LITERATURE SURVEY ON INTELLIGENT WIDE AREA SIGNALS BASED DAMPING OF POWER SYSTEM OSCILLATIONS USING VIRTUAL GENERATORS

L.Heamkumar*, PG Scholars in Power System – Electrical & Electronics Engineering,*
Dr. M. G. R. Educational and Research Institute, Chennai, TamilNadu, India.

ABSTRACT: *The aim of this project is to illustrate the need of wide area damping controllers (WADCs) which interacting with Power system Stabilizers (PSSs) of each generators connected to a grid to damp the power system wide area oscillations created by the severe disturbance and/or power market variations, at the system operating condition, be close to the stability margin. Studies are based on the simulation of three areas, 9-bus power system proposed by Anderson and Farmer. One test case is investigated where the two generators out of three in the test system, fails to damp the oscillations completely. The result was observed by monitoring generators speed and voltage signals. A need of designing wide area oscillation damping controller is ensured, herein a concept of virtual generator is introduced to exploit the realization that a group of coherent synchronous generators in power system can be controlled as a single generating unit for achieving wide-area damping control objective. The implementation of VGs based WADCs is made possible by the availability of Wide-area measurements (WAMs) from Phasor Measurement Units (PMUs).*

Keywords: Wide area damping controllers (WADCs), Power System Stabilizers (PSSs), Virtual Generators, Power System Stability, DIgSILENT PowerFactory, Automatic voltage regulator (AVR).

1. RESEARCH MOTIVATION

Industrially developed societies need an ever-increasing supply of electrical power, and the demand has been doubling every ten year. Very complex power systems have been built to satisfy this increasing demand. The trend in electric power production is toward an interconnected network of transmission lines linking generators and loads into large integrated systems, some of which span entire continents.

This Project is concerned with some aspects of the design problem, particularly the dynamic performance of interconnected power systems. Characteristics of the various components of a power system during normal behavior practical terms this means that both voltage and frequency must be held within close tolerances so that the consumer's equipment may operate satisfactorily. For example, a drop of 10-15% or a reduction of the system frequency of only a few hertz may lead to stalling of the motor loads on the system. Thus it can be accurately stated that the power system operator must maintain a very high standard of continuous electrical service.

The first Requirement of reliable service is to keep the synchronous generators running in parallel and with adequate capacity to meet the load demand. If at any time a generator loses synchronism with the rest of the system, significant voltage and current fluctuations may occur and transmission line may be automatically tripped by their relays at undesired locations. If a generator is separated from the system, it must be resynchronized and then loaded, assuming it has not been damaged and its prime mover has not been shut down due to the disturbance that caused the loss of synchronism. Synchronous machine do not easily fall out of step under normal condition. If a machine tends to speed up or slow down, synchronizing force tend to keep it in step. Condition do arise, however, in which operation is such that the synchronizing forces for one or more machine may not be adequate, and small impacts in the system may cause these machines to lose synchronism. A major shock to the system may also lead to a loss of synchronism for one or more machines.

A second requirement of reliable electrical service is to maintain the integrity of the power network. The high-voltage transmission system connects the generating station and load centers. Interruptions in this network may hinder the flow of power to the load. This usually requires a study of large geographical area since almost all power systems are interconnected with neighboring systems. Economic power as well as emergency power may flow over interconnecting tie lines to maintain continuity of service. Therefore, successful operation of the system means that these lines must remain in service if firm power is to be exchanged between the areas of the system.

Random changes in loads are taking place at all times, with subsequent adjustments of generation and major changes like a fault on the network, failure in a piece of equipment, sudden application of major loads such as a steel mill, or loss of a line or generating unit. We may look at any of these as a change from one equilibrium state to another and the required state is "stable" state. For example, if a generator is lost, the remaining connected generators must be capable of meeting the load demand; or if a line is lost, the power it was carrying must be obtainable from another source. Unfortunately, this view is erroneous in one important aspect; it neglects the dynamics of the transition from one equilibrium state to another. Synchronism frequently may be lost in that transition period, or growing oscillations may occur over a transmission line, eventually leading to its tripping. These problems must be studied to obtain "power system stability".

