Evolution of Different Review Techniques Used For Transient Stability Improvement in a Large Electric Power System

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***Abstract*: Power system stability is defined as an ability of the power system to reestablish the initial steady state or come into the new steady state after any variation of the system's operation value or after system´s breakdown. In recent years important research has been done in the area of transient stability prediction and improvement with different techniques by power system engineers. As far as from research work this paper gives the overview of different techniques for analysis and improvement the transient stability in power system.**

***Keyword*: Power system transient stability, AVR, PSS, Artificial Intelligence, Fuzzy, Neuro-Fuzzy**

1. Introduction

To provide reliable and uninterrupted service to loads depends on successful operation of power system and engineer's ability. The reliability of power supply means more than being available. Generally, constant voltage and frequency must be fed in loads at all times. To meet the load demand, the first requirement of reliable service is to keep the synchronous generator running in parallel and with adequate capacity. Under normal condition synchronous machine do not easily loss the synchronism. If a machine tends to slow down or speed up, synchronizing forces tend to keep it in step. Conditions to arise, such as a fault on the network, sudden application of a major load such as a steel meal, failure in a piece of equipment, or loss of a line or generating unit. In which operation is such that the synchronizing force in more or one machines may not be adequate and small impact in the machine may cause to lose synchronization.

The transient stability studies involve the determination of whether or not synchronism is maintained after the machine has been subjected to large disturbance. This may be sudden application of load, loss of generation, loss of large load, or a fault on the system. In most disturbances, oscillations are of such magnitude that linearization is not permissible and the nonlinear swing equation must be solved [1] [2] [3].

2. Numerical Solution of Swing Equation

The transient stability analysis requires the solution of a system of coupled non-linear differential equations. In general, no analytical solution of these equations exists. However, techniques are available to obtain approximate solution of such differential equations by numerical methods and one must therefore resort to numerical computation techniques commonly known as digital simulation [4].

Swing Equation

The relative position of the resultant magnetic field axis and rotor axis is fixed under normal conditions. Power angle and torque angle are the angle between the two axes. During disturbance, a relative motion begins because of the deceleration or acceleration w.r.t the synchronously rotating air gap mmf. Swing equation is the mathematical structure to describe relative motion. Swing equation in terms of inertial constant M,

$$M\frac{d^2\delta}{dt^2} = P_m - P_e \tag{1}$$

M=Inertia constant $\qquad$ P_m =Mechanical power

δ = power angle $\qquad$ P_e =Electrical power

Some of the commonly used numerical techniques for the solution of the swing equation are: 1) Point by point method, 2) Euler modified method, 3) Runge-Kutta method. While this approach is not suited for a detailed study of large systems, it is useful in gaining a physical insight into the effects of field circuit dynamics and in establishing the basis for methods of enhancing stability through excitation control [2] [4].

3. Automatic Voltage Regulator

In a power system the instability can be shown in different ways, according to its configuration and its mode of operation, but it can also be observed without loss of synchronism. Automatic devices control generators in its voltage output and frequency, in order to keep them constant according to pre-established values. Automatic voltage regulator (AVR) is a controller that senses the generator output voltage and then takes corrective action by changing the exciter control in the desired direction.

The automatic devices are Automatic voltage regulator and Governor. The governor is slower in is action loop than AVR. This is associated mainly to its final action in the turbine. The main objective of the automatic voltage regulator is to control the terminal voltage by adjusting the generators exciter voltage. It must keep track of the generator terminal voltage all time and under any load condition, working in order to keep the voltage within pre-established limits [5].

