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Fuzzy Based Turbine Governor for Hydro Power Plant

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Abstract

Hydroelectric energy is a major source of renewable electricity in the world. The industry is continuously searching for ways to improve the efficiency and reliability with which it produces energy. The turbine governor plays vital role in keeping frequency constant. Here we proposed a fuzzy approach to turbine governor by utilizing human experience.

The simulation model of Hydro Power Plant (HPP) was constructed based on mathematical equations that summarize the behavior of the power plant. The simulation model of power plant is useful in stability studies. It is implemented in software package MatLab/Simulink. Simulation models are suitable for use in large scale system stability studies.

The fuzzy controller is designed and tested for three phase to ground fault by simulations which are reported in this paper. Results obtained by simulation show the rapidity and robustness of the Fuzzy controller. The Fuzzy controller is able to maintain the generated electrical power's characteristics in spite of changing user load.

Keywords: Excitation systems, Fuzzy logic, Turbine governor, simulation models, Hydropower plant, Matlab/Simulink.

Introduction

Hydro-electric energy is most important renewable energy in the world [1]. It provides energy to various loads. User load requires a uniform and uninterrupted supply of input energy. The load demand varies continuously. It affects the terminal voltage and frequency.

The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits. HPP is equipped with hydraulic turbine governor and excitation control. Hydraulic turbine governor control the frequency intern speed of the turbine according to load variation. Reactive power requirement is controlled by Excitation system [2]. The control of Active and Reactive power keeps the system in the steady state [3].

The intention of this paper is to develop fuzzy controller for turbine governing system. Non-linear model of hydraulic turbine [4] is utilized. The developed hydro turbine governor system is based on fuzzy controller with one input and one output variable. To control the Frequency and power, the controller reads the speed of turbine after every sampling period. Matlab Simulink [5] is utilized in building system models and simulates their behavior.

Several controllers such as PID controller, intelligent controller, Adaptive controller have been applied for the turbine governor of hydroelectric power plant [8-13]. However conventional PID controllers are not suitable for such complex high order time delay, nonlinear system process. The fuzzy logic is an important technology and a successful branch of automation and control theory, which provides good results in control of power system. The fuzzy logic is first presented by Zadeh in 1965. It is widely used for nonlinear, complex, renewable energy, modeling and power electronics [14, 15].

Fuzzy logic system has been used successfully in virtually all the technical fields, including control, modeling, image and signal processing, and expert systems [16-20].

The practical benefits of fuzzy controllers are [21].

1. It can handle with good results the variation of the plant parameter by load disturbance or thermal variation.
2. Offer satisfactory results for an unknown non-linear system by maintaining the operating point in the stable region compared with classical linear control that shows high performance only for one unique point.
3. Offer convenient ways to incorporate heuristic laws into an easy human understanding form.
4. They are appropriate for rapid applications.

Hydro Power Plant Model

The simulation model of hydropower plant was developed by utilizing the blocks available in MatLab simpower tool. The hydropower plant model made up of following component [2], [6-7]

1. Excitation control
2. Three phase Transformer
3. Three phase Loads
4. Three phase Short Fault
5. Three phase source
6. Synchronous Generator
7. Hydraulic Turbine Governor [7]

The simulation model is depicted in Fig. 1.

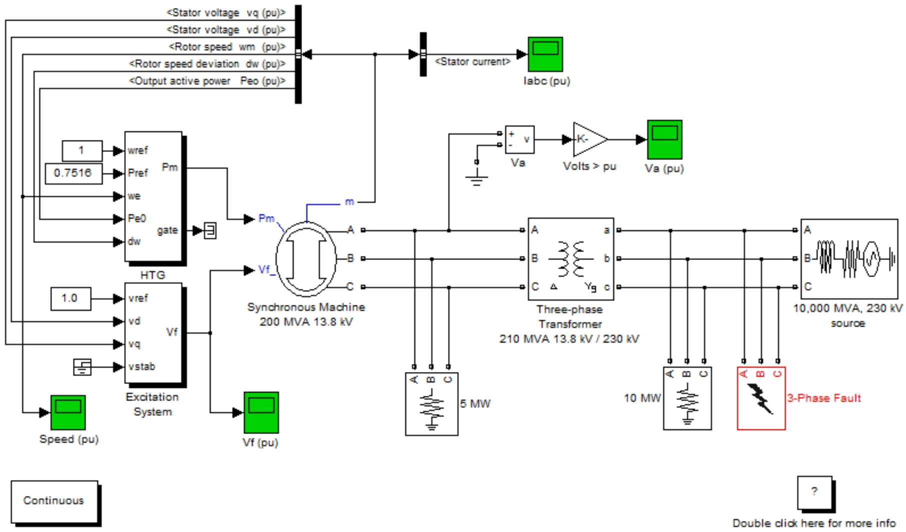

Figure 1: Simulation Model of Power Plant

Fuzzy Control System

The design of the fuzzy controller depends on experience of a human expert. Present paper describes Fuzzy control system for small HPP are to establish turbine governor.

