster selection of contingencies based on the planner's experience and intuition. But, this may be inadequate owing to the possibility of some critical lines being omitted. Pre-determination of critical contingencies which result in violations of the operational limits of various components in the system is necessary and these cases must be studied in detail. There will, certainly be a large computational saving by not analyzing the non-critical contingencies.

Eon et. al. [54] proposed a linear contingency analysis program that computes linearized real power flow changes resulting from branch outages and generator or load changes. Instead of using a current injection and bus admittance matrix, a modern formulation has been adopted. But since this method requires repeated calculations of the inverse of a matrix, the method is time consuming. Chang et. al. [29] proposed a new sensitivity method to calculate the real-time line flows. A two step sensitivity approach is used for real-time line flows by Lin et. al. [102]. Vemuri and Usher [179] compared several existing contingency selection algorithms and have proposed new updating algorithms to improve the existing sensitivity based approach. Jasmon et. al. [85] also proposed a new algorithm for outage simulations. Ekwue et. al. [45] proposed an improved decoupled contingency selection algorithm.

Most of the above algorithms consider contingencies which cause line overloads only and do not consider voltage problems. There is no correlation between contingencies causing line overload problems and those causing voltage problems. Lauby et. al. [99] proposed a
new algorithm for contingency selection of branch outages causing voltage problems.

Albuyeh et. al. [2], using the first iteration of the FDLF method for each outage, computed the systemwide performance index reflecting the voltage levels; also, a ranking list is prepared corresponding to the magnitude of the performance indices. Ejbe and Wollenberg [40] developed an automatic contingencies selection algorithm to separate the critical contingencies from the non-critical ones. Performance Indices based on voltage analysis and power flow analysis have been defined and the sensitivities of these indices are computed with respect to line outages and an ordered ranking list is prepared for all primary contingencies followed by a subsequent list of secondary contingencies. The concept of adjoint networks is used to calculate these sensitivities. Studies have revealed that this method is unreliable as it produces misrankings also, and requires the user to tune the adaptive stopping criterion. Irissari et. al. [77] have reported the results of the real-time tests performed on an AEP-EHV system using the method of Ejbe and Wollenberg [39]. It was found that this algorithm gave misrankings even when second order sensitivities were considered. Later, Irissari and Sasson [78] improved the DC load flow approach to compute the system performance index (PI) using forward and backward substitution. Mikolinnas and Wollenberg [111] developed important expressions for computing the change in the performance index for the real power flow based on a DC load flow approach. This method is also found to have given misrankings. Medicherla and Rastogi [110] proposed a technique in which the load curtailment, necessary to bring voltages back to pre-contingency levels, is treated as a measure of the severity of contingency. Ekwue et. al. [41-43] proposed techniques which determine performance indices for voltage drops and line overloads using a second order load flow program employing rectangular coordinates and including a compensation procedure for single line outage evaluation.

Fischl et. al. [58] used an entirely new approach for screening contingencies. They used an Artificial Neural Network (ANN) employing back propagation model. Sobajic et. al. [161] also used an Artificial Intelligence (AI) technique for contingency screening. Taylor and Maahs [172] proposed an algorithm to analyse reactive power flow contingencies using
MW distribution factors in conjunction with newly developed VAR distribution factors to solve for post-contingencies bus voltage magnitude changes.

The rapid expansion of power systems in the recent past, require more and more sophisticated monitoring and control schemes to keep the power system in a secure and efficient mode of operation. Implementation of advanced control schemes can be carried out in real time with large computer installations. Future applications of computers to control the power systems demand the development of algorithms which are economic with respect to the storage requirements and computer time. Hence, the development of advanced techniques and new solution methods for solving the above problems is necessary.

In this thesis two new bus impedance matrix building algorithms have been developed. The building time required by these algorithms are compared with the Brown’s algorithm [21].

A constant matrix method of load flow in rectangular coordinates has been discussed, and a relation has been established between the inverse of the constant matrix and the bus impedance matrix. Performance of constant matrix load flow is compared with the other constant matrix model and FDLF model.

Fast decoupled state (FDS) estimators is the fastest of the estimators available in the literature. In this thesis an attempt has been made to develop estimators which are faster than the FDS estimator and are reliable. This is achieved by using only one constant information matrix against two in the FDS estimator. A new decoupling technique is also proposed to enhance the speed of convergence and reduce the storage requirements.

Among the methods available in literature for studying the line outages, the method proposed by Sachdev and Ibrahim [145] appears to be superior as the analysis is carried out with base case sensitivity matrix. In this thesis the method of Sachdev et. al. [145] and Mamandur et. al. [108] is used and its efficiency is enhanced by using constant sensitivity matrix derived from the bus impedance matrix. Some modifications are also suggested over the existing methods for single and multiple line outages.
Contingency ranking algorithm is the latest step in security studies. Most of the methods available deal with either line overload problem or voltage degradation problems following an outage. And most of the methods provide systemwide performance indices but the actual quantities are not known. There is, therefore, a need to develop an algorithm which takes care of line overloads, unacceptable voltage levels, reactive power capability of generators and also gives complete scenario of the system. Such an algorithm has been derived in this thesis.

