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**APPLICATION OF ARTIFICIAL INTELLIGENCE ALGORITHMS FOR ELECTRIC
VEHICLE-CONNECTED POWER SYSTEMS TO CONTROL ELECTRICAL LOAD
FREQUENCY**

Gaurav Gupta¹, Saurabh Gupta² and Deepak Gupta³

¹Department of Electrical Engineering, Faculty of Engineering, University of Lucknow,
Lucknow, Uttar Pradesh, India - 226021

² Department of Electrical and Electronics Engineering, Technocrats Institute of Technology and Science,
Bhopal, Madhya Pradesh, India - 462021

³ Department of Applied Science and Humanities, Faculty of Engineering, University of Lucknow,
Lucknow, Uttar Pradesh, India - 226021

Email: gauravmits@gmail.com, saurabhgupta.sgsits@gmail.com, dg61279@gmail.com

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Abstract

There are a few challenges confronting electric vehicle producers. This study looks at the influence of electrically powered vehicles on load frequency deviation. However, the load fluctuates throughout time and cannot be constant. Multiple remedies have been proposed in academic literature to tackle the deficiencies of traditional controllers. This study presents an innovative method for creating a multi-load frequency controller for a single-zone power system by utilizing various artificial intelligence (AI) optimization methods such as fuzzy logic and ANN tuners. Research on controllers has demonstrated enhancements in frequency offset signal, peak crossover, and frequency output signal resolution. The functionality of the suggested system is confirmed through the utilization of *MATLAB/SIMULINK* tools.

2020 Mathematical Sciences Classification: 93C05, 34A30

Keywords and Phrases: Artificial Intelligence (AI) , Electric Vehicles (EV) , Fuzzy Logic Control (FLC) , Load Frequency Control (LFC).

1 Introduction

Power system stability requires a balance between total output, total load demand and system losses. Due to the change in load demand, the balance of real and reactive power is disturbed. This results in system frequency and tie-line power deviations from the designed value. Excessive fluctuations in system frequency can cause system failure. For the efficient operation of the electrical system, the frequency must remain constant [2, 9]. Several problems related to frequency fluctuations can directly affect the reliability, efficiency and effectiveness of an electrical system. Critical frequency deviations can impair load performance, harm equipment, overburden transmission lines, and disrupt system protection mechanisms [3,10]. These frequent deviations at a high rate can in the long run result in the collapse of the system [5, 15]. Changes in frequency can adversely affect the operation and speed control of both asynchronous and synchronous motors [1, 2].

2 Need for Load Frequency Control

Load frequency control (LFC) is critical in a large-scale power system with interconnected regions to keep the system frequency and interconnection power close to expected levels Load Frequency Control [2,9]. A well-designed power system should be able to handle changes in demand and disruptions in the system [9, 11]. It also needs to produce the right levels of high-quality energy while maintaining safe voltage and frequency [2, 5]. Load frequency control is an important control element in the operation of electrical systems [15]. Load frequency control (LFC) has long been used in electrical systems as part of the AGC (Automatic

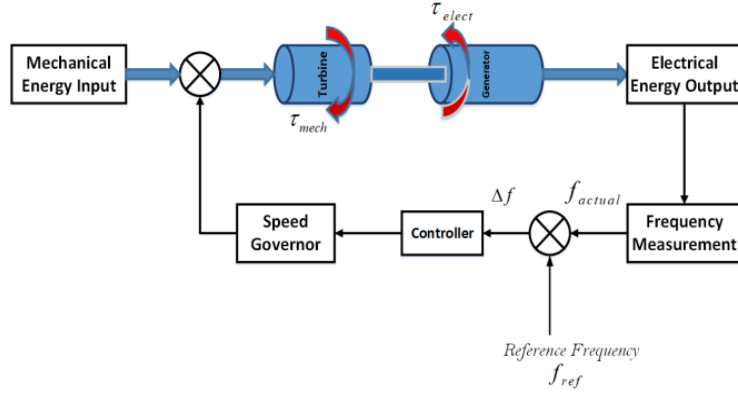


Figure 2.1: The AGC system

Generation Control) system [2, 10]. Maintaining the system frequency at its nominal value of 50 Hz is one of AGC's goals [2, 9].

