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Load Frequency Control and Automatic Voltage Regulator of a One Area Power Network System Using Adaptive Neuro Fuzzy Inference System

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ABSTRACT

Maintaining the dynamic balance between generation and demand in modern power networks requires robust and intelligent control strategies capable of addressing nonlinearities, parameter uncertainties, and rapidly varying operating conditions. This research presents an advanced investigation into Load Frequency Control (LFC) and Automatic Voltage Control (AVC) for a single-area power system, using an Adaptive Neuro-Fuzzy Inference System (ANFIS)–based coordinated control framework.

To capture the coupled frequency–voltage dynamics, a comprehensive mathematical model of the one-area network is developed, including governor–turbine dynamics, generator inertial characteristics, excitation system behavior, and load–damping sensitivity. A comprehensive dataset created from nonlinear time-domain simulations under a variety of disturbances, including as step load perturbations, random load changes, and parameter drifts, is used to train the suggested ANFIS-based LFC–AVC method. Hybrid learning techniques that combine least-squares estimation and back-propagation are used to optimize the controller settings. The ANFIS-based approach dramatically increases transient responsiveness, lowers steady-state error, and strengthens robustness against uncertainties and external disturbances, according to comparisons with traditional PI/PID and fuzzy-logic controllers.

1. INTRODUCTION

Applications of MATLAB are countless and here in this application of the MATLAB, we would be using SIMULINK a MATLAB application to design a power system network. Showcasing the load frequency control and automatic voltage regulator systems and also analysing the responses of the systems when using and PID controller and an Adaptive Neuro Fuzzy Interference system. The design would be done via the block diagram perspective on SIMULINK and both responses compared to know the most efficient (Laghari 2021).

A PID controller is a control loop feedback mechanism widely used in industrial control systems to automatically adjust a process variable to a desired setpoint. It achieves this by combining three control actions:

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proportional, integral, and derivative giving its name PID controller (Gupta *et al.* 2016). In this project while using an Integral controller for the Load frequency controller (LFC). This is mainly because when the LFC has done its job of stabilizing the power system frequency during a disturbance, the frequency doesn't go back to its nominal setpoint. It therefore needs a rest action to take it back to its original setpoint. In the case of the automatic voltage system, a complete PID controller is necessary to get the system back to steady state quickly with minimum overshoot.

Adaptive Neuro-Fuzzy Inference System also referred to as ANFIS, is a kind of artificial neural network which combines both adaptive neural networks and fuzzy logic. It's a data-driven approach used for approximating functions, especially useful when dealing with uncertainty, unprecise or non-linear data. ANFIS uses fuzzy logic to model systems using terms like "low," "medium" and "high" and neural networks to optimize the model's parameters based on data (Satyanarayana *et al.*2014), Sharma and Kumar (2018), and Sekyere, and Al-Maamary (2021).

ANFIS uses fuzzy logic to show system characteristics using fuzzy sets and rules, allowing for handling of uncertainty and it also adds neural networks for learning and adapting the systems parameters of the fuzzy system, such as membership functions and rule (Narmada *et al.* 2014), and Iqbal *et al. 2019.*

2. METHODOLOGY

The Transfer function modelling of the power system was used in this project. The parameters assigned to the different system components are listed in the table below. Using the SIMULINK application in MATLAB, the system's speed governor, turbine, synchronous generator and load were assembled and the automatic voltage regulator and load frequency control were attached to the system. With the aid of a scope, the system response for both the voltage and the frequency were analysed. After the response analysis of the original system, the PID controllers of the original system was replaced with a fuzzy logic controller. The input and output data of the previously replaced PID controllers was collected and stored. The stored input and output data was passed on to an adaptive neural system for artificial training. The newly obtained data from the training is later put inside our fuzzy block, thereby making it and adaptive neural fuzzy interference system. The new system is simulated and its results compared with the previous results.

Table 1 shows the design and simulate that combined AVR and LFC power system network

Table 1: System Parameters

Parameter	Gain	Time Constant
Turbine	KT = 1	TT =0.5
Governor	KG =1	TG = 0.2
Amplifier	KA =10	TA =0.1
Exciter	KE = 1	TE = 0.4
Sensor	KR = 1	TR = 0.05
Inertia	H = 5	
Regulation	R = 0.05	
Generator	KG = 0.8	TG = 1.4

The load varies by 0.8 percent for a 1 percent change in frequency, D = 0.8.

Assume the synchronizing coefficient Ps is 1.5, and the voltage coefficient K6 = 0.5.

