PREFACE

Voltage stability is one of the key concerns for power system researchers and engineers. Several incidences of voltage collapse as a result of voltage instability have been observed in different parts of the world. Significant efforts have been made in estimation of voltage stability margin and planning control measures to minimize system failures caused by voltage instability phenomenon. However, most of the research has concentrated on offline estimation of voltage instability. Online monitoring and real time control of voltage stability is still a challenge. Online monitoring of voltage stability margin seems feasible with the help of synchrophasor technology. Phasor Measurement Units (PMUs) optimally placed at few selected locations may be able to completely monitor voltage stability of the whole system through its phasor measurements. Different controllers may be tuned with PMU measurements to adjust their parameters based on voltage stability margin requirements. Thus, security of the power system networks may be enhanced through real time monitoring and control of voltage stability margin. In this thesis, an attempt has been made to monitor voltage stability of the system in real time framework using PMU measurements. Real time control of voltage stability margin has been suggested with optimally placed Static Synchronous Compensator (STATCOM). Reactive power injected by STATCOM has been varied based on voltage stability margin estimated through PMU measurements, at regular intervals, and thus voltage stability is controlled for online system.

The thesis has been organized in following six chapters:

Chapter 1 presents a comprehensive literature survey on related work, and sets motivation behind work carried out in this thesis.

In Chapter 2, optimal placement of phasor measurement units based on voltage stability criterion has been proposed. 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, under widely varying load patterns. Critical contingencies have been selected based on lowest Voltage Stability Margin (the distance between the base case operating point and the nose point) under varying load patterns. Proposed PMUs placement strategy has been validated by comparing nose curves computed based on phasor measurements obtained by optimally placed PMUs with nose curves computed using Continuation Power Flow (CPF) method. Simulations have been carried out on IEEE-14 bus system, New England 39-bus system and a practical 246-bus Northern Region Power Grid (NRPG) system of India. Results obtained on three test systems show that proposed approach of optimal placement of PMUs based on voltage stability criterion is very much effective in estimation of system loadability. Maximum loadability of the system obtained based on PMUs data have been observed to be quite close to maximum loadability obtained by CPF method for the system intact case and voltage stability based critical contingency cases. It is also observed that proposed PMUs placement strategy yields in complete network observability even in case of loss of few PMUs.

In Chapter 3, quadratic fitting of nose curves using PMU measurements have been proposed. Proposed approach determines maximum loadability of each bus based on PMU measurements performed at three operating points corresponding to two step continuation power flow. This ensures speedy estimation of voltage stability which is an important aspect for voltage stability assessment of real time systems. Nose curves estimated by proposed approach have been compared with nose curves estimated based on full continuation power flow. Case studies have been performed on IEEE 14-bus system, New England 39-bus system and practical NRPG 246-bus system. It is observed from simulation results that maximum loadability (λ_{max}) estimated by existing approach using phasor measurements based two-step continuation power flow closely match with λ_{max} estimated by full continuation power flow.

In Chapter 4, online monitoring of voltage stability margin using PMU measurements has been proposed. The approach proposed in this chapter estimates voltage stability margin using measurements obtained at three different operating points. Maximum real power loadability as well as maximum reactive power loadability of each bus are separately obtained based on PMU measurements obtained at three operating points. Because of highly dynamic nature of the power system, voltage stability margin keeps on changing. Therefore, proposed approach computes of updated voltage stability margin at regular intervals using new PMU measurements obtained. Change in operating conditions has been simulated in PSAT software considering various single line outage cases. Accuracy of proposed approach has been compared with voltage stability margin obtained by continuation power flow method (an offline approach for estimation of voltage stability margin) under same set of operating conditions. Case studies were performed on IEEE 14-bus system, New England 39-bus system and NRPG 246-bus system. Case studies performed on three test systems show that maximum real power loadability as well as maximum reactive power loadability of the system obtained using proposed approach closely matches with maximum loadability obtained by continuation power flow method.

In Chapter 5, online enhancement of voltage stability margin based on optimally placed Static Synchronous Compensator (STATCOM) has been proposed. STATCOM has been placed at the critical bus obtained based on minimum real and reactive power loadability for majority of line outages. STATCOM injects reactive power to the bus based on deviation of bus voltage from its reference value. Bus voltages are determined at regular intervals using measurements obtained by PMUs, and reactive power is injected to the bus online, accordingly. Enhanced voltage stability margin as a result of reactive power injection by STATCOM is monitored at regular intervals. Effectiveness of proposed approach of online monitoring and enhancement of voltage stability margin through reactive power injection by STATCOM has been validated based on simulations carried out on IEEE 14-bus system, New England 39- bus system and NRPG 246-bus system.

Chapter 6 presents concluding remarks on the PMUs placement, online monitoring and control of voltage stability margin, and suggests future research required in this direction.

Following are the key findings of the thesis:

- Optimal placement of phasor measurement units based on voltage stability criterion has been suggested in Chapter 2. 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, under varying load patterns.

- Quadratic fitting of nose curves using PMU measurements have been proposed in Chapter 3. This approach determines maximum loadability of each bus based on PMU measurements performed at three operating points corresponding to two step continuation power flows.

- Online monitoring of voltage stability margin using PMU measurements has been proposed in Chapter 4. This approach estimates system maximum loadability using measurements obtained at three different operating points under simultaneous increase of demand at all the buses. Maximum real power loadability as well as maximum reactive power loadability of system has been separately obtained based on PMU measurements obtained at three operating points. Maximum loadability information is updated at regular intervals based on new measurements obtained by PMUs.

- Online enhancement of voltage stability margin based on optimally placed Static Synchronous Compensator (STATCOM) has been suggested in Chapter 5. STATCOM is placed at the critical bus obtained based on minimum real and reactive power loadability for majority of line outages. Enhanced voltage stability margin is obtained at regular intervals using PMU measurements.

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