The electrical system consists of a main controller, turbine and generator with generator input [1, 3]. The electrical system also includes the generator phase load. The purpose of the load frequency controller is to simultaneously perform frequency control and actual current change through the transmission line [6, 10]. The power frequency is detected by the frequency sensor [12]. The alteration in rotor angle δ can be used to measure the variations in line frequency and real power [5]. The load frequency controller enhances and transforms the error signal, specifically [4]. The change in the current power control signal ΔP_{ci} is transmitted to the power source via the controller (valve mechanism control).

3 Methodology

A complete block diagram representation involving the turbine, generator, governor, and load is typically modeled by individual components [1, 3, 5]. Because of the system's actual performance as a result of a step change in load, the controller does not take any action in this instance [10]. In this case, no controller action is applied because of actual system performance due to a step change in load [2, 10]. The dynamic behavior for the nominal system, as reflected in the change in frequency, consists of the hydraulic amplifier, turbine, and generator model as shown in Fig. 2.1.

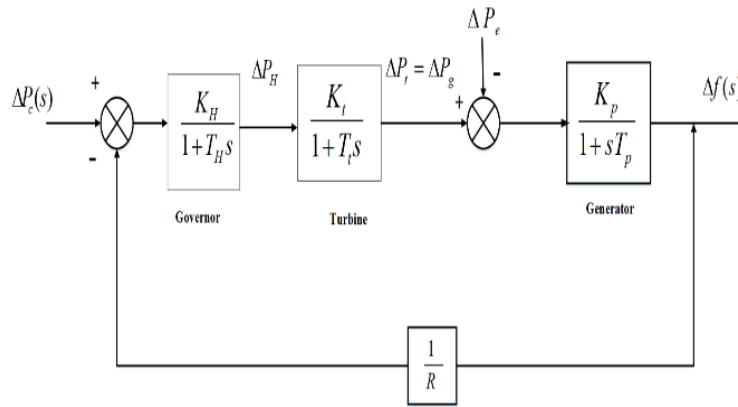


Figure 3.1: LFC Block Diagram

An alternative way to represent Fig. 3.1 is to use the matrix equation in state space form.

$$\dot{x} = Ax + Bu + F\rho. \quad (3.1)$$

Here,

$$A = \begin{bmatrix} -\frac{1}{T_p} & \frac{K_p}{T_p} & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} \\ \frac{1}{RT_H} & 0 & -\frac{1}{T_H} \end{bmatrix}, \quad (3.2)$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_H} \end{bmatrix}, \quad (3.3)$$

$$F = \begin{bmatrix} -\frac{K_p}{T_p} \\ 0 \\ 0 \end{bmatrix}, \quad (3.4)$$

$$\rho = [\Delta P_E]. \quad (3.5)$$

Here, x^T = State vectors, $[\Delta f \quad \Delta P_T \quad \Delta P_H]$,
 u = When not under control, the control vector equals zero.

4 Introduction to Electric Vehicles

Mechanized vehicles utilize a significant portion of the oil supply, and their operation leads to considerable air pollution, which is harmful to the environment [9, 11]. Technologies such as battery-powered Plug-in Electric Vehicles (*PEV*) and Plug-in Hybrid Electric Vehicles (*PHEV*) are gaining momentum to combat greenhouse gas emissions and air pollution, especially in regions where the vehicle industry is heavily dependent on petroleum-based fuels [9, 14]. Device regulators powered by Electric Vehicle Supply Equipment (*EVSE*) are essential for linking *EVs* to the electrical grid [7]. The *AC* to *DC* converter, with single or three-stage connectors, is a key component of these regulators. Recently, there has been a significant number of new advancements in *EV* charging technologies being developed and supported worldwide [8]. Furthermore, if numerous electric vehicles charge simultaneously from the grid, it can lead to increased peak load demands and system harmonics, potentially causing operational issues for the power system [7, 14]. It is important to analyze how multiple *EV* charging stations impact the electric power distribution system *EPDS* [9]. Because of the high demand for *EV* charging, this study focuses on the main challenges that *EPDS* operators are likely to face [9, 11].

