POWER SYSTEM DYNAMICS, STABILIZATION AND EVALUATION METHODOLOGIES BY

Nwagu Chukwukadibia C[1] and E.N.C Okafor[2]
Lordcondusresources1@yahoo.com
Department of Electrical Electronics Engineering
Enugu State University of Science and Technology, Enugu

Abstract: *Oscillation generated in power system dynamics poses threat to the stability of power system. Oscillation has caused great havoc to the power system and therefore, need to be reduced to increase the stability and reliability of power system. In solving this problem, various methods were adopted in addition with power system stabilizer. These methods could be conventional or optimization. They were reviewed in this paper to select the best enhancement method to improve the stability of power system.*

Keywords: Oscillation, Power System Stability, Power system Stabilizer and transient methodologies

I ***INTRODUCTION:***

Electric power system is nonlinear system and as such causes disturbance that can make the entire system unstable and constitute threat to the security of power system .The disturbance could be low frequency electromechanical oscillations due to insufficient damping effect. These oscillations with small magnitude and low frequency often persist for long period of time and in some cases present limitation to power transfer capability. (k5054) .In tackling and controlling the oscillation caused by the operations, modes of oscillation are to be analyzed to giving the best way of increasing the stability of the power system. To dampen out the oscillation easily, a supplementary control signal in the excitation system and the governor system of the generating unit are used. Recently, most attentions have been given to controlling of the signal to the excitation to ensure efficient damping of the oscillation, which characterize the phenomena of stability. Practically, it has been confirmed useful to incorporate transient stabilizing signals derived from speed, terminal frequency and power superimposed on the normal voltage error signal to provide for additional damping of the oscillation.

II OSCILLATION

Oscillation is the deviation in the value of the system voltage from the mean value in an alternating current, if oscillation is not properly controlled and regulated; it causes instability in power system, which will lead to the breaking down of the whole power system. Oscillation is majorly classified based on the power system components they adversely affect.

INTRA-AREA OSCILLATION: This is the oscillation that affects machines that are on the same generating site, causing them to oscillate against each other within the frequency of 2HZ to 3HZ.Intra-area oscillation does not affect other machines in other generating sites.

LOCAL-AREA MODE OSCILLATION*:* Local area mode oscillation comes into play when one single generating site swings against the rest of the system from 1HZ to 2 HZ. This oscillation affects only that generating site and its line connected to the grid.

INTER-AREA MODE OSCILLATION : This is the oscillation that influences two generating sites on the same network causing them to swing against each other at frequency of 1HZ or less. This oscillation causes change in tie-line power. It is ,therefore, strength of tie-line, nature of loads and power flow through the interconnection and the interaction of loads with the dynamic generating sites determines the damping effects of inter-area mode oscillation.

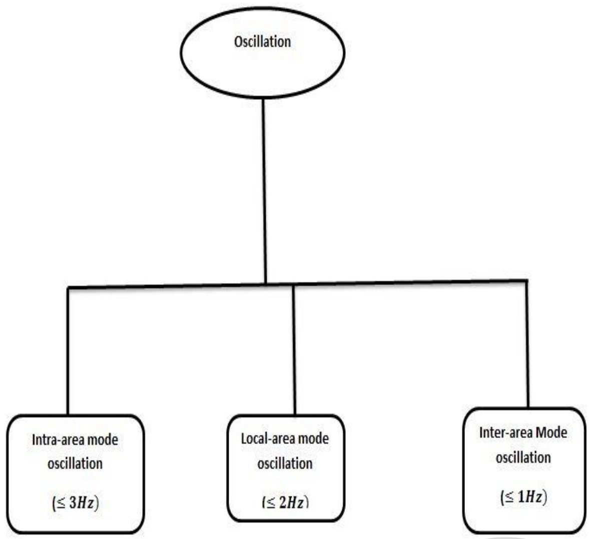

Fig 1: Classifications of oscillation

III POWER SYSTEM STABILITY

Stability in power system is the ability of the system to retain or return to its initial operational conditions during or after disturbance so that the entire system remains intact. In other words, Stability is the ability of a system to bring back its operation to steady state condition within least possible time after having undergone disturbance. Some systems might not maintain their steady state, especially when one of the components of the system is damaged. The duration of the disturbance and the nature of the disturbance have serious inference on the stability of the system and as well as the classification of stability. Small disturbance results in small transient oscillation in the system , and it is easily dampen out while a larger disturbance causes larger oscillation in the system. Synchronous system stability can be in form of voltage, frequency and rotor stability. And when there is any shortfall in any of the forms of synchronous stability, it leads to instability of the system.

