Design of Augmented Fuzzy Logic Controller to improve stability in Power System Stabilizer

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Abstract: In this paper, structure of fuzzy logic controller is presented. Power systems are subjected to low frequency disturbances that might cause loss of synchronism and an eventual breakdown of entire system. These oscillations limit the power transmission capability of a network and cause loss of synchronism. Power system stabilizers (PSS) are used to damp these low frequency oscillations by providing an additional signal by using fuzzy logic controller (FLC). The fuzzy logic has the features of simple concept, easy implementation and efficient. Fuzzy logic controllers are based upon empirical control rules. Fuzzy logic based power system stabilizer is used to improve the closed loop performance of a power system and to maintain the stability of system.

Keywords: Fuzzy logic control, adaptive control, synchronous generator, PID stabilizer, transient perturbations.

I.   Introduction

The main cause to use fuzzy logic based power system stabilizer is to improve the stability of system. Power system stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium. The power system is a dynamic system. Low frequency oscillations are a common problem in large power systems. The basic function of a power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To provide damping the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations. Fast acting exciters with high gain AVR can contribute to oscillatory instability in power systems. This type of instability is characterized by low frequency oscillations. This type of instability can limit power transfer. The objective of designing PSS is to provide additional damping torque without affecting the synchronizing torque at critical oscillation frequencies.

Due to cost efficient, easy implementation and there flexibility PSSs has been extensively studied and successfully used in power system for many years. It can be generally said that need for PSS will be felt in situations when power has to be transmitted over long distances with weak AC ties.

Most PSS is used in electric power system on a linear model of a fixed configuration of the power system. Such PSS are called the conventional power system stabilizer (CPSSs). Conventional power system stabilizer is a fixed parameter lead-lag compensator, is widely used by power system utilities. Conventional power system stabilizers are basically designed on the basis of linear model for the power system. Assuming that the disturbances are small such that the linear model remains valid the CPSS is designed. Therefore, a CPSS is most useful for improving the dynamic stability of the power system. To overcome the drawbacks of conventional power system stabilizer (CPSS) many techniques have been proposed such as fuzzy logic, genetic algorithm, neural network etc.

In an attempt to cover a wide range of operating conditions, fuzzy logic control has emerged as a powerful tool and is used in various power system applications. Fuzzy logic controllers are easily constructed by using microcomputer. The supplementary stabilizing signal is determined using fuzzy membership.

The FLC also applied to the multi-machine system to demonstrate its ability to damp electromechanical oscillations following both small and large disturbances, while at the same time, it controls the terminal voltage of the generator and prevents negative interactions between voltage and power control loops.

II.   Representation of Saturation in Stability Studies

For stability studies the following assumptions are made in the representation of magnetic saturation:

- The leakage of inductance is independent of saturation and only elements that saturate are mutual inductances.

- The leakage fluxes do not contribute to the iron saturation and the saturation is determined by the air gap flux linkage.

- The saturation relationship between the resultant air gap flux and the mmf under loaded conditions is the same as under no load conditions.

- There is no magnetic coupling between d and q axes.

III.   System Modelling

For stability assessment of power system adequate mathematical models describing the system are needed. The model must be computationally efficient and be able to represent the essential dynamics of the power system.

The basic system consists one non linear synchronous generator connected by two parallel transmission lines to an infinite bus. The output signal of proposed and other compared PSS is given to summing point of AVR (Automatic voltage regulator) and thus obtained signal is given to the excitation system of synchronous generator and by regulation current of the exciter we can achieve to necessary damping torque and thus oscillations will damp in settling time.
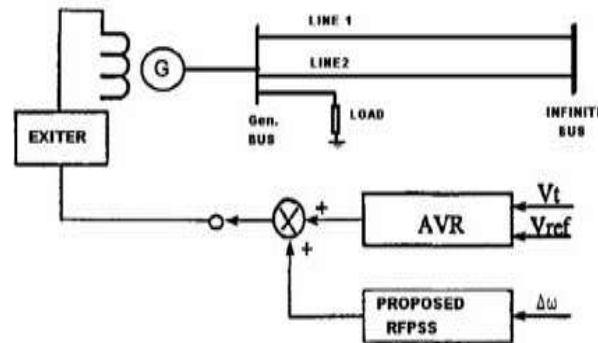

Fig.1 Model of synchronous generator connected to infinite bus

The instability in power system can be shown in different ways, according to its configuration and mode of operation, but it can be observed without synchronism loss.

When a power system under normal load condition suffers a perturbance there is synchronous machine voltage angle rearrangement. If for each perturbation that occurs an unbalance is created between the system and the load, a new operation point is established and consequently there is voltage angle adjustment. The system adjustment to its new operating condition is called "transient period" and the system behavior during this period is called "Dynamic Performance".

IV.   Fuzzy Set Theory

Fuzzy sets can be considered as a generalization of the classical set theory. In a classical set an element of the universe either belongs to or does not belong to the set. Thus the belongingness of an element is crisp. In a fuzzy set the belongingness of an element can be a continuous variable. Mathematically, a fuzzy set is mapping from the universe of discourse to [1]. The higher the membership value of an input pattern to a class. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. One may obtain the membership function from an expert or from the data. Fuzzy logic deals with reasoning with fuzzy sets and fuzzy numbers. It is to be noted that fuzzy uncertainty is different from probabilistic uncertainty.

