UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

DIRECT ASSESSMENT OF MULTI-MACHINE POWER SYSTEM STABILITY USING CATASTROPHE THEORY

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DECLARATION

I declare that this thesis entitle "Direct Assessment of Multi-Machine Power System Stability Using Catastrophe Theory'' is the result of my own research except as cited in the references .The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature ....

Name Maithem Hassen Kareem

Date ..18/2/2014.....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of master of electrical engineering (industrial power).

Signature ....

Supervisor name ...DR. ISMADI BUGIS...

Date ...18 FEB 2014...

DEDICATION

To My Beloved Parents, Wife and Kids

ABSTRACT

In this dissertation catastrophe theory is used to determine the transient stability regions. Taylor series expansion is used to find the energy balance equation in terms of clearing time and system transient parameters. The energy function is then put in the form of a catastrophe manifold from which the bifurcation set is extracted. The bifurcation set represents the transient stability region in terms of the power system transient parameters bounded by the transient stability limits. The transient stability regions determined are valid for any changes in loading conditions and fault location. The transient stability problem is dealt with in the two dimensions of transient stability limits and critical clearing times. Transient stability limits are given by the bifurcation set and the critical clearing times are calculated from the catastrophe manifold equation. The method achieves a breakthrough in the modeling problem because the effects of exciter response, flux decay and systems damping can all be included in the transient stability analysis. Numerical examples of one-machine infinite-bus and multi-machine power systems show a very good agreement with the time solution in the practical range of first swing stability analysis. The method presented in this dissertation fulfills all the requirements for on-line assessment of transient stability of power systems.

ABSTRAK

Dalam Disertasi ini teori malapetaka digunakan untuk menentukan kawasan kestabilan sementara.Pengembangan siri Taylor digunakan untuk mencari persamaan kuasa seimbang dari segi penjelasan masa dan parameter sistem fana. Persamaan kuasa tersebut diletakkan dalam bentuk manifold malapetaka dimana set pencabangan dua diekstrak. Set pencabangan dua mewakili rantau kestabilan fana dari segi parameter sementara sistem kuasa yang dikelilingi oleh had kestabilan fana. Kawasan kestabilan fana ditentukan adalah sah bagi apa-apa perubahan dalam keadaan beban dan lokasi kesalahan (fault). Masalah kestabilan fana dibincangkan dari dua dimensi, iaitu had kestabilan fana dan masa penjelasan yang kritikal. Had kestabilan sementara yang ditentukan oleh set pencabangan dua, manakala masa penjelasan kritikal dikira dari persamaan manifold malapetaka. Kaedah ini mencapai kejayaan dalam masalah model kerana kesan tindak balas penguja, kerosakan fluks dan redaman sistem semua boleh dimasukkan dalam analisis kestabilan fana. Contoh berangka satu mesin terhingga-bas dan sistem kuasa mengadungi pelbagai mesin menunjukkan perjanjian yang sangat baik dengan penyelesaian masa dalam pelbagai analisis praktikal kestabilan swing pertama. Kaedah yang dibentangkan di dalam Disertasi ini memenuhi semua keperluan untuk penilaian dalam talian kestabilan fana dalam sistem kuasa.

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Aa	-	Kinetic Energy
Ad	-	Potential Energy
CT	-	Catastrophe Theory
COA	-	Center of Angle
COI	-	Center of Inertia
CCT	-	Critical Clearing Time
EAC	-	Equal Area Criterion
GSU	-	Generator Step Up
LEB	-	Load to Equivalent Bus
L.H.S	-	Left Hand Side
RAD	-	Rotor Angle Deviation
R.H.S	-	Right Hand Side
TSA	-	Transient Stability Assessment
TCSC	-	Thyristor controller series compensation
UEP	-	Unstable Equilibrium Point

LIST OF PUBLICATIONS

Bugis.I, Maithem Hassen Kareem, Dual Generator Cluster Transient Stability Assessment Using Swallowtail Catastrophe Theory. *International Review on Modelling and Simulations IREMOS,*, Vol. 6, No. 3, June, 2013.