FREQUENCY STABILITY: Frequency stability is the ability of the stored kinetic energy on rotating parts of the synchronous machine and other rotating electrical machine to restore the frequency of the system after a disturbance. The restoration of the system frequency is a function of bringing back the active power generated and consumed to a balance .If the total power fed into the system by the prime mover is less than what is consumed by the loads, including the losses; this imbalance will influence the frequency of the whole system. When the imbalance is not too large, the generators participating in the frequency control will regulate the active power input from their prime movers, and bring back the frequency deviation to acceptable values.

Whenever there is sudden shortage of the generation in a synchronous system as a result of increase in load or failure of any of generating unit, the system frequency always falls. A serious damage could occur in the synchronous system of multiple generating units operating away from the nominal system frequency, most machines have protection capability which automatically isolate or disconnect them whenever the system frequency is not correct. The fall in system frequency can be as a result of one generating unit's failure and this can cause the other generating units' protection circuits to trip causing low in system frequency. Lack of frequency stability in the system leads to poor coordination of operation control in protection devices, weakness of equipment response and deficiency in the generation reverse. So the ability of the system to restore its operating frequency to nominal frequency when there is perturbation is called the system frequency stability. For any of the generating unit to withstand the change in load during load application or surge, there is need to regulate a constant frequency through a process called Flat Frequency regulation. When the multiple generating units are sharing the load, they need to regulate their generation to maintain constant frequency through a process called Parallel frequency regulation. Whenever there is change in frequency on a particular generating unit , the generating unit tends to adjust its operation to maintain the tie -line loading, which is known as Flat tie-line loading control.

VOLTAGE STABILITY: Voltage stability is the ability of a synchronous system to bring back its voltage to the rated value on all the buses under normal conditions after application of disturbance .The voltage of the system is as a function of reactive power in the same system and needs to be maintained within a specific limit. The balance between the produced reactive power and consumed reactive power is not as clear and simple as concerning active power ,though there is always a balance of consumed and generated reactive power in every node of network. The complexity of reactive power in balancing at low load might be such that the injected reactive power could be high, resulting in a very high voltage which might be higher than the rated value for the equipment. This high value of reactive power and voltage is not desirable and should be controlled to avert instabilities in the system. Low voltages can occur at high load conditions while high voltages can occur at low load conditions. Depending on the time scale of the voltage instabilities, the instabilities can be classified as short-term or long-term. The instabilities that take a couple of seconds and the one that takes tens of seconds are termed short-term and long-term voltage instabilities respectively.

Voltage instability in synchronous system is witnessed by a progressive decline in voltage, which could be as a result of the synchronous system not meeting up with the increasing demand for reactive power. This instability could be caused by some form of disturbance or change in the operating conditions leading to higher demand of reactive power beyond what the system can supply. Some factors that can affect Voltage stability are loads characteristics, location of reactive compensation devices and other control actions like the one from load tap changing transformers, automatic voltage regulating equipment, speed governing mechanism on the generating units. Therefore, the ability of the synchronous system to bring back the system voltage to its rated value after perturbation is known as synchronous voltage stability.

ROTOR ANGULAR STABILITY: Rotor angle stability is referred to as the ability of synchronous generators to return to their rotor angle in the power system after a disturbance .This could either be as a result of small-disturbance rotor angle stability or large-disturbance rotor angle stability. The output mechanical power from the prime mover on turbine is fed into the generators to bring about electrical power which is fed into the power system for transmission and distribution. The total active electrical power fed into the power system by the generators is equal to the active power consumed by the appliances, loads, and the power losses in the system. Any disturbance against the balance between the electrical power generated by the generators and the power consumed by the loads including the losses in the rotating parts of the generators and other rotating parts of the plant act as buffer, and the kinetic energy stored in them will either increase or decrease depending on the nature of the disturbance. Rotor angle stability can be transient or small signal stability.

Transient stability is the ability of the power system to remain in synchrony after application of large disturbance on a small time scale .the typical time scale for this instability to develop is from a second to couple of seconds. This forms an instability known as large-disturbance rotor angle instability.

Small signal(Steady state) stability is the ability of the power system to retain its synchrony under small disturbance .This forms an instability known as small-disturbance rotor angle stability and it is associated with insufficient damping of oscillations.

