TUNING OF POWER SYSTEM STABLIZER FOR SMALL SIGNAL STABILITY IMPROVEMENT OF INTERCONNETED POWER SYSTEM

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ABSTRACT

With the development of electric power system and continues interconnection of regional electric grids, the stability problem becomes more complex in nature, especially low frequency oscillation which play an important role to influence the stability and efficient operation of inter connected grids. The low frequency oscillations in the power system network especially the inter-area oscillations (0.1 to 1 Hz) is the key factor that influence the stable operation of interconnected grids and limits the transmission capacity of large-scale power system. Inter-area oscillations mainly represent the power oscillations among different generators located in different area of power systems. In the local control strategies adopted, local control signals for the controller can't achieve the effective damping control for these inter-area oscillations.. The selection of most suitable stabilizing feedback signal to the wide-area controller is the key objective of the controller design. In this dissertation two different methods of signal selection for wide area damping controller of power system have been exercised with emphasis on damping of critical inter area mode.

I .INTRODUCTION

The current installed capacity of electricity generation in India is 304.761 GW as of the end July 2016, [Wikipedia, 2016]. Nowadays, the continuous inter-connection of regional electric grid is the developing trend of modern power system all over the world, such as interconnection of national grids of India, Europe network, the Japan power grids, the national grids of China and North American power grids. The main reason for interconnection of electric grids is that it can efficiently utilize various power resources distributed in different areas and achieve the optimal allocation of energy resources. Moreover, in case of fault or disturbance in operating condition, it can provide additional supporting power of each area of interconnected grids which can increase the reliability of generation, transmission and distribution system.

The inter area oscillations inherent to the large inter connected grid becomes moredangerous to the system's security and the quality of the supply during transient situation. Hence it can be said that the low frequency oscillations put limitations on operation of the power system and network's control security. The increased interconnected network of power system carries out heavy inter change of electrical energy which invokes such poorly damped low frequency oscillation that the system stability becomes major concern.

Oscillations in power systems are classified by the system components that they effect. Electromechanical oscillations are of the following types:

1.Intra-plant mode oscillations(2.0 -3.0 Hz)
2.Local plant mode oscillations(1.0-2.0 Hz)
3.Inter-area mode oscillations(0.1-1.0 Hz)
4.Control mode oscillations mechanical oscillations
5.Torsional modes between rotating plant (10-46 Hz). [Pal, 2005]
Some other examples of power system black-outs due to inter-area oscillations are as follows:
1.In early 1960 and 1985 oscillations were observed when the Detroit Edison (DE), Ontario Hydro (OH) and Hydro-Québec (HQ) systems were inter-connected.

In 1969, oscillations were observed under several operating conditions in the Finland-Sweden (and Norway)-Denmark interconnected system.
In 1971 and 1972, over 70 incidents of unstable inter-area oscillations occurred in the Mid-Continent Area Power Pool (MAAP) system in North America.
1.In 1975, unstable oscillations of 0.6 Hz were encountered on the interconnected power system of New South Wales and Victoria.
2.In 1982 and 1983, the State Energy Commission of Western Australia (SECWA) experienced lightly damped system oscillations in the frequency range of 0.2-0.3 Hz.
In case of interconnected electric grids Low Frequency Oscillations (LFOs) especially inter-area oscillations are easily excited where there is fault or disturbance in the system. Such type of oscillating phenomena influence the stable operation of interconnected electric grids and sometimes black out or brown out type of abnormal phenomena occurs. Some blackouts of interconnected grids in worldwide are mention below:

II.POWER SYSTEM COMPONENTS

Synchronous Generator Modelling

Synchronous generators are the principal source of electric energy in power system. The power system stability is the main problem that deals with the inter connections of synchronous machines in synchronism. The synchronous generator mainly consists of two essential components. First one is field and the second is the armature. The field winding carries direct current and produces a magnetic field which induces alternating current and produces a magnetic field which induces alternating voltages in the armature windings. The three-phase armature windings are distributed 120^0 apart in space.