1.3 Organisation of the thesis

In this thesis, algorithms in rectangular coordinates have been developed for bus impedance matrix building, constant matrix load flow, state estimation and contingency evaluation. All the computer programs have been developed in Turbo-Pascal 5.0 and executed on 8 MHz, PC-AT/386 computer.

In Chapter II two algorithms for faster assembly of $Z_{\text{bus}}$ are developed and compared with the Brown's algorithm [21]. In the Brown's method, the selection of a chord for addition is considered as and when that chord is encountered in the bus list and there is no optimal selection of the level of inter-connection of the chord. It may be noticed [21] that when a tree branch is added to the system, the system matrix is enlarged by a row and a column and only the diagonal element of the row is required to be computed. On the other hand, when a chord is added to the system, the size of the matrix remains the same but all the $N^2$ elements of the matrix are modified and this step involves large number of arithmetic operations. In the first method proposed in this thesis, $Z_{\text{bus}}$ corresponding to the tree graph of the system is economically assembled. When all the branches have been added, chords are added one at a time. When the first chord is added, elements of the partial $Z_{\text{bus}}$ are not modified but the factors computed for effecting the modifications are stored subsequently. As the remaining chords are taken up for the addition, the modification factors are stored. After the last chord is added, the modification factors stored are used to modify the $N^2$
elements. This algorithm works well for small systems only and depends on the inter-connections.

In the second algorithm, optimal level of inter-connection for each chord is identified on the basis of fundamental circuits to ensure a minimum order of the matrix, when a particular chord is added. This algorithm works well even for large networks and the formulation time is unaffected if the buses are renumbered. The algorithms developed have been applied to some sample examples and the results are tabulated and highlighted. The limitations and applications of the algorithms are also presented.

In Chapter III, a constant matrix load flow model in rectangular coordinates is studied and its performance is compared with its polar counterpart, as well as, existing FDLF methods in polar and rectangular coordinates. It also demonstrates that the inverse of the Jacobian may directly be formed with the elements of $Z_{BUS}$. This step thus avoids the computationally expensive generation of the inverse of the Jacobian matrix of large size. It is also shown that even in the presence of P-V buses, the same $Z_{BUS}$ with appropriate modifications may be used to avoid computation of the inverse of the Jacobian matrix. It is shown that the computational efforts required to modify the constant matrix used for load flow is minimised by generating the constant matrix from the elements of $Z_{BUS}$. Use of $Z_{BUS}$ also proved to be advantageous when the system configuration changes due to addition or deletion of a line (tree or chord) and capacitance switching. The algorithm has been applied to some standard test systems and results are presented.

In Chapter IV, a rectangular coordinates version of algorithmic decoupled state estimation using a constant matrix is reported. This algorithm is developed in two parts. In the first part, only line injections are used and real time load flow equations are solved to obtain the approximate state of the system. Subsequently, using the available line flow information, the final state of the system is obtained in the second part. The information matrix used in the first part of the algorithm is again derived from the bus impedance matrix. This technique has been compared with the reliable first order state estimator (FSE) presented by Srinivasan et. al. [164]. The algorithm developed has been applied to some sample examples and the
results are tabulated.

In Chapter V, a new decoupled state estimator in rectangular coordinates is presented. The decoupling is performed in a novel way in the information matrix itself, rather than in the Jacobian. The proposed decoupling is justified by the relevant proof given in the Chapter. This algorithm has been compared with the modified fast decoupled state estimator (FDS) proposed by Srinivasan et. al. [164] and an exact decoupled method proposed by Habiballah et. al. [65] and is found to be highly reliable, efficient and accurate.

Chapter VI simulation techniques based on the methods proposed by Sachdev et. al. [145] and Mamandur et. al. [108] for simulating the outage of a line or a transformer are presented and its efficiency is enhanced by using the elements of a constant sensitivity matrix and rectangular coordinates. The elements of the constant sensitivity matrix are derived from the corresponding elements of the system bus impedance matrix. The elements of the constant sensitivity matrix corresponding to the terminal buses of the outaged elements are used to calculate the required change in injection to simulate the outage without modifying the sensitivity matrix. A new technique is also proposed to compute the changes in line injections using the elements of the bus impedance matrix and the line flows of the basic system. Finally, using the sensitivity matrix the post outage state of the system is calculated. For the cases of multiple line outages a new sequential technique using $Z_{BUS}$ is proposed and is found to be fast and reliable than the other algorithms.

This Chapter also discusses a method to rank the contingencies due to outages based on performance indices. An infinite norm is used to filter out the non-critical contingencies. The results obtained from the simulation on various test systems are tabulated and highlighted.

Chapter VII briefly summarizes the main results of the thesis.

The text is followed by appropriate appendices and selected references at the end of the thesis.