2. LITERATURE SURVEY

Now power systems are being pushed to operate closer to their stability limits. This trend is caused by increasing electrical energy demands coupled with limited investment in transmission infrastructure and energy market deregulation. One of the manifestations of this stability reduction is the emergence of low-frequency inter-area oscillations [**1**]. Some power systems report a noticeable increase in the number of events involving these oscillations. In general, power system oscillations are mitigated (or damped) using Power System Stabilizers (PSSs).

A PSS injects a supplementary signal to the excitation system of the synchronous generator it is connected to. This supplementary signal is generated using only local measurements, which limits its effectiveness for system-wide damping control. In [**2**] the authors describe the principal of operation of PSSs and provide a step-by-step methodology for designing them. It is not clear that the conventional damping control approach using local PSSs will be effective enough to damp low-frequency inter-area oscillations [**3**]. However, the advent of Phasor Measurement Units (PMUs) and advanced communication infrastructures has opened the door to improved damping control algorithms due to the availability of time-synchronized wide-area signals. It has been shown that controllers that make use of these signals could damp power system oscillations more effectively than conventional local controllers [**3**]- [**4**]. However, the techniques and methodologies for designing these wide-area damping controllers (WADC) are still being refined by the research community.

The work in [**5**] presents a decentralized/hierarchical approach for the coordinated design of PSSs, that make use of wide-area signals to improve the damping of low-frequency oscillations in the Hydro-Quebec system. The approach relies on linear system identification and control design techniques, and therefore the performance of the resulting controllers is likely to degrade as the system's operating point shifts away from that used for controller design. An attempt to deal with this issue can be found in [**6**], where the controllers are developed using a linear model of the power system and robust control techniques. The resulting controllers were then tuned using the full non-linear model of the system to ensure appropriate performance. A neural network based method for dealing with the non-linear and time-varying nature of power systems is presented in [**7**]. The adaptive nature of these controllers allows them to maintain their level of performance even as the operating conditions of the power system change. However, as the size of the system grows, the computational expenses for achieving acceptable performance from neural networks become prohibitive and make this type of controller less practical for realistically sized systems [**8**]. Wide Area control realies the the concept of a Virtual Generator (VG). **[9]** Virtual Generator simplifies the representation of portion of the power system that allow wide area controllers to control of group of generator, combine to form one single generator. An Intelligent Local Signals based damping controller (ILADC) for damping electromechanical oscillation in power system. **[10]** The use of the virtual generator makes the proposed ILADC more scalable than the intelligent damping controller. This Intelligent Local Signals based damping controller (ILADC) can be achieved using the SSSC based stabilizer with the Genetic Algorithm(GA).**[11]**

3. POWER SYSTEM OSCILLATION

3.1. INTRODUCTION

In an interconnected power system, the synchronous generators should rotate at the same speed and power flows over tie-lines should remain constant under normal operating conditions. However, low frequency electromechanical oscillations may occur when a disturbance is applied to the power system. These oscillations can be observed in most power system variables like bus voltage, line current, generator speed and power. In India, low frequency power oscillations were repeatedly experienced in the Talcher-Balimela line linking the southern and eastern regions of India. A 210 MW thermal unit in Raichur, Karnataka, which was linked through a long tie-line (Xe ~ 0.9 p.u.) could not deliver the rated power, since low frequency power oscillations would set in as soon as the generator was loaded beyond 160 MW. Thus the Oscillations in power systems are classified by the system components that they affect. Some of the major system collapses attributed to oscillations are described.

3.2 INTRAPLANT MODE OSCILLATIONS

Machines on the same power generation site oscillate against each other at 2.0 to 3.0 Hz depending on the unit ratings and the reactance connecting them.

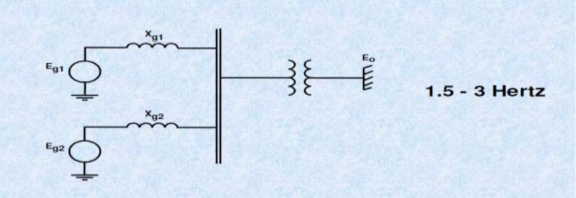

Fig – 1 : Intraplant Oscillation

This oscillation is termed as intra-plant because the oscillations manifest themselves within the generation plant complex. The rest of the system is unaffected.

3.3 LOCAL PLANT MODE OSCILLATIONS

In local mode, one generator swings against the rest of the system at 1.0 to 2.0 Hz. The impact of the oscillation is localized to the generator and the line connecting it to the grid. The rest of the system is normally modeled as a constant voltage source whose frequency is assumed to remain constant. This is known as the single-machine-infinite-bus (SMIB) model.