Also, the coupling constants are K2 = 0.2, K4 = 1.4, and K5 = -0.1.

Construct the combined Simulink model and obtain the frequency deviation and terminal

voltage responses for a load change of ΔPL1 = 0.2 per unit.

In the AGC topic, it was found that a small change in the real power is the product of the synchronizing power coefficient Ps and the change in the power angle Δδ. If we include the small effect of voltage upon real power, we obtain the following linearized equation.

$$\Delta P_e = P_S \times \Delta\delta + K_2 E \quad (1)$$

Where K2 is the change in electrical power for a small change in the stator emf. Now, the small effect of rotor angle upon the generator terminal voltage may be included as below:

$$\Delta V_t = K_5 \times \Delta\delta + K_6 E \quad (2)$$

Where K5 is the change in the terminal voltage for a small change in rotor angle at constant stator emf.

Where K6 is the change in terminal voltage for a small change in the stator emf at constant rotor angle.

Finally, modifying the generator field transfer function to include the effect of rotor angle, we may express the stator emf as

$$E = \frac{Kg}{1+Tg} \times V_f - K_4 \times \Delta\delta \quad (3)$$

The above constants depend upon the network parameters and the operating conditions. Including the above equations in the AGC system, and the AVR system, a linearized model for the combined LFC and AVR system is obtained.

The governor speed regulation R = 0.05 per unit. Therefore, 1/R will become

$$\frac{1}{R} = \frac{1}{0{,}05} = 20$$

3. RESULT DISCUSSION

Firstly, the power system network was designed including the load frequency controls system and later added the automatic voltage regulator system. Knowing that the effect of the LFC and AVR on each other is negligible. The coupling parameters for combining the two control systems had to be considered. The excitation power, the terminal voltage due to change in the rotor and lastly the excitation voltage due to the change in stator angle. After the system was designed and all the parameters and gains were fixed into their respective blocks. The SIMULINK simulation settings were set to run for 100 seconds. The model was simulated and the obtained frequency response and terminal voltage response to a step input load was observed and shown in figure 2 and figure 3. From the figure 2 shows a 5% overshoot in response to the new load and the frequency deviation plot took approximately 32 seconds to return to a steady state after the step input load was applied to the system while the terminal voltage to approximately 30 seconds to attain its steady state after the load input. The Figure 1 to 6 shows the SIMULINK simulations and results