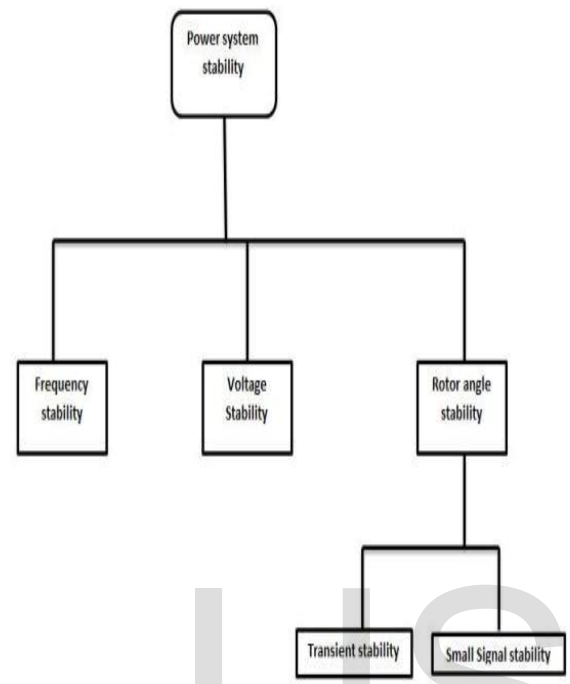

Fig 2: Classification of power system stability

***POWER SYSTEM STABILIZER*:** Low frequency oscillation poses challenge to the dynamic stability of power system, due to the large and complex nature of power system, there is need for a device that can damp out the said oscillation in order to maintain reliability and stability of the power system. Power system stabilizer is known to be the most efficient device to damp the power system oscillation, Eslami et al,(2011). To provide damping and improve the dynamic performance of power system, a supplementary control signal in the excitation system and /or stabilizing signal to the governor system of the generating unit through power system stabilizer is essential , Eslami et al,(2011). The function of power system stabilizer is to primarily generate torque on the rotor of the machine in such a way that the phase-lag between the exciter input and the machine electrical torque can be compensated. This electrical torque generated is called damping torque and is proportional to the rotor angle and speed change ,Eslami et al,(2011). Therefore, with the addition of power system stability the steady state stability and transient stability will be enhanced. But in multi-machine systems, addition of power system stabilizer to one generator may be insufficient in improving the damping of other generators. Also, addition of power system stabilizer, turbine governor system of all generators in multi or single machine help to dampen out local and inter-area oscillations. In power system stabilizer, a phase compensation approach is always used .Any electromechanical oscillation or local mode frequency, a phase lead of the PSS(Power System Stabilier) is chosen to compensate for the combined lag of the excitation system and the generator ΔVt-ref to ΔPe. PSS quickly provide a component of electrical torque in phase with the speed deviation thereby contributing to the system damping .The compensator gain determines the magnitude of the damping component. Figure 3 shows schematic of a generator, excitation system and power system stabilizer.

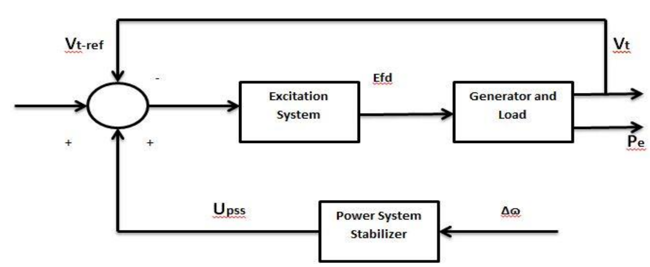

Fig 3: Schematic of Conventional Power system Stabilizer

A conventional power system stabilizer can be modeled as a two stage and lead-lag network which is represented by a gain Ki, washout blocks and phase compensation blocks as shown in figure 4 below. The washout blocks acts as a high-pass filter with constant Tw that allows the signal associated with the oscillation in rotor speed to pass unchanged and also it does not allow steady state changes to modify the terminal voltages. The phase compensation blocks with time constants T1i-T4i supply the suitable phase-lead characteristics to compensate the phase lag between the input and output signals. The phase lag in the power generation always take place at the output of the excitation and once the power system stabilizer is added in the power system generation, it tends to supply the input of the excitation system with phase lead to compensate the phase lag sensed. Power system stabilizer utilizes some input signals to function properly.

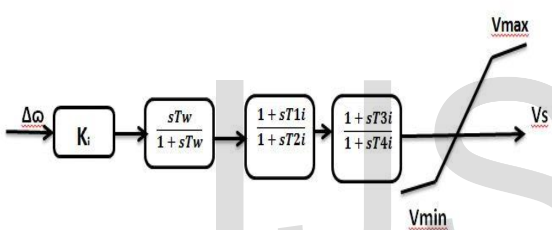

Fig 4: Structure of conventional power system stabilizer

In the design of power system stabilizer, some parameters are used as input signals to enable efficient damping out of the oscillation associated with the said inputs. Input signals such as speed, power and rotor frequency are considered. Based on the classification of the input signals of the power system stabilizer comes the types of power system stabilizer such as Single input and dual input power system stabilizer. This paper covers only single input power system stabilizer

SPEED AS INPUT SIGNAL **:** In synchronous system, the shaft speed is used as one of the input signals with which power system stabilizer utilizes to compensate for the lags in the transfer function in producing a component of torque in phase with the speed changes, so as to increase damping of the rotor oscillation.