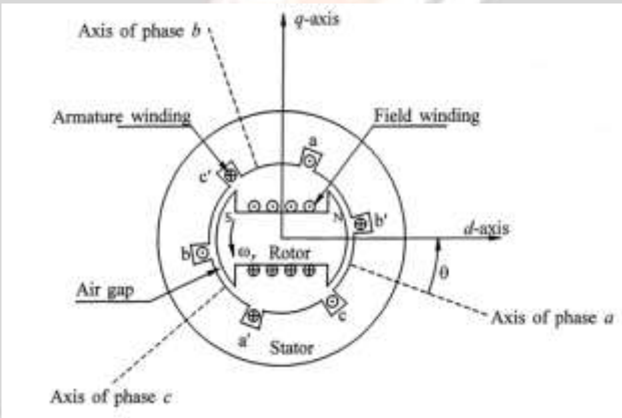

Figure 1 Schematic Diagram of a Three Phase

2.1Governor Modelling

The prime mover provides the mechanism for controlling the synchronous machine speed and hence voltage frequency. Consecutively to automatic control speed and frequency, adevice must be there to sense either speed or frequency in such a way that comparison with a desired value can be used to create an error signal to get corrective action. The control system diagram of such amodel for time constant governor 'T_G' with speed regulation 'R' is shown in figure.3.2)

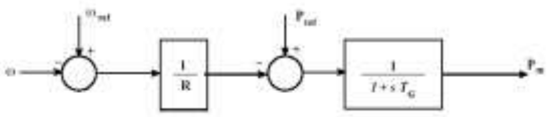

Figure 2 Block Diagram of Governor Model

Legends:
R - Regulator
$\boldsymbol{\omega_{ref}}$ - Reference input of speed

ω - Actual speed
R - Regulator constant
T_G - Gain of time constant of turbine governor system

Legends:

K_{STAB} - Gain of power system stabilizer
T_w - Washout time constant
T_1 and T_2 - Lag and lead time constant
T_R - Terminal voltage transducer time constant
K_A - Exciter gain

2.2 Load Modelling

In study of stability modeling of load is a complex problem due to the uncertain nature of aggregate loads (e.g. a mix of fluorescent, compact fluorescent, incandescent lamps refrigerators, heater, motor, etc.). Load models are usually classified into two broad categories: static and dynamic. The loads can be modeled using constant impedance,constant current and constant power static load models. Dynamic load models are more complex in nature and mainly used for transient stability analysis. Conversely, static models are better suited for power flow and small disturbance stability analysis. The load models can be described by polynomial equation.

$$\mathbf{P_L = kP_0\left[A_1 + A_2\frac{V}{V_0} + A_3\left(\frac{V}{V_0}\right)^2\right]} \quad (1)$$

$$\mathbf{Q_L = kQ_0\left[B_1 + B_2\frac{V}{V_0} + B_3\left(\frac{V}{V_0}\right)^2\right]} \quad 2)$$

Where,

$\boldsymbol{A_1 + A_2 + A_3 = B_1 + B_2 + B_3 = 1}$;'$\mathbf{P_0}$' and ' $\mathbf{Q_0}$' are called nominal powers. The nominal real and reactive powers consumed by the load is under nominal condition i.e. at nominal voltage '$\mathbf{V_0}$' and nominal frequency '$\mathbf{f_0}$' .The actual consumed load powers '$\mathbf{P_L}$' and ' $\mathbf{Q_L}$' are under the current condition of voltage '$\mathbf{V}$' and frequency '$\mathbf{f}$'. The variable 'k' used in the equation is known as loading factor. This kind loads are often called as ZIP model.

1.1 Power System Stability

Power System Stability

Power system stability may be broadly defined as property of power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain acceptable state of equilibrium after being subjected to a disturbance [Kundur, 2004]

In the evaluation of stability the concern is the behaviour of power system when subjected to a transient disturbance. This disturbance may be small or large. Small disturbances in the form of load changes take place continuously. The system must be able to operate satisfactorily under these conditions and successfully supply the maximum amount of load. Large disturbance occur due to severe change in nature such as short circuit on a transmission line, loss of a large generator or load, or loss of a tie- line between two subsystems. The power system stability can be classified into different category and sub-category as shown in figure 3.4.[Kundur, 2004], [Martins, 1999]

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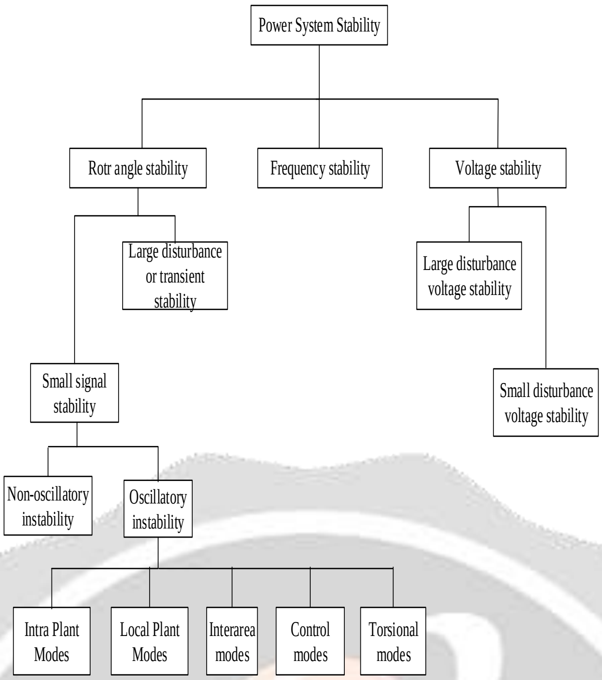