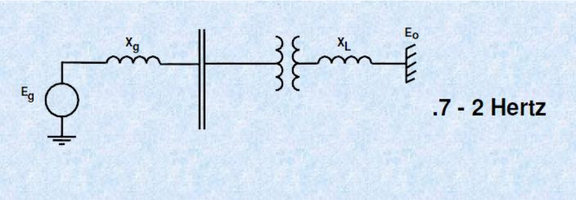

Fig – 2 : Local plant Oscillation

The damping and frequency vary with machine output and the impedance between the machine terminal and the infinite bus voltage.

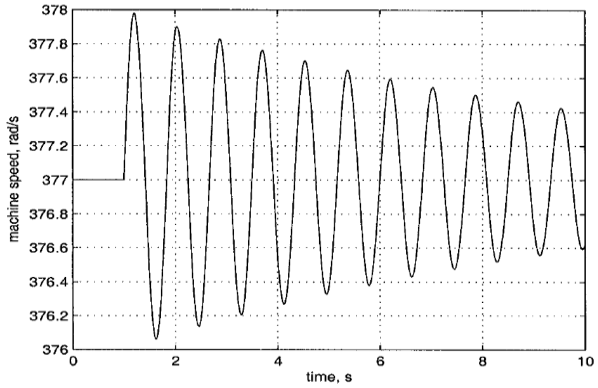

Fig – 3 : Damping in the Local plant oscillation

The oscillation may be removed with a single or dual input PSS that provides modulation of the voltage reference of the automatic voltage regulator (AVR) with proper phase and gain compensation circuit.

3.4 INTERAREA MODE OSCILLATIONS

This phenomenon is observed over a large part of the network. It involves two coherent group groups of generators swinging against each other at 1 Hz or less. The variation in tie-line power can be large. The oscillation frequency is approximately 0.3 Hz. This complex phenomenon involves many parts of the system with highly non-linear dynamic behavior.

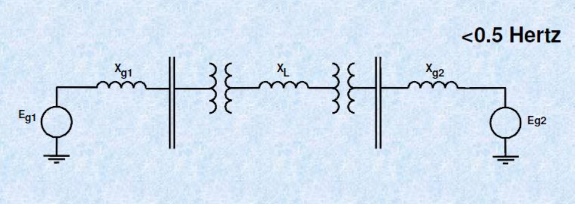

Fig – 4 : Interarea Oscillation

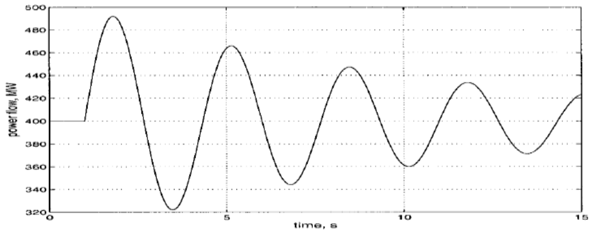

Fig – 5 : Damping in the Interarea oscillation

The damping characteristic of the inter-area mode is dictated by the tie-line strength, the nature of the loads and the power flow through the interconnection and the interaction of loads with the dynamics of generators and their associated controls. The operation of the system in the presence of a lightly damped inter-area mode is very difficult.

These are associated with generators and poorly tuned exciters, governors, HVDC converters and SVC controls. Loads and excitation systems can interact through control modes. Transformer tap-changing controls can also interact in a complex manner with non-linear loads giving rise to voltage oscillation

3.5 TORSIONAL MODE OSCILLATIONS

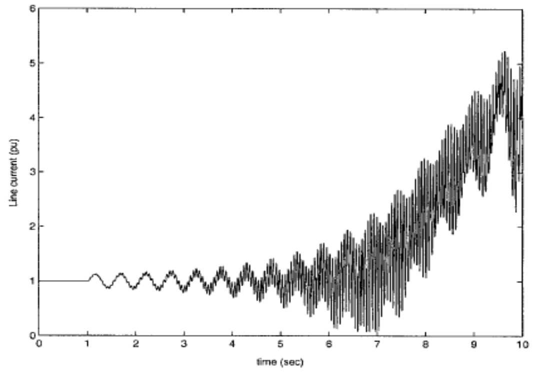

Fig – 6: Torsional oscillation

These modes are associated with a turbine generator shaft system in the frequency range of 10-46Hz. Usually these modes are excited when a multi-stage turbine generator is connected to the grid system through a series compensated line. A mechanical torsional mode of the shaft system interacts with the series capacitor at the natural frequency of the electrical network. The shaft resonance appears when network natural frequency equals synchronous frequency minus torsional frequency. \