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. The fuzzy controller is an artificial decision maker that operates in a closed-loop system in real time. It gathers plant output data, compares it to the reference input, and then decides what the plant input should be to ensure that the performance objectives will be met. [22]

We take the speed difference from the measuring system as an input for FIS. Rotor speed is compared with referenced speed to find speed deviation. This speed difference is input for FIS. The output control signal of FIS is control signal for Gate opening mechanism. The gate opening mechanism consists of servomotor. This control signal drives the servomotor which intern controls the gate opening.

Fuzzy control system for defining the control signal of turbine gate opening mechanism is mentioned in present paper. Fuzzy Based System Suggested is shown in fig.2

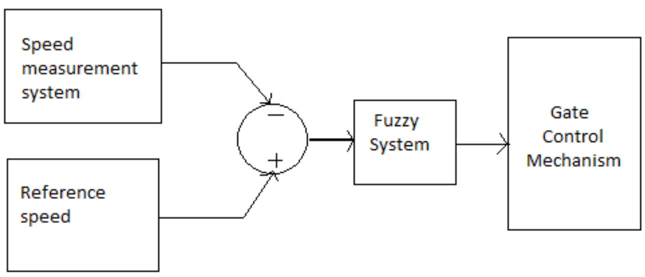

Figure 2: Fuzzy Based Turbine Governor

Fuzzy Inference System (FIS)

Fuzzy Inference process formulates the mapping of a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions are made. The process of fuzzy inference includes membership functions, fuzzy logic operators, IF-THEN rules and knowledge base. The fuzzy based system decides the gate limit value to avoid the damage. It consists of

1. Fuzzification
2. Inference mechanism
3. Defuzzification

The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base. The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system. The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be. The defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant [22]. Fig .3 shows the block diagram of a fuzzy controller.

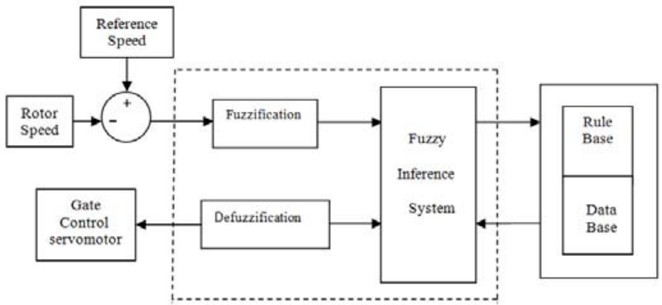

Figure 3: Block Diagram of a Fuzzy Controller.

Here one inputs and one output of the fuzzy controller. The input is the error between reference value that is desired output value and generator output value.

The proposed fuzzy controller as a turbine governor is shown in Fig. 4.

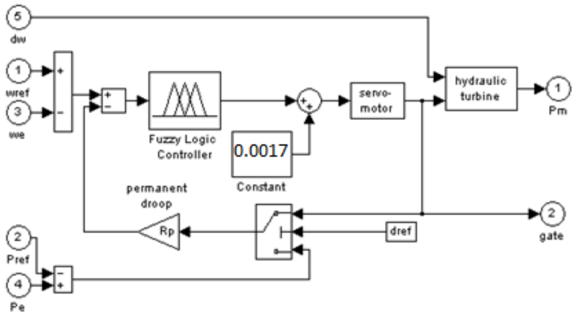

Figure 4: Fuzzy Controller as a Turbine Governor

Fuzzification [23-25]

The fuzzification stage is determined by the choice of the range, shape and number of the membership functions. Seven triangular membership functions are chosen for both input and output variable.

Input Scaling

Seven triangular functions are chosen for input variable error "E". The range of the input variable is [-0.092 0.0486]. The input variable error "E" is defined as

Fuzzy set for Input error "E"
μN_L (E) = L [-0.092 -0.06309]
μN_M (E) = Λ [-0.092 -0.06309 -0.04337]
μN_S (E) = Λ [-0.06309 -0.04337 -0.01053]
μZ (E) = Λ [-0.04337 -0.01053 0.01575]
μP_S (E) = Λ [-0.01053 0.01575 0.0289]
μP_M (E) = Λ [0.01575 0.0289 0.0486]
μP_L (E) = Γ [0.0289 0.0486]

The linguistic variable are NL, NM, NS, Z, PS, PM and PL, where NL is negative large; NM is negative medium; NS is negative small; Z is zero; PS is positive small; PM is positive medium; PL is positive large. The membership functions of the input variables error" E" are shown in Fig. 5.