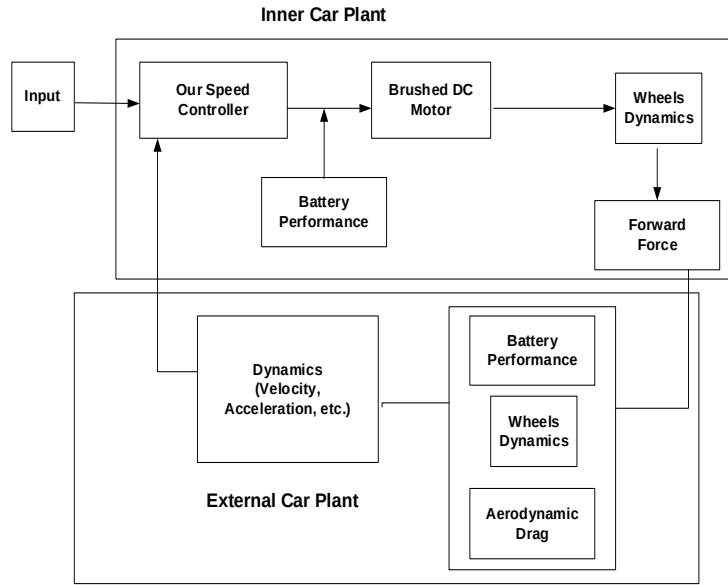


Figure 4.1: Model Diagram for EV

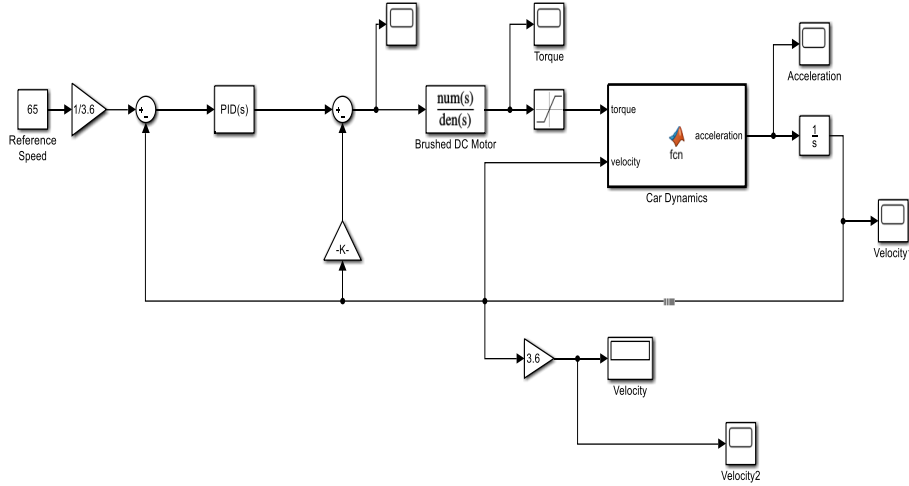


Figure 4.2: Simulink Model for EV

5 Mathematical Modeling of EV

With K_E the back *EMF* constant and (t) the rotational speed of the motor in rad/s. Hence, we can write:

$$V(t) = I(t) * R + L * \frac{dI}{dt} + K_E * \omega(t) . \quad (5.1)$$

Transforming this equation to the Laplace domain, we get:

$$V(s) = R * I(s) + sL * I(s) + K_E * \omega(s) . \quad (5.2)$$

We can also apply this to the torque equation to obtain:

$$T(s) = K_T * I(s) . \quad (5.3)$$

Hence, we can write:

$$I(s) = \frac{V(s) - K_E * \omega(s)}{sL + R} . \quad (5.4)$$

Replacing to get Torque as a function of Voltage Input and rotational velocity:

$$T(s) = K_T * \frac{V(s) - K_E * \omega(s)}{sL + R} . \quad (5.5)$$

The control methodology proposed in this work is the *ANFIS*, which stands for Adaptive Neuro-Fuzzy Inference System, combines neural networks and fuzzy logic to create artificial intelligence (*AI*) [4, 11]. This type of soft computing method is capable of predicting or determining outcomes for complex nonlinear systems using input data [4, 6]. *ANFIS* proves particularly useful in situations involving complex systems, uncertainty, dynamic behavior, and nonlinear relationships, where traditional rule-based or statistical models may be inadequate [11, 14].

The parameters that can be adjusted to modify the shape of the membership function generally determine the structure and behavior of the membership function in *ANFIS* models [3, 4].

