Ain Shams University
Faculty of Engineering
Electrical Power & Machines Department

Adaptive Damping of Inter-area Oscillations in interconnected Electrical Power Systems

By

Mohamed Waheed Fikry Mohamed Amer

This Thesis is submitted to the Faculty of Engineering at Ain Shams University

in partial fulfillment of the requirements for the degree of

Master in

Electrical Engineering (Power and Machines)

Ain Shams University

Faculty of Engineering

Under Supervision of

Prof. Ahmed Hassan Amer
Electrical Power & Machines Department
Faculty of Engineering – Ain Shams University

Assoc. Prof. Mohamed Abd El Aziz Hassan
Electrical Power & Machines Department
Faculty of Engineering – Ain Shams University

Cairo – Egypt

2009

APPROVAL SHEET

Student Name:

Eng. Mohamed Waheed Fikry Mohamed Amer

Thesis Title:

Adaptive Damping of Inter-area Oscillations in Interconnected Electrical Power Systems

Committee's Members

No	Prof. Name	Position
1	Prof. Mohamed Abd El-Lateef Badr	Ain Shams University Faculty of Engineering
2	Prof. Abbas Aly Metwaly El Hefnawy	President of Delta University
3	Prof. Ahmed Hassan Amer	Ain Shams University Faculty of Engineering
4	Assoc. Prof. Mohamed Abd El-Aziz	Ain Shams University Faculty of Engineering

Thesis defense date: 1-2-2009

Committee's Members

No	Prof. Name	Signature
1	Prof. Mohamed Abd El-Lateef Badr	
2	Prof. Abbas Aly Metwaly El Hefnawy	
3	Prof. Ahmed Hassan Amer	
4	Assoc. Prof. Mohamed Abd El-Aziz	

ACKNOWLEDGMENT

I would like to thank every person who helped me to achieve my goal for preparation and completing this thesis, especially my father **Waheed Fikry Mohamed Amer**, his wise words were always welcome and I thank him for his patience and encouragement.

I thank my **mother** for her kindness and deep considering always.

My heart full thanks go to my **father and mother in law** for their support and kindness.

I would like to thank a man who made the dream comes true who is **Prof. Dr. Ahmed Amer** whom I really appreciate his role with me in this long and tiring road to achieve this goal.

I am especially grateful for my co-supervisor **Dr. Mohamed Abdel Aziz** for his invaluable and fruitful suggestions.

In this moment, I want to send a special thanking to the soul of my **grandmother** who was the first guide for me in my career.

Also I would like to thank all my friends and my colleagues for their sincere help.

Finally I would like to make a special and heart full thanks to my beloved and wonderful wife **Nouran** and my little son **Omar**.

Mohamed Waheed Fikry Mohamed

ABSTRACT

Recently, inter-area oscillations have been of increasing importance. This is due to the interconnection between power systems within the same country or between many countries together to operate as one grid.

Inter-area oscillations are a phenomenon inherent to power systems where their damping is important to be studied to keep power systems stable, due to the instability of these large connected power systems where disturbance may occur in one of their components. Different aspects were used to attain satisfactory performance of power systems, especially using the static VAR compensator. The concept of reactive power compensation has been introduced to increase the damping rate of the inter-area oscillations. Conventionally, static VAR compensators (SVC's) are designed to keep the system voltage constant. The SVC is introduced in this thesis to damp inter-area oscillations with proportional integral differential controller (PID controller) acting as the brain of SVC

There are classical solutions used to damp inter-area oscillations which in some cases do not guarantee proper damping of these oscillations. The (power system stabilizer) PSS is mainly used for local oscillations damping since their signals are taken locally from the machines' shaft speed or accelerating power. The effect of PSS on inter-area modes of oscillations is limited.

Systems with power transmission over long distances from source generators tend to be poorly damped and the control of PSS will be ineffective. This situation leads to the utilization of SVC to achieve adaptive damping of oscillation.

The benefit of damping these oscillations is clear through the ability to increase the tie line power flowing in the proposed system under study. Time-Domain simulation is used to verify the robustness of the controller used during severe events.