The inertia and load are given by

$$\frac{1}{2HS+D} = \frac{1}{2\times 5s\times 0.8} = \frac{1}{10s\times 0.8}$$

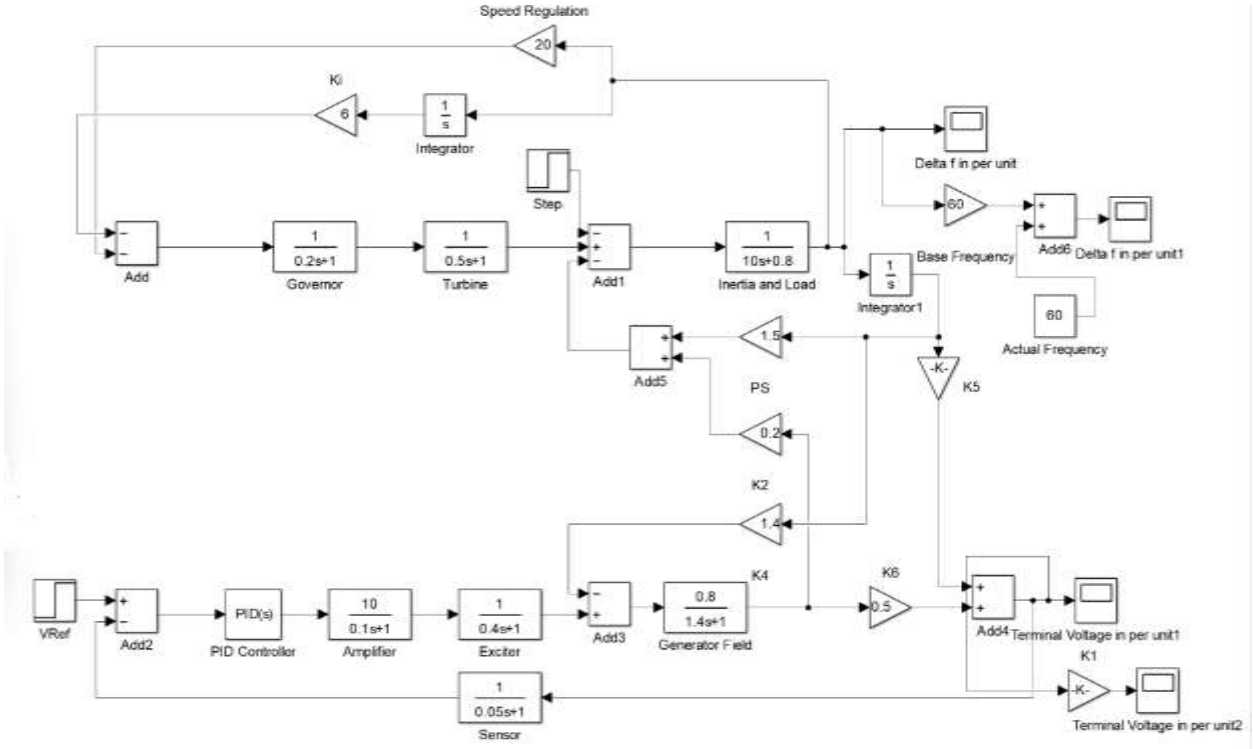


Figure 1: Combined LFC and AVR circuit using integral and PID controls (Glover *et al.* 2016)