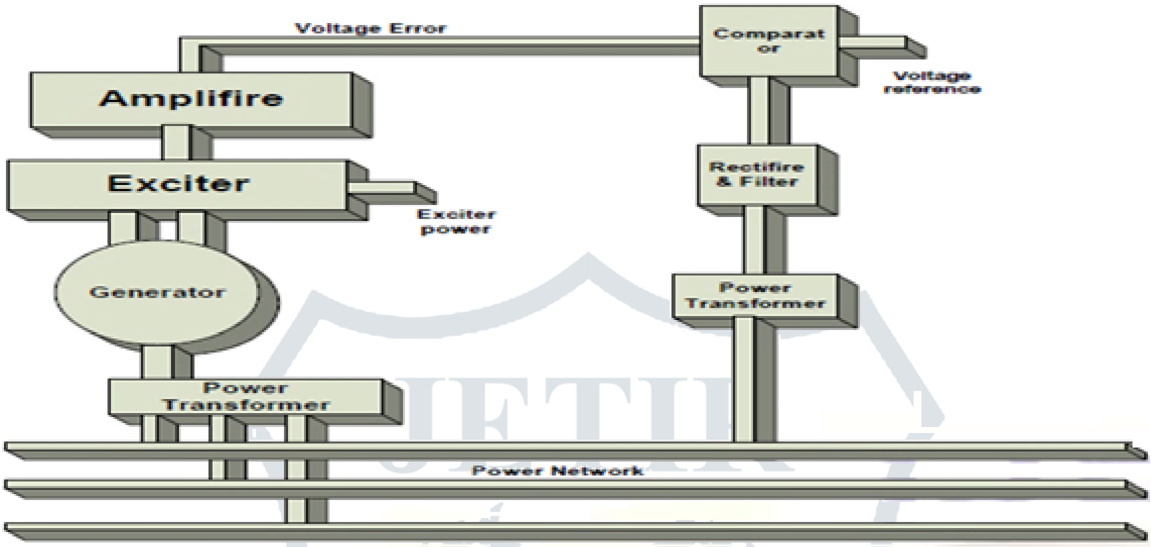

Figure 1 Typical arrangement of simple AVR

The AVR quality influences the voltage level during steady state operation, and also reduces the voltage oscillations during transient periods, affecting the overall system stability. However, use of AVR has detrimental effect on the dynamic stability or steady state stability of the power system as oscillations of low frequencies persist in the power system for a long period and sometimes affect the power transfer capabilities of the system [5] [6].

4. Power System Stabilizer

Traditionally the excitation system regulates the generated voltage and there by helps control the system voltage. The automatic voltage regulators (AVR) are found extremely suitable for the regulation of generated voltage through excitation control. The power system stabilizers (PSS) were developed to aid in damping these oscillations by modulation of excitation system and by this supplement stability to the system. The basic operation of PSS is to apply a signal to the excitation system that creates damping torque which is in phase with the rotor oscillations [7].

Design Considerations:

The main objective of PSS is to damp out oscillations it can have strong effect on power system stability. As PSS damps oscillations by regulating generator field voltage it results in swing of VAR output. So the gain of PSS is chosen carefully so that the resultant gain margin of Volt/VAR swing should be acceptable. To reduce this swing the time constant of the "Wash-Out Filter" can be adjusted to allow the frequency shaping of the input signal. During the loading/un-loading or loss of generation a control enhancement may be needed when large fluctuations in the frequency and speed may act through the PSS and drive the system towards instability. Apart from the low frequency oscillations the input to PSS also contains high frequency turbine generator oscillations which should be taken into account for design of PSS.

PSS Input Signals:

Till date numerous PSS designs have been suggested. Using various input parameters such as electrical power, speed, rotor frequency several PSS models have been designed. Among those some are depicted below [8].

a) POWER AS INPUT:

The power as input is mostly suitable for closed loop characteristic of electrical power feedback. The use of accelerating power as an input signal to the power system stabilizer has received considerable attention due to its low level torsional interaction. By utilizing heavily filtered speed signal the effects of mechanical power changes can be minimized.

b) SPEED AS INPUT:

A power system stabilizer utilizing shaft speed as an input must compensate for the lags in the transfer function to produce a component of torque in phase with speed changes so as to increase damping of the rotor oscillations.

c) FREQUENCY AS INPUT:

The sensitivity of the frequency signal to the rotor input increases in comparison to speed as input as the external transmission system becomes weaker which tend to offset the reduction in gain from stabilizer output to electrical torque, that is apparent from the input signal sensitivity factor concept.