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CHAPTER 1

INTRODUCTION

1.1 Background

Instability in electric power systems, leading to loss of system synchronization, is a very sensitive problem for power utility engineers. In assessing power system stability there are two separate criteria (Duncan Glover and Mulukutla Sarma, 1994) to be considered, viz :

- Steady-state stability, for small perturbations, i.e., leading effectively to linear system analysis.
- Transient stability, for large system disturbances and involving non-linear system analysis.

The stability problem of power systems became very important following the famous power blackout in north eastern U.S.A. in November 1965. Planning, operations and control procedures of power systems had to be revised to ensure secure and reliable operation of power systems. Considerable research effort has gone into the stability investigation both for off-line and on-line purposes (Kimbark .E and Byerly .K,1974).

A stable power system implies that all its interconnected generators are operating in synchronism with the network and with each other. These generators start to oscillate when a disturbance occurs due to a transmission fault or switching operation. Loss of synchronism must be prevented or controlled because it has a disturbing effect on voltages, frequency and power, it may cause serious damage to generators, which are the most expensive components in a power system (Kimbark E. W., 1948). The generators which are losing synchronism due to the disturbance should be tripped out, i.e. disconnected from the system before any serious damage occurs, and afterwards brought back to synchronism. Loss of synchronism may also cause some protective relays to operate falsely and trip the circuit breakers of unfaulted lines. In such cases the problem is very complicated and may result in more generators losing synchronism.

Therefore, an understanding of system stability requires a thorough knowledge of both the mathematical modeling of the system and effective numerical techniques. In most of the cases, the model consists of a set of linear or non-linear algebraic and/or differential equations depending upon the type of study that is to be performed. It is important to select a numerical method which will provide accurate results, but the rapid growth of power systems makes it extremely difficult, expensive and time consuming to carry out these careful and detailed stability studies through solution of the system equations.

The increasing growth demand for electrical energy has led to the requirement of even larger interconnected power systems and a maximum power generation. This raises great concern about the security of power systems when subjected to large disturbances. Transient stability, therefore, becomes an increasingly important consideration in system planning and operation. Extensive stability studies are needed in order to ensure system security before a planning or operating decision is made. Each contingency for each disturbance considered requires a large number of stability studies to determine the critical clearing time or system stability limits.

A typical transient stability study consists of the obtaining the time solution to the power system differential and algebraic equations started with the system conditions prior to the transient.

The power system equations should include all significant parameters that influence the stability such as load flow, generator controls, system model and protective devices.

The desired objectives of a transient stability analysis are:

i- The operating point of the power system. Is it stable or not, to what degree is it stable, and how far is it from the stability limits?

ii- Time responses of generator variables, bus voltages, currents, active and reactive power.

iii- System quantities that affect the performance of protective devices.

The above objectives are key issues in power system design, planning and operation to ensure system stability for different prescribed disturbances.

The time solution method of stability analysis, although it is very reliable, accurate, and suitable for different modeling orders, has the following disadvantages;

1. The method involves numerical integration of a large number of differential equations for each disturbance considered. A large numbers of repetitive simulations are required for each case to determine either the stability limits or the critical clearing time. This procedure is very time consuming in the system planning stage where a large number of cases need to be considered.

2. In system operations, there are situations where fast solution is needed to make operational decisions. These situations could be different from those previously considered during planning. Since the time solution method is slow, the system operator has either to overreact to ensure system security or to make decisions that may put the stability of the system at risk.

3. The power system operating conditions change during the course of the day and year, while stability studies are done off-line for certain severe cases. This leads to improper decisions in some cases and, therefore, may increase operational expenditures.

1.2 Motivation For Research

The motivation for this work is to search for a method which is suitable for an on-line assessment of transient stability that can be used for every individual generator in the power system. If such a method can be found then the problem of transient stability can be dealt with on-line stability assessment. The most suitable method (from existing methods) for such an application is pattern recognition because of the fact that it is independent of the systems equations which couple the generators together. This brought up the idea of using catastrophe theory to define the stability region (Sallam.A.A, 1988).

1.3 Objectives of Research

The main objectives of this thesis are:

1. To prove the application catastrophe theory for the assessment of transient stability of power systems.
2. To improve the power system model used by including all necessary options to get as accurate a system response as possible.
3. To predict the comprehensive transient stability region with security boundaries for possible on-line assessment of transient stability.