Figure *Error! No text of specified style in document.***- Classification of power system stability**

Rotor Angle Stability

Rotor angle stability is the ability of interconnected synchronous machines of a power system to remain in synchronism. The rotor angle stability depends on the ability of each synchronous machines of a power system to maintain/restore equilibrium between electromagnetic torque (generator output) and mechanical torque (generator input). If any of the synchronous machines fails to maintain synchronism with the rest of generators, then this will gives the result of instability.

In an inter-area connected power system the change in electromagnetic torque (ΔT_e) of a synchronous machine following a perturbation can be resolved into two components namely (a) Synchronising torque component and (b) Damping torque component. The synchronising torque component is in phase with rotor angle deviation whereas, damping torque component is in phase with speed deviation of the synchronous machines. This can be mathematically expressed as $\Delta \mathbf{T_e} = \mathbf{T_s}\Delta\boldsymbol{\delta} + \mathbf{T_D}\Delta\boldsymbol{\omega}$ $\quad (3)$

Where,

'$T_s\Delta\delta$' is the component of torque change in phase with the rotor angle perturbation '$\Delta\delta$' and is referred to as the synchronising torque components, 'T_s' is synchronising torque coefficient.

'$T_D\Delta_\omega$' is the component of torque in phase with the speed deviation 'Δ_ω' and is referred to as damping torque component, 'T_D' is the damping torque coefficient.

Both components of torque for each of the synchronous machines. Lack of sufficient synchronising torque results in instability. On the other hand, lack of sufficient damping torque results in oscillatory instability.

For convenience in analysis and for gaining useful insight into the nature of stability problems, it is usual to characterize the rotor angle stability phenomena in terms of the following two categories:

1.Small-signal (or small-disturbance) stability

2.Transient (or large-disturbance) stability

3.***Small-signal (or small-disturbance) stability*** is concerned with the ability of the power system to maintain synchronism under small disturbance. Such small disturbance occur due to continual change in loads and generations. Though the disturbance is very small linearization of the system can be permissible for the purpose of analysis [Kundur, 2004][CIGRE, 1996] [IEEE PES, 1995] Powerful analysis tools [PST, PSD software] can be used for the analysis of stability characteristics and for the design of corrective controls. The results of system response to a small disturbance can be represented in terms of eigenvalues and eigenvectors. The power system suffers from stability problem can be classified of two types: *(i) steady increase in rotor angle due to lack of sufficient synchronising torque* *or (ii) rotor oscillations of increasing amplitude due to lack if sufficient damping torque.*[Kundur, 2004] However in today's power system the stability problem usually associated with insufficient damping torque oscillations.[Kamwa, 2011] Small signal rotor angle oscillatory stability problem may be due to local modes, inter area modes, control modes, or torsional modes. [Martins, 1999]

1.Intra plant mode of oscillations concern about the oscillations of machines on the same power generation site oscillate against each other at 2 to 3 Hz. Though the oscillations take place within the generation plant complex this is categorized into intra plant mode.

2.Local plant mode of oscillations are referred to as swinging of one generator to the rest of the system at 1 to 2 Hz. The impact of the oscillations is localized to the generator and the line connected to the grid.

3.Inter-area mode of oscillations phenomenon is observed over large part of the network. It involves two or more no. of coherent groups of generators swing against each other at 1 Hz or less. The damping characteristic of the inter-area mode is detected by the tie-line strength, nature of the loads and the power flow.

4.Control mode of oscillations are associated with generators and poorly tuned exciters, generators, HVDC converters and SVC controls loads.

5.Torsional mode of oscillations are associated with turbine generator shaft system in the frequency range of 10 to 46 Hz. Usually these modes are excited when a multi stage turbine generator is connected to the grid system through a series compensated line.