POWER AS INPUT SIGNAL: Accelerating power as an input signal is an important parameter that is used as a mechanical power which is minimized by utilizing filtered speed signal.

FREQUENCY AS INPUT SIGNAL : The use of frequency as an input signal to rotor is of importance when compared with speed especially when the transmission system becomes weaker ,which tends to offset the reduction in gain from the power system stabilizer output to electrical torque.

IV *OVERVIEW OF POWER SYSTEM STABILIZER TECHNIQUES*

To enhance the capability of power system stabilizer, two major control strategies such as classical and modern control techniques are applied to increase the damping effect towards eliminating or if not, total elimination of oscillation in the synchronous system to bring about more stability or reliability on the generation, transmission and distribution aspect.

A. Classical control strategies

Several techniques under classical control have been proposed in the design of power system stabilizer; these techniques are as listed below:

1. Pole-Placement :All controllers from simultaneous stabilization techniques having fixed gain constant when compared with adaptive controllers, Othman et al(1989) investigated the application of pole-placement on these controllers in multiple operating conditions .In this investigation, a set of gains were designed separately and then a special root locus techniques was applied to adjust these gains. The new designed stabilizer performs better especially when the machine outage occurs. In 2004, Abdel-magid et al implemented the use of pole-placement method to tune the decentralized output feedback of the power system stabilizer. Objective function was selected to enable ascertain the location of all real part and damping ratios of the electromechanical modes. These electromechanical modes move to the location if the objection function converges to zero at the end of every iteration process.

2. ***Linear Quadratic Regulator(LQR):*** **In** 1996, Nambu et al used differential geometric linearization approach on power system stabilizer, where the stabilizer utilized the signals on the secondary of the step-up transformer as inputs to the generator. These signals from the secondary bus were defined as reference bus instead of infinite bus. Power system stabilizer based LQR proved more stable during faults in the power system, Guo-qiang et al,(2004)

3. ***Quantitative Feedback theory****:* Rao et al applied quantitative feedback theory on power system stabilizer to handle parametric uncertainty in small signal linearized model of the plant. Sedigh et al and okuo et al applied same techniques on power system stabilizer and overcome the setback of parameters variations.

B ***Modern control strategies***

The modern control strategies are applied on power system stabilizer to enhance the stability of the power system via the improvement of the damping torque of the power system stabilizer. Modern control strategies are grouped into two main categories such as adaptive control and intelligent control or optimization control technique. Adaptive control technique has subdivision of adaptive automatic and self-tuning or self-scaling. Intelligent control techniques can be Fuzzy logic, Artificial Neural network, Genetic Algorithm etc .These strategies have more and better operation performance when compared with the conventional designed stabilizer. Therefore, in mitigating the shortcomings of conventional stabilizers, modern control techniques especially intelligent optimization techniques are to be applied in the design of power system stabilizer.

1.***Fuzzy Logic :*** Zadeh et al ,(1965) brought about fuzzy logic .fuzzy logic controller are rule-based, rules are written in natural language and later translated into fuzzy logic .The translation started by converting the crisp inputs values through fuzzification process to linguistic fuzzy set with membership values using normalized member functions. Information about fuzzy memberships and rule base are being comprised by the knowledge base. The proper control action based on the rules was being decided by the inference engine. Finally, defuzzifire converts the linguistic variable to crip values using normalized membership functions and out gains, Tsoukalas et al, (1997). Mitra et al (2000) introduced fuzzy power system stabilizer with new input signals, these signals are speed deviation and the tie-line connecting the two area. The use of this controller gave better dynamic performance when compared with conventional PSS with usual speed deviation and acceleration input signals. Fuzzy logic controllers have better speed when compared with conventional controllers. All controllers for fuzzy logic design have their rules and membership tuned subjectively, thereby making their design so labourious and time consuming.

