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AVR and Fuzzy Logic Power System Stabilizer for The Excitation Control of Synchronous Generator

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Abstract: power system always being a dynamic system is constantly being subjected to some sort of disturbances. Day by day the increase of electrical products is being increased and hence the chances of the system to be disturbed are being increasing. With the use of the advanced electrical products the power system stability requirement is being increasing. We are using the synchronous generators as the source of power supply. So our machines excitation system should be in such a way that the voltage should be controlled and the generator should not be a cause for the un-stability of the power system. Till now we are using mathematical models to analyze the power system. But the mathematical models are linear models. So here in this paper we are going to discuss the design of fuzzy logic controller which not only takes into account the non linearity of the system but also easy to analyze and to control.

Keywords: excitation system, fuzzy logic, AVR (automatic voltage regulator), PSS (power system stabilizer), fuzzy logic power system stabilizer.

Introduction

Power system is not a static system since always some disturbances will be occurring in our power system which in other words is called as a dynamic power system. The disturbances occurring in the system should not to be in such a way that the system goes into an unstable state. If we see from the power system point of view then the excitation system of the synchronous generator or alternator should be in such a way that the system will not easily lose its stability. Day by day as we are using more and more electrical equipment such as geysers, fridges, coolers and many more modern house hold equipments, not only in house hold but also in industries, the stability of the power system gets affected adversely. To overcome this problem and obtain a better power quality we should be able to study the power system in a very precise manner. Now a day's we are testing or simulating the power systems based on some mathematical modeling techniques (generator model, motor model). Though we are able to model the power system mathematically, there are some problems while we are modeling such as lightening, sudden change in load, and fault at unknown point. Now a day's fuzzy logic has been coming into picture as it is making the power system operated very easily, in a much revised manner. If some system is said to be operated in a very controllable manner then it is said to be using fuzzy logic, as it is the most accurate system up to now.
Hence my intension here is to develop a fuzzy logic based controller for the controlling of the excitation of the synchronous generator. If we include a power system stabilizer for this system which is using fuzzy logic, then the system not only is said to be controlled for the changes in the excitation, but it is also said to be having the capability to make the system stable for the sudden changes or sudden disturbances. Here we will consider a single machine system which is connected to an infinite bus. This machine is tested for various disturbance conditions and changes in the load, and then the results are observed. So in this thesis my intension is to present a brief discussion for the design of fuzzy logic controller.

Synchronous Generator

Mostly synchronous generators are used as sources of electrical energy. By using a turbine as a prime mover, generator is supplied with real power. When we are going to use a single generator for a purpose where it can be used individually in spite of connecting it to a bus bar, then there are no such cases that we should to consider about the stability (mostly transient stability). If we use the machine connecting it to an infinite bus called as bus bar, here the stability problem comes into picture. Due to the continuous change in the load conditions the terminal voltage of the generator gets changed. As the terminal voltage of the generator changes there will be a potential difference between the bus bar and the generator terminal, which results in the circulation of circulating currents in this machine. Due to the circulating current in this machine there will be an excessive voltage drop in the machine, which makes the machine to fall out of synchronism. So we should be careful so that the machine doesn't go out of synchronism.

Need of control of excitation

Synchronous generators can be using two control techniques

- Terminal voltage control
- Power factor control

The selection of the control technique depends upon either the machine is small or large.
If the machine is large then in this type of machines the KVA is significant. So the terminal voltage is always regulated by using the terminal voltage control. If the machine is smaller, then the voltage variations are not appreciable as the smaller generator will always try to share the reactive power loading. Incase if the voltage changes are rapid, then the smaller generator will continuously add the terminal voltage such that the voltage is maintained constant. So here we use the power factor control. Any how the above both controls are a part of the excitation control since the excitation of the synchronous machine is responsible for the generation of the terminal voltage, we need to focus on the excitation control of the synchronous machine.
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Excitation System

A. Control of excitation system

In view of synchronism

Synchronous generator is a doubly excited machine. There are two major parts namely stator and rotor. The stator is connected to the bus bar. So any variations in the corresponding machine due to the stator effect are balanced by the remaining machines connected to that bus or the bus itself. But in case of the rotor as it is a separate input irrespective of the bus, there needs a control of it for the satisfactory operation of our machine. This rotor on which field winding is placed and the supply given to it are together known as excitation system. Excitation system plays an important role in the satisfactory operation of the machine. As the excitation of the synchronous machine decreases the terminal voltage of the machine decreases which if persists for a long time causes the machine go out of synchronism.