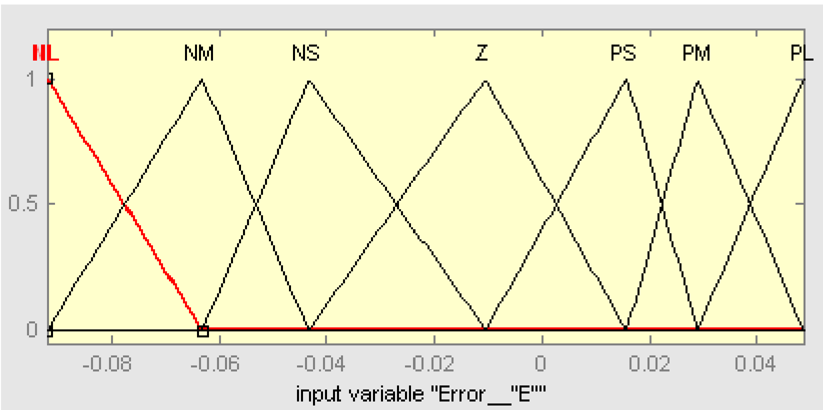

Figure 5: Membership Functions for Error "E"

Output Scaling

The range of the output variable control signal "CS" is [0.658, 0.77]. The output variable control signal "CS" is defined as

Fuzzy set for Output control signal CS
μD_H (CS) = L [0.658 0.679]
μJ_D (CS) = Λ [0.658 0.679 0.695]
μD (CS) = Λ [0.679 0.695 0.725]
μG (CS) = Λ [0.695 0.725 0.74]
μI (CS) = Λ [0.725 0.74 0.75]
μJ_I (CS) = Λ [0.74 0.75 0.77]
μI_H (CS) = Γ [0.75 0.77]

The linguistic variables are DH is decrease high; JD is just decrease; D is decrease; G is good; I is increase; JI is just increase; IH is increase high. The membership functions of the output variable control signal "CS" is shown in Fig. 6.

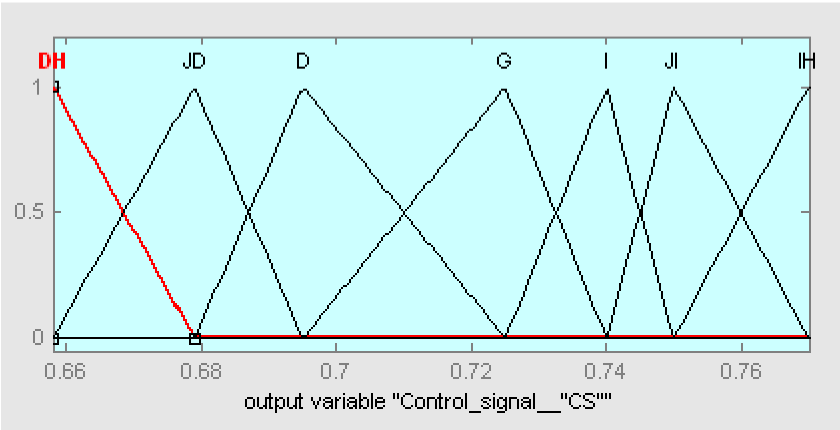

Figure 6: Membership Functions for Control Signal "CS".

The fuzzy controller is used the max-min inference method that called as the Mamdani type inference. Centroid Defuzzification method is chosen.

We have seven linguistic levels of input error and seven linguistic levels of control signal. So this rule base is composed of seven rules as given in Table-I.

Table I: Rule Base

If Error "E" is	NL	Then Control signal "CS" is	DH
	NM		JD
	NS		D
	Z		G
	PS		I
	PM		JI
	PL		IH

Inference Scheme [24]
Mamdani's individual rule based fuzzy logic inference is utilized in this system. It computes the overall decision outcome based on the individual contribution of each rule in the rule base.

In the inference process each rule is individually fired depends on crisp –value of input variable error "E" from fuzzification module. In this process clipped fuzzy set formed, which represent the overall fuzzy output variable as shown in fig.7. These clipped fuzzy set are then aggregated to compute single value.

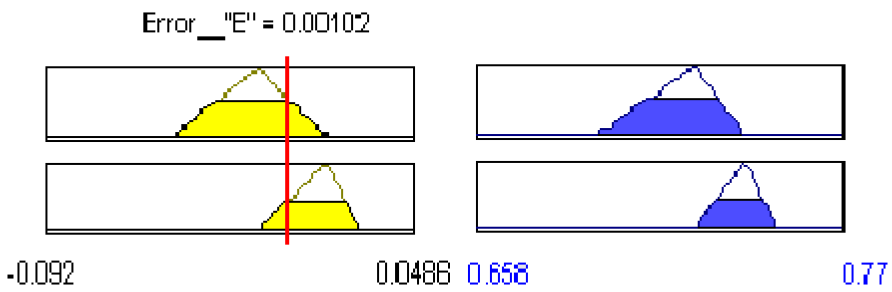

Figure 7: Mamdanis Fuzzy Inference Scheme

Defuzzification [25, 27]
It is the last step in fuzzy Inference scheme. It is carried out to find a compromise value from all clipped fuzzy sets that represent the overall fuzzy output variable. It converts each fuzzy output variable resulted in inference process into the crisp value.

