Chapter-VII
CHAPTER - VII

CONCLUSIONS

7.1 Introduction

In this Chapter the contributions of this thesis are summarised and scope for further research is pointed out.

7.2 Contributions of the thesis

In this thesis, an attempt has been made to develop some efficient algorithms for bus impedance matrix building, constant matrix load flow, static state estimation and security studies in power systems using rectangular coordinates. These algorithms have been found to be superior to many of the existing methods reported in literature.

A brief summary of the contributions of this thesis are given below:

In Chapter II, algorithms have been developed for building the $Z_{BUS}$. In the first algorithm, the bus impedance matrix is constructed as a series of partial networks. The initial part of the partial network is a spanning tree of the lines (branches) of the system, to which the remaining elements (chords) are added in sequence and the overall $Z_{BUS}$ obtained in one stroke. A generalized tree is developed using the depth first search (DFS) technique. In the second algorithm, a unique bus list reordering technique is developed and the optimum levels for connecting system chords are identified. Cantilever branches and cantilever sub-networks are separately assembled and added to the partial network after the addition of all the remaining system chords. These algorithms are compared with the existing Brown's technique. The first algorithm takes less time as compared to the Brown's for smaller systems, but is computationally uneconomical for larger systems. The second algorithm requires less arithmetic
operations and computer time even for larger systems and is found to be more economical than the Brown's technique. Even when bus numbering is changed the time required by the proposed algorithm is not affected, while it changes for the Brown's algorithm.

**Chapter III** deals with a constant matrix method for load flow solution in rectangular coordinate. Performance of the constant matrix load flow method on various standard test systems is reported in this Chapter. A relationship is also established between the inverse of the constant matrix and the system bus impedance matrix. In this Chapter, it has been shown that the inverse of the constant matrix can be easily derived from the $Z_{bus}$ of the system. This speeds up the method considerably, as the inverse of the constant matrix is a major step in the computations. Further, this reduces the storage requirements because only $Z_{bus}$ needs to be stored now. The inverse of the new constant matrix can also be easily obtained from the stored $Z_{bus}$ for PV bus switching during the iterative process. This is done by modifying the elements of $Z_{bus}$ using the expressions derived in Section 3.3. The overall solution time thus reduces mainly due to the fact that, when the Q-limit violations take place the constant matrix has to be modified and a fresh inversion is required, which we obtain directly from the $Z_{bus}$. Since the existing $Z_{bus}$ can be easily modified for simple system modifications, e.g., addition or deletion of a line or switching of capacitive series branches, the inverse of the constant matrix of the modified system can be easily derived from the $Z_{bus}$ as explained in Section 2.6 of Chapter II. In this Chapter, it is found that the constant matrix method of load flow, works well for well-conditioned as well as ill-conditioned systems and the use of the bus impedance matrix reduces the overall solution time drastically. The proposed algorithm is compared with the constant matrix method in polar coordinate and FDLF methods in polar and rectangular coordinates and is found to be superior in terms of speed and storage requirements. It is also found that the proposed algorithm has reliable and faster convergence when PV bus switching takes place. It has better convergence characteristics even in the presence of single and multiple capacitive series
branches and also at varying loading condition.

In Chapter IV an algorithmic decoupled technique is developed in rectangular coordinates for static state estimation. A constant matrix is used in the first part of the algorithm and the same matrix is used as constant gain matrix in the second part of the algorithm. The proposed algorithm is compared with the reliable first order state estimation algorithm in polar coordinates proposed by Srinivasan et. al. [164]. The proposed algorithmic decoupled state estimator is quite accurate and robust, because the first part is a conventional state estimator and the second one is non-iterative in nature. The constant matrix used in the first part of the algorithm is derived from the bus impedance matrix. The total time required for convergence is, in general, lesser than that required by the other methods [164].

The algorithmic decoupled technique proposed in Chapter IV is fast, but is not accurate as compared to the decoupled algorithm proposed in Chapter V. The other major drawback of the algorithmic decoupled technique is that, it always requires a high ratio of redundancy. Therefore, in this Chapter, a new decoupled static state estimation algorithm in rectangular coordinates is proposed which is more efficient and performs well even with minimal data redundancy. The proposed decoupling is performed in a novel way, in the information matrix instead of the Jacobian matrix. The method is compared with the exact decoupled algorithm proposed by Habiballah et. al. [65] and the modified fast decoupled state estimation (modified FDS) proposed by Srinivasan et. al. [164]. The proposed algorithm has faster and reliable convergence for most types of ill-conditioned systems as compared to others [65], [164]. The accuracy of the state is very near to the actual state of the system and also the proposed algorithm converges to a satisfactory state estimate even for minimal data redundancy. The time required to generate the constant matrix of Chapter V and the number of iterations required for convergence is less. Hence, the solution time required is much less with increased system size as compared to that required by others [164].
The current state of the system as obtained from the various state estimators explained in chapters IV and V is used for security analysis in Chapter VI. Outage studies are the most important component of the security studies of a power system. Outage of a line causes a change in the system configuration and as a result, the system matrix and the Jacobian matrix also change. A fresh load flow solution requires updated system and Jacobian matrices, and thus, is a time consuming process. Methods based on base case sensitivity matrix are found to be fast, reliable and efficient. Sachdev & Ibrahim [145], Mamandur & Berg [108] and Srinivasan et. al. [163] have developed simulation techniques for outage studies based on similar approach using some elements of the sensitivity matrix. In this Chapter, three algorithms in rectangular coordinates has been reported. These algorithms use a constant sensitivity matrix derived from the system bus impedance matrix. For the cases of multiple outages, a new sequential technique has been used employing the modified $Z_{BUS}$ and the voltages of pre-outaged state. This sequential technique has been found to be fast and reliable.

It has also been observed that outages of most of the elements in a system may not cause security problems and therefore it may not be necessary to study the effect of these element outages. Hence, an algorithm is developed to identify the critical contingencies which may lead to security limit violations. A ranking and filtering method [163] is used to identify critical contingencies and rank them on the basis of performance indices based on line overloads, voltage level and reactive power generations. An infinite norm is used to arrange the contingencies in order and this eliminates the masking problem. The proposed method is found to be highly reliable and efficient for real time applications.

7.3 Further Scope
- The bus impedance matrix building algorithm developed in Chapter II has not been used for the mutually coupled lines. This needs to be explored.
- In Chapter III, it has been shown that the inverse of the constant matrix is useful in load flow studies and can be obtained easily from the Z_{bus}. This is made use of in state estimation and contingency analysis. Several other problems in power systems also require load flow informations. The application of Z_{bus} for these problems can be explored.

- In Chapter IV and V of this thesis, for state estimation a constant information matrix has been derived using the sparsity of the gain matrix. This is a new approach to static state estimation. Its applications to other estimation problems is another promising area of research.

- In Chapter VI of this thesis, a constant sensitivity matrix obtained from the Z_{bus} is used for outage simulations. The same constant matrix approach can also be applied to the line load alleviation, load shedding and economic dispatch problems. This has to be pursued.