In view of VARS

If there is a reduction in the voltage available, then this reduction in voltage results in the local area generators to deliver or supply higher and higher VARS into the utility system. This is done forcibly because if this happens the demand of the system is met. In fact the generator can either supply or generate the reactive power depending on the terminal voltage available at the buses. Once this happens, then depending upon the impedance of the transmission system and the impedance of the distribution system at the local area the voltage regulation of the bus changes which results either in overload or the under excitation of the corresponding bus. Voltage variations are common in the utility system. When they are low we should take care that there is load sharing generator and the interconnected bus such that there is compensation in the reactive power. This makes the reactive power on the either of the machines to be in limits either in overload or under excitation conditions.

Excitation Control

We will supply the real power from the prime mover to the generator. The excitation system provides the excitation current. Exciter supplies the exciter voltage. The excitation voltage is controlled by the use of the AVR. Its aim is to keep the terminal voltage of the generator to a preset value. Though we are using AVR there is a need of a stabilizer which is called as a power system stabilizer. This is because the AVR may be very efficient during steady state operating conditions but while coming to the situation following a disturbance which is called as a transient state the AVR may have negative influence on the damping of the swings of power range. If the power swings occurs these swings make the voltage generated voltage to oscillate. In such a situation the AVR reacts to be influenced by the changes in the field current. This may have a negative impact such that the damping currents of the rotor induced by the speed deviation caused by the rotor get introduced. These negative damping may be nullified by the use of another control called as power system stabilizer which are briefly described in the later sections.

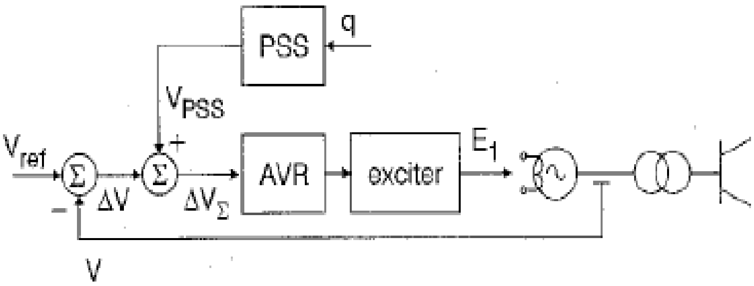

Figure 1: Functional diagram of excitation control

We are using different types of the excitation systems and different types of the controllers. For the control or analysis there should be a media. And this media may be of the digital or may be of the analog. We can give different forms of supply to the rotating parts winding. They are as follow:

a) A DC generator which we are running it by turbine having steam as input [prime mover] mounted on the same shaft of the generator or AC induction generator with high frequency.
b) Static exciters are solid-state devices widely used. These devices consist of some form of Rectifier Bridge on the rotor, or thyristor bridge type having firing angle being controlled.
c) Other types are Chopper type excitation with triggering of the power transistor. The power for the system is supplied either from the AC bus of the generator

Automatic Voltage Regulator

It is controlling the required values of all quantities and is considered to be the key part of the system. Any change if we see in the required values say voltage then this acts as a controller which is increasing or decreasing the value based on any mechanism. The excitation system controls the EMF of the generator and therefore also controls not only the output voltage but also the various values of reactive power as well can be achieved.

A. Working

The response of the AVR is of great interest in studying the analysis of the stability. The field windings inductance is very high, and as a result we can vary the values of its current in a very broad range whatever we need. This makes the design of the regulating system get lag behind i.e., this is one of the area in which our system should develop in a very better manner. So the system should be in such a way that the values of the output are always tracked and can be controlled whenever needed. We are making the various values like power factor of the system; reactive power also gets managed if we can control our machine. But what we studied is the AVR is controlling the machine. So the conclusion here is the controlling function is that of the AVR.
So if we use better AVR a better result can be obtained in the steady state system. It doesn't give better results not only here but it also gives the better results in the transient periods also which are the reasons due to the low frequency oscillations in the system