Here we employ centroid defuzzification method [25, 26]. The centroid method is illustrated in fig. 8 that computes control signal for gate opening required to match speed. The system results are carried using MATLAB Software GUI tool.

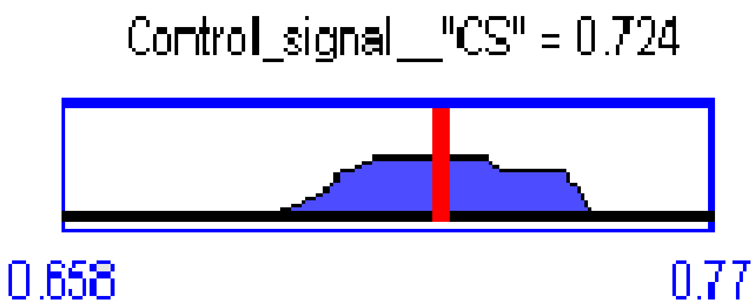

Figure 8: Centroid Defuzzification

System Initialization
We have selected synchronous machine of active power 150MW, Terminal voltage (Vrms) = 13800. Reactive power Q = 3.4 Mvar, Pmec = 150.32 MW (0.7516 pu), Field voltage Ef = 1.291 pu.

Simulation

The model is considering of regulator servomotor, turbine and generator. The servomotor is used as governor and it is regulated depending on the signal come from fuzzy controller. The model was designed using Matlab-Simulink. After the fuzzy based hydraulic controller was designed, the simulation results were obtained for three phase to ground fault.

Results are observed on four scopes which show parameters such as generator terminal voltage, excitation voltage, stator current, rotors speed.

Sample Results

At t = 0.1 s, a three-phase to ground short circuit occurs on the 230 kV bus. The following changes are observed

1. The Va falls to about 0.4 pu.
2. The speed of the machine increases to 1.01 pu.

The three phase fault is cleared after 6 cycles (t = 0.2 s) Then

The voltage Va returns quickly after fault is cleared. This is due to the fact that the excitation System output Vf can go as high as 11.5 pu this is during the fault.

The speed takes much longer than the terminal voltage to stabilize. This is mainly because the rate of valve opening/closing in the governor system is limited to 0.1 pu/s.

Fig. 9 shows simulation results for effect of three phase to ground short circuit.

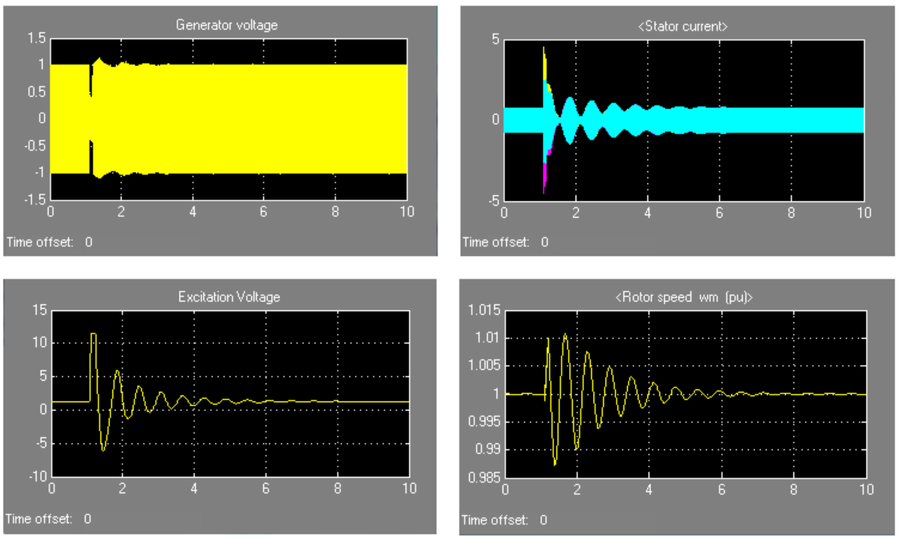

Figure 9: Simulation Results of Short Circuit

Conclusion

The significance of fuzzy logic in HPP control system is to implement the system operator knowledge to higher degree. A fuzzy based turbine governor was proposed.

It maintains the frequency constant in spite of changing user load at any operating point. The Simulation results prove that fuzzy based turbine governor has good performances. Moreover, good transient and steady state responses for different operating points of the processes can be achieved. As synchronous generators are nonlinear systems fuzzy controller will suitable for it.

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