CHAPTER VII

SUGGESTIONS FOR FURTHER WORK

7.1 SOME REMARKS

After briefly introducing the topics of the thesis in Chapter 1 we have presented some new results concerning the problems of generation of appropriate Liapunov functions for the single and multimachine power systems in the post fault state. We have systematically exploited the simple techniques of pole shifting, Kalman's procedure for generating the Lure'-Postnikov type of Liapunov functions starting from the Popov's inequality and of bounding the effects of interactions originally introduced by Bailey for the stability analysis of interconnected nonlinear systems. A review of the existing literature would show that the derivation of the Popov type inequalities for the interconnected power system model is a significant new contribution. Not only it is much simpler to check these inequalities but we are also able to generate the desired Liapunov function for the multimachine system as the sum of scalar Liapunov functions of the decoupled subsystems. This simplifies the task of estimation of regions of stability and of the critical fault clearance time. We have also examined the question of obtaining estimates of quality of transient response of the single and multimachine systems through the Liapunov functions generated by us.
Though we have confined our discussions to the question of the transient stability only it should be possible to analyse the dynamic stability of the multimachine power system by utilizing the aggregation technique adopted in Chapters IV and V. Since the dynamic stability analysis is carried out on the basis of linearised models the procedure would become simpler. For example, the ith subsystem in this case would have the following form:

\[
\dot{x}_i = A_{ii}x_i + \sum_{j \neq i}^m A_{ij}x_j
\]  \hspace{1cm} (7.1)
\[
y_i = c^T_i x_i, \ \text{i}=1,2,\ldots,m
\]  \hspace{1cm} (7.2)

Where \(A_{ii}\) is obtained from \(A_i\) after merging the effect of linearised feedback term \([\text{grad}(b_i f_i(c^T_i x_i))]^T x_i\) and the linearised interaction term \([\text{grad} h_i(x)]^T x_i\) whereas the matrix \(A_{ij}\) contains the other terms obtained by linearising \(h_i(x)\).

So far as the interaction free subsystem

\[
\dot{x}_i = A_{ii}x_i
\]  \hspace{1cm} (7.3)
\[
y_i = c^T_i x_i
\]  \hspace{1cm} (7.4)

is concerned we have the simple criterion that the eigen values of \(A_{ii}\) should have negative real parts. A simple Liapunov function for this case is the quadratic form

\[
V_i(x_i) = x_i^T P_i x_i
\]  \hspace{1cm} (7.5)

where \(P_i\) is a real symmetric positive definite matrix. We can find an appropriate value of \(P_i\) from the Liapunov equation

\[
A_{ii}^T P_i + P_i A_{ii} = -Q_i
\]  \hspace{1cm} (7.6)

where \(Q_i\) is a real symmetric positive definite matrix. If we choose \(Q_i=I\), the value of \(P_i\) can be found from eq.(7.6). Now if we use this \(V_i(x_i)\) and utilize the bounds
We can adopt the procedure of Chapter IV in order to show that for the multimachine system an appropriate Liapunov function would be

\[ W(x) = \sum_{i=1}^{m} W_i(x_i) \]  \hspace{1cm} (7.8)

with \( W_i(x_i) \) given by

\[ W_i(x_i) = x_i^T P_i^T x_i \]  \hspace{1cm} (7.9)

where \( P_i \) satisfies the equation

\[ A_{ii} P_i^T + P_i A_{ii} + 2\sigma_i P_i = -Q_i \]  \hspace{1cm} (7.10)

The aggregated interaction coefficient \( \sigma_i \) has the same value given earlier in Chapter IV.

It would thus appear that the problem of dynamic stability of the multimachine power system with any selected type of generators can be carried out in decoupled manner without much difficulty.

### 7.2 SOME FURTHER SUGGESTIONS

The results of the thesis should be extended further by considering the following cases:

#### 7.2.1 Effects of Excitation Control

Both the single machine and the multimachine state variable models become somewhat more complicated if we include the effects of voltage excitation control systems which are generally present in practical systems. A simplified study of the effects of the voltage exciter control system can be made by incorporating a first order state model analogous...
to the model utilized by us for incorporating governor action. However, this would raise the dimension of the subsystem state vector to four and the problem of spectral factorization of $\mathbf{M}_i(\omega)$ becomes somewhat difficult. The problem becomes even more difficult if the effect of flux decay is also incorporated [25] since an additional nonlinearity appears in the model. It would be interesting to examine the possibility of decomposing the subsystem model with two nonlinearities into two different subsystems each with one nonlinearity and each having a reduced state vector.

7.2.2 The Case of Tight Interaction

The analysis presented in this work is based on the assumption that the interaction among the subsystems are loose [45], [70]. If the interactions are tight, as may happen, for example, in practice for machines located at close geographical locations, it would be necessary to modify the methods of this work before we can obtain useful stability results. A possible solution may be sought through dynamic equivalence.

7.2.3 Use of Dynamic Equivalents

Several workers [71] - [80] have recently suggested the use of coherency based dynamic equivalents for simplifying the problem of multimachine stability analysis. The main advantage of this approach is that a group of machines which may be swinging together (possibly due to tight interactions) is represented as single machine thus reducing the dimensionality of the problem. After a given system is decomposed into a number of
loosely coupled equivalent machines, we can adopt the aggregation
techniques of Chapter IV and Chapter V in order to obtain the
simplified stability criteria.

7.2.4 Development of Computer Programmes

Since the size of modern power systems has grown very big, it appears almost essential to utilize digital
computers for carrying out most of the manipulations involved
in the generation of Liapunov functions, in obtaining the
decompositions and aggregations, in computing the regions of
stability and fault clearance time etc. A recent paper by
Gupta and El-Abiad[81] provides the necessary lead in this
direction. It will be interesting to adopt our analysis while
following the concept of Gypta and El-Abiad.

The above four areas seem to be of immediate major
interest in our view. There are, of course, many other
problems in the field of multimachine stability analysis.