B. Types of excitation systems

Depending upon the source the excitation system, it is classified into two types. One is static excitation system and one more is the dynamic excitation system. In case of the dynamic system, as the name itself denotes that it is of moving nature, it is of the form directly connected to the rotor without any brushes intermediate. As we are not using the brushes here this is having one more name called brushless excitation system. Here the required function is done by the use of some special types of machines; so the responses of these types of systems are poor though their functioning is very much important. Static system means all the parts are maximum of static in nature i.e, major of the parts are not moving. The current is directly given to the field of the generator using the slip rings through the rectifier which is static in the nature. From the main generator or through the auxiliary station the power to the system is obtained through a transformer using intermediate.
By seeing this much importance and the controlling function in the system the AVR is called as the brain of the system. The functioning's of the AVR is to maintain the building up, of the voltage at the start and also the regulating of the voltage and also to regulate the reactive power in the system that is in use by us. The AVR that we are using should have a very high value of the gain to increase the operational variations effects, good response under the open circuit

condition, minimum value of the dead band and high value of the speed of response (denotes that the response or the pickup is very high).
The principle on which the AVR works is the detection of the error the output given by the alternator (3 phase) is compared with the value of that of the reference. When the alternator is connected to a network, to control the active power as well as the reactive powers, the signal delivered and which is compared are the output voltage and output current. By these two values the output active and reactive powers are calculated, measured, and compared and then accordingly we will find how much more value is required and then the excitation value is increased accordingly.

C. Disadvantages

The function of the AVR is to keep or maintain the voltage at the terminals to a constant value or to a certain value which is prescribed. As this is working on the voltage of the system the obviously the stability of the system is going to be effected by this AVR. Though the AVR can improve the steady state stability in the system the transient stability is going to be a big deal for the AVR. Unlike steady state stability the transient stability decreases the values of the corresponding parameters either to a very low value or else to a very high value which makes it very difficult or sometimes impossible to transfer the power.

D. Remedy

So to improve this drawback we should have to implement the power system stabilizer so that this gives one of the inputs in our stabilizer circuit so that the damping is achieved to reduce the most possible number of oscillations.

Power System Stabilizer

A power system stabilizer (PSS) provide extra feedback signal which is of stabilizing type in the excitation system and equipped to the alternator, which produces an additional signal into the control loop and thus it can compensate voltage oscillations.

A. Working

Besides the normal stability problems there are also angular stability problems which are related to the change in the shift of the rotor. The shift may be either in clock wise or in anti-clockwise direction. What the PSS does is it tries to reduce the effect of the change in the deviation in the effect on its output. The PSS gives the voltage as an output. The effect of the change in the deviation of the rotor is produced as a suitable signal. The deviation is as follows. The deviation will be clockwise in motor and anti- clock wise in generator. This denotes that the function of the PSS is same in both the motor and generator. We should find how much there is a change in the deviation of the torque or the displacement of the rotor. Then we need to make a suitable value of this deviation in a corresponding value. Generally the change is achieved first by producing a voltage signal which is the output of the PSS given as an input to the AVR. Then the AVR generates a suitable value of current which is again given to the system so that this current as it is proportional to the torque, produces a suitable torque which can damp the changes in the torque. That means once there is a deviation, that means the value of torque is changed and this change is taken by us in the form of voltage and then current which again generates a torque which nullifies the change in the torque. This is called as the damping phenomena. But the major challenge here is that how fast the PSS can sense the change in the deviation of the rotor and how fast it can send the signal to the AVR. Not only for the PSS it's a challenge but also for the regulator it is a challenge since this should generate a current signal which in turn makes the production of the torque opposite to that in the system or the damping torque.

