Chapter 6

Conclusions

6.1 General

The present day power system networks are running under stressed conditions. Therefore, dynamic monitoring of the system is necessary to ensure its stable and secure operation. In order to have the real time picture of the power system network, it is necessary to have time synchronized measurements from the geographically dispersed power system network at a faster rate. With the development of phasor measurement units (PMUs), it has become possible to obtain the real time picture of the power system. In this thesis, studies have been carried out using phasor measurement units (PMUs) for voltage stability monitoring and control. The main contributions of this thesis are as follows:

- Optimal placement of phasor measurement units based on voltage stability criterion under changing operating scenario.
- Predicting nose point (critical point) using generalized curve fit method with the help of phasor measurements obtained from PMUs.
- Online voltage stability monitoring using phasor measurement units (PMUs) has been carried out.
- Voltage stability enhancement using STATCOM in online environment using data obtained from phasor measurement units (PMUs)

Summary of important findings of research work carried out in this thesis and few suggestions for the future work in this area are presented in the next sections.

6.2 Summary of Important Findings

In Chapter 2, optimal placement of phasor measurement units to monitor voltage stability of power systems under changing operating conditions has been carried out. PMUs have been placed based on results of binary integer linear programming run for the system intact case and voltage stability based critical contingency cases. Critical contingencies have been selected based on lowest Voltage Stability Margin (the distance between the base case operating point and the nose point) under various load patterns. Nose curves estimated under different operating conditions by optimally placed PMU measurements closely match with offline continuation power flow based nose curves. The main conclusions from the study on IEEE 14-bus system, New England 39-bus system and a practical 246-bus Northern Regional Power Grid (NRPG) system of India are as follows:

- PMUs have been optimally placed in the system based on voltage stability criterion.
- Critical contingencies are selected based upon lowest voltage stability margin calculated using continuation power flow method.
- Total observability index (TOI) with optimally placed PMUs is well above the number of buses of the system. This ensures complete observability of the system.
- Simulations have been carried out under changing load patterns.
- The nose curves obtained using phasor measurements closely match with the nose curves obtained without using phasor measurement.

In Chapter 3, quadratic fitting of nose curves using PMU measurements have been proposed. Nose curves estimated by proposed approach have been compared with nose curves based on continuation power flow method. Maximum loadability (λ_{max}) estimated by proposed approach closely match with λ_{max} estimated by full continuation power flow. Proposed approach of voltage stability margin assessment based on PMU measurements is more suitable for real time systems as dynamics of power system components in determination of voltage stability margin is taken care by phasor measurements except few cases. The conclusions from the study on IEEE 14-bus system, New England 39-bus system and 246-bus Northern Region Power Grid (NRPG) of India are as follows:

- Generalized curve fitting of nose curve based on phasor measurements have been carried out.
- Maximum loadability estimated by proposed curve fitting technique matches with the loading margin estimated by continuation power flow method.
- For few cases, proposed approach yields in different loading margin compared to continuation power flow method. This may be due to consideration of dynamics of power system components such as induction motors, exciters which are ignored by continuation power flow method.
- The proposed technique is suitable for voltage stability assessment of real time systems.

In Chapter 4, online monitoring of voltage stability margin using PMU measurements has been proposed. Proposed approach estimates voltage stability margin based on measurements obtained at three operating points. Due to highly dynamic nature of power systems, voltage stability margin keeps on changing. Therefore, proposed approach suggests computation of updated voltage stability margin at regular intervals based on new PMU measurements obtained. Change in operating scenario has been simulated in PSAT software considering different single line outage cases. Accuracy of proposed approach has been validated by comparing voltage stability margin obtained by proposed approach with margin estimated using continuation power flow method under same operating conditions. Case studies performed on three test systems show that maximum real power loadability as well as maximum reactive power loadability of the system obtained by proposed approach closely matches with maximum loadability obtained by continuation power flow method. The main conclusions from the various studies, carried out on IEEE 14-bus system, New England 39-bus system and 246-bus Northern Region Power Grid (NRPG) of India are as follows:

- The proposed approach estimates online voltage stability margin using PMUs measurements at three different operating points.
- Change in operating scenarios has been simulated in PSAT software considering various single line outage cases.
- The maximum real power loadability as well as maximum reactive power loadability of the system obtained by proposed approach closely matches with maximum loadability obtained using continuation power flow method.
- The proposed approach simulates the dynamic nature of power system network using updated voltage stability margin obtained at regular intervals with the help of fresh PMU measurements.

In Chapter 5, the proposed generalized curve fit method using PMU measurements is used for online control of voltage stability using STATCOM. STATCOM has been placed at critical bus of the system. With the placement of STATCOM in the system, results show that there is good improvement in voltage stability margin of the system. STATCOM injects reactive power at regular intervals as per voltage stability requirement, and is capable to enhance voltage stability margin regularly to make the online system voltage secure. Results of simulations on IEEE 14-bus system, New England 39-bus system and 246-bus NRPG system validate effectiveness of proposed approach of voltage stability control using STATCOM. The main conclusions of this chapter are:

- With the placement of STATCOM in the power system network a good improvement in voltage stability margin has been observed.
- STATCOM injects reactive power to bus based on its voltage magnitude.
- Reactive power injection by STATCOM at regular intervals keeps on enhancing voltage stability margin.

6.3 Scope for Future Research

This thesis has focused on carrying out research work on the power system voltage stability monitoring and control. The research in this area can be extended further considering the following issues:

- The PMUs placement method proposed in Chapter 2 can be replaced by another PMUs placement method to achieve better accuracy in results and further reduction in the optimal number of PMUs required. Also an index can be developed to monitor voltage stability of the system. The index can be explored to monitor voltage stability of the system which may include voltage angle measurements.

- The generalized quadratic curve fitting method proposed in Chapter 3 can be replaced by Bessel's function curve fitting approach to provide better curve fitting and thereby better accuracy in results. The real time digital simulators (RTDS) can be used for better utilization of voltage phase angle measurements obtained by PMUs.
- The online voltage stability monitoring method proposed in Chapter 4 can be done using real time digital simulators (RTDS).
- The work proposed in Chapter 5 can be extended to place other FACTs devices like SSSC, UPFC etc. An index can be developed to find critical line of the system using phasor information obtained by PMUs. After evaluation of critical lines of the system these FACTs devices can be placed in the system to achieve a good improvement in voltage stability margin of the system.
- The work proposed in Chapter 5 has considered voltage stability enhancement using optimally placed single STATCOM. Further effort is required to be carried out in investigating voltage stability enhancement using optimally placed multiple STATCOMs.