The system considered for the study consists of two multimachine areas connected through a weak tie line. The loading conditions on every area are changed independently, where power is transmitted through the transmission line of 230kV and 220kM length.

This thesis presents the SVC as a controller to damp inter-area oscillations. PID controller is the regulator of this SVC. A sensitivity analysis is presented to observe the effect of changing the PID controller parameters on the oscillations' damping effect of the SVC.

The best values for the PID parameters under different loading conditions are obtained based upon the sensitivity analysis and the system performance.

A look up table was made so that at different values of power transfer between the two areas, different parameters for the PID controller was reached, finally SVC was observed to be used as an adaptive controller working efficiently under different loading conditions.

Also an additional study was made by implementing a power system of two nonequal inertia areas system where the inertia of one area is higher than the other area.

An assumption was made that the location of SVC was changed on the transmission line and observe the effect of the location of SVC on damping inter-area oscillations.

An observation was concluded that as the SVC is located near the higher inertia side the inter-area oscillations were damped successfully as the power transfer is from the higher inertia to the lower inertia side.

CONTENTS

List of Figures

Chapter (2)

Chapter (3)

Chapter (4)

Chapter (5)

List of Tables

List of Abbreviations

Chapter 1

Introduction

PID: Proportional-Integral-Differential Controller
PSS: Power system stabilizer
SVC: Static Var Compensator

Chapter 2

Dynamic Analysis of inter-area oscillations

M: Diagonal inertia matrix
D: Diagonal damping matrix
δ: rotor angle
ω: angular frequency
Kij: Synchronizing coefficient matrix
YGij: admittance matix
Gij: Conductance between i and j generator
Bij: Susceptance between i and j generator
Ei: magnitude of internal E.M.F of generator i
Ej: magnitude of internal E.M.F of generator j
Φij: mutual admittance angle
Vb: Base Voltage
Sb: Base Power
ZT.L: Per unit impedance
YT.L: Per unit impedance
ZGen: Generator impedance
YGen: Generator admittance
ZLoad(1) : Sending area load impedance
YLoad(1) : Sending area load admittance
ZLoad(2) : Receiving area load impedance
YLoad(2) : Receiving area load admittance

Chapter 3

Transient Analysis of inter-area oscillations

P: Active load power
Q: Reactive load power
$\Delta\omega$: Change in angular frequency
Δf: Change in machines' frequency
$\theta 1$: Rotor angle of machine (1)
$\theta 2$: Rotor angle of machine (2)
$\theta 3$: Rotor angle of machine (3)
$\theta 4$: Rotor angle of machine (4)

Chapter 4

Inter-area Oscillations damping

Swing Equation:

Tacc: Acceleration Torque
Tmech: Mechanical Torque
Telec: Electrical Torque of load

Steam Turbine:

Wref: reference speed
Wm: mechanical output speed
Pref: Reference power output

Excitation system control:

Vd: direct axis Voltage
Vq: Quadrate axis Voltage
Tr: Low pass filter time constant
Ka: Regulator Gain

Ta: Regulator time constant
Ke: Exciter Gain
Te: Exciter time constant
Vf: field Voltage

Power system stabilizer constants:

K: Power system stabilizer (PSS) gain
T1n: Lead Time constant
T1d: Lag Time constant
T2n: Lead Time constant
T2d: Lag Time constant
Vs: Output compensated voltage of PSS
In: Input signal to PSS (shaft speed)

SVC constants:

Bsvc : SVC variable susceptance
Vt: Terminal Voltage
Vref: Reference Voltage
Xs: Droop of SVC
Bcmax: Maximum capacitive susceptance
Blmax: Maximum iductive susceptance
TCR: Thyristor Controlled Reactor
TSC: Thyristor Switched Capacitor

PID controller parameters:

Kp: Proportional Gain
Ki: Integral Gain
Kd: Differential Gain

SVC impact on power system:

E': Transient E.M.F behind a reactance X'
X1: Reactance of generator and transformer