However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS on the rotor. The reason for this is that PSSs are tuned around a steady-state operating point; their damping effect is only valid for small excursions around this operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism in an attempt to control its excitation field.

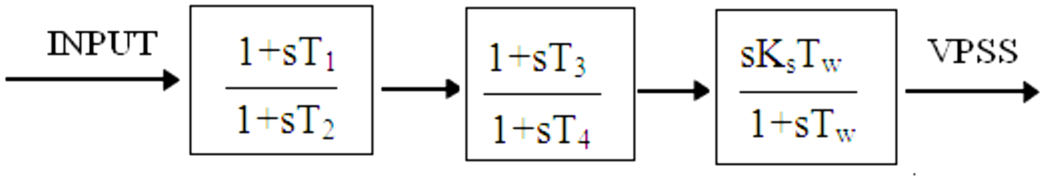

Figure 2 Lead-Lag power system stabilizer

A “lead-lag” PSS structure is shown in Figure 2. The output signal of any PSS is a voltage signal. This particular controller structure contains a washout block, sTW/ (1+sTW), used to reduce the over-response of the damping during large disturbances. Since the PSS produce a component of electrical torque which is in phase with the speed deviation, phase lead blocks are used to compensate for the lag between the PSS output and the control action, the electrical torque. The number of lead-lag blocks needed depends on the particular system and the tuning of the PSS. The PSS gain Ks is an important factor as the damping provided by the PSS increases in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. All of the variables of the PSS must be determined for each type of Generator separately because of the dependence on the machine parameters. The power system dynamics also influence the PSS values. The determination of these values is performed by many different types of tuning methodologies. Differences in these two designs lie in their respective tuning approaches for the AVR/PSS ensemble; however, the performance of both structures is similar to those using the lead-lag structure [7] [8].

5. Application of Intelligent Systems

The loading of power system varies with time. Components attached with power system operate over very wide range and the range has become even wider since restructuring of utility. The variation of PSS parameters with variation in operating point to assess impact on robustness of conventional PSS. It is found that slight change is required to be made when a synchronous machine operates with positive reactive power and active power.

PSS variables need drastic tuning with slight shift in operating domain has been observed when the synchronous machine operates with negative reactive power. This has paved the way for nonlinear controller implementation in recent times and has been proved better over wide range of operating conditions. Generally, effective robust performance of closed loop system is proportional inversed with controller response time. Therefore, it can be concluded that classical and nonflexible controllers do not represent good solutions due to nonlinear, multivariable and uncertain power system containing a wide array of devices each having different response rate. Additionally, contingencies and load variations smoothed the way for fast and highly flexible control schemes.

In recent years it has been recognized that it is necessary to incorporate other elements, such as logic, reasoning and heuristics into algorithmic techniques of conventional adaptive and optimal control theory to impart more flexible control systems. The intelligent control is defined as having the ability of learning, adaptation and operating over a wide envelope satisfactorily. Three paradigms of Intelligent Systems (IS) have been used in intelligent control: Fuzzy Logic, Optimization Algorithms-mostly Genetic Algorithm (GA) and Artificial Neural Networks (ANN). Fuzzy Logic (FL) is good at making decision and logic designing, once data is processed and GA performs well in optimization. ANNs have done well in data processing. Reference [9] has compared not only IS-based adaptive control but the conventional adaptive control, called analytical techniques too, and amalgamation of AI and conventional techniques. It was concluded that the approach to be used depends upon expertise and confidence of the designer. While, in comparison to conventional control margin of transient stability limit is increased by using adaptive control system [9].

Problem solution with FL becomes complex with increase of involved variables. Apart from that FL control is more empirical-based. GA, stochastic in nature and insensitive to initial configuration, has the ability of derivative free global optimization and that lies in their so called notion of evolution behind their evolution. Overall performance of GA is fitness function dependent and hence, the function requires expert knowledge.