2. ***Artificial neural Network (ANN)*** : This is a mathematical model based on biological neural network. Artificial neural networks consist of a number of simple nodes connected together to form either a single or multiple layers. This is an effective tools that has been used for identification and control of complex system due to its non-linear mapping properties .ANN may be used as a controller instead of conventional PSS especially when sufficiently trained. The training is done with the inputs and outputs of conventional power system stabilizer. In 1949, Hebb presented the training algorithm and verified how a network of neurons could exhibit learning behavior. Shamsollahi et al

,(2002) investigated a feed-forward neural networks with a single hidden layer to develop a neural adaptive PSS. This proposed neural adaptive PSS includes two sub-networks: adaptive neuro-identifier which tracks the dynamic characteristics of the plant and adaptive neuro-controller to damp the low frequency oscillations. These sub-networks were trained in an online mode utilizing the back propagation method. For some decades now, ANN controllers have been put to use as power system stabilizers. ANN is more robust and it has higher speed when compared with other classical controllers. ANNs have the better capability of learning and adaptation, though it needs training.

3. ***Genetic Algorithm(GA):*** is an evolutionary algorithm used as a search technique for optimal or near optimal solution for problem especially in power system.it is categorized as global search heuristics (Piyush et al,2017). GA evaluates from population by creating numbers of parents to form the population. The population to be formed depends on the fitness values of the selected parents. Parents with low fitness values are replaced with parents with higher fitness value and the formed population is called mating pool. In this mating pool as selected, operators of GA (crossover and mutation) are being applied to produce a child of better value and this process is repeatedly done until number of child is equal to the population size. GA is most successful among evolutionary algorithm. It is very useful in some conditions when; there is no mathematical analysis is available, the search space is complex and poor, the problems are complex and loosely defined .As result of these advantages, GA is used to tune multiple controllers in different operating conditions and as well enhance power system stability through power system stabilizer.

V. *CONCLUSION:*

This paper has a brief description of power system stability with it classifications. Highlights of oscillation were done with its consequence on the power system stability. Power system stabilizer as a device to enhance power system stability and eliminate oscillation was explained alongside with techniques that will improve the functions of the power system stability.

REFERENCES

A.F.Okou,(2000).Towards a systematic procedure to design robust PSSs, IEEE, pp. 2361-2366

A. K. Sedigh, & G. Alizadeh,(March 1994). Design of robust PSS using quantitive feedback theory *IEE contl Conf., pub*. no.389, pp. 416-421.

Eslami .M,Shareef .H & Mohamed .A,(2011).Application of artificial intelligent techniques in PSS design:a survey of the state-of-the-art methods

Eslami .M, Shareef .H,Mohamed .A & Khajehzadeh. M,(2011).Damping controller design for power system oscillations using Hybrid GA-SQP

Hu Guo-qiang, Xu Dong-jie, He Ren-mu (2004).“Genetic Algorithm Based Design of Power System Stabilizers” *IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies* (DRPT), Vol. 1 pp:167-171,

L.H. Tsoukalas, and R.E. Uhric,(1997) Fuzzy and neural approaches in engineering, John Wiley & Sons, Inc, pp. 15.

M. Nambu, and Y. Ohsawa,(May 1996).Development of an advanced power system stabilizer using a strict linearization approach,*IEEE Trans. Power Sys*., vol. 11, no. 2, pp. 813-818.

Monika,balwinder Singh & Rintu Khanna,29th March,2014. Power System Stability and Optimization Techniques

Othman H. et al ,December 1989."On the design of robust power system stabilizers," *IEEE Proc of 28th conf on Dec. & control,* pp. 1853-1857.

P. S. Rao, and I. Sen,(July 1999. "Robust tuning of power system stabilizers using QFT," IEEE Trans.Cont. Sys. Tech., vol. 7, no. 4, pp. 478-486.

P. Mitra, S. Chowdhury, S.P. Chowdhury, S.K. Pal, R.N. Lahiri, and Y.H. Song,(2006) "Performance of a fuzzy power system stabilizer with tie line active power deviation feedback," *Power Systems Conference and Exposition,* PSCE 2006 IEEE PES, vol. 29, no. 1, pp. 884- 889

Piyush A,Jitendra K.D & Vishnu M.M (2017).Stabilization of Power system Using Artificial Intelligence Based System

Shamsollahi P. ,Malik O., (2002) An adaptive power system stabilizer using on-line trained neural networks*. IEEE Trans. Energy Convers*. 12 No. 4, 382-387.

Y.L. Abdel-Magid and M.A. Abido,(2003). "Optimal Multi objective Design of Robust Power System Stabilizers Using Genetic Algorithms" *IEEE Transactions on Power Systems*, Vol.18,No. 3, pp: 1125 -1132.

Zadeh L. (1965), Fuzzy sets Information and control, 8 No. 3, 338-353.