3.6. ROLE OF OSCILLATIONS IN POWER BLACKOUTS

Inter-area oscillations have led to many system separations but few wide-scale blackouts. Note worthy incidents include:

(a) Detroit Edison (DE-Ontario Hydro (OH)-Hydro Quebec (HQ) (1960s, 1985)

(b) Saskatchewan-Manitoba Hydro-Western Ontario (1966)

(c) Italy-Yugoslavia-Austria (1971-1974)

(d) Western Electric Coordinating Council (WECC) (1964,1996)

(e) South East Australia (1975)

(f) Scotland-England (1978)

(g) Western Australia (1982,1983)

(h) Taiwan (1985)

(i) Ghana-Ivory Coast (1985)

(j) Southern Brazil (1975-1980,1984)

The power blackout in the Western Electricity Co-ordination Council (WECC) (formerly WSCC) area is described below. It indicates the importance of understanding and managing oscillations for secure operation of the grid.

3.7 OSCILLATIONS IN THE WECC SYSTEM

Power transfer capability in this system has been limited by stability considerations for 40 years because of the long distance between load centers and power sources. Oscillations have resulted in system separation on several occasions. They were caused by insufficient damping and synchronizing torque. The history of inter-area oscillations in this system has influenced the system planning, design and operation strategy. Insufficient damping turned out to be the major constraint when in 1964; the Northwest United States and Southwest United States were interconnected through the Colorado River Storage Project. In less than a year of interconnected operation, there were at least a hundred tie-line separations due to system oscillations of power, frequency and voltage. In 1965, the problem was solved by modifications to one of the hydro-unit governors.

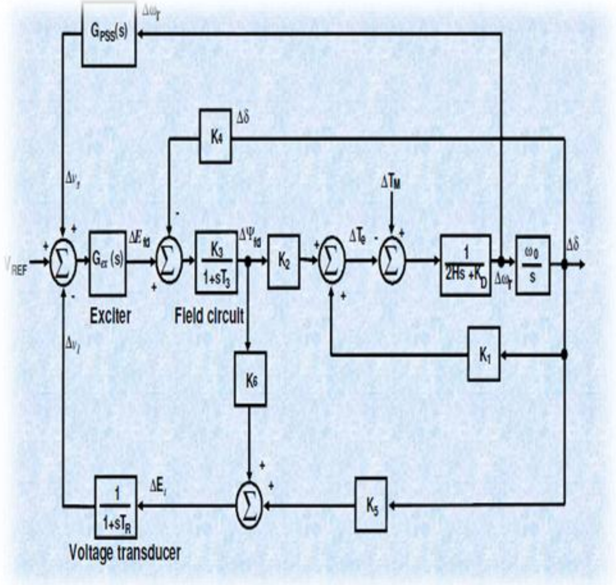

Fig – 7 : PSS with AVR, Exciter, and Generator

About that time work was initiated to develop time domain stability programs for more detailed analysis of interconnected systems. This was very useful since it coincided with the planning of many 345 kV and 500 kV transmission projects, including the Northwest-Southwest Inter-tie which consisted of two 500 kV ac lines and ± 400 kV dc 11 circuits. The initial plan was to carry 2000 MW through the ac circuits and 1440 MW through the dc line. Stability performance assessment showed that there was insufficient damping torque for ac power flows exceeding 1300 MW. It was found from the study that un-damped oscillations of power, frequency and voltage at about 0.33 Hz were the major restraint on a larger transfer. It was later realized that many of the generator high gain automatic voltage regulators (AVR) produced negative damping at around 0.33 Hz which led to the development and application of PSS. It was found from the time domain simulations that there would be sufficient damping for the most severe disturbance with 1800 MW transferred through the ac lines if all generators in the system were equipped with PSS. After all the units were retrofitted with PSS, the oscillations disappeared and the stability limit depended only upon the synchronizing torque.