Furthermore, GA requires considerable time to converge and its efficiency is variable of many control parameters. ANN on the other hand has intense parallel interconnections of simple processors. Although ANN has poor interpretation, it is one of the most promising control approach compared to all other approaches available. The promise of fast computation, ability to map any nonlinear function satisfactorily, fault tolerance and robustness have made ANN to carryout sophisticated control tasks. The current trend is towards amalgamation of all three AI paradigms to implant features of each to cover up demerits of other such as to feed expert knowledge into ANN or optimize free parameters or structure of ANN [9].

6. Fuzzy Logic

The fuzzy control systems are rule-based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The fuzzy logic controller provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzy logic is based on data sets which have non-crisp boundaries. The membership functions map each element of the fuzzy set to a membership grade. Also fuzzy sets are characterized by several linguistic variables. Each linguistic variable has its unique membership function which maps the data accordingly. Fuzzy rules are also provided along with to decide the output of the fuzzy logic based system. A problem associated with this is the parameters associated with the membership function and the fuzzy rule; which broadly depends upon the experience and expertise of the designer. Differences in these two designs lie in their respective tuning approaches for the AVR/PSS ensemble; however, the performance of both structures is similar to those using the lead-lag structure. The fuzzy logic controller (FLC) design consists of the following steps [5], [8], [10].

Design procedure:

1. Identification of input and output
2. Construction of control rules.
3. Establishing the approach for describing system state in terms of fuzzy sets, i.e., establishing fuzzification method and fuzzy membership functions.
4. Selection of the compositional rule of inference.
5. Defuzzification method, i.e., transformation of the fuzzy control statement into specific control actions.

The conventional power system stabilizers work well at the particular network configuration and steady state conditions for which they were designed. Once conditions change the performance degrades. This can be overcome by an intelligent non-linear PSS based on fuzzy logic. Such a fuzzy logic power system stabilizer is developed, using speed and power deviation. As inputs and provide an auxiliary signal for the excitation system of **a** synchronous motor. In this thesis, the FLPSS's effect on the system damping is then compared with **a** conventional PSS and without PSS [10], [11], [12].

Fuzzy Logic Controller

Fuzzy logic control is a method based on fuzzy set theory, in which the fuzzy logic variables can be of any value between 0 and 1 instead of just true or false. FLC controls have been demonstrating their feasibility in the field use. Ex- pert's knowledge can be incorporated into fuzzy rules. Design of FLC's are generally used to determine the in- put and output variables, parameters of membership functions, fuzzy rules and to improve performance of FLC.

Figure 3 shows the design methodology for implementation of fuzzy logic controller. It consists of two parts namely design and control. The design part carries out defining the system, defining the fuzzy universe of discourse, defining control rules and finally simulating it. The control part consists of fuzzy controller and implementing it on the process [13].