ANN adopts numerical computations for learning. But numerical quantities lack representative power in situations where the information is expressed in linguistic terms only. The linguistic information can be incorporated using the membership function values of the fuzzy sets. Use the concept of fuzzy sets in ANNs is also supported by the fact that human reasoning does not employ precise mathematical formulation. Specifically the fuzzy set theory can be used in ANN at various levels such as input, output and target and also for the weights, basis functions and the output functions. Introduction of fuzzy set theory into the perception learning algorithm makes the decision boundary a soft one, so that the class labels of the input patterns can change slowly from one class to another class rather than abruptly and hunt.

V.   Fuzzy Logic Controller

Fuzzy control systems are rule based systems in which a set of so called fuzzy rules represent a control decision mechanism to adjust the effects of certain stimulus. The aim of fuzzy control systems is normally to replace a skilled human operator with a fuzzy rule based system. The fuzzy logic controller provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy.

VI.   Fuzzy Sets

Fuzzy sets as the name implies, is a set without a crisp boundary. The transition from "belong to a set" to "not belong to a set" is gradual and this smooth transition is characterized by membership functions. The fuzzy set theory is based upon fuzzy logic, where a particular object has a degree of membership in a given set that may be anywhere in the range of 0 to 1. On the other hand, classical set theory is based on Boolean logic, where a particular object or variable is either a member of a given set (logic 1), or it is not (logic 0).

VII.   FLC Design

The design process of an FLC may split into following steps:

Selection of control variables

The selection of control variables (i.e controlled input and output) depends upon the nature of controlled system and the desired output. Usually the output error (e) and the rate or derivative of the output (de) is used as controller inputs. Some researchers have also proposed the use of error and the integral of error as an input to the FLC.

Membership function definition

Each of the FLC input signal and output signal, fuzzy variables ($X_j=\{e, de, u\}$) has the real line R as the universe of discourse. In practice, the universe of discourse is restricted to a comparatively small interval [X_{minj}, X_{maxj}]. The universe of discourse of each fuzzy variables can be quantized into a number of overlapping fuzzy sets.
The number of fuzzy sets for each fuzzy variable varies according to the application. The reasonable number is an odd number (3,5,7…). Increasing the number of fuzzy sets results in a corresponding increase in the number of rules. Membership functions can be in variety of shapes mostly triangular, trapezoidal, singleton and exponential.

VIII.   Fuzzy Systems

The fuzzy inference system or fuzzy system is a popular computing framework based on the concept of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. The fuzzy inference system basically consists of a formulation of the mapping from a given input set to a output set using FL. The mapping process provides the basis from inference and conclusion can made. The basic structure of fuzzy inference system consists of three conceptual components: a data base, which defines the membership functions used in the fuzzy rules and given facts to drive a reasonable output.

The fuzzy logic controller comprises of four principle components i.e. fuzzification interface, knowledge base, decision making logic and defuzzification interface.

  i. **Fuzzification**: In fuzzification, the values of input variables are measured i.e. it converts the input data into suitable linguistic values.
 ii. **Knowledge base**: The knowledge base consists of a database and linguistic control rule base. The database provides the necessary definations which are used to define the linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control policy of domain experts by means of set of linguistic control rules.
iii. **Decision making logic**: The decision making logic has the capability of stimulating human decision making based on fuzzy concepts.
 iv. **Defuzzification**: This is a process of converting the FLC inferred control action from fuzzy values to crisp values. This process depends upon the output fuzzy set, which is generated from the fired rules.

IX.   Adaptive PID Fuzzy Controller

Controllers based on the fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies. These are the steps for development of control based fuzzy logic:

- Data base building
- Rule base elaboration
- Fuzzification strategy
- Defuzzification strategy
- Inference machine elaboration

In addition, the design of fuzzy logic controller can provide the desirable signal both small and large signal dynamic performance at same time, which is not possible with linear control technique. Therefore, fuzzy logic controller has the ability to improve the robustness of the synchronous generator. The development of the fuzzy logic approach here is limited to the design and structure of the controller. The input constraints were terminal voltage error and its variations: the output constraint was the increment of the voltage exciter.

The inputs of PID like FLC are defined as the voltage error (e_u) and change of error (de_u). The fuzzy controller ran with the input and output normalized universe [1,-1].
Fuzzy sets are defined for each input and output variable. There are seven fuzzy levels (LN – large negative, MN - medium negative, SN - small negative, Z - zero, SP - small positive, MP - medium positive, LP - large positive). The membership functions for input and output variable are triangular.