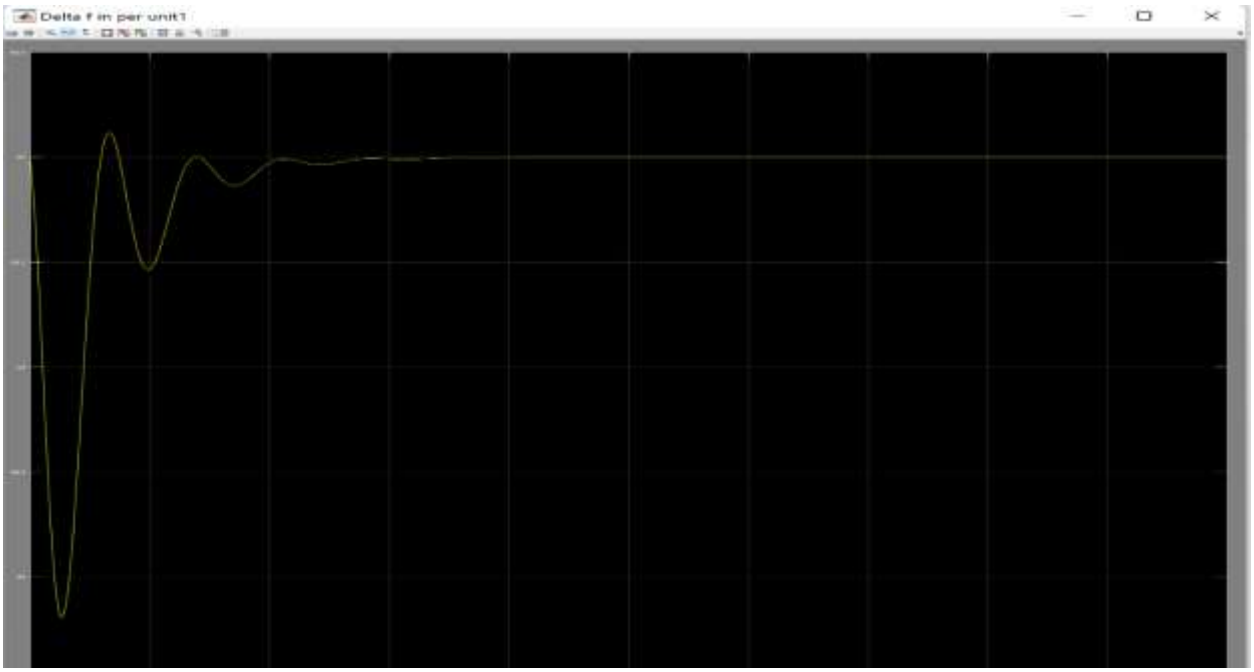


Figure 2: Frequency deviation response



Figure 3: Terminal Voltage response

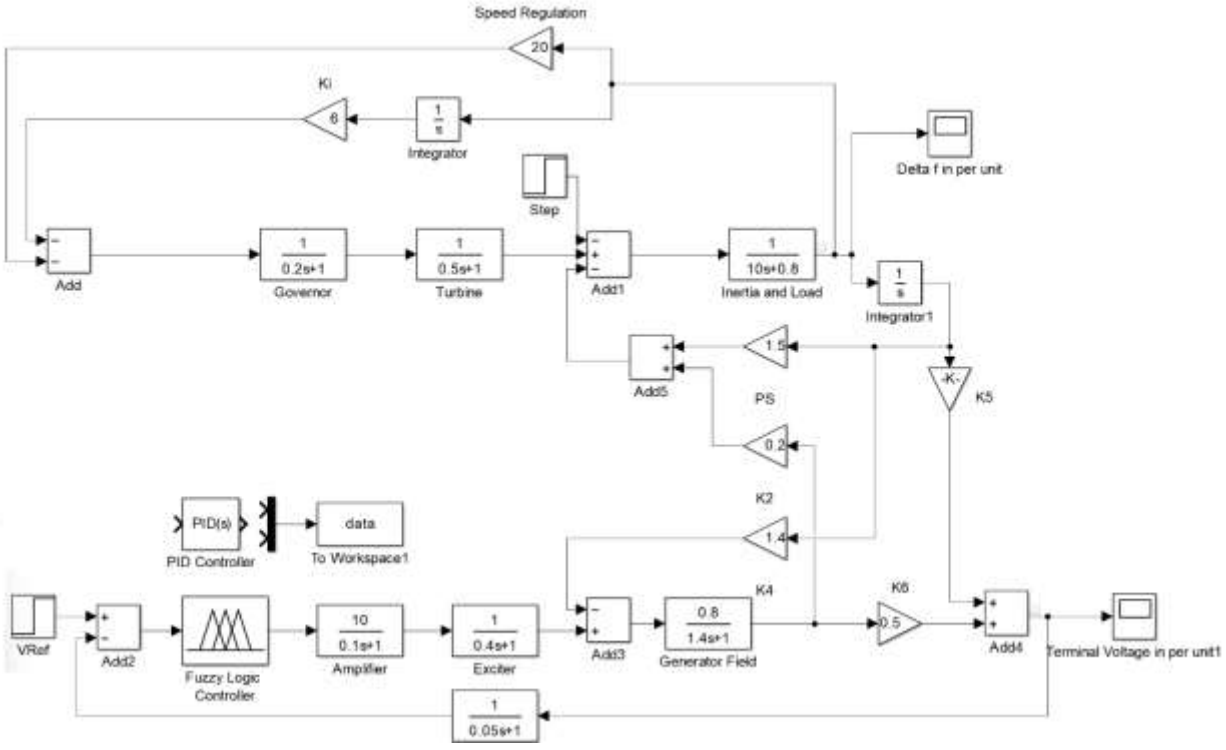


Figure 4: Combined LFC and AVR circuit using ANFIS controller (Singh *et al.* 2013)



Figure 5: Frequency response using ANFIS



Figure 6 Terminal Voltage response using ANFIS

After the first simulation, a workplace block was added to the model to acquire the input and output data of the PID controller used in the first model. This data is necessary for the Adaptive neuro fuzzy interference system

(ANFIS) training process that is likely to a much better response that the PID controller.

The I/0 data is obtained and stored as DATA1. Using the command window of MATLAB, we run the ANFIS code "ANFISEDIT" to perform the ANFIS training on the data obtained from the PID controller. In the process of ANFIS training, the Adaptive neural system was set to 10 membership functions and its errors set to zero. The trained data was saved as ANFIS1.

Back in the designed SIMULINK model, the PID controller is replaced with a fuzzy logic block and the saved ANFIS training file was log in the fuzzy logic block. The new model is simulated and the scope is observed to view the system response. The figure 3 shows the model when the PID controller is replaced with a fuzzy logic block. And the figure 4 and 5 shows the frequency deviation response and the terminal voltage response.

From the figure 5 that represents the frequency deviation plot, its obvious to see that the system was able to reach a steady state at 19 seconds which is 13 seconds faster and also with zero overshoot compared to the model using a PID controller while the figure 5 representing the terminal voltage reached steady state in 10 seconds which is 20 seconds faster than the first model.

4. CONCLUSION

This simulation project has a whole new potential of what a hybrid of Adaptive Neural system and Fuzzy logic system can achieve in power system stability. This is an example of how to make a great system better. The PID controlled system was already doing an excellent job but replacing it with computerized adaptive neuro fuzzy interference system was able to drastically reduce the timing by more than 50% thereby increasing the system's efficiency.

This project has shown a dimension to the MATLAB software by using it to prototype a model and viewing the system's response before actually building it on ground. MATLAB software plays a very important role in engineering and this exercise has helped to further increase our knowledge in programming and simulations in MATLAB.

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