B. Input Signals

It is also difficult or in race to decide the input signals to the power system stabilizer. After doing considerable amount of research and experiments they found that the most possible and suitable inputs are accelerating power, active power, frequency and the speed deviation. As we studied the machines output is developed based on the rotation of the rotor the speed deviation is considered to be the first ordered input or the most common input to be used. In the design which we are considering the speed deviation as the input the differential regulation is used and also this is having a gain of very high value in order. But this is not practically possible or doesn't work in reality; the formerly mentioned lead-lag structure is commonly used by most of them. On the other hand, one of the limitations of the speed input of the PSS is that it may excite torsional oscillatory modes.
We also studied the controller which is using the frequency also as the input. But we know that the frequency of the system is very sensitive as its tolerance level is very less compared to speed and the power, care should be taken in the control actions while we go with the use of this frequency as the input. One more limitation is there is a sudden increase in the transient values called as rapid or high range transients due to the sudden change in load, as there are shifts when

the load is suddenly changed. In stability point of view the frequency is the most sensitive to the changes or oscillations of the inter-area mode than the speed this is going to be a plus point for us with the frequency as the input. We can also use any types of powers which are mentioned above as a reason they are responsible for a torsional oscillations of a very less range.

C. Disadvantages

Conventional PSSs use transfer functions. Where ever we are going to use the transfer functions then almost all the performance is considered to be done on the assumption of a linear model. But this assumption of the linear model is acceptable only in the cases when the generator is operating very much closer to the normal operating range. If it goes out of the normal operating range then these assumptions are going to be not reliable since the deviations in the system increases beyond the ranges in case if the machine goes out of the operating range and this prob problem is due to the increased or decreased electrical quantity values if the range is out of the limits.

D. Remedy

So we can conclude that the use of the linear controller or linearly modeled controllers is good enough if the operating range is not exceeded by the machine I.e, in case of the only one state where there is no transition. But if we are going to a situation where there is a transition in the state of the machine for ex: - the synchronizing of the unit, switching from one state to another or any sudden fault, then we should have to go for non linear models. So better study of the non linear models is done by us and we should to implement the non linear models so that we can control the system even in a transition state.
Efforts are being done to design a PSS which is suitable in all conditions which is often called as an adaptive PSS. Here what this type of adaptive model does is that it estimates the uncertainties and accordingly tries to react for these uncertainties. Drawback here is the adaptive model can only react successfully for a unit which is already known. Not only this, but the adaptive models cannot use the intelligence of the human. So we should have the capability to design the models which will also make use of the human intelligence. This problem is reduced by using artificial intelligence (fuzzy logic, neural networks, decision trees, genetic algorithms)-based techniques in designing our PSS. In this thesis my intension is to increase not only the transient stability but also the dynamic stability by the use of the above mentioned methods which can use the human intelligence we have used a fuzzy logic controller along with PSS to improve transient as well as dynamic stability of the system.

Fuzzy Logic Controller

Daily our power system has been improving. As the improvements in the power system is being increasing the number of additional components and hence the complexity of the system to analyze is being increasing. Recently we used to work on the analog systems which take into account the conventional power system stabilizers. But now a days to reduce the complexity and hence to increase the effectiveness of the power system analyzing the fuzzy logic is being implemented. To implement the system with fuzzy logic controller the speed deviation and accelerating power of the synchronous generator are taken as input signals to the fuzzy logic controller. The above variables have a very good impact in damping of the oscillations of the generator. The feedback signal given to the excitation system is modified as a function of the accelerating power to increase the stability of the system. As the generator oscillations depend upon the change in the speed per unit time which is nothing but the acceleration which is in turn dependent on the accelerating power, ultimately good result can be observed in the stability of the machine and hence the system.
Any human being who is highly skilled in the area which is to be controlled or implemented are replaced by the fuzzy logic control systems. This means these controllers take into account the already done or existing operating conditions and then based on these observations they form certain rules which are further implemented.

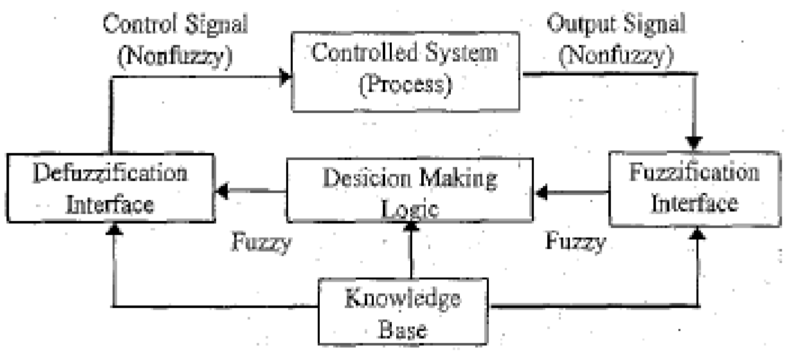

Figure2. Principle design of fuzzy logic controller

Fuzzy Logic Power System Stabilizer

The fuzzy logic controller design involves the following steps:

A. Selection of control variables

Here in this step we will select the control variables that are the input variables. The input variables here are speed deviation and acceleration. The output variable generated is through the membership function is given as an input to the excitation system.

