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Electrical Power & Machines Department**

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

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**Mohamed Waheed Fikry Mohamed**

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## **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.

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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.

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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.

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# 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

$\delta$ : rotor angle

$\omega$ : angular frequency

Kij: Synchronizing coefficient matrix

YGij: admittance matrix

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

$\Phi_{ij}$ : 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

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## Chapter 3

Transient Analysis of inter-area oscillations

P: Active load power

Q: Reactive load power

$\Delta\omega$ : Change in angular frequency

$\Delta f$ : 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: Quadrature axis Voltage

Tr: Low pass filter time constant

Ka: Regulator Gain

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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 inductive 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