6 Mathematical Modeling of ANFIS

While there are several algorithms to train the *ANN/ANFIS* model [13], one of the fastest and most efficient algorithms is the Levenberg Marquardt (*LM*) algorithm which is a modified version of the steepest gradient descent. Taking a look at the nature of the steepest descent algorithm, it is concluded that it is 1st order derivative of the minimization function which makes it an asymptotic convergence[11]. Considering the gradient of the error concerning weights for loss minimization, we obtain the derivative gradient as:

$$g = \frac{\partial E(x, w)}{\partial x} = \left[\frac{\partial E}{\partial w_1} \frac{\partial E}{\partial w_2} \quad \cdots \quad \frac{\partial E}{\partial w_N} \right]^T . \quad (6.1)$$

Considering the loss/cost function as the mean squared error, the weight update rule for the (*LM*) algorithm is:

$$w_{k+1} = w_k - [J_k J_k^T + \mu I]^{-1} J_k^T e_k . \quad (6.2)$$

Here, k is the iteration number,

w_{k+1} is the weight of the next iteration,

w_k is the weight of the present iteration,

J_k is the Jacobian Matrix and is given by the terms $J_k = \frac{\partial^2 e}{\partial w^2}$ i.e. the second-order rate of change of errors concerning weights,

J_k^T is Transpose of Jacobian Matrix,

e_k is an error of the Present Iteration,

μ is step size i.e. amount by which weight changes in each iteration,

I is an identity matrix, with all diagonal elements equal to 1 and other elements 0.

The training is truncated as the cost or loss function is stable or the maximum iterations are over. The cost or loss function is defined as:

$$MSE = \frac{1}{N} \sum_{t=1}^N e_t^2 \quad H < return > . \quad (6.3)$$

The mean absolute percentage error can also be computed as:

$$MAPE = \frac{100}{N} \sum_{t=1}^N \frac{|V_t - \hat{V}_t|}{V_t} . \quad (6.4)$$

Here,

N is the number of predicted samples,

V is the predicted value,

$\hat{V}_t$ is the actual value,

e is the error value.

The complete implementation and validation of the results can be performed by sequentially implementing the steps in the flowchart of the proposed system:

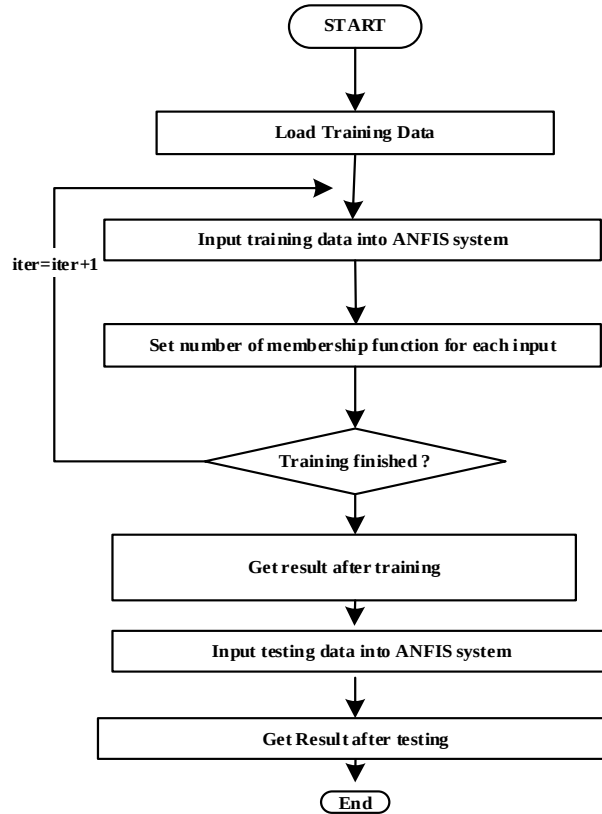


Figure 6.1: ANFIS Flowchart

7 Results and Discussions

The system has been designed on *MATLAB/SIMULINK*. Figure 7.3 displays the output signal of Change in frequency response using the *ANFIS* controller.