X.   Input Membership Functions

As explained earlier, three separate inputs are created from the speed deviation and fed in the RFLPSS. The next step is to determine the number and shape of the membership functions. For this particular design, numerous membership functions were tried and the functions under consideration proved most promising. For the inputs, a total of six membership functions are used for the fuzzification. For example, the Pin 1 is the positive input membership function of the first input while Nin2 is the negative input membership function of the second input. Here, the input (antecedent) membership functions are arctangent functions describing the Gaussian curve membership functions, namely, Pin (positive) and Nin (negative), one for each of the three inputs is chosen.
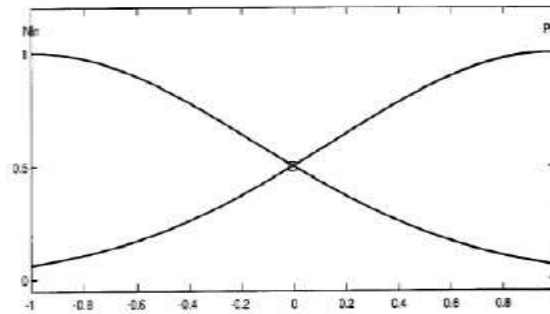

Fig. 2 Input membership function

The input membership functions Pin and Nin are shown in Fig. 2. The membership functions for each of the three inputs are considered identical. This shape of the membership function produces an effect similar to a PID controller and compensates any large differences coming from the 1st level difference, 2nd level difference or 3rd level difference. For example, if any of RFLPSS input is large, then the RFPSS would output a large compensating signal of appropriate polarity due to the chosen shape of the membership functions. Thus, the tendency of the generator rotor would be neither accelerate nor decelerate (i.e. maintain constant value).

XI.   Output Membership Function

For output there are two membership functions: P_{out} and N_{out} are used for defuzzification process where the subscript indicates the output membership function. The functions consist of two opposite sloped lines as shown in figure:
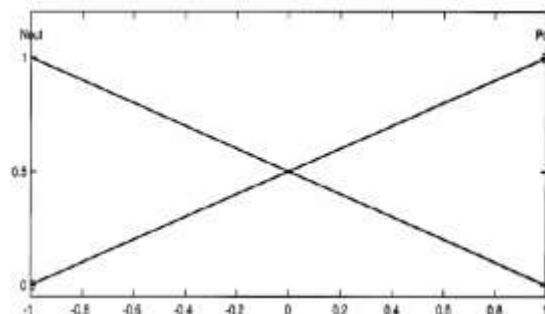

Fig. 3 Output membership function

The reason for choosing a linear relationship is because the output membership function is usually a linear representation of the input membership functions. In the design, this was accomplished using the trapezoidal membership functions. Once the membership functions are formulated, these can be used to develop the rule base.

XII.   Rule Base

The designed rule base consists of the following rules:

a.   if (U1 is pin1) then (out FLC is P_{out})
b.   if (U1 is Nin1) then (out FLC is N_{out})
c.   if (U2 is pin2) then (out FLC is $P_{out)}$
d.   if (U2 is Nin2) then (out FLC is N_{out})
e.   if (U3 is pin3) then (out FLC is P_{out})
f.   if (U3 is Nin3) then (out FLC is N_{out})

The interference from the rule based is altered if changing the weight of any rule is changed. In this design each rule has been given equal importance and provided with a weight of 1.

Conclusion

Implementation of a Robust Fuzzy Logic controller as a power system stabilizer is described in this paper. The stabilizing signal generated by the controller is computed using a standard fuzzy membership function. The expected outcomes of this type of power system stabilizer are shown followed.
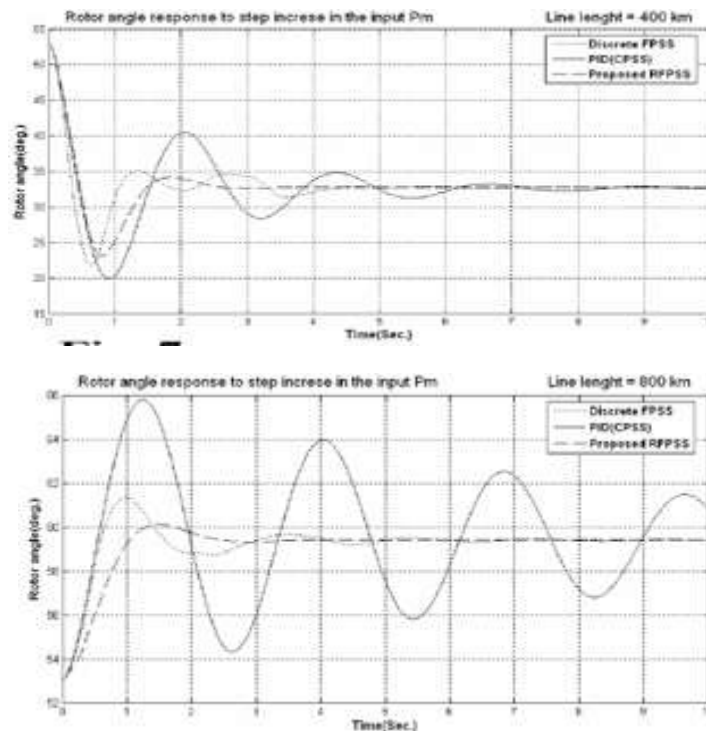
Figure shows the rotor angle response to step increase in the input for various line length

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