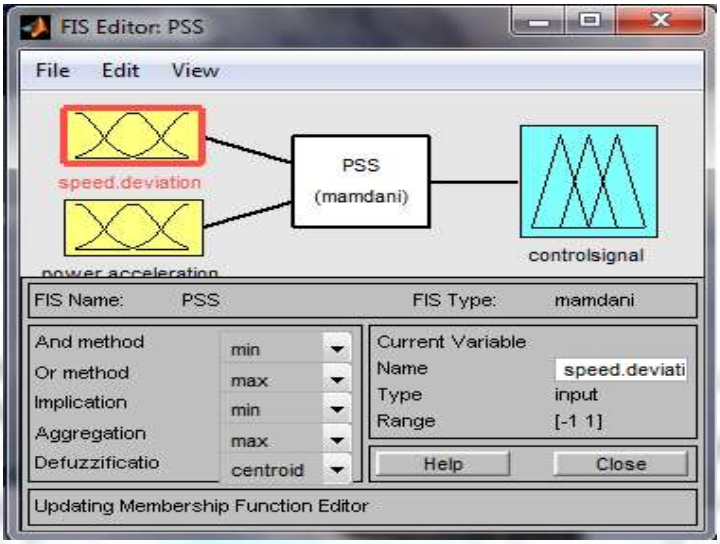

Figure 3. Fuzzy logic controller with two inputs

B. Defining membership function

For the input and output variables we should set the membership functions. In this part for the inputs speed change and the accelerating power we will consider membership functions from negative large value to positive large value(-1 to +1). These membership functions are set in triangular shaped. For each input and output fuzzy variables each fuzzy subset varying from negative large value to positive large value is assigned.