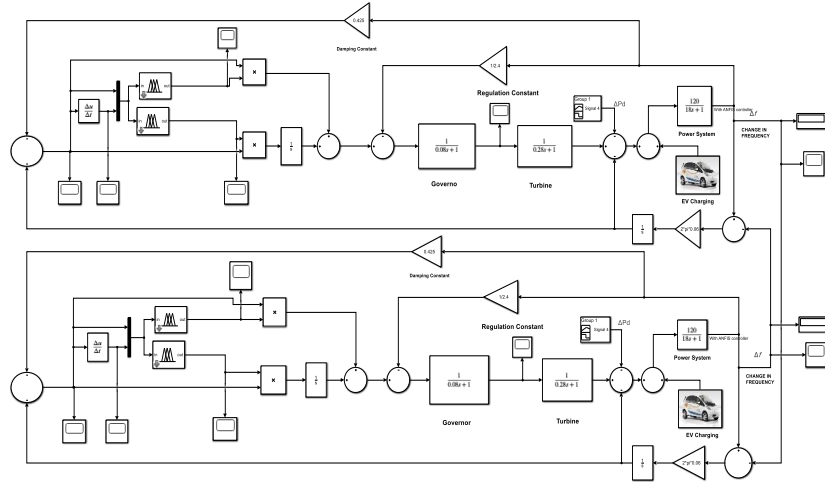


Figure 7.1: *ANFIS Controlled LFC Model*

Table 7.1: *Summary of Results*

Parameter	ANN	ANFIS
Rise Time	1.5593×10^{-5} sec	1.3832×10^{-5} sec
Settling Time	11.8526 sec	11.0145 sec
Settling Min	-0.5747 Hz	-0.3966 Hz
Settling Max	1.8975 Hz	0.6361 Hz
Overshoot	7.2653×10^6	6.6417×10^5
Undershoot	2.2007×10^6	3.2790×10^6
Peak	1.8975 Hz	1.9579 Hz
Peak Time	5.5281 sec	5.4959 sec

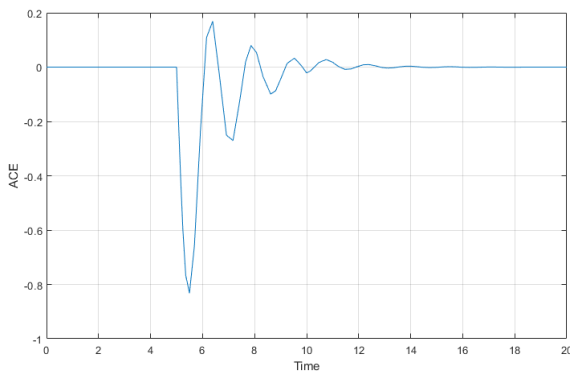


Figure 7.2: *ACE for ANFIS Controller*

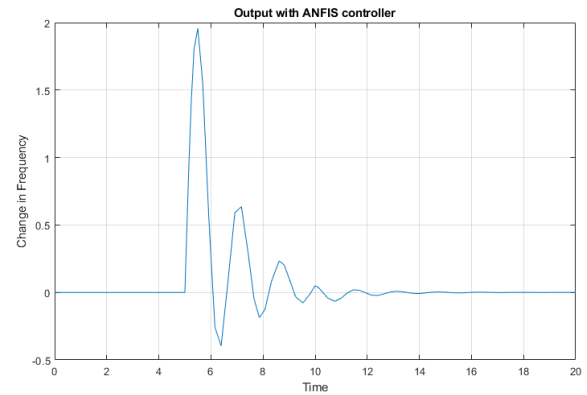


Figure 7.3: *Change in Frequency for ANFIS Controller*

Table 7.1 shows the value of *LFC* response parameters for the *ANFIS* controller. Based on these parameters comparison between the two controllers will be done to check their performance.

8 Conclusion

Load frequency control, or *LFC*, is utilized to maintain and adjust the frequency signal of the electric power output within a specific region for electric vehicles when there are fluctuations in system loads. This article discusses the impact of electric vehicles on load frequency deviation. This project demonstrates how to design a controller that can sustain optimal performance in a two-area power system even when the system's input parameters are changed. Two approaches to load frequency control were examined while taking an isolated power system into account.

The controller's performance is confirmed using *MATLAB/SIMULINK* tools. In comparison, *ANFIS* exhibited the smallest percentage overshoot and shortest settling time.

In the future scope, a signal processing tool can be utilized to check their effect on results.

Some of the Hybrid techniques like Wavelet Neural Network etc. can be checked to see improvement in results.

The system will appear more realistic and nonlinear if generation control and governor deadband are added.

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