The Bonneville Power Authority (BPA) implemented a 1400 MW braking resistor at Chief Joseph Dam in 1974 to improve first swing stability of the system. This indicated that the system could operate with up to 2500 MW flowing through the AC interconnection with adequate stability margin following severe disturbances such as a close in three phase fault. With even higher loading, however, slowly growing oscillations were observed, indicating that insufficient damping torque was again a problem at the higher loading level. The problem was relieved by the development of a scheme to modulate the northern terminal of the Northwest-Southwest dc line in such a manner as to provide positive damping to the ac system at the inter-tie frequency.

Overall the transmission capacity was increased from 1300 MW to 2500 MW without adding any transmission circuits. The only system additions were PSS, braking resistors and HVDC modulation. Many other interfaces in western USA are limited by insufficient damping torque and are highly dependent on PSS and other devices to provide positive damping. Currently there is a 0.7 Hz lightly damped inter-area mode identified from system models and analytical techniques. In one interface, nearly 750 MVAR of static VAR compensators have been installed to add damping so that the full planned transmission capacity will be available.

On August 10, 1996, the Pacific AC inter-tie (PACI) emerged from the dormant state that had lasted since 1974 when the entire inter-connected system split into four islands with the loss of approximately 30 GW of load. More than 7 million customers were 12 affected by this catastrophic event. The mechanism of failure was a transient oscillation, under conditions of high power transfer on long paths that had been progressively weakened through a series of fairly routine resource losses. This series of events was simulated based on the dynamic model data base with data assembled from the data bases of the utilities. The simulation showed a well damped response for the critical set of contingencies but did not show any voltage decay. The power flow through the pacific HVDC tie was observed constant because of constant power control in the simulation model. The simulated frequency dip was also only 60% of the recorded value. On the other hand, un-damped oscillations in the inter-tie power flow were recorded whilst voltages at several locations were depressed. Also the power flow through the HVDC tie was observed to vary thereby showing a serious discrepancy between the simulation model and the actual system dynamic characteristics. The over simplified model of the HVDC tie and its control were replaced with four-terminal links and control at converter levels. The automatic governor control (AGC) was included during the transient which is normally omitted from dynamic simulations. The presence of large turbo-generators delayed the power output pick-up immediately following frequency decay. This was done by not representing the governor action for large units. With all these modifications, the simulated system response differed appreciably from the recorded observation until a dynamic load model was included.

4. DIG SILENT POWER FACTORY

DigSILENT stands for **D**igital **S**imulation and **E**lectrical **N**etwork calculation program and it was developed by DigSILENT Power Factory. It is a computer aided engineering tool that is widely used for industrial, utility, commercial and academic applications. DigSILENT has the ability to simulate load flow, fault analysis, harmonic analysis and stability analysis for AC, DC and AC-DC systems. Both converter faults and DC line faults can be modelled in DigSILENT.

DigSILENT can import and export data from PSS/E version 23 to 29. The output file can be converted to Microsoft Excel easily. User defined model in DigSILENT can be written with drag-and-drop transfer functions. The code can be written with C++ programming language. Many user defined models can be obtained from the support website. Ones can write their own model based on those models straightforwardly.

For voltage stability, PV and QV curves are not standard functions in DigSILENT. PV curve is obtained by increase the loading factor in the loads; only the power output of swing bus is increased. QV curve is obtained by putting a synchronous condenser at the considered bus. Therefore, the generation direction analysis cannot be done by DigSILENT.

For small signal stability, the participation factor can be calculated only with the generator speed variables. ABCD matrices cannot be obtained by DigSILENT; therefore it is difficult to use DigSILENT for controller design purposes.

Sample Load flow in the DigSILENT Power Factory had been given for the project enhancement for running the load flow in the project and to have to stabilize the power system oscillation using the virtual generator.