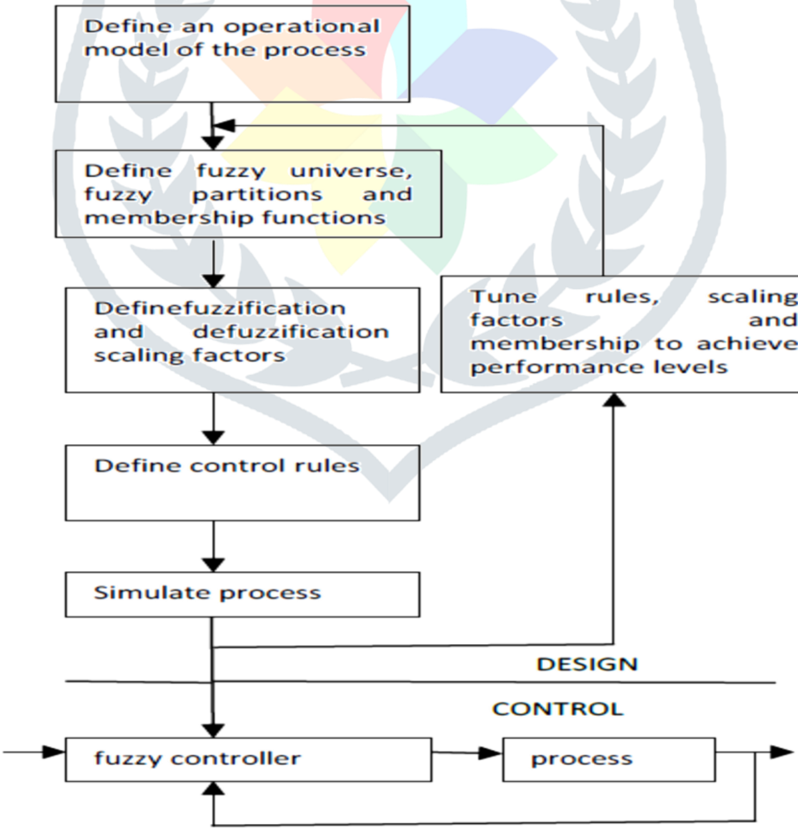

Figure 3 Fuzzy design methodology

In order to mitigate these Low Frequency Oscillations (LFO), (PSS) are used in conjunction with (AVR). Normally the parameters of the conventional controllers are determined at a nominal operating point to give good performance. However, the system dynamic response may regress when the operating point changes to some extent. Again, in many cases it is observed that, the PSS designed for damping local mode of oscillations, are practically unsuitable for the inter-area mode of oscillations. The aforesaid limitations of the conventional PSS have lead to the use of artificial intelligence. In artificial intelligence fuzzy logic is the chosen one. The advantage of fuzzy logic control appears to be the most promising, due to its lower computational burden and robustness [9].

Also, in the design of fuzzy logic controllers, a mathematical model is not required to describe the system under study. However, in case of fuzzy control, the main problem is that the parameters associated with the membership functions and the rules depend broadly on the intuition of the engineer. To overcome this limitation ANFIS is used. In ANFIS, rather than choosing the parameters associated with a given membership function arbitrarily, this parameters are chosen so as to tailor the membership functions to the input/output data in order to account for this types of variations in the data values. The parameters associated with the membership functions and rules change through the learning process. The computation of these parameters, or their adjustment, is facilitated by a gradient vector, which provides a measure of how well the fuzzy inference system is modeling the input/output data for a given set of parameters. Once the gradient vector is obtained, an optimization routine is applied in order to adjust the parameters so as to reduce the sum of the squared difference between actual and desired outputs.

7. Neuro-Fuzzy Systems

ANN and FL are two different paradigms of intelligent systems. Individually both these paradigms suffer disadvantages. The main concern with ANN training is the requirement of efficient and sufficient data and unavailability of algorithms to optimally select ANN structure. On the other side, the performance of FL controller depends on the operating conditions of systems, although its sensitivity is lesser than a conventional controller. Additionally, FL requires expert knowledge explicitly. This is conceived as merit as well as demerit. To harvest full advantage of ANN capability to fine tune expert information by employing learning techniques and FL's ability to incorporate expert knowledge, these two classes of AI have been combined [9].

In controlling generator excitation and PSS, combination of FL and ANN is applied in different ways. One way to incorporate advantage of both paradigms is to use Adaptive Neurofuzzy Inference System. The other way is the usage of ANN like Multi-Layer Perceptron (MLP) in which weights are represented by membership functions, called fuzzy weights, and activation functions are defined with respect to the *t*-norm and *t*-conform. The synergized neural and fuzzy networks called Generalized Neuron (GN). The last method of applying both FL and ANN is to synthesize controller by FL and model identifier using ANN.

Adaptive Neurofuzzy Inference System (ANFIS) is a more systematic approach relying less on expert knowledge. It can serve as a basis to construct a set of fuzzy If-Then rules with suitable membership functions for generating sets of input-output pairs. It, basically, consists of fuzzy and defuzzy, knowledge base and decision making unit. It can incorporate various types of fuzzy membership functions inference. Unlimited approximation power of ANFIS is claimed yet it is linked with constructing ANFIS properly. The architecture of ANFIS is shown in Figure 4. The ANN topology should be feedforward.