1.4 Problem Statement

The question of whether the power system will settle down to a new stable operating state or not is known as the transient stability problem.

Although extensive research has been conducted in this area, little of the previous requirements have been achieved so far. A great deal of research still needs to either improve the existing methods or propose new methods in order to fulfill all these requirements.

From the above, it is clear that the power industry greatly needs an alternative method for time solution method to solve the transient stability problem. The alternative method cannot entirely replace the time solution, but it should reduce the number of simulations for each case and hence save a great deal of computation time. A new method is also needed for system operations where the system operator has only minutes or hours to make an important operational decision. The best solution, of course, is to have an on-line method that deals with system operations on a real-time basis.

1.5 Scope of Research

In this reseach we are interested in power system transient stability analysis by direct methods and we will concentrate on a simplified model called the classical model (Anderson .P.M and Fouad .A.A, 1977). All of the books on power system transient stability by direct methods begin their study with the classical model. As previously mentioned; because we are interested in assessing the use of direct methods for on-line stability prediction where computing time is an important factor, this model will also be used throughout this thesis. More advanced analysis using direct methods must consider a more detailed model of the power system.

1.6 Contributions of Research

1. For the first time, the catastrophe theory is applied with new data to the transient stability problem. Comprehensive transient stability regions are calculated in terms of the power system parameters. These regions are valid for any loading condition and fault location. All existing direct methods, on the other hand, require new computation for any change in operating conditions. This is an important consideration in implementing direct methods for real-time assessment of transient stability and system security.
2. Another unique advantage of the method presented is the inclusion of the excitation response during the transient period in the stability analysis. All existing direct methods are limited to the classical model which neglects the exciter response. With the inclusion of damping, flux decay and excitation response in the presented method, all factors that directly affect transient stability are taken into account. This result makes the direct methods more realistic.
3. Existing direct methods either neglect or approximate the effect of the transfer conductances. However, in some cases transfer conductances can have an appreciable effect on system performance (Sastry .V.R, 1973). In this research, the transfer conductances are fully represented.

1.7 Outline of Chapter

This dissertation is composed of five chapters. A brief background of stability, motivation for research, objectives of research, problem statements, scope of research and contributions of research have been covered in Chapter 1.

Chapter 2, contains a brief review of the stability problem and presently available solutions are presented followed by a literature review of the different methods used and suggested to the analysis stability problem of power system.

In Chapter 3, a preliminary application of catastrophe theory, a mathematical method, to the stability assessment of power systems is introduced in this chapter and the next section the theory reviewed followed by applications to both steady state and transient stability of a simple one machine infinite bus power system.

In Chapter 4, the technique is applied to multi-machine power systems using dynamic equivalents and Taylor series expansions. Transient stability regions are also given by using the catastrophe theory. In the next section, the discussion and analysis of the obtained results are elaborated. The results in this section have shown the feasibility of catastrophe theory application to multi-machine power systems.

Finally, Chapter 5 summarizes the conclusion, achievements of this project and suggestions for further work.

CHAPTER 2

REVIEW OF STABILITY PROBLEM AND ITS SOLUTION

2.1 Introduction

The stability problem of power systems has been given a new importance since the famous blackout in Northeast U.S.A. in 1965. Considerable research effort has gone into the stability investigation both for off-line and on-line purposes. It started a chain reaction affecting planning, operation and control procedures of electric power systems. Since then several studies have been conducted and new concepts and directions have been suggested to prevent instability and ensure security and reliability of power systems.

2.2 Literature Review

Direct methods of stability analysis are currently under consideration and investigation (Ribbens-Pavella.M and Evans.F.J., 1985). One of these methods catastrophe theory is a new way of thinking about changes such as in a course of events, a systems behavior, or even change in ideas themselves. Its name suggests disaster, and indeed the theory can be applied to literal catastrophes. The mathematical principles we are used to are ideally suited to analyses smooth, continuous and qualitative change (Saunders 1980), but there is another kind of change, that is less suited to mathematical analysis : such as the discontinuous transition from ice at its melting point to water at its freezing point or the transition from stable to unstable state for a power system following a disturbance. The foundations of catastrophe theory were developed by the French mathematician Rene' Thom