1. INTRODUCTION

1.1 Power System Stability

As the interconnection of power systems has been introduced, large power systems have been able to provide more reliable power supply to the loads in the integrated system. However, new stability problem such as low-frequency electromechanical oscillations has also emerged.

Power system stability has been an area of study for several decades. As the stability of a power system is dependent on the size and type of a disturbance, a steady state operating condition may be stable for one disturbance but not for another. This leads to the classification of stability [1]: steady state or small disturbance stability; and transient or large disturbance stability. It is recommended that the terms *static* and *dynamic stability*, which are sometimes used for the steady state stability without and with automatic controls, respectively, be avoided [2].

A small disturbance is a disturbance for which the equations that describe the dynamics of the power system can be linearized for the purpose of analysis. The steady state stability of a power system is the stability following any small disturbance. A system is said to be steady state stable for a particular operating condition, following such a disturbance, if the system can reach another steady state condition that may or may not be identical or close to the pre-disturbance operating condition of the power system.

A large disturbance is a disturbance for which the equations that describe the dynamics of the power system can not be linearized for the purpose of analysis. The transient stability of a power system is the stability following a large disturbance. A system is said to be transient stable for a particular operating condition and for a specified disturbance if, following that disturbance, it can reach an acceptable steady state operating condition.

The principal task following a disturbance is to determine whether the system will be stable or not. As the cause of instability is the unbalanced energy in the system, it is important at first hand to decide whether this unbalanced energy is positive or negative. If positive, the unbalanced energy will accelerate generators while if negative, it will decelerate them. If the system is not capable of settling down to the original equilibrium point or to a new one by redistributing the energy in the network automatically, then corrective measures will have to be taken to resolve this unbalanced energy by tripping generators or shedding some loads according to a pre-determined plan.

As our society's demand for and consumption of electrical energy has increased steadily, power systems over large geographic areas have been interconnected to meet this demand and to provide a reliable electrical power service. At the same time, sophisticated control equipment and protection schemes have been added to power systems to enhance its stability. As a result the analysis of power system stability has become more difficult. Fortunately, enriched mathematical modeling and better computation facilities have made it possible to solve the complicated problem of stability investigations.

1.2 Methods of Solution

The mathematical representation of the problem of power system stability is based on the modeling of various power system components. The number of such components included in a study and the complexity of their mathematical description will depend on the type of the problem and the nature of the system to be investigated. Appropriate modeling is essential to ensure that the results obtained are correct and reliable. Accurate modeling may be difficult to achieve due to:

a) lack of actual parameters
b) discrepancies between available data and the actual state of equipment because of modification, deterioration, etc., after years of operations
c) impracticality of obtaining useful data through field tests
d) inappropriate choices of component models.

For a large power system with its numerous machines, lines, loads, and other components, the mathematical representation of the system for conducting stability studies can be immense, depending on the complexity of the models to be used in the study. The analysis of the consequences of a disturbance can also be very complicated.

Differential equations are utilized to describe the dynamic behavior of power system components. On the other hand, algebraic equations are sufficient to represent the relationship of electrical quantities in the network of the transmission lines. The key part of a stability study is to solve these differential and algebraic equations simultaneously.

According to the nature of the study, techniques for analysis of power system stability fall into two categories. Those for steady state stability studies are based on linear system analysis. For example, eigenvalue analysis has been the most commonly used technique for this purpose. Other methods such as root-locus plots, frequency domain analysis, and Routh's criterion have also been widely used. Those for transient stability studies are based on numerical integration, such as trapezoidal rule, and modified Euler.

In the study reported in this thesis, eigenvalue analysis and sensitivity study techniques are utilized for steady state stability studies. The implicit integration technique for numerical solution of differential equations is employed for transient stability studies.

1.3 Statement of Objectives

The objectives of this thesis are (i) to fully investigate the steady state and transient stability of a realistic power system, i.e., the Athabasca-Points North Power System (APNS) in northern Saskatchewan, Canada and (ii) to design more effective power system stabilizers to improve both steady state and transient stability of the APNS. Specifically, the following tasks were carried out to achieve the stated objectives.

1. A Simulation Tool

To solve a large and nonlinear mathematical system of a stability problem, a numerical simulation tool is compulsory. A number of commercial packages serving this purpose are available in the market. As the author of this thesis has no access to them due to financial restrictions, the development of a simulation package was the first objective of this thesis. This task was accomplished by developing a transient stability simulation package (TSSP) [3].

2. Stability Investigation of APNS

As the purpose of the project reported in this thesis was to investigate the stability of APNS, analysis of its steady state stability becomes the first step to tackle the problem. This analysis was conducted with eigenvalue analysis and sensitivity study techniques. The investigation of the transient stability was conducted by utilizing the newly developed package (TSSP).

3. Stabilization of APNS

The final objective of the study was to improve the overall system stability of APNS by introducing newly designed controllers, such as PSSs. A coordinated PSS design and application algorithm was introduced and new PSSs were designed. A comprehensive simulation study was carried out to verify the effectiveness of the newly designed PSSs.

1.4 Overview of the Thesis

This thesis consists of seven chapters and five appendixes. In Chapter 2, mathematical or block diagram representations of various power system components, i.e., generators, AVRs, PSSs, and SVC, used in the studies reported in this thesis, are presented. The modeling of disturbances that cause system contingencies is discussed. Different load representations are also presented. The modeling of network and transformers is briefly covered.

In Chapter 3, a simulation tool, i.e., a transient stability simulation package, for power system stability studies is presented. The structure, database and modeling foundation of the package are discussed. The package consists of four parts: a fast decoupled load flow program (FDLF), a short circuit calculation program (STCC), the transient simulation main body

(TSSP) including a coordinator, and a plotting program (WPLOT). It is implemented on an IBM PC in FORTRAN language. A minimum of 410K conventional memory is required to do a stability study of a system of 100 buses and a CGA, EGA or VGA graphics card to run the WPLOT program.

Chapter 4 deals with steady state stability studies of APNS. Eigenvalue analysis and sensitivity study techniques have been utilized to investigate the factors that affect the damping of the various system swings. The best PSS installation sites are determined based on the magnitude of functional sensitivities of the swing modes with respect to PSS transfer functions.

Chapter 5 deals with transient stability studies of APNS. An introduction to the purposes of transient stability studies of a power system is given. In order to facilitate the analysis and presentation of simulated results, generators in the system are divided into coherent groups. The system is also divided into three geographic areas. The system stability under different disturbances at various areas is studied.

A coordinated design procedure for power system stabilizers (PSSs) is discussed in Chapter 6, after carrying out a parametric sensitivity study of the primary controls by time simulation. The design procedure is based on generation coherency, lead/lag time constant spread and the total coupling factors among strongly coupled generators. New eigenvalues are computed with the newly designed PSSs in service. A comprehensive simulation study and comparison of the results obtained is also presented in this chapter.

In Chapter 7, conclusions have been drawn from the studies reported in this thesis.

Appendices A, B, and C contain the three data files required for the stability studies of the Athabasca-Points North system (APNS). Part of the results of a load flow study of the system is also given in Appendix A. Appendix D presents detailed mathematical derivation of a two-axis model with subtransient of a generator. Appendix E discusses the procedure for inclusion of the saturation of both the generator and its excitation system in simulation studies.

1.5 Summary

An introduction of the basic concepts of power system stability has been presented at the beginning of the chapter. It is recognized that the source of power system instability is the unbalanced energy and its redistributing process. Then, a review of the methods of solving the stability problem has been conducted. In the last two sections, the objectives of the thesis and its structure are outlined.