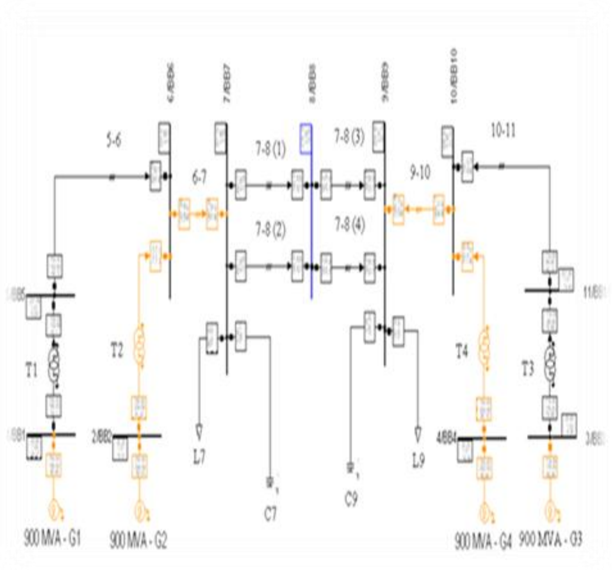

Fig – 8: Load Flow Model

5. CONCLUSION:

The Project proposes the development of test system with power system software DIgSILENT PowerFactory. DIgSILENT produces an equivalent representation of the power system network and calculates its parameters. This equivalent representation is valid for both load flow and short-circuits calculations. With the first step of investigating transient stability result, the power oscillations are found without any controller in the system i.e. simulation in open loop. Further works to damp this oscillation using exciting close loop are to be investigated to design for a near optimal damping solution. Many research topics to damp this oscillation are presented, but deep review is to be carried to obtain the near optimal damping solution.

REFERENCES

1. M. Jonsson, M. Begovic, and J. Daalder, "A new method suitable for real-time generator coherency determination," *IEEE Transactions on Power Systems*, vol. 19, no. 3, pp. 1473-1482, Aug. 2004.
2. P. Sauer and M. Pai, *Power system dynamics and stability*. Upper Saddle River, NJ: Prentice Hall, 1998.
3. M. E. Aboul-Ela, A. A. Sallam, J. D. McCalley, and A. A. Fouad, "Damping controller design for power system oscillations using global signals," *IEEE Transactions on Power Systems*, vol. 11, no. 2, pp. 767-773, May 1996
4. I. Kamwa, A. Heniche, G. Trudel, and M. Dobrescu, "Assessing the technical value of FACTS-based wide-area damping control loops," *Power Engineering Society General Meeting*, vol. 2, pp. 1734-1743, Jun. 2005.
5. I. Kamwa, R. Grondin, and Y. Hebert, "Wide-area measurement based stabilizing control of large power systems-a decentralized/hierarchical approach," *Power Systems, IEEE Transactions on*, vol. 16, no. 1, pp. 136-153, Aug. 2002.
6. Y. Zhang, WA, and A. Bose, "Design of Wide-Area Damping Controllers for Interarea Oscillations," *Power Systems, IEEE Transactions on*, vol. 23, no. 3, pp. 1136-1143, Aug. 2008
7. S. Mohagheghi, G. K. Venayagamoorthy, and R. G. Harley, "Optimal Wide Area Controller and State Predictor for a Power System," *Power Systems, IEEE Transactions on*, vol. 22, no. 2, pp. 693-705, May 2007
8. D. Molina, J. Liang, R. Harley, and G. K. Venayagamoorthy, "Comparison of TDNN and RNN performances for neuro-identification on small to medium-sized power systems," in *Computational Intelligence Applications In Smart Grid (CIASG), 2011 IEEE Symposium on*, Paris, Apr. 2011, pp. 1-8.
9. Diogenes Molina, Student Member Jiaqi Liang Student Member, IEEE, Ronald G. Harley, Fellow, IEEE, and Ganesh Kumar Venayagamoorthy, Senior Member,IEEE “Virtual Generator: Simplified online power system representations for wide area damping control” *978-1-4673-2729-9/12/$31.00@2012 IEEE*.
10. Diogenes Molina, Student Member IEEE, Ganesh Kumar Venayagamoorthy, Senior Member,IEEE, Jiaqi Liang Member, IEEE and Ronald G. Harley , Fellow IEEE “Intelligent Local Area Signal Based Damping of Power Signal Oscillatios using Virtual Generator and Approxiate Dynamic Programming” *IEEE Transaction on Smart Grid, Vol.4, No.1, March 2013*.

11. J.Barati, A. Saeedian, and S. S. Mortazavi “Damping Power Systwm Oscillation Improvement by FACTS Devies: A Comparison between SSSC and STATCOM” *World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer Energetic, Electronic and communication Engineering, Vol:4, No.2, 2010.*
12. Magdy E. aboul-Ela, A.a. Salla,, James D. McCalley, A.A. Fouad, “ Damping Controller Design for Power System Oscillations Using Global Signals, *IEEE Transaction on Power Systems, Vol.11, NO.2, May 1996.*