Links between nodes do not carry any weights and represent the signal flow direction solely. The first layer represents membership function and fourth layer is for consequent parameters. Output of each node in second layer is firing strength of rule and third layer normalize firing strengths. Function of fifth layer is to sum all inputs and its output is control signal, $u(t)$. ANFIS can be trained on different learning algorithms, but a hybrid learning algorithm based on least square error and gradient descent has been proposed and claimed to be fast. For further detail interested readers are referred to.

Reference [9] has used indirect adaptive control system methodology to update the first layer parameters of ANFIS online. The strength of the proposed controller has been depicted on multi machine system. The results have shown that the proposed controller has performed better in terms of overshoot, undershoot as well as damping. The work presented in is based on indirect adaptation of input link weights (Link Connections) of ANFIS as shown in Figure 4.

The objective is to introduce ANFIS-based PSS with a new signal, in small-signal stability with less dependence on human intuition. Generally the fuzzy PSS use speed deviation and derivative of speed deviation as their input signals use speed deviation and as their input signals for ANFIS based PSS. But also some researches use tie line active power deviation is in conjunction with speed deviation for ANFIS based PSS.

Figure 4 ANFIS architecture

Where, $x1(t)$ and $x2(t)$ are inputs, $u\ (t)$ is control output and boxes are representing scaling factors [9].

The advantage of this input is that, the same signal can be fed to each of the ANFIS based PSS, which reduces cost, scanning time and thus simplifies the structure. The effectiveness of the proposed ANFIS based PSS is then demonstrated through digital computer simulation for drastically different operating conditions. Also its performance is compared with a conventional PSS and a speed and tie line active power deviation input based fuzzy PSS [14].

Design of ANFIS-Based PSS

A step-by-step method of designing ANFIS-based PSS is presented as follows [15]:

a) Choice of input variable: In this step it is decided which state variables must be taken as the input signals to the controller. In this paper, generator speed deviation (w) and acceleration (a) are taken as input signals of the ANFIS based PSS.

b) Choice of linguistic variables: The linguistic values may be viewed as labels of fuzzy sets. In this paper, seven linguistic variables for each of the input variables are used to describe them. These are, LP (Large Positive), MP (Medium Positive), SP (Small Positive), ZE (Zero), SN (Small Negative), MN (Medium Negative), LN (Large Negative).

c) Choice of membership functions: In this design, Gaussian membership functions are used to define the degree of membership of the input variables.

d) Choice of fuzzy model: A first order Sugeno fuzzy model is chosen for ANFIS-based PSS. Figure 2 shows the surface of designed fuzzy controller with first order Sugeno fuzzy model. We use this fuzzy PSS in ANFIS editor for training and designing the ANFIS based PSS.

e) Preparation of training data pair: In preparing the training data pair, the data should be representative of different kinds of disturbance situations, such that the designed PSS can be used for highest flexibility and robustness. In this paper, the training data pair are prepared by simulating different multi-machine systems with conventional PSS under abroad range of small and large disturbances.

j) Optimization of unknown parameters: Using the training data matrix, the unknown parameters of the Gaussian input membership functions and the output parameters of each rule of first order Sugeno fuzzy model are optimized. Initially, it is assumed that the input membership functions are symmetrically spaced over the entire universe of discourse.

7. Conclusion

Large scale power systems are the one where a number of generating units are connected together by a transmission line. As physical limitation on the system structure makes information transfer among subsystems unfeasible, so decentralized controllers might be used in large scale power system control. Transient stability is a major requirement in power system operation which is concerned with the maintenance of synchronism between generators following a severe disturbance. The switching controller with switching time stabilizes the system but it does not always do so as switching time is varied. So, it can be concluded that the strategy by simply switching between different control actions is not reliable due to non-existence of universal switching time. Review of Different methodology including, conventional like AVR, PSS as well as some of non-conventional techniques present in this paper for analysis of transient stability. From this it can be say that because having some of drawback in conventional techniques, it is better to used modern non convention techniques based on artificial intelligence. The fuzzy logic as well as Combination of ANN and FUZZY (Neuro-Fuzzy) having advantages such as simplicity, better oscillation than conventional to use in problem such as transient stability in power system.

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