CHAPTER 1

DYNAMIC EQUIVALENTS

1.1 Introduction

The growing size and complexity of power system, on the one hand and the need to obtain accurate, and fast results regarding transient stability, on the other hand, requires the development and use of efficient power system equivalent and simplifying techniqes [1].

Interest in simplified representation for power system is not new, and equivalents have been used in the three classical problem of power system analysis ,namely , load flow , short circuit , and stability.

This thesis presents a method to derive dynamic equivalent for transient stability studies of power systems.

1.2 What are dynamic equivalents

In power systems, generators which are closely coupled in electrical sense tend to swing together during disturbances. The characteristic of generators swinging together is referred to as coherency and illustrated in Fig 1 which shows the swing curves for a coherent group of generators when a fault occures in the system.

In the coherency-based method which has been developed for forming dynamic equivalents, each coherent group of generators is replaced by a single generator [1]. By such substitutes the total network can be reduced in size which facilitates studies of power system performance.

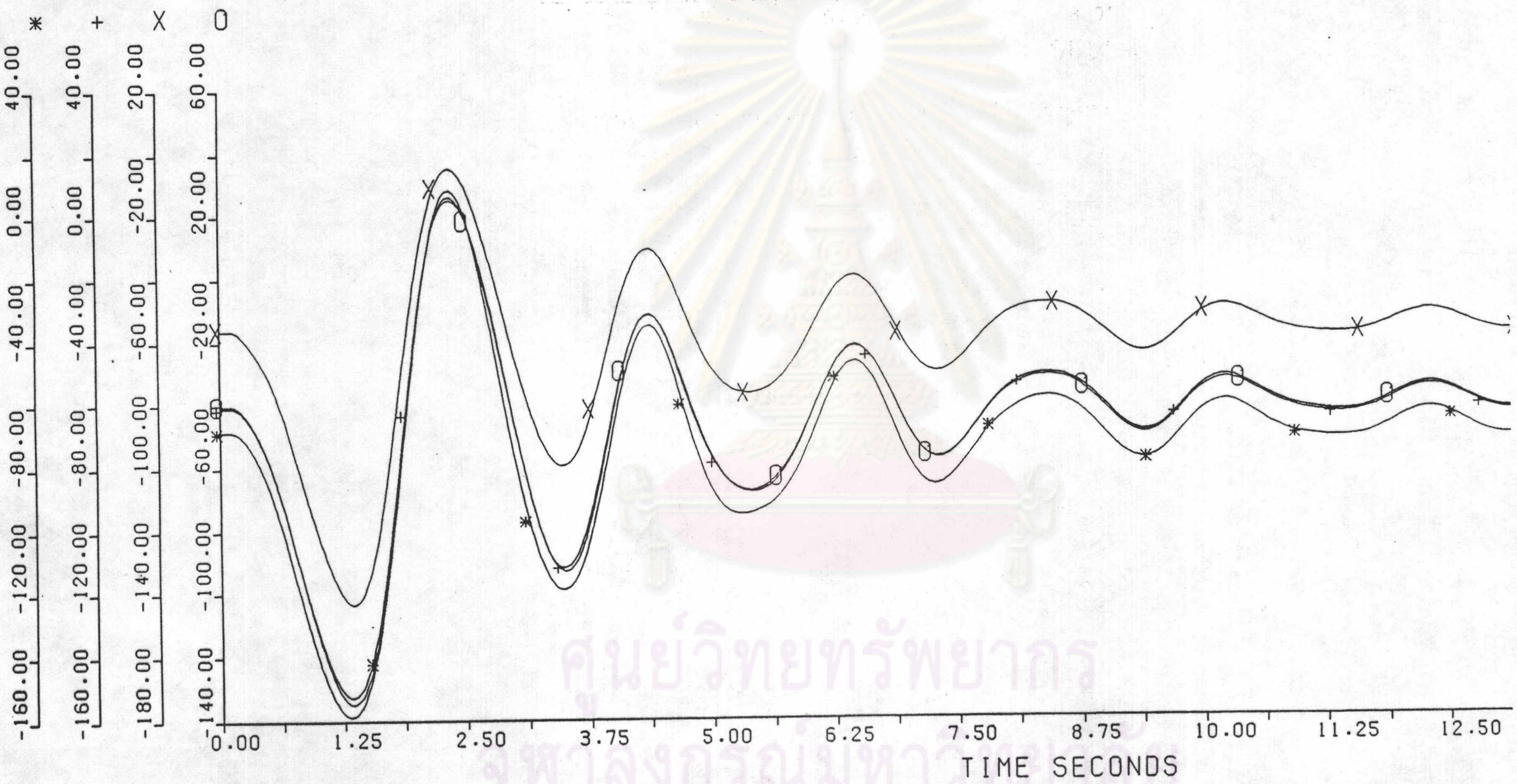

Fig 1 The swing curves for a coherent generators

In order to simplify calculation and analysis it is therefore proposed to develop a method for proper and compact modelling of power system to be used at dynamic studies. In this thesis the simplifying technique for transient stability studies is derived based-on the properties of the coherent generators.