Transient stability(large disturbance stability)is the ability of the power system to maintain synchronism after being subjected to a severe transient disturbance. When subjected to a large disturbance the system response is in the form of large excursion of rotor angles and influenced by the non-linear power angle relationship. Transient stability depends on both the initial operating state of the system and severity of the disturbance. Usually, the system is altered so that post disturbance steady state operation differs from that prior to the disturbance. When the instability occurs due to insufficient synchronising torque then it is manifested as first swing instability. The phenomena of first swing instability results in the form of aperiodic angular separation. [Kamwa, 2011] In large power system transient instability may not always occur as first swing instability; rather it could be the result of superposition of slow inter area swing mode and a local plant swing mode causing a large excursion of rotor angle beyond the first swing.

Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable drop in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.
system-loadand discrete controls and protections.

Though the time frame of interest for voltage stability problems may vary from a few seconds to tens of minutes, voltage stability may be either a short-term or a long-term phenomenon.

III.RESULTS ANALYSIS AND DISCUSSIONS

The effectiveness and robustness of the methods are analysed by the following process:

Small Signal Stability Assessment
To evaluate the effectiveness of the controller under system nonlinearities, the two area 4 machine system has been disturbed by changing the reference voltage of Generator 1. The tie-line active power, Positive sequence voltage of bus-1and bus-2, speed response of Generators and rotor mechanical response of generator-1 w.r.t. generator-4 have been observed for 20s under the presence of selected feedback signals by both the residue and geometric approach**.**

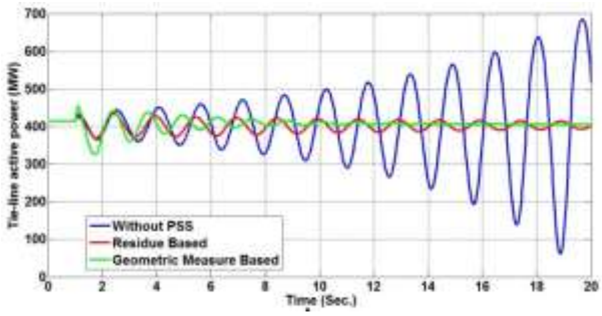

Figure 4 Tie-line active power flow after stepping up voltage reference at Generator-1

In figure. 4 horizontal axis represent the simulation time in seconds (sec) and vertical line represent the tie-line active power flow in Mega Watt (MW). The graph explains the responses of the line active power flow connecting the tie-line from area-1 to area-2 in both the cases of signal selection by based on residue and geometric measure approach along with without PSS. The plots have been taken by perturbing the voltage reference of Generator 1 AVR input. It can be observed that the signal selected by geometric approach gives better response as compared to the stabilizing signal selected by residue approach with respect to its settling time, peak over shoot and no. of oscillations.

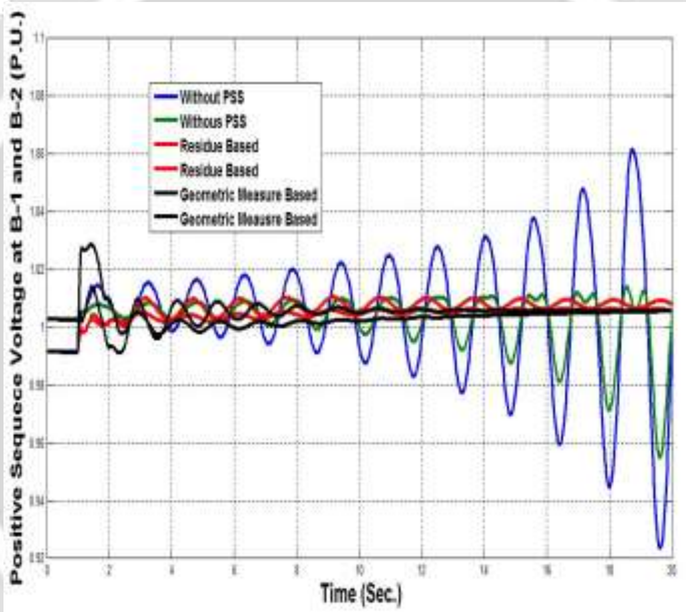

Figure 5 Positive sequence voltage at Bus-1 and B-2 for step change at Generator no. 1

Figure 6.2 shows positive sequence voltage at bus-1 and bus-2 for step change in AVR input voltage of generator 1. It can be seen in this figure that there are more no. of oscillations present in the system if the signal selected by residue approach is used as wide-area signal. In this case also geometric approach for signal selection performs well with respect to with respect to its settling time, peak over shoot and no. of oscillations.