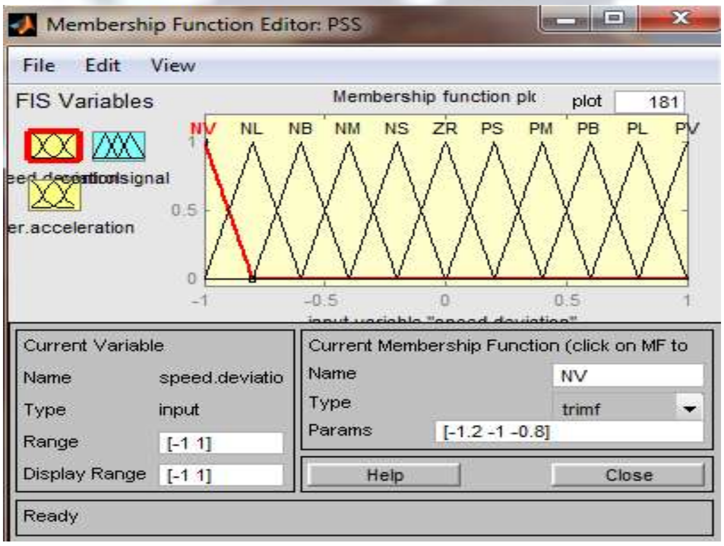

Figure 4: Membership function of input1

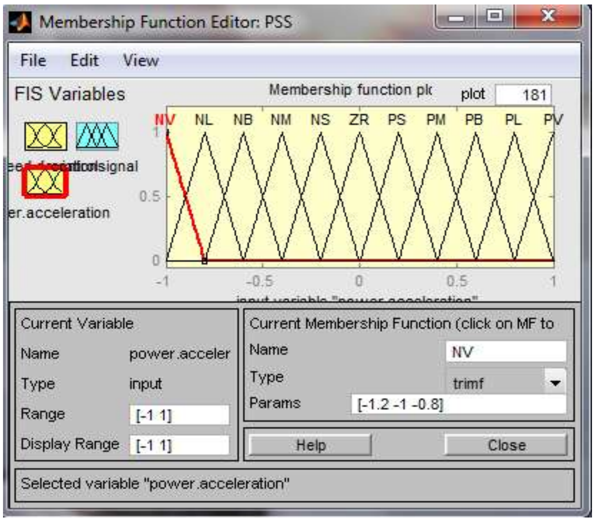

Figure 5. Membership function of input 2

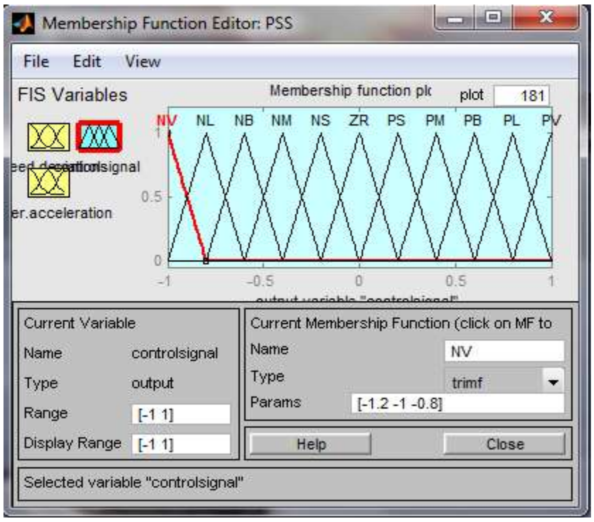

Figure 6. Membership function of output

C. Rule formation

When any human in place of this controller is present, then his brain will decide what to do what not to do. It means will do some actions. The fuzzy logic controller similar to a human brain based on experiences set some rules.

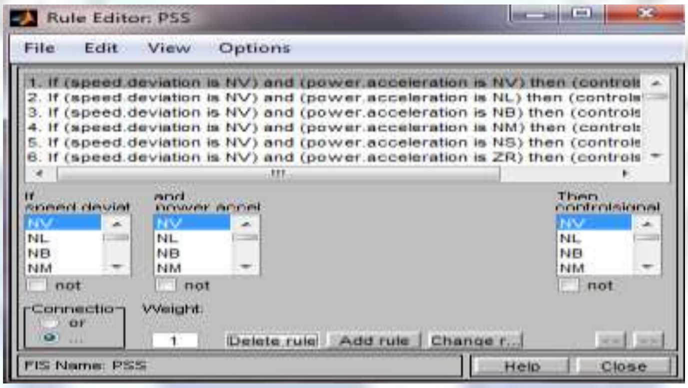

Figure 7. Rule editor

D. Defuzzification

In this section the control actions obtained from the fuzzy logic controller are converted to crisp sets. The Defuzzification process dictates the performance of the fuzzy logic controller because the overall performance of the system which is under the control is determined by the controlling signal which is nothing but the signal obtained after Defuzzification.

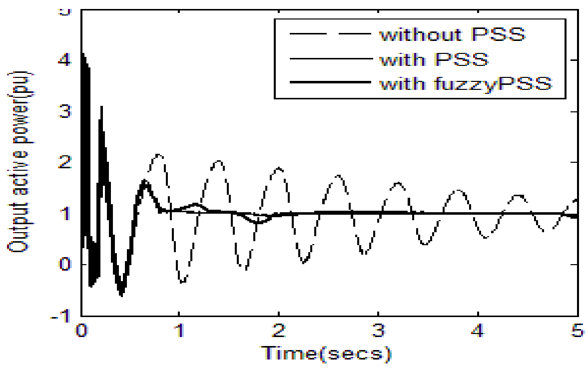

Figure 8. Output active power with use of different cases

Conclusion

Any how the steady state stability can be attained by the use of AVR and the dynamic stability can be improved by the use of the power system stabilizer. If the power system is in such a way that it can damp out the oscillations in a finite time to a new steady state value then it is said to be stable. If the output active power is compared with different cases it can be noted that the system using fuzzy logic power system stabilizer is achieving the steady state at 1.33 seconds where as in case of use of conventional power system stabilizer steady state is attained at 1.46 seconds. So the settling time of the system can be attained quickly by using a fuzzy logic power system stabilizer.

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