1.3 Why use dynamic equivalents

The initial motivation for dynamic equivalents of power system was to reduce the computation time for transient stability studies. Decades ago, a transient stability study could easily take many hours of computer time. The evaluation of computers and software have reduced this problem, and the speed and memory capacity of present computers has made transient stability analysis a manageable task. Further increase in computer capacity will be used by analysis to study large systems in details.

Although modern computer systems have capability to represent very large system a too detailed representation have disadvantages, especially;

- Stability simulation require a lot of computer time, CPU times of over four hours can be needed for simulation of 20 seconds' real time. As a stability study often involves many simulation runs, the total required time can be very considerable.
- Large models produced an enormous quantity of output data so that it can be difficult to comprehend the result.
- Many stability studies are routinely required for both long-term and short term planning studies.

One method to tackle these problems is to use simplified but adequate representation of the system. Typically , the simplified system representation , hereby define as the dynamic equivalents, is 1/2 to 1/10 the size of the original system representation , thereby offering savings in the time of computer studies while maintaining adequate study accuracy.

1.4 The method for calculating dynamic equivalents

Available method for calculating dynamic equivalents can be divided into three main group;

- Dynamic equivalents based-on eigenvalue.
- Dynamic equivalents based-on coherent generator.
- Estimated dynamic equivalents.

Estimated dynamic equivalents are constructed from measured data taken from real system. These equivalents are less suitable for network planning , as there is often no real system available in such cases. For this reason , only the first two principles are discussed further in this thesis:

1.4.1) Dynamic equivalents based-on eigenvalues

This principle is based-on the use of eigenvalue analysis of the system from which a simple dynamic model can be calculated. The method of doing this is as follows;

1) Describe the system using a system of non-linear differential equations.

2) Linearize the system of equations. This can be done by assuming that small disturbances influence little on the system under investigation.

3) Calculate the eigenvalues of the system.

4) Ignore all eigenvalue with large negative real components and/or large imaginary components, i.e. ignore those oscillatory modes in the system that are highly damped or have a high fundamental frequency. Then produce a reduced system of linear differential equations.

5) Formulate the reduced system into a model that can be used in the stability program.

For large systems , having more than about 100-150 state variables , calculation of eigenvalues can become extremely time-consuming , and problems with accuracy of calculation may be encountered. These problems however can be bypassed by dividing up the system into sub-sectors and processing them individually.

1.4.2) Dynamic equivalents based-on coherent generator

This principle is based-on the assumption that a given disturbance will result in groups of generators oscillating together, i.e. they will oscillate with the same amplitude and frequency. Such a group of generators is refered to as a coherent group. Mathematically, the condition for coherence can be expressed as;

$$Q_i - Q_j = E$$

where : E = specified tolerance degree.

Q_i = rotor angle of machine i.

Q_j = rotor angle of machine j.

The basic idea of this method is that each coherent group of generators can be replaced by an equivalent single generator. A step-by-step description of the principle is as follows;

1) Identify the coherent groups in the system. This can be done in a number of different ways. One way is to perform a stability study of the entire model and to compare the rotor angles of all generators. Another more approximative way is to investigate the electrical distance between generators [2,3].

2) Connect together the buses of the coherent generators to a common bus and transfer the coherent generators to it.

3) Apply dynamic aggregation to the coherent machines in order to create an equivalent machine for each groups. This can be done by calculating the aggregated transfer functions for the models in the coherent groups. The transfer functions for rotor dynamics , turbine and turbine governing , excitation system , magnetic circuits of synchronous machines and power system stabilizers must be considered individually.

4) Reduce the passive network between the generators in the system.

This final reduced model is in the form of a number of equivalent generators with control system and connected by a reduced network. This allows the model to be used directly in existing simulation programs .

1.5 The adapted method

The following principles have been fundamental in selecting the method of creation of dynamic equivalents to be used.

- Studies have been performed on a real system (EGAT stage 1988) for identifying the coherent groups of generators and the system performance.

- Part of the simplified model must relate to real components, i.e. it must consist of buses, lines, generators etc. This means that the model will be easy to understand and easy to match to existing stability programs.
- As well as retaining the dynamic properties of the network, the simplified model must also retain the correct solution of load flow and fault currents in the network.
- The method must be developed into a computer program, the input and output data of which is suitable for use with the existing stability simulation programs.

1.6 Application and the benefits

The dynamic equivalents program is structured to interface conveniently with existing stability simulation program and data files. It may therefore be implemented by utilities with a modest manpower effort. The various benefits which would result directly from a utility's implementation and application of them are summarized below:

- Reduction of engineering efforts in preparing the system representation: The method for obtaining system equivalents for transient stability studies, will simplify the engineering work and thus be less time consuming and expensive.
- Reduction of computation costs for the transient stability studies: The coherency-based dynamic equivalencing approach achieve significant reduction in size of the system model without notable loss of accuracy.
- In operation fast simulations are important and reduction of the number of elements in the power system facilitate this.

- More effective planning studies: Engineering skill can be concentrated on system planning with less distraction by problem associated with the boundaries of system representation provides insight into the system behavior and better opportunity for testing alternative plans.