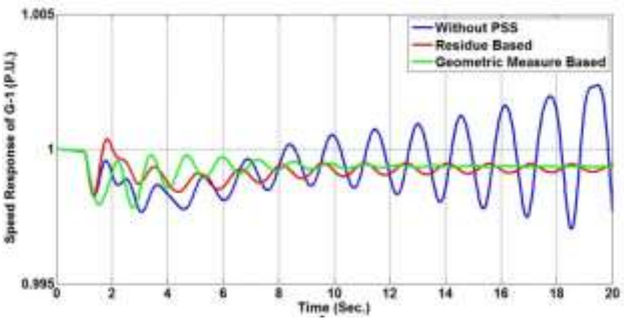

Figure Error! No text of specified style in document. **Speed response of Generator-1**

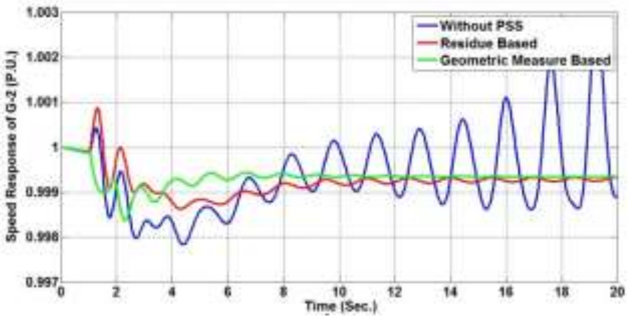

Figure 7 Speed response of Generator-2

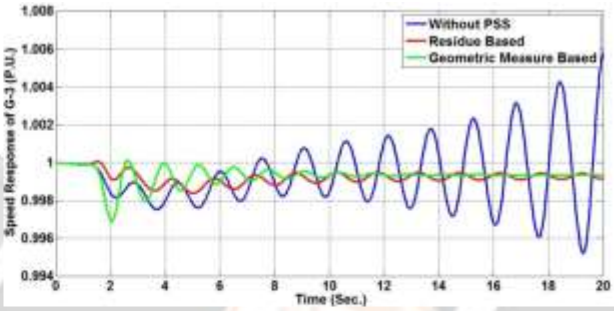

Figure 8 Speed response of Generator-3

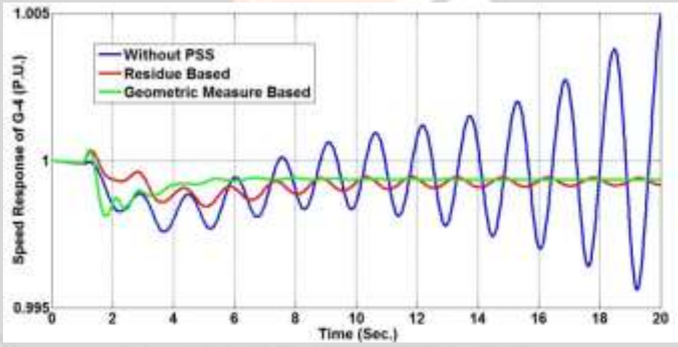

Figure 9 Speed response of generator-4

IV.CONCLUSION

The kundur's two area four machine system was illustrated as test system to examine the effectiveness of the selected control signal to damp a given inter area mode. To determine the suitable control loop both residue and geometric measure of joint controllability/observability based signal selection approaches were carried out. The effectiveness of the selected control loop was performed by small disturbance stability assessment and robustness of the selected control loop was accomplished by large disturbance stability assessment.

Based on the experimental simulation of the designed WADC, the results and conclusion that can be drawn based on the interpretation of the results, in chapter 6 the following conclusion are arrived for Kundur two area four machines system.
The selection of most suitable stabilizing feedback signal is the major objective of the controller design. In this dissertation two different methods of signal selection for wide area damping controller of power system have been exercised with emphasis on damping of critical inter area mode. The methods of signal selection is based on residue and geometric measure of joint controllability/observability. The controller used in this dissertation is as simple as a two channel lead-lag compensator based Power System Stabilizer. The methods of signal selection were illustrated on Kundur's two area four machine system. The effectiveness in damping of the critical inter area mode was assessed by both small disturbance and large disturbance stability analysis.

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FUTURE SCOPE

Although the research in this dissertation achieved a promising result of selecting a most efficient feedback stabilizing signal to the wide area damping controller, the work doesn't end here. In future some of the following aspects can be further researched:

Explanation of proposed signal selection method on large system: The research in this dissertation has been restricted for Kundur's two area four machine system. The effectiveness of signal selection can beheld with other large test systems such as New-England 39 bus 10 machine system, IEEE 14 bus system etc.

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